CORILA

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SCIENTIFIC RESEARCH
AND SAFEGUARDING OF VENICE

CORILA Research Programme 2001-2003
2002 Results

Edit by
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INTRODUZIONE

PIERPAOLO CAMPOSTRINI
Direttore del CORILA

Questa pubblicazione raccoglie i contributi del secondo anno del Primo Programma di Ricerca del CORILA, che sono stati presentati alla seconda Riunione annuale tenuta il 31 marzo e il 1-2 aprile a Venezia.

Essi costituiscono la sintesi dei risultati della parte centrale del periodo di ricerca, che fissano alcuni dei risultati del primo anno e introducono nuovi temi che saranno definitivamente esplicitati nel terzo ed ultimo anno del programma di ricerca.

Gli articoli presentati in questo secondo volume sono contributi originali che possono essere letti sia nella loro specifica autonomia, sia come riflessioni legate ai contributi dell'anno precedente ed in attesa di quelli che verranno presentati nel Rapporto scientifico conclusivo, al termine dei tre anni del programma.

La pubblicazione annuale dei risultati permette di rendere visibile la continuità di produzione scientifica in un programma di ricerca articolato e complesso come quello del CORILA, e di fornire informazioni sui risultati che nel corso del programma sono prodotti, anche alcuni di essi possono essere parziali.

Scopo primario della pubblicazione è infatti contribuire a legare, anche in maniera interdisciplinare, tutte le questioni affrontate dalle quattro Aree tematiche di ricerca, cercando di mostrare come la continuità nell'informazione e nella diffusione delle attività scientifiche, sia fondamentale per fornire reali ed utili strumenti operativi alle Istituzioni che agiscono per la salvaguardia di Venezia e della sua laguna.

Spesso dagli operatori scientifici, non solo in Italia, viene lamentata la scarsa attenzione del mondo politico e della società alle necessità della ricerca. Il "caso veneziano" evidentemente risente delle problematiche e delle contraddizioni generali, ma può rappresentare un esperimento efficace di maggiori e positive interrelazioni tra Ricerca ed altre Amministrazioni pubbliche.

Il mondo della ricerca, anche attraverso il CORILA, è impegnato in questo sforzo e qui corre l'obbligo di ringraziare per l'attenzione ricevuta da tutte le Pubbliche Amministrazioni coinvolte. Esse, per la soluzione dei problemi di Venezia sono riunite in un Comitato misto che comprende il Governo centrale, quello regionale e dei Comuni lagunari. Tale Comitato, nel quale siede anche il Ministro per l'Istruzione, l'Università e la Ricerca, ha disposto i finanziamenti statali utilizzati per le ricerche qui presentate.

Il Magistrato alle Acque di Venezia, organo periferico del Ministero dei Lavori pubblici, non solo ha incoraggiato ai diversi livelli le nostre attività, ma le ha sostenute direttamente ed indirettamente, mettendo a disposizione il suo grande patrimonio di informazioni, dati ed esperienze, anche attraverso il Concessionario di Stato Consorzio Venezia Nuova. Il ruolo del Servizio Informativo del Magistrato alle Acque è stato importante in tutte le fasi della ricerca. Le informazioni fornite dal Servizio Informativo si sono via via integrate con quelle prodotte dalle ricerche, le quali a loro volta sono stati utilizzate da progettisti ed esecutori, in un clima di fattiva collaborazione tra Magistrato, Concessionario e CORILA.

La Regione del Veneto, anche attraverso l'Agenzia regionale per l'Ambiente ARPAV, ha parimenti collaborato mettendo a disposizione informazioni raccolte in propri studi e monitoraggi, ed interagendo positivamente nelle fasi di preparazione e discussione e diffusione dei risultati.

Magistrato alle Acque ed ARPAV stanno partecipando ad un circuito di intercalibrazione di misure Chimiche promosso da CORILA con il sostegno dell'Istituto Superiore di Sanità.

La Provincia di Venezia, in particolare per gli aspetti di difesa del suolo e pesca, ha messo a disposizione le proprie strutture a supporto dell'attività dei ricercatori ed ha pure partecipato efficacemente ai momenti di discussione, ricevendo collaborazione nello svolgimento delle sue attività istituzionali.

Il Comune di Venezia è partner importante per le ricerche che riguardano gli edifici storici e l'ambiente urbano della città, ma anche per lo studio dei flussi tra laguna e mare, svolto con il concorso del Centro Maree. Alcune attività si svolgono in efficace collaborazione con la società del Comune, incaricata per la manutenzione urbana, Insula.

Il Comune di Chioggia, quello di Cona e di Cavarzere, assieme al Consorzio di Bonifica Adige-Bacchiglione sono parte attiva di un progetto relativo al controllo della subsidenza che interessa il loro territorio.

E' doveroso citare anche la collaborazione della Sovrintendenza per i Beni Architettonici di Venezia, organo periferico del Ministero dei Beni culturali, nel campo delle ricerche dell'Area Architettura e dell'Autorità Portuale di Venezia, interessata ad alcuni approfondimenti nell'area Economia ed in quella dei processi Ambientali.

Questo lungo elenco di Amministrazioni Pubbliche, con le quali si è instaurato un dialogo non formale e pressoché continuo, può dare conto della complessità istituzionale e della ricchezza delle relazioni instaurate, con molteplici sfaccettature.

In ogni caso, il CORILA ha potuto contare sul costante supporto offerto dal Ministero dell'Istruzione, dell'Università e della Ricerca, che non si è limitato a vigilare sulla correttezza formale delle attività del nostro ente, ma che è intervenuto al più alto livello di responsabilità politica e di dirigenza amministrativa, per sostenere il ruolo e l'originalità del contributo della ricerca pubblica nelle complesse problematiche della Salvaguardia di Venezia.

Tutto ciò comunque non poteva avvenire senza la passione competente e paziente dei molti ricercatori coinvolti, veneziani e di tutto il modo. Loro sono gli autori di questo libro e ad essi è indirizzata principalmente la nostra cordiale riconoscenza.

Devono essere ringraziate anche le persone dello staff operativo del CORILA, che hanno prestato le loro intelligenze ed il loro impegno ad una fatica meno appariscente eppure necessaria, ovvero il coordinamento delle attività. Comitato Scientifico, Consiglio di Amministrazione e Direttore del CORILA hanno potuto contare su uno staff affidabile e disponibile, che ha saputo farsi apprezzare anche dai componenti dei Gruppi di Ricerca.

Infine, un particolare ringraziamento per l'edizione di questo volume è dovuto ad Enrico Rinaldi, che ha curato la raccolta dei testi e la loro impaginazione

INTRODUCTION

PIERPAOLO CAMPOSTRINI
Director of CORILA

This publication gathers together the contributions from the second year of the First CORILA Research Programme, which were presented at the second Annual Meeting held in Venice on 31 March and 1-2 April 2003.

They constitute a summary of the results of the middle part of the period of research, which confirms some of the first year's results and introduces new themes that will be expressed in their final form during the third and final year of the research programme.

The articles presented in this second volume are original contributions that may be read either as they stand alone or as reflections connected with the previous year's contributions, pending those to be presented in the conclusive Scientific Report at the end of the three years of the programme.

Annual publication of results gives visibility to the continuity of scientific output in a detailed and complex research programme like that of CORILA, and provides information about the results that have emerged during the programme, even if some of them may only be partial. Indeed, the main purpose of this publication is to help to bind together all the issues addressed in the four research Theme Areas, particularly in an inter-disciplinary manner. This is an attempt to show that continuity of information and dissemination of scientific activity are basic needs if we want to provide real and useful working tools for the institutions that work to safeguard Venice and its lagoon.

Those working in the field of science, not only in Italy, often complain of lack of interest in the needs of research as regarded by politicians and society. The "Venice case" is obviously affected by general problems and contradictions, but may also be an effective experiment in closer and more fruitful relations between research institutions and other public authorities. The world of research, with CORILA as a contributor, is committed to this aim, and here we are under an obligation to express our thanks for all the attention we have received from all the public authorities involved.

To solve the problems of Venice these authorities are combined in a Joint Committee that includes the members of theItalian Government, the President of the *Regione Veneto* and the Mayors of the various lagoon Municipalities on the lagoon. This Committee, which also includes the Ministry of Education, Universities and Research, has provided the State funding for the research that is presented in this publication.

The Magistrato alle Acque di Venezia, local division of the Ministry of Public Works, has not only encouraged our work at different levels, but has supported it both directly and indirectly, placing its enormous heritage of information, data and experience at our disposal also through the State concessionaire, the Consorzio Venezia Nuova. The *Servizio Informativo* of the Magistrato alle Acque has played an important part in all the phases of research. The data supplied by this office were steadily integrated with those produced by CORILA research, which were in turn used by designers and engineers in a climate of constructive collaboration among Magistrato alle Acque, Consorzio Venezia Nuova and CORILA.

The Veneto Regional Government, also through ARPAV, the Regional Agency for the Environment, provided equally helpful collaboration, supplying information collected in its own studies and monitoring and interacting positively in the phases of preparation, discussion and circulation of results.

The Magistrato alle Acque and ARPAV are taking part in an inter-calibration of chemical measurements initiative promoted by CORILA with the support of the *Istituto Superiore di Sanità* (National Institute of Health).

The Venice Provincial Administration, particularly as regards the aspects of ground protection and fishing resources, offered its structures to support the researchers' work and also made an effective contribution in the discussion stages, while receiving assistance in the performance of its institutional activities.

The Venice Municipality is an important partner in research involving historic buildings and the city's urban environment, and also in the study of flows between lagoon and sea, conducted with the help of the Tide Forecasting Office. Some work was done in strict collaboration with the municipal company in charge of urban maintenance, Insula.

The Municipalities of Chioggia, Cona and Cavarzere, with the Consortium for the Reclamation of the Adige and Bacchiglione, are active partners in a project for the control of the subsidence that affects their areas.

It is also only right to mention the help given by the Venice Architectural Heritage Office, the local branch of the Ministry for the Cultural Heritage, with work in the Architectural Area; and the Venice Port Authority, which is interested in detailed research in some of the research Areas of Economics and of Environmental Processes.

This long list of public authorities, with whom we have entered into a dialogue that is not formal and is almost continuous, may give an indication of the institutional complexity and the wealth of the many-faceted relations that have been set up.

In any case CORILA has been able to rely on the constant support of the Ministry of Education, Universities and for Research. This Ministry did not limit itself to supervising the formal correctness of our organisation's activities, but intervened at the highest level of political responsibility and administrative management to support the role and originality of the contribution of public research to the complex problems of the Safeguarding of Venice.

All this, however, could not have been done without the competent and patient enthusiasm of the many researchers involved, Venetians and others from around the world. They are the authors of this book and it is to them that we mainly address our warm gratitude.

Thanks are also due to the operational staff of CORILA, who devoted their intelligence and commitment to a job that is less conspicuous and yet necessary, the coordination of the work. The CORILA Scientific Committee, Board of Directors and Director were able to count on reliable and willing workers who also gained the appreciation of the Research Groups.

Finally, as regards the publication of this volume, special thanks go to Enrico Rinaldi, who was in charge of obtaining and putting together the articles and their layout.

AREA 1
ECONOMICS

RESEARCH LINE 1.1
Economic evaluation of environmental goods

ECONOMIC VALUATION OF THE INTERVENTIONS FOR THE PROTECTION OF THE LAGOON'S MORPHOLOGY. THE ISLAND OF S. ERASMO: CASE STUDY

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Introduzione

La Laguna di Venezia è considerata un ecosistema unico e il mantenimento delle sue caratteristiche morfologiche è di importanza fondamentale per garantire alle generazioni future l'integrità della sua bellezza e del suo significato culturale.

Se tale esigenza è ampiamente riconosciuta a livello pubblico e privato, non altrettanta concordanza vi è sulle concrete modalità di intervento per la sua salvaguardia. Si riscontra inoltre, una mancanza di studi organici capaci di valutare il grado di apprezzamento complessivo da parte della collettività, sia in termini di valore d'uso, che soprattutto di non uso.

Il progetto di ricerca è stato quindi teso alla costituzione di un generale schema di riferimento e di un modello operativo per la valutazione degli investimenti finalizzati ad opere di salvaguardia della morfologia lagunare e di difesa dell'erosione. Il modello è stato applicato ad un concreto caso di studio rappresentativo del sistema lagunare: l'isola di S. Erasmo.

1. Objectives

The Lagoon of Venice is regarded as a unique hydrological resource and ecosystem; moreover, since 1987, Venice and the Lagoon have been placed on the UNESCO Cultural Heritage List, a registry of sites with high priority for preservation for future generations for their natural beauty and cultural significance. While public programs expediency for safeguard and protection of Venice and its lagoon is undeniable, appropriate methodological tools are required to inform cost benefit analyses with non-market benefits derived from such interventions.

WP2 research deals with the development of some methods for valuing public programs for the environmental quality improvement of the Lagoon of Venice. In particular, some up-to-date valuation techniques are tested, in order to construct an operational and comprehensive methodological frame. WP2 research refers to a specific case study, i.e. the now-in-progress environmental protection public works on the island of S. Erasmo.

2. Contingent Valuation Experiment

2.1 Database

The database includes 1330 reports. Data were collected by a telephone survey on a random sample of residents of the Veneto Region stratified by distance from the resource being valued, as we consider that, excluding the value of housing and land on the island, the total economic value of S. Erasmo is mainly the result of local recreational use and non-use values. This sample thus includes many people who are currently visiting S. Erasmo or using it in any other way.[1]

Specifically, the database includes quantitative and qualitative variables about: 1) Use of the Venice lagoon and familiarity with S. Erasmo island; 2) types of recreational use of the lagoon; 3) number of visits to S. Erasmo island during the last 12 months and related travel costs; 3) willingness to pay , for the public works in progress in and around the island and its motivations;4) characteristics of respondents (age, gender, education, income, etc.). Moreover, the database reports about a methodological issue about CV: our respondents were randomly assigned to one of two subsamples. One of these two is read a version of the questionnaire that is identical to the other group's version in all respects, except that respondents are given a reminder of the reasons for voting in favor or against the public works program that would deliver the environmental improvement at and around S. Erasmo[2].

The average respondent is married with a child, is about 50 years old, has completed the second year of high school and has a household income of roughly €21,000 a year. Most of our respondents are women (69.55%) and about 41% are employed. About 23% are retired, and roughly 32% does not work outside the home. This percentage includes homemakers (25%), students (4%) and unemployed people (2%). Finally, 4% of the respondents belongs to an environmental organization. During the last year, roughly one-fourth of the respondents has visited the Venice lagoon by public or private boats and 8% has been to S. Erasmo island. About 14% of the respondents has been to S. Erasmo island at least once in his/her life. About two-thirds of the respondents already knew S. Erasmo before taking the survey, while the remainder learned about the island only through the survey. When those who had never been to S. Erasmo island were asked if they would go to the island after the completion of the public interventions, 42% of the respondents stated they would visit the island after the public program.

[1] In addition, we conducted a travel cost survey of Lagoon anglers, and a combined travel-cost and contingent valuation survey of Lagoon recreational boaters. We plan to compare the WTP figures from these different groups of subjects in a separate paper.

[2] We are not aware of other studies that have formally examined whether provision of such a summary influences WTP, and by how much. Informal evidence from focus groups suggests that reminders of possible reasons for voting in favor and against the proposed policy offer some reassurance that both types of votes are acceptable, which may make respondents who are against the proposed public program more comfortable in saying so (Carson, 2002, personal communication).

About 39% of the Venice residents we interviewed has visited the Venice lagoon in the last twelve months. The percentage of lagoon users decreases to 16% for those who live in the municipalities with a lagoon waterfront, or within 15 km from the lagoon, and to 13.5% for those living as far as 30 km from the lagoon. The likelihood of being a lagoon user dramatically decreases among those living farther away than 30 km from the lagoon: only 6% of the respondents who live from 30 to 50 km from the lagoon frequents the lagoon, while only 3% of those living farther than 50 km visits the lagoon.

2.2 Methodology

We Contingent Valuation (CV) used to assess the total economic value of S. Erasmo island. In order to conduct a cost-benefit analysis of the public works program, we obtained the willingness to pay for the beneficiaries (broadly defined) of the safeguard program itself. We chose CV as our valuation method for mainly two reasons. First, CV elicits directly willingness to pay for the improvement of environmental quality, instead of deriving it indirectly from the demand for other market goods. Second, CV is the only technique which enables to capture both use and non-use values. S. Erasmo island, in fact, has very few historical or architectural features and is well known only to local lagoon excursionists. Non users, however, may well hold positive values for preserving S. Erasmo island. As in most recent high quality environmental surveys, we deployed dichotomous choice payment questions cast in a referendum format to elicit information about the willingness to pay. Respondents — randomly selected among the Veneto region residents — were interviewed over the telephone and were told about a hypothetical public program which should, if passed by majority vote, restore beaches, implement erosion control and improve island infrastructures. Moreover, we explored a methodological issue related to the provision of different information levels to the respondents before asking the payment questions. We examined the impact of different presentations of the benefits and costs of the program by means of a split-sample experiment. The treatment was meant to test the way, a different level of information may influence respondents' decisions in a telephone survey.

2.3 Results

The results of the CV experiment deal with the assessment of the WTP expressed by people living in the Veneto region in order to preserve S. Erasmo island. In order to obtain estimates of the mean and median WTP for the proposed policy, we assumed that WTP is distributed as a Weibull. We found that the mean WTP is €67 per household. Median WTP provides a robust lower bound equal to €20. Our WTP responses showed internal consistency, in that the WTP increases among those who know the island and, current use the lagoon, and while it increases with the expected use of S. Erasmo island, once the works have been completed, it decreases with the age of respondents. Moreover, the WTP depends in predictable ways on respondents' income, education and environmental organization membership.

Mean WTP varies considerably across households, depending on whether the household uses the lagoon for recreational purposes, and it ranges from €27 (for households expressing only non-use values) to €102 (for households expressing use values). Finally, reminding respondents about the advantages and disadvantages of the public works increases the WTP among non-highly educated respondents and decreases it among highly educated respondents. The different components of the Total Economic Value expressed by respondents, we found that mean WTP is respectively €102 for users (median WTP is €20.39), €87 for potential users (median is €29.53)and €27 for non-users (median is €9.24). Assuming that the option value is roughly the same for those who are current users and those who are not current users at present but they would be after environmental improvement on S. Erasmo island, we interpreted the amount of €27 as representing the existence and bequest value of the resource, €(102-87)=€25 as representing the use value of the resource and €(87-27)=€60 as being the upper bound of the option value of the resource itself.

Our estimates of the WTP expressed in order to preserve S. Erasmo island can be used to compute the program total benefits . The 2000 census reports that there are 1,719,811 households in the Veneto region. Hence, if the sample used in this survey is representative of the Veneto region population, the total benefits (in the Veneto region) arising from the program should be (66.60*1,719,811)=€114,539,412. A more conservative estimate of the benefits was obtained by using median WTP in lieu of mean WTP. In this case, a robust and conservative lower bound for the benefits accruing to the region residents is represented by the amount of €(20.39*1,719,811)= €35,066,946. These figures can be compared with of the public works cost in order to determine whether the policy passes a benefit-cost test.

3. Hedonic Valuation Experiment

3.1 Database

The database includes the technical and economic worth of the existing property stock and identifies the main intrinsic, extrinsic, technological and production variables which mostly contribute to the property value. First, surface and volume have been considered; then, the introduction of qualitative and quantitative variables has permitted buildings classification by type, age, historical value and position with respect to both the urban and environmental context of the island. The database includes all the buildings listed in the Venice General Urban Development Plan . Obviously, religious buildings such as churches and cemeteries, public schools and monuments (Torre Massimiliana) were not included in the database.

227 buildings were surveyed: the majority are recent residential buildings and traditional rural buildings, mainly built between the beginning of the 1940s and the beginning of the 1980s.

Almost all the buildings built before 1940 are of the rural type whereas buildings are mainly of the civil type. This result underlines the fact that agriculture was the main activity on the island until the and 2) second world war when there was a progressive abandonment of agriculture in favour of employment in the industry (Murano glass factories) and services sector (tourism).

The 27% of the buildings (rural dwellings and old military buildings) has some sort historical value. Over 75% of the buildings are located near the shoreline and most of them (50%) are on the side facing the lagoon and have a view on Venice, Burano and San Francesco del Deserto. Nearly all of the buildings have a garden or a piece of land around them. The buildings size is fairly small, the average is approximately 743 m^3 and almost 85% of them have one or two stories.

The state of the buildings is extremely various: alongside many buildings which are in precarious conditions, there are many examples of well preserved buildings both as far as regards the structural point of view on one side and the technological systems and finishes on the other one. This certify a dynamic situation, where the susceptibility to improvement is very high, due also to the protection operations now in progress.

3.2 Methodology

A hierarchical analysis was performed to assess the effects on housing deriving from the protection operations. Once it was ascertained the impossibility of using both econometric procedures and hedonimetric techniques to assess respectively property value- environmental improvements effects on property value, a hierarchical approach was developed in order to estimate value functions on the basis of judgements formulated by experts. This approach enabled to make up the deficit of information in order to build the appraisal model and represents an acceptable compromise between completeness and reliability of the moldel outputs. This technique is widely used in many applications, both in public and private evaluations, e.g. in the evaluation of environmental damages.

Hierarchical analysis has, moreover, been widely used in the assessment of environmental protection operations. As far as regards the analysis and the estimation of property values the hierarchical approach has been adopted on the one hand as a technique subordinated to others – it has been used for example to back up multiple regression analysis in order to transform qualitative variables into quantitative variables, and on the other one as a pluriparametric appraisal procedure in the presence of both non-homogeneous samples and markets mainly influenced by qualitative variables.

This approach uses a multi-attribute evaluation model to estimate a value function according to experts' judgements and calibrates it on the basis of market data available.

3.3 Results

An estimate of the expected increase in property value was derived. The increase was obtained by comparing the values estimated taking into account the effects on the variables state induced by the operations.

The value of the property stock amounts overall to 85 million €:58.1% of which is represented by residential buildings built during the second half of the last century. In terms of value, traditional rural buildings and residential buildings in precarious conditions represents respectively 24.7 % and 7.9 %of the overall value.

As a consequence of implementation of the safeguard operations, the stock value amounts to 112.5 million €. So that, the increase in property value which arises thanks to the protection operations amounts to over 27.4 million € (32% of the current value). The average increase per building is approximately 121,000 €. This is a considerable increase, which can be interpreted on the basis of the following considerations:

1. the island's environmental and infrastructural situation is at present fairly precarious;
2. the improvement that can be achieved as a consequence of the scheduled operations is substantial;
3. the extrinsic variables play an important role on the formation of the property value.

The results show that the island's property stock is highly sensitive to environmental and infrastructural qualification operations and to the improvement of accessibility from the outside. By improving the accessibility the operations will promote an increase in the demand for property, still sporadic and of the niche type.

The increase in the buildings' value can be mostly attributed to the considerable improvements of environmental quality and accessibility resulting from the operations. The model shows that the improvement of accessibility plays an important role which can be explained by the relative importance attributed to this variable, and in particular to the accessibility to the island by private individuals. The change in the status of the variable "private external accessibility", poor before the operations' completion and good after it, has a key-role in the evaluation model: the marinas rehabilitation, the creation of new berths and the construction of new moorings, boat shelters and small slip-ways should presumably lead to an increase in potential demand by both residents and owners of holiday homes and should facilitate connections by means of private vessels between the island and the work and service poles.

On the contrary the value increase due to the improvement in services provision should be fairly limited.

The contribution to the increase in property value due to the reduction of the high water frequency should be not very significant for mainly two reasons: the majority of the buildings (approximately 60%) is located in areas in which, for favourable altimetric conditions, the high water estimated return is over ten years; the island is not currently subject to substantial flooding due to overspill been flooding due to the poor condition of the internal drainage network.

Any improvement of environmental quality, on the other hand, accounts for the most significant increase in property value, given the considerable importance attributed to the environmental quality variable and in particular to the landscape and healthiness variables, whose status improve significantly from poor to good. This reflects the fact that the local market is basically a holiday home market and the demand is represented by Venetians who are willing to pay in order to purchase properties located in areas of the island which can be considered the best in terms of environment and landscape.

4. Policy implications

WP2 research involved some relevant policy implications.

1) CV experiment on the WTP for S. Erasmo environmental preservation focused on the role of information in decision processes, and hence in consensus, about similar

public programs. In fact, our esteems proved that the level of available information is positively related with the WTP express by non- highly educated respondents: therefore, -a higher level of information might highlight the benefits of the safeguard program which non-highly educated people may be not aware of. Consequently, giving a proper information about the interventions is definitely convenient, as to assure the involved community about fairness and transparency of each phase of the program implementation (from preliminary political negotiations, up to works development and management steps). An information-oriented policy is particularly strategic with public programs involving the Venice lagoon, because of the large expenditures for interventions development, their pervading characteristics and the numerousness of potentially involved people

2) Non direct use components are very relevant within the total economic value assessed by the CV experiment on the WTP for S. Erasmo safeguard program. In particular, option price is prevailing among other non use value components, i.e. bequest and existence values. This issue can be even derived from some considerations about the sample selection, as use values are limited to those who are residents in Venice and in neighbouring areas, while residents inother areas are likely to experience primarily non use values. The 2001 census reports that there are around 1.720.000 households in the Veneto region. Hence, assuming the sample used in this survey is representative of the population of the region, the total benefits accounted for the Veneto region arising from the program completion are about 114,6 million €s. With regards to only the Venice lagoon current users, the total benefits are about 40,8 million €s. Though, a conservative estimate of the benefits could be obtained by using median WTP in lieu of mean WTP. In such a case, esteems would amount to 35,1 million €s and 13,8 million €s respectively. Finally, with regard to this case study, it was found that option price, existence and bequest values are very relevant components of the total economic value; hence, we argue that non use values can conveniently contribute to make the safeguard program pass a CBA test.

3) The environmental preservation program produces relevant effects not only on recreational users but also, directly, on the island itself. We assessed such an effect from the spin offs in property value after the safeguard works implementation: it amounts to 27,4 million €s and it stands comparison with CV esteems. Note that monetary assessment of local effects caused by the safeguard program can be interpreted as a strategic way to meet with approval within residents' community, both for stating and carrying out the program objectives. Property assessment let us to pinpoint on which intervention is likely to produce the most relevant growth in the property value, and hence is likely to have a greater impact on individual benefits realisation. It was found that the greater improvement on S. Erasmo condition does not derive from protection against flooding due to high water and to filtration processes, but jointly from the improvement in both accessibility and environmental quality. In fact, these operations should positively affect both the residents' quality of life and the island's recreational value. The island should become a more attractive place to live and this should encourage a series of positive interactions leading to an increase in the demand for refreshment and accommodation on the island. Obviously this implies a change in the island's economic activities towards the services sector. However, such an impressive

trend could lead rural activity to marginality, and consequently, to further environmental degradation and land abandonment (neglected fields, dismantled agricultural facilities).

Both suitable urban planning and rural development policies are, therefore, required to rule such a transition phase and assure the proper integration between rural activity and service sector.

5. Papers

Within the research activities of WP2, the following papers were produced[3]:

Alberini A., Galvan A., Longo A., Rosato P., Zanatta V.: **"Willingness to Pay for the Venice Lagoon System. Are the Numbers for S. Erasmo?"**, Paper presented at Fondazione Eni Enrico Mattei, Venice, 17th December 2002.

Abstract: This paper reports on a contingent valuation study that elicits willingness to pay for a public program for the preservation of lagoon, beach and infrastructure in the island of S. Erasmo in the Venice Lagoon.[4]

We chose Contingent Valuation (CV) as our valuation method for two reasons. First, CV elicits directly willingness to pay for the improvement in the environmental quality, instead of deriving it indirectly from the demand for other market goods. Second, CV is the only technique that captures use and non-use values.

As in most recent high quality environmental surveys, we deploy dichotomous choice payment questions cast in a referendum format to elicit information about willingness to pay. Respondents—randomly selected among the residents of the Veneto region—were interviewed over the telephone and were told about a hypothetical public program that would, if passed by majority vote, restore beaches, implement erosion control, and improve infrastructure on the island.

The purpose of this paper is two-fold. First, we wish to obtain willingness to pay for the population of (broadly defined) beneficiaries of the program in order to conduct a cost-benefit analysis of the public works program. We focus on S. Erasmo because it is one of the several islands in the Venice Lagoon suffering from erosion problems and a lack of adequate infrastructures and services. Moreover, S. Erasmo has a very few historical or architectural features, and is well known only to local lagoon excursionists. Non users, however, may well hold positive values for preserving S. Erasmo. S. Erasmo is, therefore, a good candidate for distinguishing between use and non-use components of the total economic value of an island of the Venice Lagoon.

Second, we explore a methodological issue related to the provision of different levels of information to respondents before asking the payment questions. We examine the

[3] For copies of these papers, please contact the editors or martina.marian@feem.it

[4] The method of Contingent Valuation (CV) is a well-established technique used to assign a monetary value to non–market goods and services, such as environmental resources (Mitchell and Carson 1989). CV is a survey based technique, in that it asks individuals to report their willingness to pay for a specified and hypothetical improvement in environmental quality. Willingness to pay is defined as the amount of money that can be taken away from a person's income at the higher level of environmental quality to keep his utility constant. It is, therefore, the theoretically correct measure of the welfare–and hence the benefits–associated with the change in environmental quality.

impact of alternative presentations of the benefits and costs of the program using a split-sample experiment. Specifically, we split the sample of respondents into two subsamples: the first group of respondents received the standard format of the questionnaire, while respondents in the second group received a reminder of possible reasons for voting in favor or against the proposed program before the referendum question. The purpose of this treatment is to test how in a telephone survey a different level of information might influence respondents' decisions.

We find that mean WTP for the S. Erasmo public works is €67 per household. Median WTP provides a robust lower bound equal to €20. Mean WTP varies considerably across households, depending on whether the household uses the lagoon for recreational purposes, and ranges from €27 (for a household with non-use values only) to €102 (for a household with users). Willingness to pay increases with use, knowledge of the island, environmental membership of the respondent, income, and education, but decreases with the respondent's age. In addition, reminding respondents of the advantages and disadvantages of the public works increases WTP among less highly educated respondents, and decreases WTP among more highly educated respondents.

Alberini A., Longo A., Rosato P., Zanatta V.: **"Il Valore di Non uso nell'Analisi Costi Benefici della salvaguardia ambientale"**, (forthcoming in Aestimum).

Abstract: L'analisi costi benefici (ACB) è il metodo più usato per la valutazione della convenienza degli investimenti pubblici per la tutela dell'ambiente naturale e costruito. Tuttavia, l'impiego pratico dell'ACB può diventare problematico a causa delle difficoltà nella stima del valore monetario dei beni ambientali pubblici. Tali problemi sono connessi con alcune peculiarità dei beni ambientali, quali: a) la natura meritoria[5], b) il peso, talora rilevante, delle componenti di non uso nel valore economico totale (VET), e c) la sostanziale assenza, o inefficienza, di mercati specifici.

Nella secondo metà del secolo scorso sono stati ideati e sviluppati numerosi metodi per attribuire un valore monetario ai benefici prodotti dai beni ambientali. Fra tutti, il metodo della valutazione contingente (CV) (Mitchell e Carson, 1989) è il più utilizzato negli ultimi anni, ed è quello che ha registrato i maggiori sviluppi metodologici. La CV assume che l'incremento di benessere percepito dal consumatore possa essere stimato a partire dall'esborso monetario che produce un effetto uguale e contrario sul benessere del consumatore stesso, ovvero uguale al surplus compensativo (CS) (Hicks, 1943). Recentemente, tale esborso (WTP) viene normalmente stimato con modelli statistici a utilità casuale (RUM) a partire da interviste dirette su un campione rappresentativo della popolazione coinvolta (Hanemann, 1984; McFadden, 1974).

Nell'ambito degli sviluppi teorici e metodologici della CV una significativa attenzione è stata posta sulla definizione e valutazione delle diverse componenti del VET, dato che la CV è il metodo più adatto a cogliere le componenti di non uso e che queste ultime, spesso, sono determinanti nel decretare la convenienza degli investimenti volti a preservare beni ambientali pubblici di grande significato simbolico. Il dibattito teorico e metodologico sul significato dei valori di non uso e sulla effettiva possibilità di misurarlo è tuttora piuttosto vivace (Nelson, 1997), e si è ancora lontani dal raggiungere

[5] Il bene meritorio è un bene che viene offerto non sulla base delle preferenze del consumatore ma "coercitivamente" imposto sulla base delle preferenze dell'offerente (decisore pubblico). Vedi Musgrave (1959) e Roskamp (1975).

sia una comune tassonomia (Albani e Romano, 1998) sia un metodo di stima condiviso (Cummings e Harrison, 1995).
Il presente lavoro, dopo aver richiamato gli aspetti più significativi del dibattito teorico riguardante la considerazione dei valori si non uso nell'ACB, riporta e commenta i risultati di uno studio di Valutazione Contingente per la stima di alcuni benefici derivanti da un programma pubblico di interventi di salvaguardia ambientale presso l'isola di S. Erasmo nella Laguna di Venezia. In particolare, illustra alcune peculiarità metodologiche per la stima dei valori di uso e di non uso dell'isola lagunare ed evidenzia che solo la considerazione dei valori di non uso permetterebbe al programma di interventi di superare il test dell'analisi costi benefici. L'articolo inoltre illustra un esperimento per valutare l'effetto di alcuni aspetti cognitivi sulla disponibilità a pagare. Tale esperimento valuta l'effetto dell'elencazione delle ragioni per votare a favore o contro gli interventi descritti nello scenario ipotetico.

Alberini A., Rosato P., Longo A., Zanatta V.: **"Information and Willingness to Pay in a Contingent Valuation Study: The Value of S. Erasmo in the Venice Lagoon"**, Paper presented at 12th Annual EAERE Conference, Bilbao, Spain, 28-30 June 2003 and at Workshop "Information and Economics", Copenaghen, Apr. 2003

Abstract: This paper reports on a contingent valuation study eliciting willingness to pay for a public program for the preservation of lagoon, beach and infrastructure in the island of S. Erasmo in the Lagoon of Venice. A referendum dichotomous choice approach with a follow-up question is used to obtain information about willingness to pay from a sample of residents of the Veneto Region in Italy.
We use split samples to investigate the effect of providing different levels of information to respondents before asking the payment questions. Our experimental treatment is a reminder of possible reasons for voting in favor or against the proposed program before the referendum question. We find that reminding respondents of the reasons for voting for or against the public works increases WTP among less highly educated respondents, and decreases WTP among more highly educated respondents.

Alberini A., Longo A.: **"Valuing Environmental Resources Using the Method of Contingent Valuation"**.

Abstract: Contingent Valuation is a method of estimating the value that a person places on a good. The approach asks people to directly report their willingness to pay (WTP) to obtain a specified good, or willingness to accept (WTA) to give up a good, rather than inferring them from observed behaviours in regular market places.
Because it creates a hypothetical marketplace in which no actual transactions are made, contingent valuation has been successfully used for commodities that are not exchanged in regular markets, or when it is difficult to observe market transactions under the desired conditions.
Although it is certainly possible to employ contingent valuation for commodities available for sale in regular marketplaces, many applications of the method deal with public goods such as improvements in water or air quality, amenities such as national parks, and private non-market commodities such as reductions in the risk of death, days of illness avoided or days spent hunting or fishing.
Contingent valuation has proven particularly useful when implemented alone or jointly with other valuation techniques for non-market goods, such as the travel cost method or

hedonic approaches. It remains the only technique capable of placing a value on commodities that have a large non-use[6] component of value, and when the environmental improvements to be valued are outside of the range of available data.
Much controversy surrounds the use of CV when most of the value of the good derives from passive use, as has been typical in litigation over the damages to natural resources and amenities caused by releases of pollutants. Critics of contingent valuation allege that the quality of stated preference data is inferior to observing revealed preferences, consider contingent valuation a "deeply flawed method" for valuing non-use goods and point at the possible biases affecting contingent valuation data (Hausman, 1993).
Despite these criticisms, CV has formed the basis for a significant amount of policymaking in the US (see Cropper and Alberini, 1997, for examples). Proper application of contingent valuation can provide valuable information to policymakers and agencies seeking to evaluate the benefits of interventions and public programs.

D'Alpaos C., Marella G. e Rosato P.: **"La valutazione ex-ante degli effetti sul valore immobiliare di interventi di salvaguardia ambientale: un approccio gerarchico"**, Atti del XXXIII incontro del Ce.S.E.T. "La valutazione degli investimenti sul territorio", Venezia, 11 ottobre 2002.

Abstract: Monetary assessment of the environmental protection operations is a highly topical subject which, over the last twenty years, has generated an impressive number of methodological and application studies. Among the methods proposed, particular importance should be given to those that derive the monetary value of the environmental goods from the variations induced in the market value of private goods, first and foremost residential property. The house is a complex good, whose value depends on numerous factors, one of the most significant being the quality of the environment and the services available in the area. Immobility makes property value very sensitive to externalities (Curto, 1993; Rosato and Stellin, 2000). The analysis of property value and the factors that contribute to its formation is a very useful tool for identifying and assessing social appreciation of the protection of environmental resources (Garrod and Willis, 1992; Scarpa, 1995; Chattopadhyay, 1999).
This study concentrates on the operations for protecting the island of Sant'Erasmo, in the Venice Lagoon against high water. The island is characterised by a limited number of properties and few purchase and sale transactions; it is currently affected by extensive decay, going back to the disastrous flooding of 1966, due to the lack of an organic programme of work designed to protect the island from the phenomenon of high water and, above all, to revitalise the area by means of urban planning schemes and the development of services.
This study aims to assess the effects of the protection operations provided for by the programme agreement, promoted by the Water Board, the Venice Municipal Authorities and Consorzio Venezia Nuova, on the overall property of the island of Sant'Erasmo, in an attempt to ascertain the repercussions of the externalities deriving from implementation of the protection operations on the value of the buildings on the island in the context of the local property market which is far from lively, and characterised by

[6] Non-use values relate to the utility that a person experiences from knowing that a natural resource or amenity exists and may be experienced by other people or future generations, even though he/she has never visited it nor plans to.

very few sale and purchase transactions, making it impossible to use econometric procedures which are demanding in terms of data.
The approach adopted aims to pursue the following main objectives:

1. to permit sufficiently reliable applications of mass appraisal with regard to property markets characterised by a low level of transparency and rare sale and purchase transactions;
2. to provide a support for cost-benefit analyses, in terms of monetary measurement of the increase in collective wellbeing deriving from policies or public works characterised by strong externalities (Smith, 1992);
3. to define procedures for the development of transfer value functions, which can be extended and applied – with appropriate adaptations – also to other property markets comparable as regards environmental characteristics and socio-economic conditions (Desvousges *et al*., 1992; Loomis, 1992).

D'Alpaos C., Marella G.: **"Gli interventi di Salvaguardia nell'isola di Sant'Erasmo"**.

Abstract: L'isola di Sant'Erasmo è definita nell'articolo 12 del Piano di Area della Laguna di Venezia e dell'Area Veneziana (P.A.L.AV.) come "isola della laguna" stabilmente abitata. Il Piano di Area, previsto dal Piano Territoriale Regionale di Coordinamento (P.T.R.C.), è stato redatto per orientare gli interventi della Regione verso gli obiettivi di salvaguardia, tutela, ripristino e valorizzazione delle risorse che caratterizzano gli ambiti di valore naturalistico, ambientale e paesaggistico della Laguna di Venezia.
La variante al Piano Regolatore Generale (P.R.G.) è stata pertanto disposta per permettere l'esecuzione in tempi brevi degli interventi previsti dal Piano in modo da garantire la salvaguardia dell'isola e di arrestare il processo di degrado in atto.
Il Magistrato alle Acque di Venezia, il Comune di Venezia e la Regione Veneto hanno deciso di intervenire con una serie di opere da eseguire in tempi brevi, individuando 7 AREE di proprietà pubblica e/o privata nelle quali si prevede di operare tramite l'adozione di Progetti Unitari (P.U.).
Il piano degli interventi prevede, infatti, di operare in modo organico e sistematico nella quasi totalità dell'isola. Il suo obiettivo primario è il raggiungimento della quota di salvaguardia di +1.60 m s.m.m. nei confronti di fenomeni di allagamento da sormonto e di allagamento da filtrazione. In secondo luogo gli interventi saranno volti al ripristino dell'equilibrio idrogeologico della laguna e all'inversione del processo di degrado del bacino lagunare.
In questo studio si sono descritti in maniera puntale gli interventi previsti nell'Isola di Sant'Erasmo e si sono analizzati le diverse tipologie di costo, distinguendo tra il costo immediato di produzione, e i costi differiti di gestione e manutenzione degli interventi di salvaguardia.

Defrancesco E., Rosato P.: **"Individual Travel Cost Methods and Flow Fixed Costs"**, Feem Working Paper, 2002.

Abstract: The paper proposes an approach for evaluating the effect of flow fixed costs on the evaluation of environmental benefits with travel cost method. On a full annual perspective when recreational users incur relevant annual direct fixed expenses, their behaviour could be influenced by them. The approach introduces a) the notion of the

minimal number of annual visits that justifies the annual fixed expenses incurred by the user and b) a method to estimate it. The estimate of this minimal number permits to forecast the user behaviour on a full annual perspective, taking into account a more accurate estimate of the number of visits at different additional fees.
Travel cost method (TCM) has been developed by Clawson [1959], initially suggested by Hotelling [1949], in order to estimate social benefits from recreation in natural sites. The method is based on the assumption that the recreational benefits in a specific site can be derived from the demand function, estimated observing users' behaviour, in relation to the costs sustained by them per number of visits. In other words, the classical model derived from economic theory of consumer behaviour postulates that a consumers' choice is based not only on price but on all sacrifices made to obtain the stream of benefits generated by a good or service. Obviously, if the paid price (p) is the only sacrifice made by consumer, the demand function for a good, with no substitutes, is $x=f(p)$, given his income and preferences.
However, the consumer often incurs other costs (c), in addition to the paid price, i.e. disbursements, travel expenses, time loss and stress from congestion and/or competition, e.g. crowded local markets.
The aim of this paper is to propose a modified ITCM approach, taking into account flow fixed costs. A full annual perspective, in our view, when recreational users incur relevant annual direct fixed expenses, their behaviour could be influenced by them, on a full annual perspective. As a result, the agency managing a natural site for outdoor recreation should use caution when valuing recreational users surplus, which has to be estimated on a full annual perspective, mainly in order to define a proper fee policy.

Defrancesco E., Rosato P., Rossetto L.: **"Economic Valuation of Environmental Goods: the Appraisal Approach"**.

Abstract: Valuation of environmental goods is a theoretical, methodological and operational topic of great relevance today. Safeguarding of environmental resources is based on the use of appropriate valuation methods. Though, the operating approaches in valuating the environment have not yet been fully defined; actually is rapidly evolving.
The analysis is based on the awareness that the environmental good often has a multiple nature, and that each component can create, with the market goods, links expressing appreciation, even if indirectly. For this reason, the synthesis between economic theory and appraisal practice adopted has been inspired by the so-called "dual approach" which aims to estimate the environmental good, as far as possible, from the modifications induced in the behaviour of the individuals involved. This approach, although partial, has the advantage of referring to real behaviour, objectively observable and measurable, therefore ensuring reliable valuations at operational level. Moreover, this appears to be the direction taken by both the EU law proposal concerning environmental damage and the United States proposal which permits the use of contingent valuation techniques under rigorous procedures, established by the NOAA (Helton et al.,1999), and when damage is acute and irreversible.
It should also be underlined that the operational approach proposed does not claim to be conclusive at the theoretical level: on the one hand because it tries, pragmatically, to take account of the constraints linked to the complexity and cost of reaching adequately reliable estimates, and on the other because we are aware that the process of valuation

itself is subject to modifications, owing to methodological, operational and, above all, cognitive progress which is continuously evolving.
The study presents a summary of the results of an in-depth theoretical-methodological investigation of the use of appraisal methods in the valuation of public goods in general and environmental ones in particular and it summarises the appraisal criteria for estimation of economic goods in the light of the problems encountered in evaluating environmental goods.
Last but not least this work outlines the methods for valuating the environmental public component in the theoretical framework of the welfare economics and it is aimed to provide sufficiently reliable operational advices for practical use.

Romano D.: **"An Assessment of Italian Environment Valuation Studies, with Emphasis on CVM"**. Paper presented at workshop "Economic Valuation of Environmental Good", Venezia, 11 May 2001.

Abstract: The purpose of this paper is the assessment of environmental studies carried out so far in Italy, with special emphasis on CVM studies, using in the latter case the framework originally proposed by Mitchell and Carson (1989).
Italian contributions in the broader field of non-market goods evaluation generally present a time lag with respect to the "frontier" at international level, which in the last years has been reduced by means of an increase of the rate at which the results published in the international literature have been transferred to the Italian context. The Italian "production" totals 72 studies (52 of which published over the last ten years), a slightly majority of which empirical (53% vs. 47%).
CVM applications to the environment are late-comers in the Italian environmental and natural resource economics literature. The first study appeared at the end of eighties and by now, 26 studies have been published. Early CVM studies presented the same characteristics of early CVM studies appeared in the international literature: they focused mainly on use values, and on more evident environmental benefits (e.g. outdoor recreation). More important, they shared the same flaws with foreign early applications: little attention seems has been paid to validity and reliability issues, although the quality standards of these studies has been improving during the nineties.
The early perplexities about the Contingent Valuation Method (CVM) date back to 1947, when its original proponent, S. V. Ciriacy Wantrup, while suggesting the utilisation of the method to measure extra-market benefits from soil conservation, also conceived its limits, overall the danger of respondents' strategic behaviour. Ciriacy-Wantrup, however, thought that such issues could be avoided, or substantially reduced, through a well designed questionnaire. These two intuitions provided the basis for both the core for subsequent critiques and the direction for research aimed at improving the CVM performance.
In the half a century since its conception, CVM as well as its critics have been greatly developed (see, among others, Cummings et al., 1986; Mitchell and Carson, 1989; Hausman, 1993; USDC-NOOA, 1993; Hanemann, 1994; Hanemann and Kanninen, 1999). Many problems remain unsolved, but many researchers are confident in the potential of the method to provide valid and reliable measures of the economic value of natural resources.

Zanatta V.: **"Cognitive and Response Effects in Contingent Valuation Studies: A Review"**.

Abstract: Some important studies of last decade demonstrated that the value assessed by CV can be sensitive to theoretically irrelevant factors and insensitive to theoretically relevant ones. For example, response modes, referred as different methods for eliciting preferences, can affect the results of CV (McFadden and Leonard, 1993; Swallow, Opaluch and Weaver, 1997; Blamey, Bennett and Morrison, 1999). Moreover, answers seem widely affected by respondents' moral satisfaction when they accept to pay for a symbolic amenity instead of for the specific level of provision described in the CV scenario (Kahneman and Knetsch, 1992; Brekke and Howarth, 2000). But where does such effects come from? What are psychological mechanisms these biases derive from? The present paper links some evidences from cognition process, decision making and answering formation, to some CVM common biases, as to introduce a theoretical and methodological basis for case study experiment.

This work is focused on what a respondent may be thinking while answering a WTP question, and on the most relevant bias in CV studies deriving from psychological response effects in survey-based searches. The aim of the present analysis is reviewing some applications which could make able in controlling what CV really estimates.

This paper reports the more relevant notes about psychological bias involved in CV responding, in order to exploit the interdisciplinary debate still in act, and to register the survey improving (and thus the quality of the monetary estimates). Using a vast literary data collection, both methodological and critical, the paper presents a general introduction about the psychology of survey response (particularly about mental response process) , and then offers a taxonomy of the most relevant psycho-related bias in CVM studies. Moreover, relevant theoretical and methodological innovations are briefly noted. In the conclusions, two CV experiments (now in progress[7]) about WTP for Venice Lagoon safeguard are introduced. The first one is a typical CVM scenario modification on a split-sample, just to test if WTP increase while more information (in the present case, about different aspects of VET) are being provided.

[7] The experiment is being applied among CORILA "Economic Valuation of Venice Lagoon Safeguard" Research Line 1.1, Working Package 2.

EVALUATION OF BROWNFIELD REDEVELOPMENT PROJECTS
EL.GI.R.A. A KNOWLEDGE SUPPORT PROCEDURE FOR THE PORTO MARGHERA BROWNFIELDS (VENICE)

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Introduzione

EL.GI.R.A. è una procedura orientata alla valutazione economica degli interventi di bonifica nelle aree industriali e di aiuto alla conoscenza di contesto che, partendo da scenari d'area, vincoli e accordi generali, consente di valutare interventi puntuali e i loro effetti areali. La procedura è attualmente applicata a Porto Marghera (Venezia). EL.GI.R.A è l'acronimo di ***Electre***, ***Giuditta***, ***Rec*** e ***Aures***, modelli analitico-valutativi disposti in sequenza.

L'avvio della procedura é costituito da scenari relativi a Porto Marghera, importati dalla Variante generale al PRG per la Terraferma del Comune di Venezia, dall'Accordo per la Chimica, dagli studi preliminari al Master Plan, appena conclusi, e da altre 'visioni' o proposte in discussione (ad esempio l'accordo sulla impermeabilizzazione delle sponde dei canali portuali che ripropone l'alternativa o la combinazione fra tecniche di messa in sicurezza e bonifiche dei suoli inquinati). Gli scenari propongono 'pattern di uso del suolo' coerenti con il futuro della zona industriale e portuale. Le ipotesi a confronto sono diverse e non necessariamente disgiuntive: città industriale post-fordista, città della scienza, città 'fondaco' (o dell'ospitalità), restauro ambientale-territoriale, ognuna con destinazioni d'uso prevalenti.

La procedura viene applicata come esempio alla zona '43 ettari' per la quale si dispone della matrice di caratterizzazione ambientale. Sulla base della matrice, descritta da categorie di contaminanti e fornita dal Sis del Comune di Venezia, si avvia un primo *screening* delle tecnologie (processi) di bonifica (*in situ*, *ex situ* o miste). Le *performance* delle tecnologie selezionate sono misurate su criteri di tipo tecnologico, ambientale, sociale ed economico-finanziario. La matrice di *performance* viene trattata con procedure *Electre II e Prometheè.* L'ordinamento (la cui robustezza é testata con analisi di sensitività) consente di isolare le tecniche preferibili. La matrice di caratterizzazione ambientale costituisce l'input principale di *Giuditta*, procedura finalizzata all'analisi del rischio. Le elaborazioni di *Giuditta*, assieme ad informazioni specifiche di caratterizzazione ambientale interpolate con *MoDe* (automa cellulare), vengono quindi ospitate nel programma *Rec* che genera tre indici normalizzati di riduzione del rischio, di merito ambientale e di costo. I tre indici sono riferiti a valori massimi ammissibili delle concentrazioni, ma anche a diverse metodologie di calcolo dei parametri valutativi. *Rec* produce anche output supplementari utili alla valutazione finale, come il differenziale di rischio (confronto fra stato iniziale e finale), i differenziali di concentrazione delle sostanze inquinanti, il profilo dei costi finanziari delle singole opzioni di bonifica, l'energia consumata dalle tecniche. I risultati riferiti a singoli lotti o ad aree più estese (catturando effetti di propagazione spaziale con l'aiuto di *Aures*) vengono sottoposti a valutazione multicriteriale di sintesi.

La procedura completa (già testata su alcuni contaminanti) ha la finalità di fornire un quadro il più possibile completo ed approfondito sullo stato di degrado dell'area e delle modalità di intervento più opportune per la sua riqualificazione e ad orientare successive analisi finalizzate alla stima dei benefici economico-sociali degli interventi di bonifica .

1. Objectives

EL.GI.R.A. is a procedure designed to assess rehabilitating intervention within the highly contaminated industrial zone of Porto Marghera (Venice – Italy). It is an acronym which stands for a sequence of models *Electre*, *Giuditta*, *Rec* and *Aures*. Upgrading scenarios are assumed as operational sources, mainly as functional land use patterns, sketched by the Master Plan of Venice Municipality, the Agreement on Chemistry, preliminary outcomes of studies and analyses for the new Master Plan of the industrial zone and other visions. A recent agreement on impermeabilization of the port canal banks sets the question of alternative or combined rehabilitation techniques.The procedure under discussion is tested in a sample area (called '43 hectares'), a very contaminated site by Ipa and heavy metals, located in the middle of the industrial zone. Its spatial contaminant matrix is provided by the Land Information System (Lis) of Municipality of Venice.

The test begins with a screening of suitable technologies (on site, off-site or mixed) based on technological, environmental, social, financial and economical performances. The performance matrix (set up using data from literature and Vesta local experience) is processed with the help of *Electre II*, a multicriteria evaluation technique based on concordance/discordance analysis which provides a preliminary rank of technologies. The contaminant matrix is spatially interpolated with *Mode* (a cellular automata model) whenever the grid lacks for enough density. Based on performances of selected technologies, *Giuditta* develops a risk analysis whose outcomes become input to *Rec*, a program which generates three normalised indexes on Risk reduction, Environmental merit and total Costs. These indexes do refer to maximum concentration thresholds by single or clusters of contaminants. *Rec* supplies additional information for an overall assessment of incremental risks (before/after comparison), differences in contaminants concentrations, financial cost profiles by rehabilitating intervention and related energy consumption.Catching spatial effects of rehabilitating interventions with the help of *Aures* (another cellular automata model) is the final step the procedure whose aim is to estimate net benefits within surrounding urban areas: in terms of changes of real estate values, attractiveness, land appeal, location preferences of city users and other engaged actors.

2. Database

The main databases produced during the area test refer to the environmental characterization, remediation techniques and final output of the evaluation procedure.

The first one provides spatial data as a result of a specific elaboration of SIS databases, available at the Venice Municipality, Department of the Environment and the Land Security. The SIS data employed in the sampling point map generation (used in the MODE interpolation, whenever necessary) are *coring analysis*, *coring geographical location* and *contaminants concentrations*. Such data are operational inputs to the human risk assessment (Giuditta) as well as to the area pollution module.

Looking at Porto Marghera Master Plan (2002), which identifies brownfield remediation scenarios and actions, a set of suitable technologies has been screened out to estimate the compromise among financial cost of rehabilitating process, residual risk and environmental merit. The technologies considered are thermal desorption, soil washing in one or two lines, capping and land-fill. Every technology profiles (describing performances, constraints, impacts and cost) has been set up according to the REC input format.

In particular, outputs and outcomes from Giuditta and REC modules are organized in a specific data bases.

Specifically, Giuditta data bases describe cancerogenic risk for industrial and residential use with reference to four population categories, namely workers, residents, adults and child. More, Giuditta provides matrix of hazard indexes for any contaminant related to the users and population categories mentioned above.

On its turn, REC generates indexes for pollutants, estimates of risk by land use classes and remediation process in relation to legal limits. Besides, it provides a data series on concentration reduction over the upgrading project life cycle.

Finally, information on impacts of remediation techniques are available over a set of nine criteria, namely soil and groundwater quality, soil and groundwater losses, energy consumption, air, surface and water emissions, waste formation, and surface of land used.

3. Methodology

What has been described so far might be considered as a flexible contextual knowledge support procedure (Ksp). It has been set up and preliminarily tested with actual data in one sample area. Additional tests are in progress within and outside the Porto Marghera mega-site. Based on a wide review of existing models, the procedure develops the above mentioned sequence of analytical and evaluation modules.

During the preliminary test in a zone called ’43 hectares’, a number of remediation techniques have been screened based on an environmental matrix. That gives a complete list of contaminating residues (then classified) as detected through surveys by private and public enterprises in different periods. The residue classification contributes to shorten the list of techniques locally suitable.

The assessment of selected remediation techniques is done against a set of criteria related to technological, economical, social and environmental factors.

For this purpose, an Electre (and Promethée) ranking procedure has been designed. Besides, a partial multicriteria aggregation, based on dominance test, generated inputs suitable to carry out a scenario-led sensitivity analysis on weight vector, performances and thresholds. The output (that is a final pre-order outranking) became the input to Giuditta, an experimented procedure already in use by public institutions which is mainly oriented to health risk analysis. The results of such an analysis have then been hosted within Rec model and adjusted via interpolation with the help of cellular automata (Aures): and that only in case of scanty information of the environmental matrix. On its turn, Rec generates three normalized indexes of risk mitigation, environmental merit and final cost. Rec creates even supplementary outputs for a final evaluation such as risk differentials (before/after intervention), variation of residue concentrations, and financial cost profiles for each option, energy consumption included.

At the end of the procedure, effects by single plot or wider areas are ready to be aggregated with a second (and final) step of a multicriteria analysis. Aures might help to catch possible spatial regimes or effects following peculiar directions within neighbouring urban and natural areas.

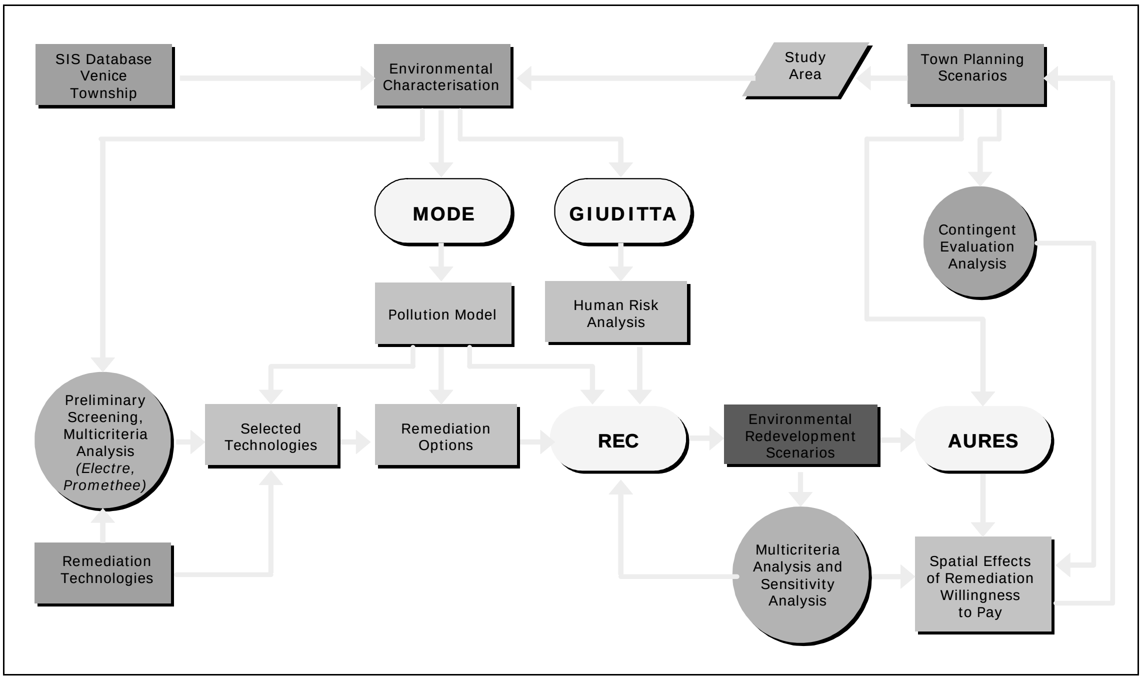

Fig 1 - General structure of ELGIRA model.

4. Results

Elgira is still under test as a general procedure, by single module (related links included) and in different contaminated areas.

Tests have been run by alternative remediation options following a strategy of risk reduction. Risk reduction evaluation has been performed by defining the following three scenarios:

1. *Industrial* with an "urban or industrial" exposure scenario for ecological risk evaluation.
2. *Agricultural* with a "countryside" exposure scenario for the same ecological risk.
3. *Natural* with a "natural area" exposure.

During the final evaluation, the single scenarios have been combined to shape four overall scenarios.

1. *Industrial, commercial, and office complexes* which combines together scenarios with the same name from environmental merit and cost module and the industrial–urban scenario from risk reduction module.
2. *Residential* which combines together the industrial–urban scenario from risk reduction module, residential scenario from the environmental merit module, and the industrial, commercial, and office complex scenarios from costs module.
3. *Agricultural* which combines together agricultural scenario from risk reduction module, residential scenario from environmental merit module, and industrial, commercial, and office complex scenarios from costs module.
2. *Natural* which combines together natural scenario from risk reduction module, residential scenario from environmental merit module, and industrial, commercial, and office complex scenarios from costs module.

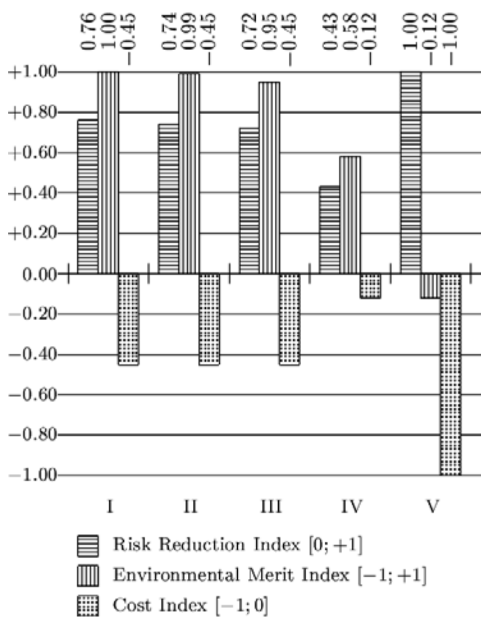

Fig 2 - *R*, *E*, and *C* indexes for the *industrial, commercial, and office complexes* ("I") scenario. The Roman numbers identify the following 5 remediation options (variants). I: Thermal desorption + soil ashing; II: Soil washing (1 line); III: Soil washing (2 lines); IV: Capping; V: Land–fill.

All the scenarios are based on remediation solutions that take into consideration the "column B" concentration thresholds (Table 1, D.M. 471/99) and set out a future use as industrial, commercial, or office complex area. In addition, the only difference between residential, agricultural, and natural scenarios resides in risk reduction hypothesis (density of exposure units) which has however no influence on the standardised environmental index.

Considering at first the industrial, commercial, and office complex scenario, it can be observed that — with the exception of the land–fill variant — all the remediation options are characterised by a relationship of proportionality between normalised risk reduction index and normalised environmental merit index, and a relationship of inverse proportionality between these two indexes on one side and the normalised cost index on the other. For land–fill variant these relationships are completely different: a high (the highest) risk reduction index is combined with a negative environmental merit index and a high (the highest, with negative sign) cost index.

— Thermal desorption + soil washing:	R =0.76	E =1.00	C =–0.45
— Soil washing (1 line):	0.74	0.99	–0.45
— Soil washing (2 lines):	0.72	0.95	–0.45
— Capping:	0.43	0.58	–0.12
— Land–fill:	1.00	–0.27	–1.00

This result can be interpreted as follows. A great risk reduction can be obtained with the first three remediation variants (thermal desorption plus soil washing and the two pure soil washing variants), less with the capping option. These results involve also acceptable environmental merit and not too high costs. However, if risk reduction is a very dominating aim, the land–fill solution scores best, but has no (negative) environmental net benefit and high costs. Finally, if financial resources are very scarce (or with a low willingness to pay), the capping solution scores best, but with significantly lower performances in both risk reduction and environmental merit.

Considering instead the residential, rural, and naturalistic (all three “quasi–“ or “pseudo–” because of industry–oriented remediation techniques) the synoptic tables changes considerably even if the first four remediation options change few. The great difference is represented by the radical change of the environmental merit index which becomes not only positive, but even the highest score among all remediation variants.

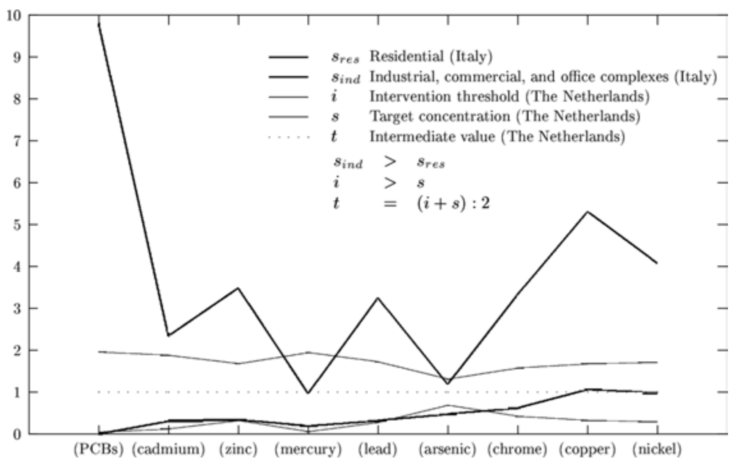

Fig 3 - Comparison of legal concentration threshold settings between Italy and the Netherlands (source of Rec). The concentrations reported in the diagram are standardised with *t = 1* and contain the most significant substances surveyed in the sample site for which legal limits are directly comparable.

— Thermal desorption + soil washing:	R =0.76	E =0.91	C =–0.45
— Soil washing (1 line):	0.74	0.90	–0.45
— Soil washing (2 lines):	0.72	0.89	–0.45
— Capping:	0.43	0.70	–0.12
— Land–fill:	1.00	1.00	–1.00

This is due to the previously explained effect represented by concentration threshold differences between industrial–commercial–tertiary and residential purposes. The situation changes only in a very slight manner even if the discussed residential PCB concentration limit is neutralised by setting its measured concentrations to zero: the environmental merit indexes for the first four variants would become 0.92 (instead of 0.91), 0.92 (0.90), 0.90 (0.89), and 0.71 (0.70). The land–fill variant obviously keeps to be the best performing option and remains at 1.00.

The interpretation of this scenario is that for residential purposes a completely different approach to remediation is required. In addition, it may be stated that redeveloping towards an optimal situation concerning risk and environmental profile has very high costs. On the other hand lower costs (less than half) might be possible only if lower performances, above all in the environmental benefits, could be accepted.

The results of the procedure (for now on test data) provide synthetic information on efficiency and efficacy of remediation activities. They allow an easy comparison between remediation techniques, sensitivity and robustness analyses. The latter two, if managed in a spatial perspective, may help to build scenarios calibrated on environmental standards and soil reuse modes.

The procedure may be used in a cyclic manner: from the scenario towards punctual/areal evaluation and vice-versa. In the first case it will document effects of the adopted remediation process; in the second, it will use punctual and zonal effects in order to carry out scenario corrections or more accurate plausibility investigations. This feedback to scenarios explicitly sets up issues of transparency and knowledge of the real condition of the environment in the sample site, as well as the economical and social costs related to the presence of residual risk.

5. Policy implications

El.gi.r.a might be utilised as a policy device to implement some of the actions foreseen by the brownfield remediation Master Plan which is now under discussion.

Supporting scenario writing, it could ease dialogue and negotiation among investors, developers and the *Società di trasformazione urbana*, a company that will be in charge of development, upgrading and mitigation investments. A second policy implication refers to risk management and setting legal thresholds in a comparative way within EU having in mind that nature and profile of users exposure have a changing correlation with expected land uses. Finally, *El.gi.r.a.* might have an effective application within the local planning processes. On one side, it could help re-designing the lagoon water front as a stage for the historic city islands and logistic platform. On the other, it might also emphasises the overall net-benefits in linking up-graded areas to the mainland urban structure.

6. Papers

Within the research activities of WP3a, the following papers were produced. For copies of these papers, contact CORILA Consortium[8], authors[9] or FEEM[10].

Cossettini P., De Polignol E., Hedorfer M., Paneghetti C., Patassini D., Rinaldi E.: **Evaluation of Brownfield Redevelopment Projects: El.Gi.R.A. A knowledge Support Procedure for Porto Marghera Brownfields (Venice) – Methodology**, CORILA Research Report 2003, Venice.

Abstract: The knowledge support procedure (Ksp) El.Gi.R.A. is an intermediate outcome of CORILA Research Programme 2000-2004, Line 1.1 Economic evaluations of environmental protection and remediation, Work package 3: Cost and benefit analysis of brown fields remediation and redevelopment. The general aim of the research refers to cost and benefit assessment of brown fields cleaning and redevelopment in the area of Porto Marghera (Venice, Italy). Three are the main objectives: a) a preliminary assessment of legal framework which sectoral policies refer to; b) case-studies on main actors of physical and functional transformation, brown fields remediation, redevelopment and creation of new market opportunities; c) economic evaluation splitted into cost and benefit analysis. Benefits perceived mainly by real estate developers and generated by remediation and redevelopment projects have been analysed within the work package 4. Two are the main reasons: firstly, they are very crucial operators within remediation and redevelopment programmes in the area under study being acting as true market makers. Be their contribution absent, any redevelopment would be hampered; secondly, they form a rather small and easily identifiable group. Furthermore, they have clear opinions on location benefits the area offers as a whole and on public actors behaviour as well. The two issues have been studied with the help of an ad-hoc sample survey which provides as main result an estimate of willingness to pay for many site specific characters and public incentives.
The first section of the research is considered a crucial issue, for the legal system seems to affect the profitability of cleaning and remediation processes. The environmental upgrading is mentioned in the economic literature as an example of market failure. For that reason the government regulation becomes a central policy matter as it determines liabilities together with economic efficiency and effectiveness of intervention in a multi-actor domain. Besides, state failure should be accounted for designing flexible and incremental policies along with consistent monitoring of effects and impacts. During this phase of the research internationallaws have been assessed, in a comparative manner, namely those of Usa, Germany and the Netherlands. Following a law and economics approach, legal and institutional structures have been linked with peculiar clean-up processes of brown fields.
In the second section of the research, activities of operators and institutions involved in the concerned policies during the last periods have been analyzed, starting from the approval of 1995 Marghera Prg revision and following interventions in the area. The

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geographical information system available at the Municipality of Venice provides environmental data on some 150 contaminants. It has been built up with the help of a spatial regular grid which partially covers the overall 2000 hectares of the old industrial areas. In addition, the research group started collaborating with a joint-stock company, the Immobiliare Veneziana (Ive), that manages lands clean-up and market allocation. Two contracts signed by Ive on Azotati and Complessi areas have been deeply assessed and finalized with a focus group conducted at Corila the February 22d 2002. The main concerned actors in the Venitian region shared the focus experiment aiming at selecting a wider sampling methodology and gaining useful support from the Municipality of Venice. The focus outcomes are available at CORILA.
ELGIRA procedure is by now in a testing phase with environmental data on selected area ('43 hectares) supplied by the Municipality of Venice. This paper introduces the overall rationale of Elgira and sends to an other paper for the application to '43 hectares' sample area.

Cossettini P., De Polignol E., Hedorfer M., Paneghetti C., Patassini D., Rinaldi E.: **MoDe. A Cellular Automata Model for Pollution Value Interpolation**, CORILA Research Report 2003, Venice.

Abstract: In mathematics, logic, and information technologies an automaton is a formalism that allows to describe the behaviour of engines. An automaton can be formalised as follows:
- a set of input information;
- a set of output information or behaviours;
- a set of internal states.

The rules establish the relationships between input, internal states, and output. If referred to phenomena which take place in space an effectual description can be done by using cellular automata. A cellular automaton can be sawn as a matrix of square cells which evolve during an "imaginary" time. At each moment each cell has a state that belongs to a finite set of possible states. At a given instant (t+1) the cell may change state on the basis of the state assumed at the previous instant (t) by the cells in its neighbourhood.
An urban cellular automaton is a particular type of automaton where the cells represent portions of a territory having a given extent. The cell states of an urban cellular automaton are characteristics related to the considered context (e.g. land–use, land value, density, quality, accessibility, etc.). The cell matrix of an urban cellular automaton is therefore the "discretised" representation of a town or a region.
MoDe is a program which performs the completion of value distribution maps, for which only few values are initially known. It has originally been developed in order to study urban degradation diffusion. The basic component of MoDe is a cellular automaton which spreads values over a map. The main diffusion criterion is an interpolation under applying arithmetical average values between the initial values. The MoDe program allows to import from and export to external databases; it allows also to perform some map value manipulation operations, such as map union, sum, difference, and other statistical computations.

Cossettini P., De Polignol E., Hedorfer M., Paneghetti C., Patassini D., Rinaldi E.: **Evaluation of Brownfield Redevelopment Projects: El.Gi.R.A. A knowledge**

Support Procedure for Porto Marghera Brownfields (Venice) - Applied to the "43 Ha Area, CORILA Research Report 2003, Venice.
Abstract: ELGIRA procedure has been employed for the '43-Hectares-Area' sample site at Porto Marghera. For this area are available both land use perspectives (scenarios) and a sufficiently dense environmental characterisation matrix (Venice Township SIS). The area is located in the second industrial area of Porto Marghera (Malcontenta) between the South Industrial Canal and the Brenta Cut (Naviglio). To the east, it borders on Decal depot of chemicals. The southern and west-southern border is market by a road, a railway, a ditch and an embankment near two meters high, whereas a grain storage is located on the west side. Owned by the Municipality of Venice, during 50s and 60s the area has been utilized for an uncontrolled dump of industrial wastes produced within Porto Marghera.
The procedure highlights two critical points. (1) The information transfer protocols are not standardised yet, and (2) generation of indicators (or indexes) may still be mproved for punctual and areal evaluation. The research continues for both issues. In particular, the punctual evaluation requires the procedure to be consolidated with the aid of the information base. Marghera offers a wide range of pollutants concentrated in a critical environment. This advises an interpretation of characterisation data also with the support of interpolations. In second order, the evaluation tries to capture effect propagation due to the remediation activities within neighbouring areas. Investigation on these effects, as well as spatial analyses, household and enterprise surveys might help to account for expected stigma variation.
The results of the procedure (for now on test data) provide synthetic information on efficiency and efficacy of remediation activities. They allow an easy comparison between remediation techniques, sensitivity and robustness analyses. The latter two, if managed in a zone perspective, may help to build scenarios calibrated on nvironmental standards and soil reuse modes.
The procedure may be used in a cyclic manner: from the scenario towards punctual/areal evaluation and vice-versa. In the first case it will document effects of the adopted remediation process; in the second, it will use the punctual and zonal effects in order to carryout scenario corrections or more accurate plausibility investigations. This feedback to scenarios explicitly sets up issues of transparency and knowledge of the real condition of the environment in the sample site, as well as the economical and social costs related to the presence of residual risk.

Cossettini P., De Polignol E., Hedorfer M., Paneghetti C., Patassini D., Rinaldi E.: **Elgira. Un sistema di supporto alla conoscenza per la bonifica dei siti inquinati a Porto Marghera (Venezia). Un'applicazione all'area '43 ettari'**, Congresso Annuale dell'Associazione Italiana di Valutazione, Reggio Calabria, 2003.
Abstract: Questo contributo presenta l'architettura di una procedura orientata alla valutazione economica degli interventi di bonifica nella zona di Porto Marghera (Venezia). Descrive, in particolare, la procedura di aiuto alla conoscenza di contesto che, partendo da scenari d'area, vincoli e accordi generali, consente di valutare interventi puntuali e loro effetti areali.
La procedura è denominata EL.GI.R.A, acronimo da *Electre*, *Giuditta*, *Rec* e *Aures*, modelli analitico-valutativi disposti in sequenza. L'avvio della procedura é costituito da scenari relativi a Porto Marghera, importati dalla variante generale al Prg, dall'Accordo

per la Chimica, dagli studi preliminari al Master Plan, appena conclusi, e da altre ‘visioni’ o proposte in discussione. La più recente rinvia all’accordo sulla impermeabilizzazione delle sponde dei canali portuali che ripropone l’alternativa o la combinazione fra tecniche di messa in sicurezza e bonifiche dei suoli inquinati.
Gli scenari propongono ‘pattern di uso del suolo’ coerenti con il futuro della zona industriale e portuale. Le ipotesi a confronto sono diverse e non necessariamente disgiuntive: città industriale post-fordista, città della scienza, città ‘fondaco’ (o dell’ospitalità), restauro ambientale-territoriale, ognuna con destinazioni d’uso prevalenti.
La procedura viene applicata alla zona ’43 ettari’ per la quale si dispone della matrice di caratterizzazione ambientale. Sulla base della matrice, descritta da categorie di contaminanti e fornita dal Sis del Comune di Venezia, si avvia un primo *screening* delle tecnologie (processi) di bonifica (*in situ*, *ex situ* o miste). Le *performance* delle tecnologie selezionate sono misurate (per ora in forma qualitativa) su criteri di tipo tecnologico, ambientale, sociale ed economico-finanziario. La matrice di *performance* viene trattata con procedura *Electre*[11]. L’ordinamento (la cui robustezza é testata con analisi di sensitività) consente di isolare le tecniche preferibili. La Matrice di caratterizzazione ambientale costituisce l’input principale di *Giuditta*, procedura finalizzata all’analisi del rischio[12]. Le elaborazioni di *Giuditta*, assieme ad informazioni specifiche di caratterizzazione ambientale eventualmente interpolate con *Aures* (automa cellulare), vengono quindi ospitate nella *subroutine Rec* che genera tre indici normalizzati di riduzione del rischio, di merito ambientale e di costo. I tre indici sono riferiti a valori massimi ammissibili delle concentrazioni, ma anche a diverse metodologie di calcolo dei parametri valutativi[13]. *Rec* produce anche output supplementari utili alla valutazione finale, come il differenziale di rischio (confronto fra stato iniziale e finale), i differenziali di concentrazione delle sostanze inquinanti, il profilo dei costi finanziari delle singole opzioni di bonifica, l’energia consumata dalle tecniche. I risultati riferiti a singoli lotti o ad aree più estese (catturando effetti di propagazione spaziale con l’aiuto di *Aures*) vengono sottoposti a valutazione multicriteriale di sintesi. La procedura completa (testata su alcuni contaminanti) dovrebbe aiutare gli operatori industriali ed immobiliari che intervengono nell’area a ‘capire dove sono’ e ad orientare successive analisi finalizzate alla stima dei benefici economico-sociali degli interventi di bonifica.

Cossettini P., De Polignol E., Hedorfer M., Paneghetti C., Patassini D., Rinaldi E.: **Elgira. Un sistema di supporto alla conoscenza per la bonifica dei siti inquinati a Porto Marghera (Venezia)**, INPUT 2003, Pisa.

Abstract: Questo contributo presenta una procedura orientata alla valutazione economica degli interventi di bonifica nella zona di Porto Marghera (Venezia). La procedura EL.GI.R.A è acronimo di *Electre, Giuditta, Rec* e *Aures,* modelli analitico-valutativi. L'avvio é costituito dalla variante generale al Prg, dall’Accordo per la

[11] Electre (Elimination et choix traduisant la realité) è una metodologia di analisi multicriteriale.
[12] Rec suggerisce l’impiego di programmi specifici per il calcolo dell’indice di rischio come CSOIL e HESP.
[13] Se confrontato ad altre realtà, in particolare a quella olandese in cui ha preso forma Rec, Porto Marghera presenta una certa complessità a causa della gamma degli inquinanti presenti, al lungo ciclo di deposito e ai caratteri della percolazione e diffusione.

Chimica, dagli studi preliminari al Master Plan e da altre ‘visioni’. Gli scenari propongono ‘pattern di uso del suolo’ coerenti con il futuro della zona industriale e portuale. Sulla base della matrice di caratterizzazione ambientale si avvia un primo *screening* delle tecnologie di bonifica. La matrice di *performance* viene trattata con procedura *Electre e Promethee.* L’ordinamento consente di isolare le tecniche preferibili. La matrice di caratterizzazione costituisce l’input di *Giuditta*, procedura finalizzata all’analisi del rischio. Le elaborazioni di *Giuditta*, assieme al modello dell’inquinamento elaborato con *MoDe* (automa cellulare), vengono ospitate nel modulo *Rec* che genera tre indici normalizzati di riduzione del rischio, di merito ambientale e costo. I risultati, catturando effetti di propagazione spaziale con l’aiuto di un altro automa cellulare *Aures*, vengono sottoposti a valutazione multicriteriale di sintesi. La procedura dovrebbe aiutare gli operatori che intervengono nell’area a ‘capire dove sono’ e ad orientare successive analisi finalizzate alla stima dei benefici economico-sociali degli interventi di bonifica.

Cossettini P., De Polignol E., Hedorfer M., Paneghetti C., Patassini D., Rinaldi E.: **Contextual knowledge generated by a support system for brownfield development: the case of Porto Marghera (Venice)**, Fifth International Workshop on ‘Evaluation in planning’, Cà Tron, DP-Iuav, Università di Napoli, Politecnico di Bari, Venice.

Abstract: The purpose of this paper is to reflect upon the communicative use of the Elgira Decision Support System which is currently in the phase of testing within the Corila research project[14]. Thanks to specific evaluation functions, and by assessing localized and widespread effects, the Elgira DSS aids strategy management in the reclaiming of polluted land within the redevelopment program for the industrial area of Porto Marghera (Venice). It has been designed and tested to operate specifically for the industrial port area. However, the area is situated in a crucial urban and environmental position, where, on landfill, industrial waste has been deposited in filling casks and buried between the Mestre and the lagoon areas.

This critical state of affairs has been acknowledged by the reconversion scenarios proposed over the last few years and taken into consideration again by the Revised City Master Plan of 1999 and the Reclaim Master Plan of 2002. Important issues have been raised therein to which this paper addresses itself and attempts to define a possible itinerary: could the DSS be instrumental in overcoming the isolation and omerta of this area and reducing the stigma with which it has long been associated[15]? As far as

[14] Corila Research Project 2000-04, Line of research 1.1 *Economic evaluation of environmental heritage*, Project: *Economic evaluation of environmental safeguarding and protection in the Venetian lagoon.* Main contractor DSE-UNIVE, Workpackage 3 (IUAV-DP), *Cost-benefit analysis of reclaim activities in the polluted sites.*

[15] Re. the economic self-sufficiency of Porto Marghera see G Ernesti, ‘Venezia da terra, Venezia da mar. Città e porto nell’età dell’industria (Venice from the land, Venice from the sea. City and port in the industrial age)’ in Aa.vv. (various authors), 2001, *Venezia: guida al porto (Venice. A guide to the port.)*, Marsilio, Venice Port Authority, in particular pp. 52-69. As regards the role of Petrolchimica from a historical perspective, also see L Pes, ‘Storia di Venezia. Gli ultimi quarant’anni 1961-2001 (A History of Venice. The last forty years 1961-2001)’, in M Insenghi (ed.), 2002, *Storia di Venezia. L’Ottocento e il Novecento (A History of Venice. The eighteenth and nineteenth centuries),* Tomo III, II Novecento, Istituto dell’Enciclopedia Italiana, Rome. On the beginnings and the development of the port and the urbanization of Marghera see also G Zucconi (ed.), 2002, *La grande Venezia. Una metropolis incompiuta*

investors and local communities are concerned, would the DSS help them in getting to know and then regain control of a territory that has been for far too long, and with dreadful consequences, under the domain of special charters?
This paper proposes a course of action that, starting with the design of the DSS itself, reflects upon the knowledge that it generates and on its ability to integrate with plans, programs and projects for redevelopment.

tra Otto e Novecento (Greater Venice. An incompleted metropolis between the nineteenth and the twentieth centuries), Marsilio, in particular pp. 19-72; S Romano, 1979, *Giuseppe Volpi. Industria e finanza tra Giolitti e Mussolini (Industry and finance from Giolitti to Mussolini)*, Milan.

COSTS AND BENEFITS ANALYSIS OF THE REDEVELOPMENT OF CONTAMINATED AREAS

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Introduzione

Le logiche di riconversione in atto nel sistema lagunare, ed in particolare a Porto Marghera (Venezia), considerano i siti inquinati sia in una prospettiva funzionale, che geografica. La prima considera il sito come un'occasione di nuovi investimenti, riferendosi a specifiche dinamiche economiche e tecnologiche. La seconda prospettiva invece, pone problemi di accessibilità e contiguità e tende ad individuare le relazioni con l'ambiente in termini infrastrutturali e di vocazione territoriale.

I processi decisionali, diventano pertanto di fondamentale importanza per lo sviluppo delle aree inquinate. La ricerca ai pone quindi l'obiettivo di stimare i benefici e i costi (monetari e non monetari) delle diverse ipotesi di gestione dell'emergenza inquinamento all'interno della area industriale di Marghera.

In particolare, il progetto ha sviluppato un analisi degli incentivi di mercato e non di mercato per la promozione della bonifica e del riuso dei siti inquinati, in riferimento ai soggetti investitori immobiliari in tali aree e i proprietari delle stesse.

1. Objectives

In the year 2002 the research activity focused on the costs and benefits evaluation of brownfields cleanup and redevelopment in the area of Porto Marghera (Venice, Italy).

Specifically the project has been devoted to the analysis and comparison of market-based and non market-based incentives to promote the environmental remediation and reuse of brownfields, with reference to real estate developers and property owners.

Brownfield cleanup and reuse are attractive to communities and policymakers because they reduce the adverse effects of the site's soil and water pollution on human health and ecological systems. Furthermore, they help to stop the conversion of agricultural land and rural sites to urban uses and other development patterns that generate environmental problems, congestion and sprawl; and finally they promote economic growth in inner cities and are, therefore, potentially important components of sustainable growth.

We try to assess the value of interventions and policies targeted at brownfields recovery from the point of view of the key economic agents involved—private real estate developers. We wanted to answer to this set of related questions.

- First, what economic incentives can be offered to developers to encourage cleanup and reuse of brownfields, and how effective are they?
- Second, what kind of site characteristics and available infrastructure make a parcel attractive for cleanup and reuse, and to what kind of developers?
- Third, are developers truly influenced by contamination stigma, whereby a parcel's potential or past contamination makes it less desirable?

2. Database

We have constructed a database in excel in which we have put all the respondent's answers. Our database contains 118 columns and 294 rows (293 respondents). In the columns you can read our variables: ID (number of questionnaire: from 1 to 292); LANGUAGE (Italian, English or French), INTERVIEWER (A stand for Aline, M for Margherita, F for Francesco, S for Stefania, E for Elena; if the questionnaire was self-administered and no interviewer is associated with it, leave this field blank); SELFCOMPLETE (YES if self-completed by the respondent; NO); SECTOR (private, NPO for non-profit organization, GOVT for government); PROFILE (if the company, or a subsidiary of the company, buy land to build or improve manufacturing plants, warehouses, retail or wholesale stores, residential units, offices for its own use and/or to sell or lease to someone else) SELL, KEEP, LEASE if developers buy real estate in order to sell, keep or lease the area; COREBUSINESS if buying, developing and selling/leasing real estate areas is the principal business of the company); DEVELOPER (if this is the activity of the respondent); PRINCIPALBUSINESS (if respondent answered 'yes' to question "what is the principal business of your company?); OTHERBUSINESS (other activity of the developer) CONSULTANT (if the respondent is a consultant) NONCONSULTANT (other respondent's business); Q0a (Countries where company does business); Q0b (Region); Q1amin and Q1amax (min and max size of the parcels); Q1bmin and Q1bmax (min and max size of buildings); Q2 (revenue of a typical project), Q2UNIT (dollar, euro, etc.) Q3IND, Q3COM, Q3RES, Q3OFF, Q3OTH (kind of projects) Q41, Q42, Q43, Q44, Q45 (ranking of project's type; Q5 (if company ever purchased, leased, or developed sites located in industrial areas); Q6 (if company ever purchased, leased or developed contaminated sites and/or buildings). Q7 (if respondent is familiar with the site cleanup legislation); Q8 (if developer ever benefited from the incentives to re-use abandoned areas); CONTAM (stands for contamination present, absent, cleaned); TRANSPO (stands for transportation network); CERTIF (certificate yes/no of no further action); OVERS (oversight by government agency) STDS (cleanup standards flexible or rigid); CITY (if city is present or absent); INCENT (government financial incentives in the measure of % 10, 20 or 30); Q9 (visitor or exhibitor); Q10 (position or title within the company); Q11 (total number of company's employees); Q12 (company's revenue); Q12UNIT (euro or dollars); Q13 (if respondent takes part in the final decision about undertaking or not undertaking a real estate development project); Q14 (if respondent collaborates with the person or the committee that makes the final decision about undertaking or not undertaking a real estate development project); Q15 (Gender); Q16 (Level of schooling); Q17 (age).

3. Methodology

We surveyed real estate developers using conjoint choice questions. Our survey questionnaire presents respondents with sets of redevelopment projects, where each project is defined by site attributes (location, contamination, access to transportation nodes) and a mix of government policies. The survey was administered in person to a sample of developers and real estate professionals intercepted at random at the Marché International des Professionnels de l'Immobilier (MIPIM) in Cannes, France, in March 2002.

Our survey questionnaire is based on **conjoint choice experiments**. Conjoint choice experiments ask respondents to indicate which is the most preferred out of ***K*** (hypothetical) alternatives. Each alternative is described by a combination of attributes, allowing researchers to infer what tradeoffs respondents are prepared to make between attributes. In our survey, we ask a sample of real estate developers to tell us which they prefer between two hypothetical alternative redevelopment projects, A and B, where each project is described by site attributes (e.g., location and contamination) and a policy mix. The policy mix includes (a) liability reduction in the form of a certificate of assurance that the developer is not going to be held responsible for future cleanups; (b) regulatory relief in the form of a faster notice of approvals and/or flexible cleanup standards; and (c) direct financial incentives to the developer.

In sum, each alternative is described by seven attributes: (i) presence/absence of contamination; (ii) cleanup standards; (iii) availability of transportation network within 20 km from the site; (iv) presence/absence of a certificate issued by a government agency that relieves the developer from liability for further cleanup; (v) time for approval of development/cleanup plans by the appropriate government agency; (vi) presence/absence of a city within 20 km; and (vii) government financial incentives, expressed as percentage of the value of the project.

4. Results

We assume that respondents select the alternative with the highest profit. We further assume that profits are a linear function of site attributes, S, including its possible contamination, and the policy mix:

$$V_{ij} = \alpha_0 + \mathbf{S}_{ij}\alpha_1 + \mathbf{Z}_{ij}\alpha_2 + \varepsilon_{ij}\,,$$

where Z is a vector of indicators and/or continuous variables capturing the extent of liability relief, regulatory relief and financial incentives, respectively, i denotes the individual and j the alternative. If the error terms ε are independent and identically distributed and follow the type I extreme value distribution, the probability that alternative k is selected out of K alternatives is:

$$\Pr(\text{resp.}\, i \text{ chooses } k) = \exp(\mathbf{w}_{ik}\alpha) \Big/ \sum_{j=1}^{K} \exp(\mathbf{w}_{ij}\alpha)$$

where w is the vector of project attributes and α is the vector of coefficients. Once model is estimated, the rate of tradeoff between any two attributes is the ratio of their respective α coefficients. The marginal value of each attribute is computed as the negative of the coefficient on that attribute, divided by the coefficient on the "price" variable (here, the subsidy).

Marginal prices of the attributes for the sample as a whole and for specific groups of developers are based on the median value of a project (€7 million, or approximately $7 million). Our results show that the presence of contamination is worth €2.5 million, in the sense that, all else the same, developers would require financial assistance for €2.5 million for a €7 million project involving a contaminated site where remediation has not been undertaken yet. An alternative interpretation is that developers would be willing to sacrifice up to €2.5 million to obtain a pristine site. This accounts for almost 37% of the revenue of the project. There is, however, much variability in the value of avoiding contamination between different types of developers. Developers with contaminated site experience, for instance, would require only €1.46 million, smaller developers €2 million, and larger developers €5 million.

The certification of completion, which exempts the developer from future liability over contamination at the site, is worth about €1.5 million, implying that developers would sacrifice this amount to secure a letter of completion by the appropriate government agency. This is approximately 21% of the revenue from the project. This time, it appears that developers with no experience at contaminated sites are willing to pay more to obtain one such a letter (€3.4 million v. €0.9 million of developers with experience).

Our model also implies that each month of delay in the approval of cleanup plans is worth €108,000. It is interesting that developers who have previously engaged in projects at contaminated sites and smaller developers attach lower values to a delay of one month in the agency's response time (€59,000 and €96,000, respectively).

Finally, the marginal price of flexible standards is €738,000, implying that respondents would pay this amount to have the opportunity to negotiate the cleanup standards with the government agency. This figure represents roughly ten percent of the value of the project here considered (€7 million).

5. Policy Implication

When dealing with brownfields remediation 'command and control' approaches fails; transaction costs are so high and solutions can be generated only by repeated interactions between involved parties open to entrance of new stake-holders. These CAC failures promote the research of alternative forms of policy measures, where CAC and litigation costs are the stick and benefits from co-operative regulation are the carrot. Facing the impasse of stigma, imposed by market and state failure in dealing with remediation processes, both privates and public agencies need to work to shape alternative approaches to policy to govern the processes of remediation.

In Marghera stigma has always been very high and it hindered transactions of areas otherwise outstandingly well located. All site sales during last 7 years were fostered by public authorities. Two major sales of dismissed sites, for a total of 36 hectares, have been carried out by IVE Immobiliare Veneziana and a third area (10 hectares) was purchased by Vega Science Park (a Public Consortium), that rents spaces to high-tech firms.

Potential buyers and developers in Marghera are attracted by the location of the site, and yet consider environmental risk too high if no cooperation with public agents is offered: our research shows that a room for manoeuvre exists in shaping the appropriate mix o policy measures, combining financial incentives with policies that tend to lower transaction costs involved in remediation processes.

6. Papers

Within the research activities of WP3a, the following papers were produced[16]:

Alberini A., Longo A.: **"Choise Models in Non-Market Valuation".**

Abstract: The purpose of this paper is to present a non-market valuation technique known as conjoint analysis, which is becoming increasingly popular in environmental economics research.

Conjoint analysis is a stated-preference technique to elicit preferences and place a value on a good, in the sense that it infers them by asking individuals what they would do under hypothetical circumstances, rather than observing actual behaviours on marketplaces. Contingent valuation, another popular method for placing a value on a good, is another example of a stated-preference technique, and can be interpreted as a special case of conjoint choice.

In a typical conjoint analysis survey, respondent are shown various alternative descriptions of a good, which is described by a set of attributes, and are asked to rank the various alternatives, to rate them or to choose the most preferred (Hanley et al., 2001). In the latter case the technique is termed "conjoint choice" or "conjoint choice experiments." The alternatives differ from one another in the levels taken by two or more of the attributes. Statistical analyses of the responses obtained in any one of these ways can be used to obtain the marginal value of these attributes and the willingness to pay for any alternative of interest.

Conjoint choice and other stated-preference (SP) techniques have recently emerged as a complement to revealed-preference (RP) techniques. While RP evaluate economic agents' behaviours in real markets, SP involve choice responses evoked in hypothetical markets. The interest in hypothetical behaviours in economics arises from different reasons, such as the necessity to investigate economic agents' preferences for new policies that might be implemented, for the development of a new product or good, or for evaluating goods that are not traded in real economic markets. All these examples make it clear that it is not possible to estimate agents' preferences using revealed preferences. Conjoint choice or analysis allows a great deal of flexibility because researchers can explore how a change in the hypothetical scenario influences people's responses, and compare the current scenario with many hypothetical alternatives. This is particular helpful for informing policy decisions before the policy itself has been decided upon. Another advantage of conjoint choice is that researchers usually obtain

[16] For copies of these papers, please contact the editors or martina.marian@feem.it

multiple observations per interview, one for each choice task from each respondent. This increases the total sample size, holding the number of respondents the same.
Usually revealed preference data from regular marketplaces (such as the labor and the housing market) contain information about actual market equilibria for the behavior of interest, and can be used to infer short-term departures from the current equilibria. In contrast, stated-preference data like responses to conjoint choice questions are especially rich in attribute trade-off information. Therefore, stated-preference data are useful in estimating future changes in agents' behavior (Louviere et al., 2000).

Alberini A., Longo A., Tonin S., Trombetta F., Turvani M.: **"The Role of Liabiliy, Regulation and Economic Incentives in Brownfield Remediation and Redevelopment: Evidence from Surveys of Developers"**, Feem Working Paper, 2002.

Abstract: We examine different market-based mechanisms and other incentives intended to promote the environmental remediation and reuse of brownfields. Policies that encourage cleanup and re-use of brownfields offer real estate developers reductions in regulatory burden, relief from liability for future cleanups once certain mitigation standards are met, and/or financial support for regeneration of brownfields.
We use conjoint choice experiments—a stated preference approach—to assess the responses of real estate developers to different mixes of these incentives. Our survey instrument was administered in person to a sample of developers and real estate professionals randomly intercepted at the Marché International des Professionnels de l'Immobilier (MIPIM) in Cannes, France, in March 2002.
Conditional and random-coefficient logit models of the responses to the choice questions indicate that developers find sites with contamination problems less attractive than others, and that they value liability relief. This confirms our expectation that contaminated sites are less desirable because of the associated cleanup costs, but refutes earlier claims that liability does not matter. Our developers are not deterred by prior contamination, once it has been cleaned up, suggesting that "contamination stigma" is not very important, and appreciate fast-track review of development and remediation plans, direct financial incentives, and flexible (negotiable) cleanup standards. Developers with prior experience with contaminated sites are more responsive to the policies than are inexperienced developers, especially for subsidies. Inexperienced developers are more responsive to liability relief and regulatory relief than they are to subsidies. Similar considerations hold true for larger developers.

Tonin S.: **"Una Rassegna sulla Stima Economica dei Costi e dei Benefici derivanti dai Progetti di Sviluppo delle Aree Dismesse"**.

Abstract: In questi ultimi anni si è assistito ad una fase di transizione storica per quanto riguarda la gestione delle aree dismesse. I progetti di rivitalizzazione dei brownfield rappresentano un'enorme e potenziale risorsa economica per lo sviluppo industriale e urbano di una città, sono in grado ad esempio di tutelare, o anche di accrescere, la qualità della vita migliorando le opportunità di tipo ricreativo, la qualità ambientale dei beni comuni e di creare nuove opportunità di lavoro. Anche per le imprese private, lo sviluppo di un'area industriale dismessa può garantire alcuni vantaggi quali ad esempio l'accesso a diversi nodi di trasporto, la disponibilità di forza lavoro e la presenza di infrastrutture già esistenti.

Molti siti abbandonati e inquinati, infatti, sono collocati in aree industriali precedentemente utilizzate, la loro bonifica e il loro sviluppo possono così contribuire in modo decisivo alla riqualificazione di vecchi centri urbani e zone rurali che non hanno potuto mantenere nel tempo la capacità di creare nuovi stimoli economici. I siti contaminati non sono più percepiti in termini di pochi e gravi episodi accidentali ma come un problema infrastrutturale di varia intensità e di notevole diffusione.
Acquisire, ripristinare e riutilizzare vecchi siti industriali, spesso anche abbandonati, può essere molto costoso sia in termini economici sia in termini di tempo. In molte situazioni i *developers* privati e i finanziatori non sono in grado, o non sono disposti ad agire in conto proprio per assicurare che sia raggiunta la completa potenzialità economica del recupero di un sito contaminato. Inoltre, le leggi ambientali sempre più severe e le possibili implicazioni negative sulla salute e sull'economia della comunità circostante hanno reso estremamente difficile sviluppare progetti di ripristino e di riutilizzo di siti industriali dismessi.
Lo scopo di questa rassegna è di fornire un quadro generale delle tecniche economiche impiegate per la valutazione dei siti contaminati, e in modo particolare, di proporre e analizzare le metodologie utilizzate per la valutazione economica dei costi e dei benefici derivanti dal recupero di queste aree.

Turvani M., Trombetta F.: **"Governing Environmental Restoration: Institutions and Industrial Sites Clean-ups"**, Atti del XXXIII incontro del Ce.S.E.T. "La valutazione degli investimenti sul territorio", Venezia, 11 ottobre 2002.

Abstract: Brownfields are defined by US Environmental Protection Agency as "*abandoned, idled, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination*".[17]
A first glance at the extension of "brownfields" areas is useful to grasp the scale and relevance of the problem at hand. Even considering only US and EU, it is clear that brownfields and clean-ups pose a major challenge to society, economy and polity.
In the European Union, estimates of the scale of the problem (Giangrasso and Tassoni, 2001) are as follows: a survey conducted around the end of the eighties found 150.000 sites presumably polluted. Over 100 millions hectares were defined polluted summing up to almost 1 billion cubic meters of contaminated soil and wastes, 20 millions of which are to be found in western Europe. The estimated cost of remediation for UE members has been calculated in 1% of the internal Gross Union Product for most critical areas. In Italy data of 1995 record more than 11.000 polluted sites. The costs of intervention were estimated in more that 30.000 billion liras. Updated Italian figures calculate 260.000 hectares of soil and 70.000 of sea polluted, summing up to 330.000 hectares, more than 1% of the national territory, and 280 km of coasts interested by the phenomenon of pollution.
In our case-study, Marghera (a site in Venice's territory) which hosts 70% of Italian oil-derived chemical production, the whole industrial area has a surface of 2000 hectares, most of which result nowadays heavily polluted [18]. More recent data collected during year 2000 in the process of completion of the Italian National Priority List, Executive Order n° 468 by Ministry of Environment on September 18th 2001, define a even

[17] http://www.epa.gov/swerosps/bf/glossary.htm#brow
[18] For major details about pollution in the area one may visit the site http://www.ambiente.venezia.it/.

broader surface that needs further investigation in Marghera and Venice: 3825 hectares of land, thus significantly bigger than the 2000 hectares of the industrial zone in Marghera, and 2311 hectares of lagoon water sheets. Even though overestimation of polluted areas might have been induced by different regions competing to obtain national funds for their own sites, the datum remains impressive.
Aim of this paper is to offer a tentative framework for an institutional set-up that best fits the brownfields problem. The study focuses on the traditional economic approach on environmental externalities trying to explain why it does not foster remediation and, quite the contrary, often leads to stalemate. The idea is that property rights must be considered dynamically and state regulation comes up as a second best solution for externality precisely because it sets in motion a process of governance of conflicting interests' emergence in environmental issues.

Trombetta F.: **"Bonifiche a Marghera: Scenario Normativo Internazionale, Evoluzione Legislativa Nazionale, Esperienze Locali"**.

Abstract: Il paper si occupa della ricostruzione del contesto normativo in cui si collocano le azioni di bonifica dei terreni contaminati a Marghera. Le norme sono fondamentali per poter affrontare il tema dei costi e benefici delle bonifiche a Marghera innanzitutto perché è proprio la legge che definisce cosa si considera inquinato, quando scattano gli obblighi legali di ripristino ambientale e chi debba sopportarne i costi, in un'ottica che risponde al market failure con strumenti di Command and Control.
Tuttavia in ambito di bonifiche dei suoli la legislazione è molto recente, specialmente in Italia dove lo strumento di legge base, il Decreto Ronchi risale al 1997. Da questo punto di vista il paper si pone l'obiettivo di confrontare le esperienze dei paesi che sono partiti per primi nella regolamentazione della bonifica dei suoli per capire quanta conoscenza sia stata prodotta su questo tema anche grazie al funzionamento concreto delle istituzioni disegnate dalla legge. Uno studio comparativo aiuta a individuare i punti dove il sistema di incentivi e i metodi di enforcement non riescono a raggiungere il loro obiettivo che è quello del recupero delle aree inquinate dismesse.
L'esperienza italiana seppure breve mostra una evoluzione verso una maggiore aderenza alla realtà dei problemi e una crescita della consapevolezza che l'analisi costi-benefici impone di non considerare sempre l'opzione clean-up completo, la quale talora è anche tecnicamente, e non solo finanziariamente impossibile. Marghera da questo punto di vista si rivela un interessante laboratorio con il suo strumento di "coregolazione" Stato-imprese che mira ad una pianificazione partecipata multiobiettivo, cioè con l'Accordo di Programma per la Chimica. Proprio in tale documento si propongono a livello locale alcune soluzioni che emergono ora anche a livello nazionale nel decreto attuativo del Ronchi.

MEASURES OF REGULATION AND PROMOTION OF THE FISHING IN VENICE LAGOON

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Introduzione

L'attuale situazione della pesca a Venezia è oggetto di numerosi dibattiti sia per i suoi impatti ambientali, che per quelli economici e istituzionali. Da più parti si propone di intervenire attraverso una regolamentazione che da un lato garantisca uno sviluppo economico dell'industria ittica nella Laguna, ma dall'altro permetta uno sfruttamento sostenibile delle sue risorse alieutiche. La compresenza in Laguna di una pesca tradizionale e di forme di pesca più "industriali" rende necessario un intervento regolamentativo che garantisca profittabilità economica e sostenibilità ambientale di tutte queste forme.

La ricerca si propone di confrontare sul piano economico e ambientale alcuni modelli di sfruttamento delle risorse alieutiche della Laguna di Venezia. In particolare, 1) il modello attuale, basato sul libero accesso alle risorse, 2) un modello di utilizzo vincolato, basato su un controllo degli accessi alle risorse, 3) un modello basato sull'impiego di tecniche tradizionali di pesca.

L'analisi è pertanto tesa alla stesura di una proposta di sfruttamento ottimale della risorsa ittica, compatibile sul piano economico e sostenibile sul piano ambientale.

1. Objectives

We focus on the estimation, and discussion, of the economic valuation results of alternative clam fishing management practices in the Lagoon of Venice. The proposed valuation approach is anchored in the use of the stated preference methodology and it is characterized by the design of a contingent choice survey, which was carried out by personal interviewers. The questionnaire was carried out in summer 2001. The sampling was executed across the two main areas of the Lagoon: the northern area, including Burano, and the southern area.

2. Database

1) Research on-site, among the fisherman having the licence for fish, on type and characteristics of our and your activity;

2) Research on-site among the fisherman working in the Venice lagoon, on availability to reconvert your activity;
3) Research on-site on the manila clam near the fish market of Venice and Chioggia;
4) Research on-site on the fisherys with a commercial value, by the bibliographic sources and by the fish market in Venice and Chioggia;
5) Statistical analysis.

3. Methodology

Stated preference methodology is characterized by the application of a survey that describes and confronts two clam management alternatives. The respondent is asked to choose one of them. Stated preferences methodology presents an important advantage to the well-know contingent valuation method since it makes the monetary valuation (at the margin) of each management attribute possible. Two important tasks describe this valuation methodology. The first refers the identification of the set of the management attributes and the specification of the number and magnitude of attribute levels. The second task refers to the design of the contingent choice survey.

Biologists, economists and fish management specialists, in conjunction with a small group of fishermen, got together and jointly developed a list of relevant attributes with important linkages to current fishing management practices in the Venice Lagoon. Three main attributes were identified during this group discussion. We refer to (1) the fishing system; (2); the size of the area, and (3) the cost of the annual permit. Furthermore, the discussion provided an indication on the different levels of attributes that affect fisherman's behavior. These attributes, together with the cost of the permits, are interpreted as the various components of any policy package that focuses on the regulation of clam management practices and their environmental damage in the Lagoon. Three fishing regime were considered for analysis. We refer to the ‘traditional’ system, the ‘present situation’ system, and the ‘vibrating and scraper’ system. Size and location of fishing areas also plays an important role on the fishermen choice behavior. In this context, and bearing in mind the hydro-morphological and scale features of the Lagoon, we followed the research guidelines of past studies. Therefore, it was considered the analysis of permits for a fishing area of 3.5 hectares and an area of 10 hectares.

On the basis of the type of clam fishing system, size of the area and cost of the annual permit, a contingent choice survey was developed. The questionnaire is characterized by using a survey narrative so as to describe a set of two alternative fishing management practices. Respondents are then asked respondents to state which one they prefer. Furthermore, each respondent is informed that the two fishing practices presented in each scenario are the only possibilities available for the next fishing season and he is asked to choose one of them. In other words, fishermen directly asked to state their preferences, choosing directly from the survey the preferred management practice. Contingent choice questionnaires give sufficient flexibility to set, alter, and combine different levels of each management attributes – see Table 1 for an illustration of a contingent choice question.

Tab. 1. Example of a stated choice question

Assuming that the following fishing management practices were the only practices available, which one of the two listed below would you consider more attractive for you, if either?		
	Practice A	Practice B
Area in concessione (ha)	3.5	3.5
Sistema pesca	Prevalentemente usata oggi (rusca+reti fisse)	Vibrante
Costo totale concessione	500,000 (Lira)	9,000,000 (Lira)

The contingent choice survey has been carried out in summer 2001. The sampling was executed across the two main areas of the Lagoon: the northern area, including Burano, and the southern area. The questionnaire was performed by face-to-face interviews, involving the participation of researchers with high levels of field knowledge as the interviewers. The interviewers contacted 193 fishermen, 114 of which completed the questionnaire. The participation rate is therefore about 61 percent. Bearing in mind respondent's answers we are able to estimate (at the margin) the monetary value of each attribute. Estimation results are presented and discussed in 'Assessing the economic value of alternative clam management practices in the Lagoon of Venice: results from a conjoint valuation application'.

4. Results

The questionnaire was performed by face-to-face interviews, involving the participation of researchers with high levels of field knowledge as the interviewers. The interviewers contacted 193 fishermen, 114 of which completed the questionnaire. The non-participation rate is therefore about 40 percent.

Monetary valuation results show that the amount of money that an individual fisherman would be willing to pay for a change in the dimension of the fishing concession is 568 €. In addition, Table 3b shows that the economic welfare impact of a change in the clam management practice, due to a change in the fishing system amounts to 1,005 €. In other words, an individual fisherman would be willing to pay 1,005 € for a change from today's fishing situation towards a fishing practice exclusively based on the vibrant rake system. We can also observe that only a relatively small part of the variance of the observed stated preference behavior can be explained by these fishing-related-attributes, the R^2 is about 19 percent. As a consequence the respective monetary valuation results are characterized by relatively wide interval estimates. For example, according to Table 3b, fishermen's WTP for a larger fishing concession ranges between 125 € and 1,732 €. In order to improve estimation results, we study the degree to which preferences for fishing programs differ between the two segments of the fishermen population. In this context, two fishing segments were defined, corresponding to two types of fishing regimes in the Venice Lagoon. One fishing regime refers to a fishing fleet that is composed of vessels jointly managed by cooperatives. The other refers to a fishing regime that is characterized by smaller and individually owned vessels. While the former are currently submitted to a set of cooperative managing rules, the latter are often managed by private individuals, who predominantly fish as a complementary income source to their main economic activity. In addition, some of these individuals are unauthorized or illegal fishermen. Therefore, we explore an additional model formulation, see Table 2a, which includes interactions of operations in collective regime and operations in individual regime (individual characteristics) with the attributes originally under consideration at the stated preferences model. In fact, the introduction of such information contributed to a significant qualitative improvement of our econometric model. This is now capable of explaining more than thirty percent of the variance of the observed stated preferences behavior – see R^2 in Table 2a. As before, estimation results show that as the price of the permit increases, utility decreases. Similarly, as the concession area increases, utility increases. In addition, regime interactions coefficients are added to the main effects for fishermen who operate in the cooperative regime. Since fishermen who operate in the individual regime are coded as zero, we can see that fishermen who operate in the cooperative regime present a higher sensitivity to the price of the permits, see the estimate for regime*price cross effect in Table 2a. In fact, for the population that operate in the individual regime, a price increase is characterized by a negative impact in the utility and estimated to be of the magnitude – 0.0007. In contrast, the fishermen population who operate in the cooperative regime this impact decreases to – 0.0028 (= – 0.0007 – 0.0011). Independently of the type of fishermen, price estimates are statistically significant indicating that, everything held constant, fishermen continue to receive more utility from lower prices.

Tab. 2a: Stated preferences model estimates with cross effects for the fishing regime [(a)]

Variable	Estimate	p-value
Price of the permit	– 0.0007	0.008 *
Area	0.5814	0.008 *
Fishing system [(b)]	– 1.7661	0.013
Regime [(c)] * Price	– 0.0011	0.316
Regime [(c)] * area	0.5856	0.492
Regime [(c)] * system	4.2996	0.052 *
Adjusted R^2	0.3023	

Tab. 2b: Economic welfare measurement

WTP for	Point estimate	95% Confidence Interval [(e)]
Area	811 € (1.97) [(d)]	[225 € ; 2 917 €]
Fishing system [(b)]	2 456 € (1.84) [(d)]	[403 € ; 8 340 €]

Notes:
* (**) Statistically significant at 5% (10%).
(a) Calculations are performed using the MULTINOMIAL LOGIT procedure in *LIMDEP*®.
(b) Ordinal categorical variable (0 = today, 1 = exclusively manual, – 1 = exclusively vibrant).
(c) Regime is a dummy variable with 1 denoting regime cooperative and 0 regime individual.
(d) t-values are computed using the delta method.
(e) CI is estimated using the asymtotic t-test method as described by Armstrong *et al.* (2001)

We can also observe that a change in the dimension of the concession area presents stronger impact on the utility of the population of the fishermen who operate in the cooperative regime than on fishermen who operate in the individual regime, 1.167 and 0.5814 respectively. Finally, estimation results show that the welfare impact of a change in the fishing system differs substantially across the two fishermen populations, which is particularly strong for the fishermen who operate in the cooperative regime. Such parameter estimates are reflected in the economic welfare measurements – see Table 2b. In fact, when comparing these valuation results with the ones presented in Table 1b, which represents the polled fisherman population, we can observe that the population of fishermen who operate in the cooperative regime present higher monetary valuation for an increase in the dimension of the fishing concession, which is now valued at 811 €. In addition, this population is characterized by a stronger willingness to pay for a change from today's fishing situation towards a fishing practice exclusively based on vibrant rake system, which is now estimated at 2,456 €.

5. Policy Implication

Finally, we addressed to the policy implications related to the economic value assessment exercise of a change in the clam management practice in Lagoon Venice due to an adoption of a clam system exclusively based the use of manual rakes, which are described as the showing the lowest environmental damage. In other words, how much would it cost to pay all fishermen, independently of their current fishing equipment, to adopt such an environmental friendly clam fishing technology? According to our calculations the financial costs associated with the adoption of such a policy is estimated to be 5,904 € per fisherman per year, ranging up to a maximum of 80,160 € per fisherman per year, depending on the type of fishermen population and current management practice. Combining this value with the total number of fishermen currently operating in the Lagoon of Venice, the total welfare loss associated with the adoption of the manual clam fishing technology is estimated to at 11.8 € million per year. This information is crucial for the evaluation of the costs due to the adoption of a clam fishing system based on the use of manual rakes, and associated forgone damages on the morphology processes and marine life functions. In fact, from an environmental protection policy perspective, the adoption of this management practice will require the payment of an annual a lump sum to the fisherman population, which amounts to no less than 11.8 € million per year.

6. Papers

Within the research activities of WP4, the following papers were produced[19]:

Nunes P. **"Exploring the use of stated preferences methods to value fish management practices: econometric modeling and survey design"**.

[19] For copies of these papers, please contact the editors or martina.marian@feem.it

Abstract: The Lagoon of Venice is a complex wetland coastal zone characterized by the presence of dynamic and open systems, involving terrestrial and aquatic, freshwater and marine ecosystems. It covers more than 50,000 hectares and extends over 50 kilometers. The water depth ranges from 8 - 14 meters in canals within the Venice lagoon, to 0.5 - 2 meters in shallow water (Rabagliati 1984). The lagoon morphology depends on the processes, functions and interrelationships between the amount of solid materials brought by the rivers together with the erosive forces of waves and sea. The lagoon silting up process has been avoided since the beginning of the Republic of Venice by diverting rivers going into the lagoon and by reducing the number of inlets. The latter is responsible for an increase of the re-flow from sea that, in turn, has been contributing for the erosion of the coastal areas. Furthermore, the socio-economic development registered during the past century has led to heavy modification of the lagoon morphology through activities such as reclaiming water areas, making new channels, building industrial areas, as well as introducing exotic clam species in the marine system. These have resulted in significant environmental damages to the lagoon ecosystem.
Many of these environmental damages, such as the erosion of the coastal areas or the loss of marine biodiversity, are not ‘cashed’ flows, i.e., there is no market price mechanism that fully captures such damages. In other words, the market price fails to capture many environmental damages. Given that most human activities are priced in one way or other, in some decision contexts, the temptation exists to downplay or ignore these damages on the basis of non-existence of prices for environmental protection. The simple and simplistic idea here is that a lack of prices is identical to a lack of values. Clearly, this is a slightly based perspective. The theory of externalities teaches us that many values cannot be incorporated in conventional market transactions. The question is then how to translate such values into monetary dimensions. This is a challenging question to be addressed by economists. In the present article we focus on the use of stated preferences methods to value alternative clam management practices in the Venice Lagoon. Such monetary information will serve as important corner stone for the identification of the benefits and costs involved with alternative clam management practices or clam regulation scenarios.

Nunes P., Rossetto L., de Blaiej A.: **“Measuring the Economic Value of Alternative Clam Fishing Management Practices in the Venice Lagoon: Results from a Conjoint Valuation Application”**, Forthcoming at the special issue of the *Journal of Marine Systems*.

Abstract: This article focuses on the estimation, and discussion, of the economic valuation results of alternative clam fishing management practices in the Lagoon of Venice. The proposed valuation approach is anchored in the use of the stated preference methodology and it is characterized by the design of a contingent choice survey, which was carried out by personal interviewers (see ‘Exploring the use of stated preferences methods to value fish management practices’ for more details on the involved econometric modeling and survey design aspects).
Estimation results show that: (1) fishermen bear an utility change whenever the price of the annual permit, the fishing technological system and the dimension of the fishing area change; (2) the probability of the choice of a management practice is positively related to the dimension of the fishing concession area and the level of technology. In

other words, any policy option that is characterized by the exclusive use of the vibrating and scrapers fishery system is associated with a positive impact in fishermen's welfare. Furthermore, (3) the choice of a management practice reveals to be negatively related to its associated costs, reflecting the fact that higher prices of the annual permit result in lower utilities.
In addition, monetary valuation results show that fishermen's willingness to pay for a larger fishing are is approximately 568 € per year. Second, an individual fisherman is willing to accept 1,005 € for a change from present fishing practice situation towards a fishing practice exclusively based on manual rake system. Third, monetary valuation results show that the welfare impact of a change in clam management practices differs substantially across the population of fishermen that operates in the cooperative regime and the population of fishermen that operates in the individual regime. In fact, the former present not only a higher monetary valuation for an increase in the dimension of the fishing concession, which is now valued at 811 €, but also a stronger willingness to pay for a change from today's fishing situation towards a fishing practice exclusively based on manual rake systems, which is now estimated at 2,456 €. Finally, monetary valuation results show the welfare loss associated with the adoption of such clam management policy that is exclusively based the use of manual rakes amounts to 11.8 € million per year. In other words, this figure can be regarded as a lower bound to an annual payment to the fishermen population so as to adopt a fishing system based on the use of manual rakes and this way forgo the damages on the morphology processes and marine life functions caused by the vibrant rake technology.

Boatto V., Galletto L., Pellizzato M., Rossetto L., Silvestri S., Orel G. Sfriso A**.: "The art of fishing in the Venice lagoon: from tradition to innovation"**, Paper presented at Fondazione Eni Enrico Mattei, Venice, 5 May 2003.

Abstract: In the last years the fish industry in the lagoon of Venice has shown a gradual decline, which has been characterized either by the reduction in the number of fish belonging to typical Lagoon species (fig. 1), or by the transition from multiple fishing methods to an activity which is based mostly on one species the bivalve *Tapes philippinarum*. The high spreading of this bivalve and its easy earnings are factors which have boosted its capture, at first realized by manual systems, which have been later refined in order to obtain higher yields. The mechanical impact of these tools (hydraulic dredge, vibrating rake, and "rusche") has had remarkable consequences on the environment: changes in the lagoon bottom morphology and composition, by modifying the texture and the webbing, suspending of remarkable sediment amounts, making the water turbid and, consequently, hindering the development of the plant population (ICRAM, 1994; Pranovi & Giovanardi, 1994; Sfriso, 2000).
Currently the production of clams, wrongly considered inexhaustible by the fishermen, is diminished of approximately 40%. According to economic data (fig. 2) one finds a progressive gap between evolution of the production, which is decreasing and prices that show, on the contrary, an increasing trend. This fact happened especially at the end of year 2001, when prices have shown a great jump that does not seem due to an unexpected increase in the demand. The more likely reason of this fact (however deserving further deepening) seems to be related to the total reduction in product amount, which has been supplied at the market.

If this hypothesis were confirmed, the price increment should be caused by the stock depletion, as a consequence of deaths and of an excessive exploitation of the natural beds. About last year supply, considering the available data, we can estimate a 25% contraction of the amount at the beginning of the year. Then, taking into account these data, it is likely to foresee that the lagoon fishing free access system should afford a deep crisis in the medium and long run and, hence, that it is necessary to make up an alternative management strategy for the alieutic resources, which makes the lagoon fishing a sustainable activity under different point views: environmental, biological, economic and social.
To pursue this goal, keeping into account the interventions which will impact the morphologic aspect of the Venice Lagoon, we have thought of analysing three alternative solutions: the free access fishing (status quo); the traditional fishing and the restricted one. For each managerial alternative we have proceeded by estimating either its technical-productive and environmental results or their economic value for the enterprises and the whole Lagoon people community.

Sfriso A., Boatto V., Ceoldo S., Facca C., Silvestri S**.: "Role of clam-fishing on sedimentation, grain-size changes and erosive processes in the central part of the Venice lagoon"**.

Abstract: Since the early '90s the lagoon of Venice has been affected by strong environmental changes. Macroalgal biomass and production have decreased to 1-2% of the biomass and production recorded in the '80s. Bottoms free of macrophytes have been quickly populated by the bivalves *Tapes philippinarum* Adams & Reeve and their catching by means of fishing devices has increased significantly sediment fluxes, changed sediment grain-size and enhanced erosive processes. Hundreds hydraulic and mechanical dredges, each day, drag surface sediments to a depth of 10-20 cm disrupting the sediment texture, the micro-phytobenthos layer, the surface and deep macrofauna and preventing the re-colonisation by seagrass beds. Moreover huge amounts of sediments are suspended in the water column thus increasing water turbidity and favoring the spread and loss of the finest sediment.
Since the late '80s, because of the clam-fishing impact in the central lagoon sediment fluxes (SPM), monitored by traps placed on surface sediments, have increased of ca. 4-11 fold on a yearly basis. At Sacca Sessola, the lagoon area which used to exhibit the highest macroalgal coverage (up to 20 kg m^{-2}, fwt) and is presently deprived of biomass, but intensively colonized by bivalves, SPM fluxes passed from 65 kg m^{-2} dwt in 1989-90 to 253 kg m-2 dwt in 1992-93 and to 759 kg m-2 dwt in 1998-99, totally increasing ca. 11.6 times.
In the mean time at San Giuliano and Fusina, which are close to the mainland, the percentage of fine sediment (fraction <63 µm) decreased from 99% and 95% in 1987-93 to 83% and 81% in 2002, whereas at Alberoni, which is near the sea-inlet, it increased from 20% to 55%. Similar changes were found when dry density (g cm-3) of surface sediments which at present is more homogenized than in the past was monitored.
The comparison of the 1987, 1998, 2002 maps of fine material in the 5 cm top sediment layers in the central part of the Venice lagoon shows that this basin can be subdivided in two sub-basins: one, situated S-SW of Venice, where the fine component has decreased significantly and another, NE of Venice, where it has increased or has

remained fairly unchanged. On an average the fine fraction has decreased from 20 to 40% with peaks up to 77% near Porto Marghera Industrial area. In that area clam-fishing activities are very intense and the fine sediment moves away because of the tidal currents of the Malamocco-Marghera canal. In contrast, the basin NE of Venice, close between islands and tidal-lands where current effects are negligible, or areas colonized by seagrasses, show a progressive increase of fine material.
In addition, in the area between the Lido watershed and the Malamocco-Marghera canal a marked bathymetric increase has been observed with a mean bottom loss of 1-3.5-(8) cm per year. In that area since 1987, the lagoon bathymetry has increased up to 0.5 m.

AREA 2
ARCHITECTURE AND CULTURAL HERITAGE

RESEARCH LINE 2.1
Protection from high waters and architectural conservation

BUILDING UPON WATER. URBAN WORKS AND URBAN ENVIRONMENT SAFEGUARD IN VENICE (15^{TH} - 17^{TH} CENTURIES)

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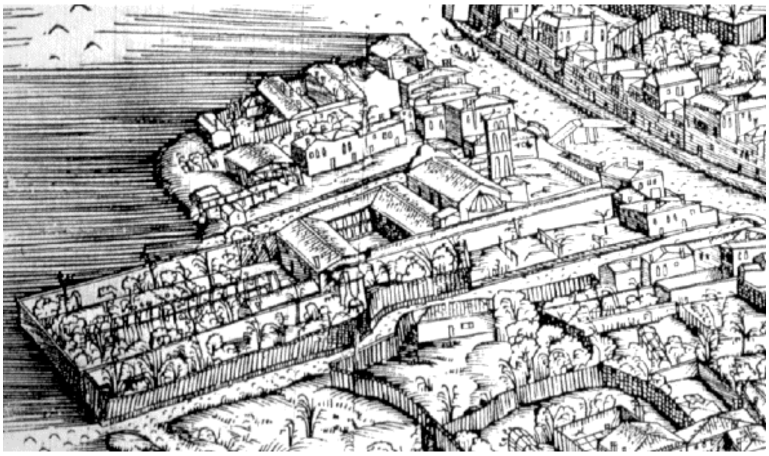

Fig. 1 - Detail from: J. De Barbari, *Veduta di Venezia,* 1500.

Riassunto

L'obiettivo del gruppo di ricerca è stato quello di individuare, attraverso lo spoglio sistematico dei documenti conservati presso l'Archivio di Stato di Venezia, gli interventi materiali, le procedure tecniche e amministrative adottate in epoca veneziana al fine di proteggere il tessuto urbano nei confronti dell'azione distruttiva delle acque lagunari.

L'analisi si è concentrata quindi sui fondi archivistici di tre magistrature preposte al controllo e alla manutenzione del tessuto urbano e dell'assetto lagunare: i *Savi ed Esecutori alle acque*, i *Giudici del Piovego* e i *Provveditori di Comun*. Le competenze esercitate dai tre uffici, sia giudiziarie che esecutive, coprivano l'insieme delle attività di gestione dello spazio pubblico e di controllo «urbanistico» della città. L'indagine si è così indirizzata alla registrazione degli interventi di rialzo del selciato, di marginatura, di costruzione di fondamenta in pietra, di risanamento dei pozzi compromessi dall'acqua alta, delle procedure di prevenzione da abusi privati nei confronti delle proprietà demaniali, di escavo dei canali, ecc. I documenti così reperiti, sono stati registrati e indicizzati mediante una scheda informatizzata che evidenzia gli estremi principali della notizia. Le schede sono finalizzate all'inserimento nel sistema GIS.

Abstract

The objective of this research group has been to identify, through the systematic consultation of documents collected by the library “Archivio di Stato di Venezia”, the material interventions, the technical and administrative procedures employed in Venice during 15th-17th centuries.

The analysis has been focused on the archives of three magistratures for the control and maintenance of the city and the lagoon: the “Savi ed Esecutori alle acque”, the “Giudici del Piovego” and the “Provveditori di Comun”. The competences of these officies, judiciary and executives, covered both the activities of management of public space and “planning” control of city. The investigation addressed the registrations of operations of increases cobble surface, banking, construction of stone quays, improving the wells damaged by high water, ways of preventing private abuses of public properties or digging canals. The collected records were organized in the form of an a electronic table, for insertion in a Geographical Information System.

1. Introduction

The ultimate aim of this contribution, which lays no claim on tracing an exhaustive outline, is that to introduce some issues. As a consequence, here we are not going to touch upon all the questions that this research study involved. On the contrary, we will simply try to give a brief summary, describing just some results of the research that is still in progress. It consists in a comparative analysis of the operations, the technical and administrative procedures adopted by the Venetian magistracies in order to protect the urban environment against the waters of the lagoon.

Initially it was necessary to choose sources defining the greatest use of one source or the other with respect to our aim. The research team carried out a systematic analysis of the documentary sources conserved in Venetian State Archives. After a preliminary study of the bibliography concerning such a topic, we chose three magistracies within the public administration that allowed the control and management of both the urban environment and the lagoon system. They were: the *Savi ed Esecutori alle acque*, the *Giudici del Piovego* and the *Provveditori di Comun*. As well their tasks were complementary.

We were particularly interested in the operation of cobble surface increase, of banking, of construction of stone quays, of improving the wells damaged by high water; in the ways of preventing private abuses towards public properties or digging canals.

The collected records were organized through a table, where the most important informations were put in evidence. This kind of table was planned to enclose in a Geographical Information System.

2. Provveditori di Comun

The magistracy of the Provveditori di Comun was instituted in 1256. At first it had mainly judicial assignments in commercial issues [Ferro, 1778-81; Gasparini, 1993]. Attributions in matter of urban spaces were assigned in 1392: the Provveditori had to supervise the private buildings in state of decay. It was then in the course of the 1400's that the magistracy assumed extensive tasks in preservation of urban environment (as: *calli* – streets -, wells, *campi* ecc.), that previously were entrusted to other offices.

At first the maintenance of *ponti e salizade delle contrade* was in charge of *Capisestieri*, which from the 14th century on divided the control on public spaces with Signori di Notte and the Giudici del Piovego. However this administrative organization demonstrated inadequate facing the complexity of the urban environment. So, in the middle of 15th century, the Senate resolved to be provisionally appoint two *soprastanti* who was in charge was to check the execution of the yards [Crouzet-Pavan, 1992].

The appointment of the two extraordinary *provveditori* was then irregular and finally their tasks were transferred to the duties of the Provveditori di Comun. From the 1480’ on this branch of the Venetian administration exercised a control on the correct development of the operations of maintenance of *salizzade* (paved streets), *fondamente* (wharves) and wells [ASVe, *Provveditori di Comun*, b. 48, c. 1-4]. The 25 of July 1484 the Maggior Consiglio transferred to the magistracy also the economic management of excavation of inner canals, the supervision on public streets and the maintenance of wells and bridges. In 1487 such duties were integrally transferred: not only the administrative control, but also the management and technical organisations of the yards [ASVe, *Giudici del Piovego*, b. 1].

At the end of the administrative reform, the Provveditori di Comun had different function, as judicial tasks and operating duties. The three nobles, elected for sixteen months, had the task to control land appropriations, to resolve real estate controversies and finally to decide and to arrange the urban environment. After all, as it has been observed, the Provveditori di Comun «divengono gli agenti principali della politica urbanistica di Venezia» [Crouzet-Pavan, 1996].

The conserved documentation of magistracy’s activities in urban works cover a period comprised between the first decades of the 1500's and 1798. In the greater part it concern: the maintenance of the streets, *campi* and *fondamente* (to repair; to reconstruct; to pave etc.); the construction and improvement of public wells; excavation of inner canals; the maintenance and new construction of public bridges. Finally we have many documents about deeds against the violations of public ground and waters by private owners.

The research we are conducing has the scope to identify and record every document pertinent to the study of the activities conducted by this magistracy to protect from the destructive actions of the water the urban environment. As first result the documents found has allowed, for example, to recognize that in the middle of the 18th century there was a substantial change of strategy to preserve urban spaces. So, in 1768 it started a great program for the reconstruction of all public wells out of order from high waters. Stating from that date the *proto* (the technician of the magistracy) had the task to compile specific reports, one for each *sestiere,* which described all the public works to do. On this basis it was then assigned the yards to private workshops.

3. Savi ed esecutori alle Acque

The magistracy of the *Savi ed esecutori alle Acque* was instituted, in a permanent form, in 1501 [Caniato, 1999; Gasparini, 1993]. It can be considered as the governement agency responsible for the maintenance of the lagoon, its canals, sea defences and for the hydrographic regulation of the mainland territory. They basically dealt with the administration and verification of transformations along the boundary of the lagoon and urban periphery and along the most important canals. These tasks resulted in series of «permits» and technical reports.

The research focuses on the analysis of the works planned by the *Savi ed esecutori alle Acque* in relation to the construction/reconstruction of banks and *fondamente* (the public quays). These kinds of works were moved by considerable efforts to protect land from the water of the lagoon: earthen embakment or stone banks could avoid increasing the mud of the lagoon.

The period of time taken into consideration is the 16th century: from the institution of the magistrate to the realization of «Fondamente Nuove» (after 1590).

Different types of records compose the archive of the magistracy: from the *capitolari* (the decrees) to the technical reports, just to quote some cases of decriptive documentary sources. In fact, a staff of technical experts, called *proti*, with experience in hydraulic projects, was on the service of the office. They were salaried figures and surveyors of works, characterized by a pragmatic culture [Rompiasio, 1771; Svalduz, *forthcoming*]. In the archives several plans and drawings are conserved: however, in most cases they date at the 17th or 18th century. We found just few sketches in relation to the decriptive documentary sources of the 16th century.

This is not the place to take into consideration the numerous issues concerning the micro-dynamics and the transformations carried out by the magistracy. Nonetheless, it is possible to describe some specific cases. One of the first data that emerged from the research regards the frequent oscillation from pragmatic and specific works to large-scale proposals. The first of several such works was the construction of the «Fondamenta delle Zattere», the long quay facing the Giudecca, which was begun after a Senate decree in 1520. When completed, it extended from Santa Marta to the «Punta della Dogana», the Customs House at the eastern end of Dorsoduro [Goy, 1997].

The 16th century saw several ambitious plans for renewal, concerning the Venice’s urban environment too. Cristoforo Sabbadino, the chief surveyor of the *Savi ed esecutori alle Acque* who was a specialist in hydrographical affairs, produced the so called «piano» for Venice (1557), including a completely new circumference of public quays all around the city (Fig. 2). First of all this plan is very important because it resolved the problem of the limits of the city and facilitated the urbanization of the peripheral areas.

In this period, the shortage of land gave rise to some large-scale reclamation projects, such as the radical one of the «Fondamente Nuove» (the New Quays). The operation showed a twofold purpose: it extended the city’s physical limits along the north shore and provided new land for urban development; but it also provided a more dignified termination to the city’s form, defining its northern shore, like the Zattere had done on the south side.

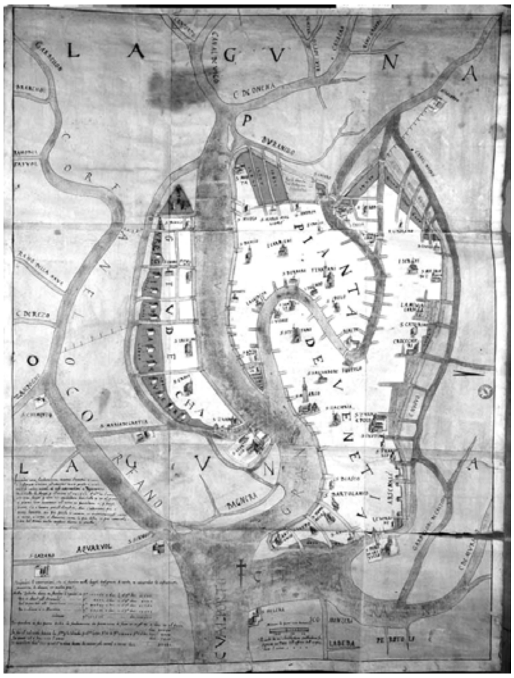

Fig. 2 - C. Sabbadino, *Plan for Venice,* 1557 [Biblioteca Marciana Venezia]

On the other hand, the long-term goal was to build up, restore and reinforce the banks or to put in place new quays: these works had to be built straight, that is without curves to avoide the stagnation of water.

There was no attempt to improve the city road network [Pavanini, 1989]: it was just necessary to protect the lagoon balance, surrounding the Venice's urban environment. Nonetheless, some case-studies (above all the Fondamente Nuove) show that these works of urban maintenance could improve the dignity of the city too.

4. Giudici del Piovego

The Giudici del Piovego was a judicial office (origin 1224, 1272) in charge to control the public space. Between the end of 15th and the mid of 16th century, their competences were restricted by the rise of other authorities dealing with the management of both the city and territory in order to find modern solution to problems of very different nature [Concina, 2001]. Their role was reduced to measurements of site, permits for new constructions and for external transformations of the single building with its immediately context. These operations took to a remarkable transformation of the whole image of the city especially in the 18th century [Cavazzana Romanelli, 1986].

The study is related to a group of licences released between 1660 and 1760 from the responsible authority. All the licenses are connected to the permission to improving operations on building as the addiction of a chimney, the construction of aerial structures (*altane*), or the elevation of a new floor above the previous building.

In the case of construction by a private owner the officers go to the site, take a series of measurements and determine the limits to be respected by the builder with the words: «giusto al vecchio e giusto ale leggi» (following the old and the laws) or following a previous decision of the magistracy. An example can be seen from what took place in august 1760 when there was the necessity to modify the alignment to the Scuola della Carità and the boundary on the small canal flanking it. In that case they proceeded in this way: «licenza a Maestro Zorzi Martinelli murer di poter costruir la facciata della Scola della Carità di pietra viva con sporto di fondamenta nel campo piedi 2 1/2 in fuori del bassorilievo di S. Cristoforo, nel canton del rivo far una scarpa di pietra viva piedi un'e mezzo circa, dovendo detta Scola far restringer la fondamenta di rimpetto in modo che resti il rivo, secco della larghezza di piedi 12 1/2 ca. come s'attrova, et in tutto et per tutto come nella terminazione del 13 luglio prossimo passato» [ASVe, *Giudici del Piovego*, b. 24, Registro intestato «17. Licenze Piovego» 1754, 29 nov. - 1760, 26 nov., n° 23, 1757, agosto 18]. Requests related to ecclesiastical improvements or modifications are too submitted to a permission: some examples are the licenses released to the builders of the church of S. Stae [ASVe, *Giudici del Piovego*, b. 23, registro segnato «14. Misure Piovego» 1687, 11 mar.-1692, 17 dic., s.n., c. 31*r*, 1688, settembre 16; Moretti, *forthcoming*] or S. Rocco [ASVe, *Giudici del Piovego*, b. 24, cit., n. 91, 1757 (1756 mv), febbraio 8], or Scalzi to advance with their façade or to construct a new chapel in both cases occupying public soil.

The measurements («dal spigolo della fondamenta sopra il rio e dalla fondamenta che si deve disfar sul canton della calle di S. Cristoforo piedi dodeci dalla fabrica che deve disfar al spigolo della fondamenta sopra il rio piedi 11») [ASVe, *Giudici del Piovego*, b. 24 cit., n. 55, 1755 aprile 16] take consideration of the nearness of other buildings of which we have the names of the owners, the presence of a canal, of a bridge, a church and of the alignment direction (*recto tramite*), in any case elements that give us the possibility to find it on an actual map of the city. This procedure is not only present in Venice, but also in other *Ancien Régime* towns as Siena [Franchetti Pardo, 1994], Florence [Goldthwaite, 1984], etc.

These licenses are important to achieving knowledge of the gradual transformation of the city but also for the possibility to reconstruct a data bank of builders and craftsman like the existing data bank of stonemasons and sculptor (Iuav/DSA presented to the first CORILA annual meeting 2002) [Connell, 1988].

From the 17th century on, a group of these documents include a series of drawings with a description of nearly all the case of transformation [Calabi, 2003]. These drawings offer very useful evidence under a normative and typological point of view.

5. Data bank and structure of the reports

The complete cataloguing of the three series was realized on a format based on *Acces* system. The information taken from the descriptive documentary sources were structured on the basis of some informative typologies. The first part of the report concerns archive information: the archive place, the specific *serie*, the date. The second kind of information concerns the operation site, that is where the work had to be realized. The greatest difficulty with the analytical process is that of the exact location of the information available, because of the alteration of the toponyms. That's why we decided to record the actual toponym and the historic one too. As well, GIS codes are reported in this second section.

The principal part of the format is dedicated to describe the work to be recorded. Data are structured according to some specific types of works. In addition, we planned a free text space to write significant details or a summary of the decriptive documentary sources. In the last part of the record one can find information about archive drawings or sketches enclosed to the original record.

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Abbreviation:

ASVe = Archivio di Stato di Venezia

THE CATALOGUE OF VENETIAN EXTERNAL PLASTERS: MEDIEVAL PLASTERS

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Riassunto

Il trattamento di gran lunga dominante a Venezia nel medioevo è costituito dal *regalzier*, un finto ammattonato dipinto a fresco su intonaco in monostrato. A partire dalla seconda metà del XIV secolo ai *regalzieri* uniformemente dipinti in rosso con fugature bianche si affiancano decorazioni bicrome con finti laterizi disposti a losanga. Nell'edilizia civile al finto ammattonato si affiancano fasce verticali e orizzontali che compartiscono i prospetti.

Abstract

The finish treatment widely used in Venice in the Middle Ages consists in the so-called *regalzier*, a dummy brickwork reproduced by a fresco painting a one-layer plaster. Starting from the second half of 16th century, alongside with regalzieri painted in a uniform red colour with white painted flutes, other decorations can be found, in two colours, with dummy bricks arranged according to a lozenge scheme. Housebuilding shows some examples of dummy brickworks alongside with vertical and horizontal bands dividing the fronts into sectors.

1. Introduction

The catalogation work of Venetian external plasters is so far progressed to allow a quite accurate account of the technical and formal evolution of the outside front surfaces of the urban houses.

This study focuses on the far-off period of the Venetian building story, on the finish treatments of the external building surfaces during the Middle Ages.

The total amount of the most ancient plasters surveyed so far is 282, all belonging to the medieval and Renaissance "skim coats" class, representing approximately the 3,7% of the 7.646 building unities surveyed so far. A remarkable number of cases indeed: this kind of plaster is often found in small traces, it sometimes covers the whole surface of fronts and is in a quite good preservation condition.

The oldest finish traces still present on the walls of the urban houses, for which an accurate dating is possible, go back to 16th century.

Before that date, all information available to us is collected only on the basis of iconographic evidences, of some occasional trace of painted plaster still stuck to the bricks of pulled down buildings found on occasion of past restoration works, eventually of the rare fragments discovered during recent excavations.

Evidence of how the fronts of a whole urban wing of late 16th century, overlooking *S. Marco* square looked like for instance, in particular of the final section of the old *Orseolo* hospice and of 15th century *Casa dei Procuratori* (House of Procurators), adjoining to S. Marco tower (Fig. 1), is clearly shown in the large *teler* (canvas) by *Gentile Bellini* with the “Procession in S. Marco Square”.[20] The area where the Bon houses are located in *Ca’ Rezzonico* courtyard, where excavations have been carried out on occasion of some works performed by the Venetian Municipality twenty years ago approximately, or the late 15th century filling works of the cross vaults of the Summer Refectory of *Frari* Monastery in *San Polo*, cleared away during early 80’s of 20th century, have disclosed the presence of single *altinelle* (small bricks, 17-18 cm. long, which is equal to approximately ½ Venetia foot) belonging to buildings which have been pulled down in XII-XIII century. They are still coated with one-layer plasters, with dummy bricks or twisted flower garlands painted on them.[21]

Fig. 1 - Gentile Bellini, *Processione in piazza San Marco*, Gallerie dell’Accademia. Particular with the *Ospizio Orseolo* and the house of *Procuratori*.

During the excavations of *San Lorenzo di Castello* – just to mention a further example – extraordinary information has been collected on the oldest inside and outside plaster coats of the lagoon. The most remarkable findings consist in plaster fragments, whitish and red, the former found on the corbels of the crypt, the latter, probably with

[20] Almost all palaces and houses portrayed in the “Procession” have disappeared; nevertheless we can consider their description as faithful because of the extreme accuracy with which the still existing buildings are depicted, for instance the polychromes and gildings of the West front of San Marco Basilica.

[21] The picture of an *altinella* with a fragment of painted plaster coming from the filling works of the cross vaults of the Summer Refectory of Frari Monastery is portrayed in Armani E. – Piana M., 1985, mentioned work.

dummy bricks painted on them, placed on the connecting point between pillars and the tessera flooring of the nave - both can be dated back to the second half of 12th century – furthermore in a segment of dummy brickwork discovered on the external face of a parting wall of the building structures leant against the right aisle of the preceding church dating back to 13th -16th centuries.[22]

Observations and findings might prove that the decorative taste and the techniques applied for the finish treatment of the outside building surfaces have persisted from the beginning and throughout the whole 15th century without any clear break.

2. The regalzier

The finish treatment most widely used - widespread however in other Italian and European areas in those same centuries - consists in the dummy brickwork, known in Venice under the name regalzier. The term refers actually to the reproduction of a brickwork painted a fresco on a one-layer plaster.

Fig. 2 - The *regalzier*, Corte Nuova 2896.

In this kind of plaster coats the reddish ground painted with wide brush-strokes is overlapped by the white texture of painted flutes, with bold vertical lines, which seems to be laid according to horizontal grooves marked with a nail on the wet plaster coat, generally in correspondence with the fillings below.

The main techniques used to form regalzieri are two. The former consisted in laying down a thin coat of lime and sand, 2-3 mm thick, which covered the whole wall surfaces; the latter was based on the application of a mortar coat trimmed through a metallic paddle heavily pressed onto the brick wall faces. In this case the layer thickness

[22] The excavations works have been carried out in the 90's of 20th Century by Superintendence for Monuments and Environmental Assets, under supervision of archaeologist Ms. Maurizia De Min.

was higher in correspondence with the fillings between bricks, progressively decreasing up to zero in the core portions of each brick. This accounts for the conditions in which many regalzieri have been found in our times: they show that the treatment residuals have been mainly preserved close to the joint portions, that is where the mortar fillings, well carbonated thanks to their bigger thickness, have better stood up against the disrupting action of weather agents.

Fig. 3 - Castello, Corte Bressana 6786. Remains of *regalzier* preserved along with the subduing mortar.

Also the false flutes, made with brush-strokes in *San Giovanni* white colour (obtained by mixing, drying and grinding lime repeatedly), often look almost completely faded through rain water for the same reasons: the paint coat of texture, painted on a by then half-dry plaster, was not completely absorbed into the layer already carbonated in part.

It can also happen that, in those wall joint portions which underwent a dressing process, the regalzier seems to be painted with the addition of a bonding agent – of an organic or oleoresin nature - laying a coat directly onto the brick surface. This is still to be seen - just to mention some examples – on the embrasured arches of windows and rose windows, of pilasters, fringes or shaped elements of the Churches of *Frari, Santi Gioavanni e Paolo, Santo Stefano, Carmini* and *Madonna dell'Orto* (Fig. 4).

We are quite certain that entire fronts of some buildings have been completely decorated with oil-based regalzier, whenever the good surfaces co-planarity of their covers was allowed through well smoothed bricks; this was indeed a widespread practice in the late Venetian Gothic age. Evidence of this might be found in some written source. In the agreement signed on 19th May 1431 by *Marino Contarini*, *Antonio di Martino* from *San Stin* and by *Giovanni Benzon* from *Ca' Zane*, related to *Ca' d'Oro*, for instance, a term is contained providing for the smoothing of brick wall faces and relevant subsequent painting. According to the contract the masonry masters agree on "*fregar tutti i muri e tirar a peneleti*" ("dressing the whole walls and painting them"), beside putting a bordonale (decorative border) and a marble tracery made by Bons in the *portego* ("arcades") at the ground floor, facing the water bank. Most likely it is not a regalzier plaster, but it is a real paint layer; small traces of a red-brown paint coat can still be seen on the wall faces of the inner courtyard of *Ca' d'Oro*.[23]

Fig. 4 - *Frari*'s Church , San Polo. Remains of red painting on polished bricks.

So far however no medieval building has been discovered yet – among hundreds of examples spread all over the old town centre on which regalzier residuals are preserved – where the remnants of the old finish treatment are a clear evidence of the fact that this kind of finish had been laid down on all brickwork surfaces only by painting.

The only Venetian building having a brick front entirely dressed and covered with a coat of paint dates back to the Modern Age: it is the Palladian Peristyle of the *Convento della Carità* (Charity Convent) which was built in the 60's of 16th century.[24] All brickwork surfaces of the convent portion have been covered with a red coat of paint, called in different ways in the past, as red stucco or "very thin plaster (...) similar to dressed bricks".[25] Unfortunately the "very thin reddish coat, by now almost completely

[23] The document is published by Paoletti P., 1920, *The Ca' d'Oro,* in "Venice, studies of art and history", I, pages 116; it is most likely an oil-based *regalzier* , the only example known so far, evidence of which is found in a written source.

[24] About treatment of Peristyle front see Piana M., 1999, *The Convento della Carità: materials, techniques and structures*", in "Annals" n°. 10-11, Review of the International Centre for Architecture Studies Andrea Palladio; section on Palladio as an architect edited by Pier Nicola Pagliara and Mario Piana, pages 310-321.

[25] This treatment is called "red Stucco" by Inigo Jones who had visited the complex of Carità in the early XVII century (Iones I., 1741, *Notes and remarks upon the Plates of the second book of Palladio's Architecture*, Oxford, page 71); "A very thin reddish plaster, perhaps treated with linseed oil, similar to

worn away"[26] has been for the most part erased by the 19th century restoration works, in the attempt to reduce the contrast between ancient portions and subsequent rebuildings.[27]

Between 15th and 16th centuries some one-colour plasters can be seen as well – for instance the building overlooking the *campiello* (small square) *Pozzo Longo* and *calle* (narrow Venetian street) *Colloalto in San Polo*, street numbers 2356-2358, quite similar to regalzier as far as the technique is concerned, although with no texture of false fillings (Fig. 5).

Fig. 5 - San Polo 2356-2358. Plaster made of one layer with red colour.

The oldest regalzier known so far, found during the excavations carried out in San Lorenzo Church at *Castello*, dates back to 12th century; the latest one, by far an isolated

dressed brick, covers the columns, pillars and any other portion. Everywhere convents are covered with it and bricks rows hence show off, and this is made so well that everyone thinks that the building has no plaster". (Temanza T., 1762, *Life of Andrea Palladio from Vicenza*, Venice, page XCVI).

[26] Lazzari F., 1835, *Of Palladio's Building in the Convento della Carità, now belonging to Fine Arts Academy in Venice*, Venice, pages 8-9.

[27] "And speaking of the brickwork newly built, they were all adjusted in their joints and then wholly dressed with pumiced stone and with brick itself, for last cleaning, in the place of water, linseed oil, and this to obtain that very thin reddish plaster already mentioned by Temanza in Life of Palladio. This cleaning, limited then only to the added portions, will be now extended to the whole front, while the complete restoration we are speaking about is going on, so that the new building can match the old one also in the natural colour of bricks".(*Idem*, pages 18-19).

example, is present in the 18th *Maddalena* Church and can be related to the Palladian specimen of the *Carità* rather than to the false Gothic brickworks.[28]

Concealing systematically an original brick wall face through a false cover seems really inadequate, but it is not: the reason for this procedure was that of conforming all building surfaces to one another both as far as colour and texture are concerned.
This was mainly due to the remarkable changeability of medieval brick masonry in *Veneto*, built with *piere cote* ("baked stones"), different in colours from one another of course: as a consequence of the manufacturing systems of bricks, which progressed only after the second half of 19th century, the bricks – although belonging to a single lot, manufactured using a single clay bank and baked all at once - changed considerably from yellow to red depending on the place they had in the kiln and on the way the baking process occurred, with a rich or poor oxygenation.

The false cover was required also because bricks of different dimensions were present at a time, since it happened very often that materials coming form pulled down buildings were re-employed, or in some other cases much time elapsed from starting and completion of buildings, a lapse of time which was in some cases so long that the dimensions of bricks changed as well.

Fig. 6 - Dorsoduro, Church of Carmini.

In the Church of *Frari*, for instance, actually built in the same period when bricks dimensions had been changing remarkably, it is possible to find bricks of any size

[28] Notice by courtesy of architect Claudio Menichelli who supervised the restoration works of Maddalena Church.

spread out in *Veneto*, from altinelle (maximum size cm. 17,5 approx.) to the big elements of the late Gothic period (cm. 28-29 size approx). In this case the flutes pattern on dummy brickwork could hardly coincide with the location of texture below. A further example is the bell tower of *San Giovanni Elemosinario*, in *San Polo*. The bottom segment of the base shows two overlapped regalzier layers; the late Gothic re-make, concerning approximately the third upper portion of the base, necessarily resulted in the uniformation of the oldest wall faces with those built later. On the cornice level of the bell tower some rows of flat-walled bricks in a vertical position show line-engravings on the surface in order to repeat the same course of the other rows of false brickwork. A particularly well preserved example of false brickwork where the pattern of brick rows differs from the one of the bearing masonry below (Fig. 6), is the small portion which can be seen on an apsidal pilaster of the *Carmini* Church.[29] A difference in pattern between the fillings of walls and the painted flutes of regalzier is also visible on the inside plaster coats of the Churches of *Santi Giovanni e Paolo, Sant'Alvise* and *Santo Stefano*. Anyway judgements must be expressed with any possible due caution, as these plasters underwent remarkable re-makings during 19^{th}, 20^{th} centuries restoration works.

Fig. 7 - Castello, Church of San Zaccaria. Two-colours brick covering.

3. Decorative variations

While the oldest plaster coat of dummy brickwork wall faces show a prevalent uniformity of colour, some two-colours regalzier can be found starting from the second half of 14^{th} century, made up of elements arranged in such a way to build up a lozenge scheme, evidence of which is the only preserved example of two-colours wall face, straightly built with red and yellow bricks (it is most likely that at the beginning it had

[29] A boundary wall, which was once leaning to the apsidal pilaster of the church and was then pulled down in the XIX century, protected throughout centuries the *regalzier* below.

been given a coat of reinforcing paint as well), the 15th century parting wall adjoining to the front of *San Zaccaria*.

Decorations made up of red and rosy bricks and relevant usual painted texture can be seen on the fragments still preserved on the courtyard front of *Palazzo Contarini* of *Bovolo*[30] (Fig. 8), on the inside walls of *Santo Stefano* Church[31] (four-colours brickwork with small white crosses, small black squares and red-rosy lozenges) or in the row houses of *Corte Nova in San Lorenzo*: this last plaster coat is evidence of the fact that this decoration pattern persisted throughout the Renaissance period and the early 16th century, at least in row house building.

This kind of decoration patterns with a lozenge arrangement can be also found in white and red with no painted flutes, as shown by the large fragment preserved at the ground floor of *Palazzo Cavalli in San Luca*,[32] a clear imitation of the stone coating of *Palazzo Ducale* (Fig. 9).

Fig. 8 - San Marco, Palace Contarini del Bovolo. *Regalzier* with red-rosy lozenges.
Fig. 9 - San Marco, San Luca, Palace Cavalli. Two-colour *regalzier* imitating a stone covering.

Traceable to the same extent both in house and religious buildings, dummy brickworks are usually decorated by bands painted with plant and geometrical patterns, or they copy marble crushed stone (Fig. 10, Palazzo *Gritti Badoer*).

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[30] In the late XV century the leaning of the big helicoidal staircase against the framework of the palace has included a vertical plaster band which once covered the front looking out on the courtyard; the two-colours *regalzier* found during XIX, XX century restoration works, has been left in full view in two points by removing some bricks from the liner of the helicoidal staircase.

[31] The decoration of the inside walls of *Santo Stefano* dates back to the first decades of XX century, but it is to a certain extent a faithful portray of the lozenge pattern of the beginning; a well preserved fragment of the original decoration has been recently found (July 1997) on the left wall of the main chapel, when some damaged stone elements have been removed which were once part of the *barco* (porch).

[32] The plaster segment which can be seen at the ground floor in the small entrance courtyard has been well preserved thanks to the building of an old arcade that saved it from weather injuries. Further to that it has been coated later with a plaster which was removed twenty years ago.

Fig. 10 - Castello, Palace *Gritti Badoer*.

A well preserved example of bands and fringes combined together with regalzier has been recently found on the right wall of Santo Stefano church, showing a band with coloured stripes all around a window eye. The fragment was incorporated into the loft of a Renaissance building which had been leant against the church some decades after it had been built, from then on saved from aggression of environmental agents.[33] A further example is that of a portion of painted ornament on the left apse chapel of the *Frari* Church, the so called *Milanesi* chapel, combined with three fresco painted lunettes portraying *San Giovanni Battista*, the Virgin and the Child and Sant'Ambrogio. It was incorportaed as well between the cross vaults and the roof of *San Pietro* chapel, built against the church at the end of the second decade of 15th century and it is a fine example of the extraordinary colour and decorative range of these medieval decorations (Fig. 11).[34]

[33] Notice was given by architect Ms. Anna Chiarelli who has recently carried out restoration works at the church and the rooms linked to it.
[34] For decorations in Frai Church see the study by Bistrot A., 2000, *The outside frescos of Santa Maria Gloriosa dei Frari*, in: *Gothic architecture in Venice*, mentioned work, pages 189-194.

Fig. 11 - Santa Croce, corte Zane. *Regalzier* with band.

In the churches, however, the fresco bands do not interrupt the homogeneous development of regalzier on the walls surfaces, whereas in the houses it is often represented in the shape of panels bounded by a frame made of horizontal and vertical friezes (string-course, eaves all around doors and windows) which squares and separate them.

Conclusions

It is not an easy task to fancy nowadays how rich and widespread these decorative elements were in the past, as we have to derive them form the faded fragments found on the few buildings which have been preserved in part or in all: the main front of *Ca' Magno at Bragora*, for instance, or the first courtyard of *Palazzo Soranzo Van Axel ai Miracoli*. The brightness of the polychrome decoration treatments of medieval housebuilding in Venice can be now only enjoyed by observing the paintings of the Veneto Painting School: the big canvas by *Carpaccio* depicting *Ponte di Rialto*, for instance, evidence of the magnificent decorations of the fronts – the *fonteghetto* (small square) of Persians - reaching as far as the chimneys, or the other big *teler* (canvas) portraying the Miracle of the True Cross, representing a town portion close to *San Lorenzo di Castello* square (Fig. 12), where the regalzier band decoration of *Ca' Cappello* is also visible, made of both one- and two-colours panels to build up a lozenge pattern, partially preserved even up to our times.

Fig. 12 - Vittore Carpaccio, *Miracolo della Reliquia della Croce*, 1494, Gallerie dell'Accademia, Venice.

A further example of the variety of front surface treatments once present in town can be seen on the front of *Ca' d'Oro*: if we well consider, it isn't anything else but an example of plastic translation of the a fresco decorations of the palace fronts of that same period. The bands engraved with leaves and twisted flowers and animals pattern, the ribbons with small roses, the long line of white and red square tiles, the dentilled reliefs which were once also painted and gilded[35], they make up altogether in the *domus aurea* of *Contarini* family string-course bands flowing all around the windows including homogeneously treated wall portions, covered with marble slabs in this case: indeed the same decoration pattern followed to paint the facades of the most part of late Gothic buildings in Venice.

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[35] On polychromy and gildings of Ca' d'Oro, described in every single detail in the agreement dated 15th September 1431 signed by Marino Contarini and the painter *Zuan de franza*, traces of which have been all found on occasion of the newly completed restoration of the front, see: Cecchetti B., 1886, *The front of Ca' d'Oro by the chisel of Giovanni and Bartolomeo Buono,* in "Archives of Veneto", XXXI, pages 203-204; Boni G., 1887, *Ca' d'Oro and its polychrome decorations*, in "Archives of Veneto", XXXIV, pages 115-132; Schuller M., 2000, mentioned work.

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THE CATALOGUING OF VENETIAN EXTERNAL PLASTERS: THE PROGRESS OF RESEARCH

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Riassunto

La catalogazione degli intonaci esterni del centro storico di Venezia è ormai in fase avanzata. Compiute l'elaborazione e la verifica delle schede e dell'applicativo informatico (GIS), necessario alla gestione dei dati raccolti sul campo, si avviano ormai alla conclusione le operazioni di rilievo. Rimangono da rilevare 5.629 unità architettoniche, meno del 40 % sul dato totale, la cui schedatura verrà ultimata entro il mese di giugno 2003.

Abstract

The cataloguing of the external plasters of Venetian old town centre has by now far progressed. Survey works are nearly concluded, while processing and check of record cards and of the software (GIS) needed to manage the data obtained through field collection are already accomplished. 5.629 architectonic units remain to be surveyed – less than 40% of the total amount, and they will be completely indexed by the end of June 2003.

1. Introduction

Preservation and protection of the external wall faces of the buildings in Venetian old town centre seem to be a very high goal to reach, if we consider that historic plasters have been scrapped and re-made time and time again. Cataloguing is certainly the most effective means to reach the goal and, after over an year since these research works have been going on, while the first experience is over, we are all the more persuaded that a systematical data collection is really necessary.

2. The progress of research

For the index campaign, a particularly demanding job considering the complexity of operations and the remarkable amount of data to be collected, the materials for each isle have been provided for. Each of them represents a survey unit committed to a single person, thus splitting up the whole investigation field into macro-areas which are more easily to manage. So far 75 DB (Data Bases) have been completed, that means 75 surveyed islands out of 110 to be surveyed in total (in this cataloguing stage the 15 Dorsoduro isles of Giudecca Island are not included; the total amount of the old town centre isles is indeed 125). Table 1 outlines the total amount of Venetian old town centre isles, comparing the surveyed data with the data to be still surveyed with regard to the isles only.

The record cards filled up so far are 8.822 out of 14.451, corresponding to the GIS items 'built item', then to the filed architectonic units (AU) (see Table 1). To these data, deriving from the Index compiled by the Municipality known as 'Venetian old town centre', used as a basic reference for data [Ferrighi, 2002], all those AU-items have been added which have not been recorded into the DB link layer by mistake or because they did not exist or have been transformed at the time the record card has been digitised (the former area Saffa at Cannaregio for instance). The survey of the isles of San Marco (1.870 filled up record cards out of 1.870) and of Castello quarters has been completed, except for the Sant'Elena area only (3.218 record cards out of 3.754). The survey of Cannaregio (2.251 filled up records out of 3.726), San Polo (678 out of 1.185), Santa Croce (412 out of 1.560) and Dorsoduro quarters (393 out of 2.356) is now going on.

Tab. 1 - Isles and AUs divided into quarters, derived from GIS Index.

Quarter	Total amounts		already surveyed		to be surveyed	
	isles	AU	isles	AU	isles	AU
Cannaregio	33	3.726	26	2.251	7	1.475
Castello	25	3.754	20	3.218	5	536
Dorsoduro	17	2.356	5	393	12	1.963
S. Croce	14	1.560	6	412	8	1.148
S. Marco	14	1.870	14	1.870	0	0
S. Polo	7	1.185	4	678	3	507
Total	**110**	**14.451**	**75**	**8.822**	**35**	**5.629**

To these first data, some results deriving from the queries to DBs (see Table 2) can be added. As a feed-back from a first query, those AUs are given which have been wholly surveyed, compared to those which have one non visible face at least, either because it is not possible to reach them from an open crossing or because they are concealed with scaffoldings. Right this first outcome gives back the AUs which have been actually examined compared to the total result data deriving from GIS. As a matter of fact only the first result will be considered good for any further query and assessment on the historic plaster of the wall fronts.

Tab. 2 - AUs , divided into quarters, data derived from the actual survey.

Quarter	Total amount of AUs	Surveyed and partially surveyed AUs	Non surveyable AUs	AUs with specimen
Cannaregio	1.882	1.721	159	190
Castello	3.225	2.864	349	329
Dorsoduro	394	289	104	34
S. Croce	416	341	74	50
S. Marco	1.871	1.782	89	298
S. Polo	679	651	28	118
Totale	**8.467**	**7.648**	**803**	**1.019**

Among all surveyed AUs (both completely and partially), 12% only shows some small traces of historic plasters, examined and described in the specimen record card. In this case anyway we have to consider that the external fronts haven't been entirely surveyed, as faces of internal fronts, those overlooking a canal or concealed with scaffoldings cannot be examined. Only once this survey campaign is over, we will consider the possibility to extend and then complete the data collection as far as these hardly 'accessible' fronts. The remaining 88% shows no historic coat at all, or they are not visible any longer as they have been covered with further plaster layers later.

3. Some outcomes

The tools used for the research – although two different paper record cards have been taken up, one for the overall data of the AUs and another for the noticeable portions of historic plaster to be described, with over 40 items on the whole - have proved effective to reach the cataloguing aims. Both the data collection system during the survey campaign, by filling up the paper record cards and taking pictures, and the PC processing of the collected data have been considered successful by the team during these working months.

A precise remark only shall be done with regard to the 'simplification' of the tools used to catalogue such architectonic units as those of the so peculiar Venetian old town centre. For instance, the plaster sections themselves, divided into chrono-typological classes, have seemed at first sight quite restrictive if compared to their actual complexity: two big plaster sections have been devised, on one hand the historical plasters including the XIV up to XIX century plasters, on the other hand all plasters started as from the beginning of XX century. For the first section 4 plaster coat classes have been defined according to relevant performing techniques: then they can fall under '*regalzieri*', (a dummy brickwork reproduced by fresco painting a one-layer plaster), frescoes, marble-dust coats and the traditional plasters made of lime and sand. Eventually for each class relevant hallmarks have been distinguished [Piana and others, 2002].

Tab. 3 - AUs with surveyable historic plasters on fronts divided into chrono-typological classes derived from actual survey.

Quarter	Skim coats and historic plasters (XIV-XIX century)				Late plasters
	Skim coat	Fresco	Marble dust coat	Traditional	
Cannaregio	57	4	171	139	1459
Castello	96	2	395	419	1909
Dorsoduro	7	1	35	16	184
S. Croce	5	0	98	14	297
S. Marco	83	9	335	228	1581
S. Polo	34	**7**	83	57	573
Total	**282**	**23**	**1117**	**873**	**6003**

Table 3 shows the first results coming out of the queries to already complete DBs. The data are related to the plasters which can still be seen on external fronts; on one single unit more plaster classes can be identified because of the repeated stratification of plaster coats occurred in different ages. For instance, on a single AU on a single front it is possible to find both the ‘regalzier’ along with later lime and sand plaster layers and an E class plaster on it: that means three coats corresponding to three different layerings. A first remark shall be made on the amount of the oldest traditional Venetian lagoon plasters (A class) – even if the survey has not been completed yet - which have come out to be more than expected and are still to be found in house building. A second remark shall be made on the several examples of marble-dust coats (C class) and on the quality of the performing technique they show with regard to their preservation condition. The complexity and the rich beauty of this particular coat, typical of many buildings of the old town centre, is a further evidence of the innovative skill of the lagoon workers who knew how to meet the new building technique requirements and at the same time how to protect the walls below, indeed by using a coat which proved ‘to stand’ time and its action on things.

The biggest difficulties met so far are those connected with the bulk of paper record cards (3 meters approximately of record cards all collected in card holders), with the 39.000 Gb of the data bank and the approx. 10.000 pictures with a total amount of 4.000 Gb. And this refers only to the 75 isles which have been already surveyed out of the total 110 isles of the old town centre. The survey shall be completed by the end of June 2003, and the single DBs will be checked only after that date. For each isle a DB has been created, and all DBs will be collected into a single overall data bank, one for each quarter and eventually, once the data check is over, into a single final DB including all surveyed data.

Fig. 1 - Surveyed isles are painted in dark grey. Isles being surveyed are painted in white (except for the Giudecca Island)

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CATALOGUE OF VENICE EXTERNAL PLASTERWORK: WEB GIS TOOLS

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Riassunto

La conoscenza approfondita e l'efficace monitoraggio del patrimonio degli intonaci storici di Venezia è reso più efficiente dall'utilizzo di strumenti informatizzati orientati alla possibilità di gestione distribuita dell'informazione.

L'utilizzo di un sistema informativo geografico (GIS) utilizzato in unione con le tecnologie Internet (WEB) consente di rendere disponibile a molteplici categorie di utenti la conoscenza sviluppata su questo tema.

Il GIS-WEB in corso di realizzazione si propone come strumento di consultazione remota delle banche dati in corso di completamento relativamente alle attività della linea di ricerca 2.1 del Primo Programma di Ricerca del Corila.

Abstract

Extensive information and efficient monitoring of external Venetian plasterwork is more effective using geographical information tools.

The information and knowledge collected in Geographical Information System and web tools can be made accessible to different user communities.

In particular, *the Venice Municipality, the Monuments and Fine Arts office* as well as *local residents, architects, builders, restores* and *the web user community.*

The Web GIS, currently being designed and built, is set to become an easy and simple way to make available all the information collected in various databases, from the research activity of line 2.1 line of CORILA's first research programme.

1. Introduction

The intense research activity, which has analysed almost 15,000 architectural units, covered the entire Historical Centre of Venice.

Common census techniques were linked to an advanced methodology information management, which georeferences all data.

This work was based on previous specific research carried out by Prof. Piana, related to the historical evolution of the urban centre of Venice. This has facilitate the design of a specific report format to catalogue every type of historical plasterwork in Venice from the XIV century to the modern times.

2. Building the GIS application

Using the cartographical supports available from the Venice municipality the framework for the geographical Information System was constructed.

To connect together the data and information produced, a unique key code was developed to georeference and link the different databases create.

For each architectural unit, an electronic report was compiled and three different types of database were built: the alphanumerical data base, the geographical data base and the images data base.

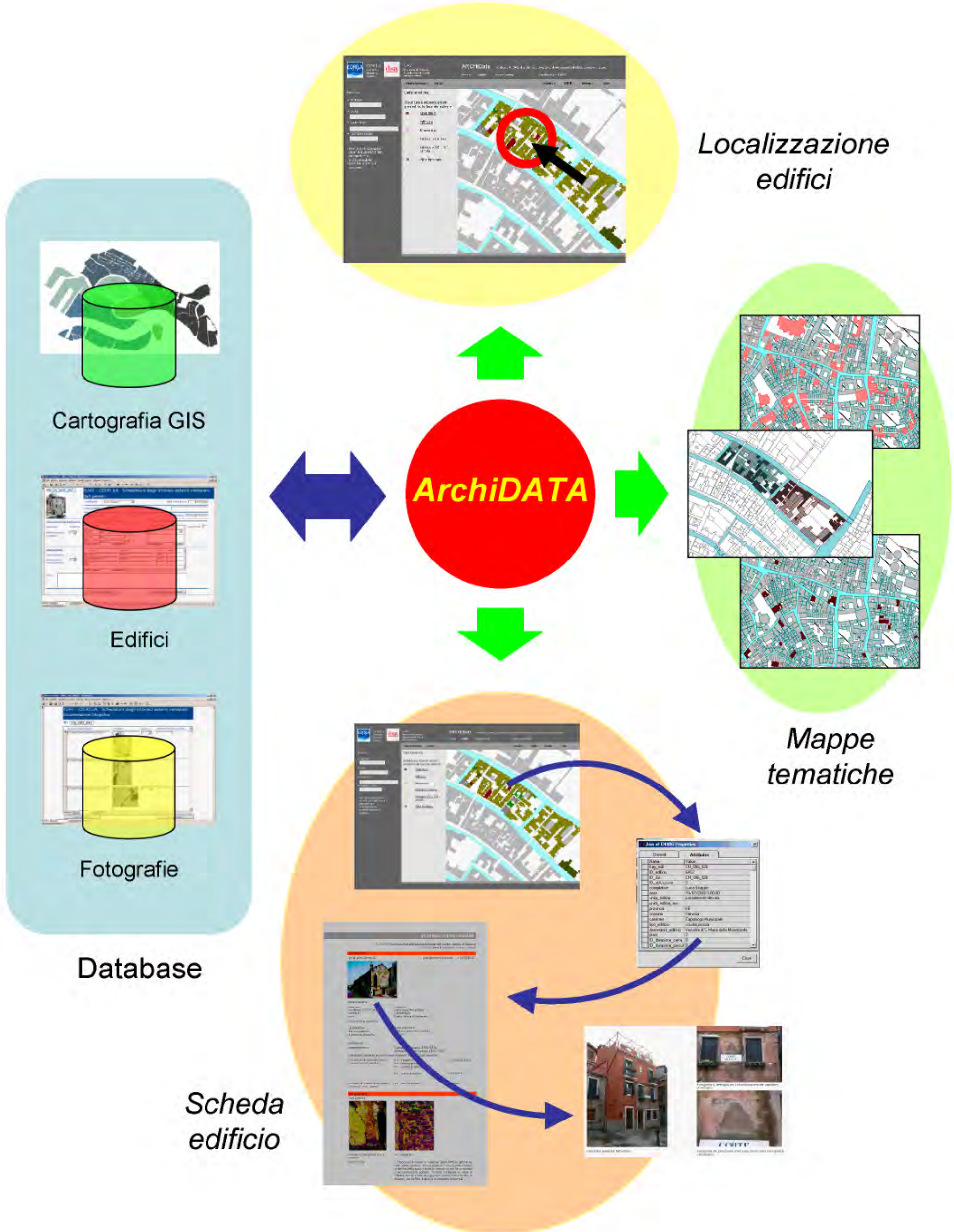

Fig. 1 - Work flow scheme used to build the Geographical Information System

The survey area was divided in "*sestieri*" (districts) and "*isole*" (islets) which constitute the Venetian centre. Almost 110 different databases, one for island, were build.

To increase the quality of the collected data, all databases were normalised on standard dictionary and legend fill-text. Following the data quality criteria, procedures were developed to filter and repair all logical and structural errors related to the data entry activity.

After the "cleaning process", the 110 databases were integrated into six different database structure, one for each "Sestiere".

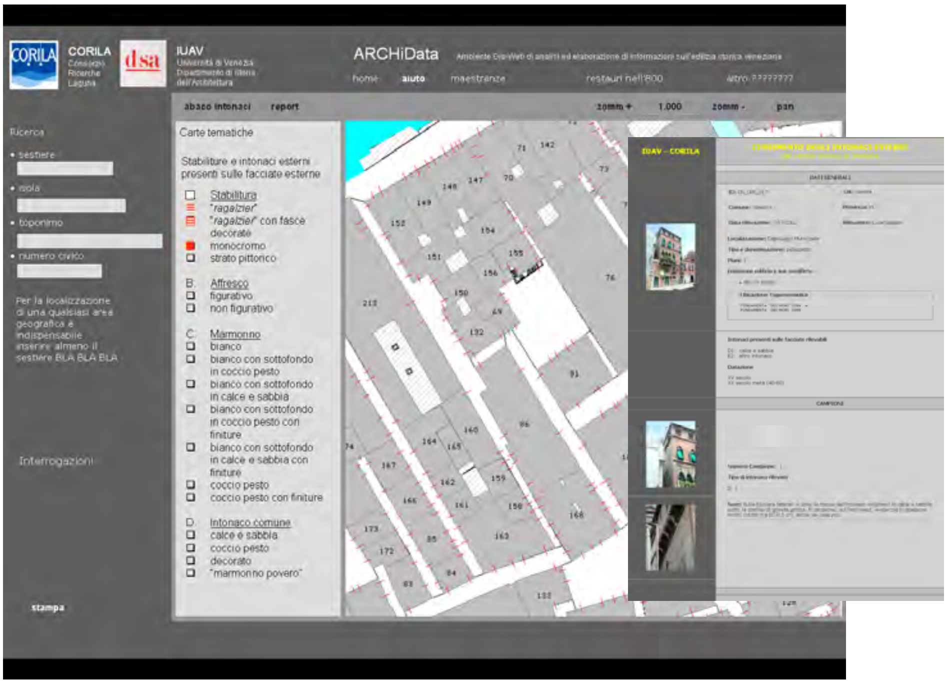

Fig. 2 - Example of user interface for the website..

Amalgamating this information and the databases constituted the Integrated Geographical Information System.

One of the main functions is the opportunity to select a single building using different sorts of querying, for example: street address, key code, type of plasterwork, etc.

For each building a detailed report is presented, which is divided in two areas: the general part, related to the building general characteristics, and a specific report which describe the single sample of plasterwork.

3. Analysis and thematic maps on the web

All information collected and structured on a geographical data base, is used to produce thematic maps, wide and synthetic, which enable evaluations of the historical asset.

The Geographical Information System allows, in an easy and simple way, data and image management regarding Venetian plasterwork.

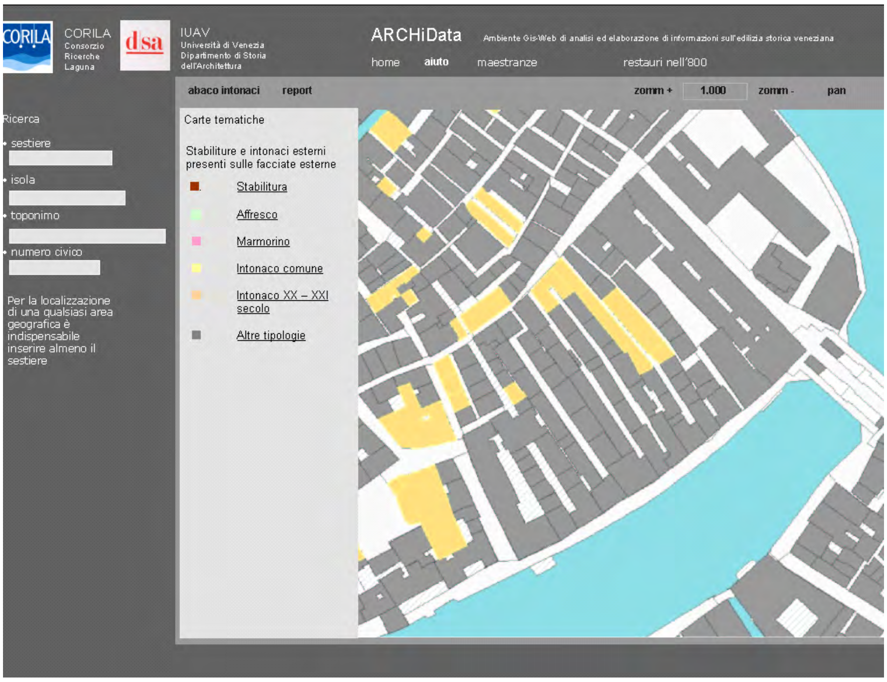

Fig. 3 - Web GIS example

Conclusions

In the future, the catalogue of external plasterwork of Venice will be a crucial reference and research instrument especially for evaluation, restoration and conservation.

Web tools, under password control, will delivery the database and the Geographical Information System to Venetian Municipality and all the public offices related to urban modifications and transformations.

Further more, publishing on the web, make this information accessible to architecture professions and residents, to establishing the studying and significance of value and age of Venetian Plasterwork..

AREA 3
ENVIRONMENTAL PROCESSES

RESEARCH LINE 3.1
Trends in global change processes

REVERSIBLE / IRREVERSIBLE PEAT SURFACE DISPLACEMENTS AND HYDROLOGICAL REGIME IN THE ZENNARE BASIN, VENICE

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Riassunto

In un comprensorio agricolo a drenaggio meccanico ubicato nella parte meridionale del bacino scolante in Laguna di Venezia è stato allestito un sito sperimentale per quantificare la subsidenza dovuta all'ossidazione della torba ed individuare le relazioni funzionali che legano il regime idrologico all'entità del flusso di CO_2 dal terreno organico nell'atmosfera ed al conseguente tasso di subsidenza.

Il monitoraggio in continuo dello spostamento della superficie del terreno e delle principali grandezze idrologiche è stato condotto da novembre 2001 ad ottobre 2003. I dati raccolti in questi due anni attraverso un'accurata strumentazione progettata, acquistata e realizzata ad hoc hanno messo in luce come lo spostamento verticale della superficie torbosa sia formato dalla sovrapposizione di due contributi, una deformazione reversibile caratterizzata da una breve scala temporale, al più stagionale, ed un abbassamento permanente che si manifesta su tempi più lunghi. L'applicazione di un semplice modello tarato sui dati a disposizione ha confermato che quest'ultima componente, dell'entità di 1-2 cm/anno, è riconducibile al processo di ossidazione. Gli spostamenti elastici sono principalmente dovuti alla variazione del volume della torba a seguito della variazione del contenuto d'acqua. Un'espansione del terreno è stata misurata in concomitanza ad ogni precipitazione con un rapporto costante tra l'innalzamento della superficie del terreno e quello della superficie di falda pari a circa 0.3 mm/cm. La dinamica dello spostamento risulta assai rapida nella fase di innalzamento mentre la fase di ritorno alla condizione iniziale appare più lenta con tempi caratteristici compresi tra alcune ore ed alcuni giorni. Spostamenti significativi, caratterizzati da una dinamica ancora più veloce, sono stati registrati nel periodo invernale quando, a seguito del congelamento del terreno durante le ore notturne, si verifica un rigonfiamento del suolo dell'ordine del centimetro. Tale rigonfiamento rapidamente regredisce allorché la temperatura di giorno aumenta con una velocità di abbassamento dell'ordine di 0.5 cm/ora.

Abstract

A field experimental study has been performed in a drained cultivated peatland located south of the Lagoon of Venice, Italy, to measure land subsidence due to peat oxidation and to address the expected relation between the hydrological regime, the soil loss in the form of CO_2 fluxes to the atmosphere, and the settlement rate. Continuous measurements of land surface displacement and some basic hydrological parameters have been carried out over the time period from November 2001 to October 2003. The data collected by an ad-hoc accurate instrumentation show that the vertical movement of the peat surface consists of the superposition of short/seasonal time-scale reversible deformations and of a long-term irreversible subsidence. The latter, in the order of 1-2 cm/year rate, has been proved to be related to peat oxidation by a simple mathematical model calibrated on the available collected data. Significant elastic peat volume changes are caused by the variation of the soil moisture. Peat swelling has been measured after every rainfall event with a constant ratio between the surface uplift and the water table rise equal to 0.3-0.4 mm/cm. The swelling dynamics progresses very rapidly after a precipitation event while it decreases slower following the water table behavior, exhibiting a time scale from few hours to few weeks. On a shorter time scale, significant displacements occur in winter in relation to temperature changes. Soil temperature below freezing at night, induces a ground surface rise of the order of 1 cm. Uplift is quickly dissipated in the morning when the temperature increases at a rate approaching 0.5 cm/hour.

1. Introduction

It is generally recognized that irreversible long-term land subsidence of drained peat soils is mainly related to biochemical aerobic oxidation of the organic matter [Stephens et al., 1984, Deverel and Rojstaczer, 1996]. In an anoxic environment the action of anaerobic micro-organisms breaks down the plant structure and creates peat which accumulates faster than it decomposes. Drainage for agricultural purposes leads the soil to aerobic condition and microbial activity oxidizes the carbon of the peat causing carbon loss mainly in the form of gaseous CO_2 flux from the soil to the atmosphere [Rojstaczer and Deverel, 1993; Clair et al., 2002].

Experimental field and laboratory studies show that the magnitude of this process is primarily controlled by soil temperature and moisture content. Soil microbial activity becomes significant when soil temperature is larger than 5°C and generally doubles for each 10°C increase in temperature [Stephens et al., 1984]. CO_2 fluxes from the peat are thus influenced by depth of drainage, the higher the water table the lower the loss of soil mass [Silvola et al., 1996]. These relations are supported by the worldwide subsidence rates recorded in drained peat areas, which range from about 1-2 mm/year in the polders of the Western Netherlands at a very shallow depth of drainage (0.1-0.2 m) [Nieuwenhuis and Schokking, 1997], to 2-3 cm/year in the temperate Sacramento - San Joaquin delta in California [Deverel and Rojstaczer, 1996], up to more than 5 cm/year in tropical peatlands, such as in Malaysia [Wösten et al., 1997].

Quite recently, a few research studies have pointed out that peat surface may experience significant partly or totally reversible vertical displacement as it relates to changes in the water table depth. This peculiar peat characteristic ("mire breathing") has usually been observed on a seasonal time scale and has been attributed to changes in soil volume both above and below the water table. Peaks in bulk density in the unsaturated zone correspond to drier periods when the larger matrix suction results in a decrease of pore volume (shrinkage). Lowering of the water table induces a saturated peat compression as the effective stress increases [Price, 2003]. Deverel et al. [1998] suggest that changes in the peat surface elevation related to a fluctuating water table are probably due to buoyancy effects, as the bulk density of the organic soil is close to if not less than that of water. Due to its high water content, peat is highly compressible with a volumetric change up to 10 times larger than in swelling clay soils [Hobbs, 1986]. Peat displacements induced by water content changes are relatively small (1 cm) in highly mineralized and amorphous organic soils [Deverel and Rojstaczer, 1996], whereas fibrous, poorly decomposed, peatlands, with a very high water content, may experience seasonal movements of 10 cm [Price and Schlotzhauer, 1999] or even 50 cm [Roulet, 1991]. Note that the elevation changes is also a function of the peat thickness.

On the basis of daily measurements of water table and land surface elevation in a cutover peat field in Quebec, Schlotzhauer and Price [1999] found settlements of the peat surface range between 11 and 23% of the lowering of the water table, with a considerable hysteresis, being the vertical displacement 5 times greater in response to water loss compared to rewetting. This is somehow inconsistent with the results obtained in laboratory by Hyama et al. [2002] through controlled shrinkage/swelling tests on 10 10 40 cm undisturbed peat specimens showing an almost elastic behavior of the sample length for a number of following water table fluctuations ranging from 15 to 40 cm. Price [2003] himself concludes that peat subsidence resulting from water table drawdown is largely reversible when wetter conditions are restored.

A field site was instrumented at the end of 2001 to investigate land subsidence due to organic matter oxidation in the Zennare Basin, an agricultural farmland in the south catchment of the Venice Lagoon, Italy. Drainage of outcropping peat soils has resulted in an overall land subsidence of 1.5 - 2 m since the basin reclamation in the 1930's, thus causing a dramatically rise of the pumping and drainage costs with an adverse effect on the sustainable development of the area. Yearly soil ploughing for cereal cropping has systematically brought up poorly-decomposed peat to ground surface, hence enhancing the oxidation process. Continuous measurement of the hydrological regime and peat surface displacement by an ad hoc tool proposed by Deverel and Rojstaczer [1996] has allowed for an accurate estimate of both the peat reversible movement and irreversible subsidence.

This paper presents the results of the continuous measurements of peat surface displacements and major hydrological parameters controlling the oxidation process from November 2001 to October 2003. After a short description of the study area and experimental site, the collected data are shown and discussed. The reversible and irreversible components of the measured displacements are evaluated on the basis of a direct analysis of the recorded time series and by use of a simple mathematical model relating peat oxidation to soil temperature and depth to the water table. Finally, some conclusive remarks are provided.

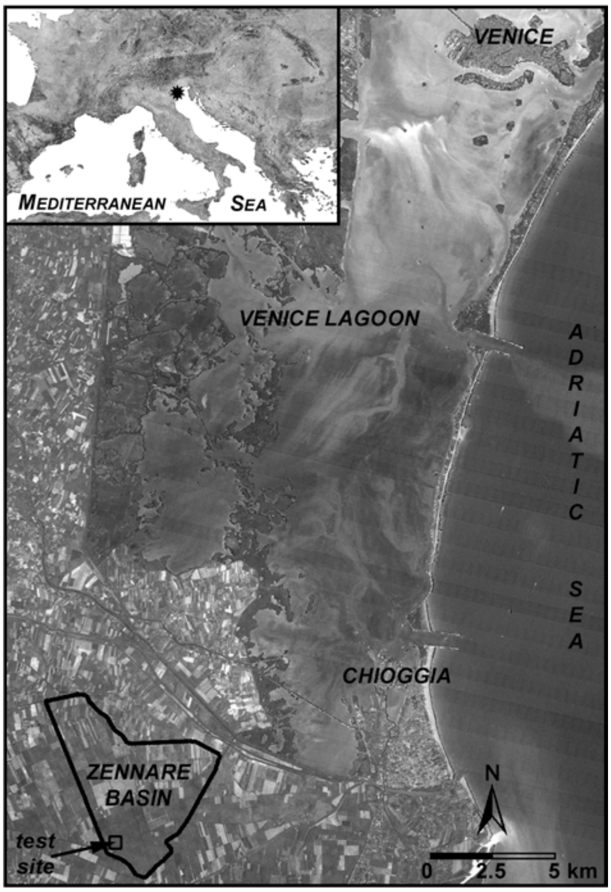

Fig. 1 – Location of the Zennare Basin south of the Venice Lagoon. The position of the test site is also shown.

2. Description of the Study Area

The Zennare Basin (45° 10' East and 12° 9' North) is a 23 km^2 area located just south of the Venice Lagoon, approximately 10 km from the Adriatic Sea (Fig. 1). The basin, lying at present almost entirely below mean sea level (down to -4 m), is drained by a network of open ditches connected through a few major waterways that convey the surplus water to the Zennare pumping station.

Field surveys, geophysical investigations and remote sensing analyses have been used to map the areal extent and the thickness of the outcropping peat deposits [Rizzetto et al., 2003; Nicoletti et al., 2003]. The peatland, located in the southern part of the basin and characterized by an organic-rich surface layer presently less than 1.5 m thick, derives from the accumulation of reeds (*Phragmites Australis*) providing evidence of ancient swamps. The upper 40 cm of the organic soil is composed of black oxidized amorphous granular peat with an organic matter content ranging from 40 to 60%. The underlying layer is constituted by brown fibrous slightly decomposed peat, up to 80% rich in organic matter, below which a thick plastic clay unit is found [Gatti et al., 2002].

Subsidence history in the Zennare Basin has been assessed from the protrusion of a number of old hydraulic structures funded on the mineral soil underlying the outcropping peat. Weirs, culverts and bridges constructed during the basin reclamation and presently unusable, as well as the lowering of the water level at the pumping station entry provide documentary evidence of an average subsidence rate of 2-3 cm/year over the last 70 years. These values have been recently confirmed by comparing a DEM (Digital Elevation Model) based on an aerial photographic survey performed in 1983 with the results of a kinematic GDPS (Differential Global Positioning System) survey carried out in March 2002 [Gambolati et al., 2003].

3. Experimental Methods and Measures

A test site has been selected in the southern tip of the basin (Fig. 1) on a portion of the bog fen unplowed during the last 10 years. An ad hoc structure for monitoring peat surface displacement (*d)* has been established following the indication by Deverel and Rojstaczer [1996] (Fig. 2). It consists of a steel tripod with 2 m length sides anchored on three piles set into the ground to a depth of 11-12 m where an over-consolidated clay layer is located. Each pile was pushed through a PVC tube that extends within the organic layer to minimize friction between the immobile anchoring and the subsiding/swelling peat. A displacement transducer (LVDT) is attached at one end to the triangular structure in the middle of each side and the other end is connected to the land surface through a 0.5 cm thick, 10 10 cm aluminum plate that rests on the soil surface. The three LVDTs are characterized by an accuracy of 0.125 mm and a measurement range of 0-25 mm. This allows the recordings of short time soil displacements. The bodies of the LVDTs are attached to the steel triangle through a threaded rod that can be adjusted to follow the soil movements at longer times.

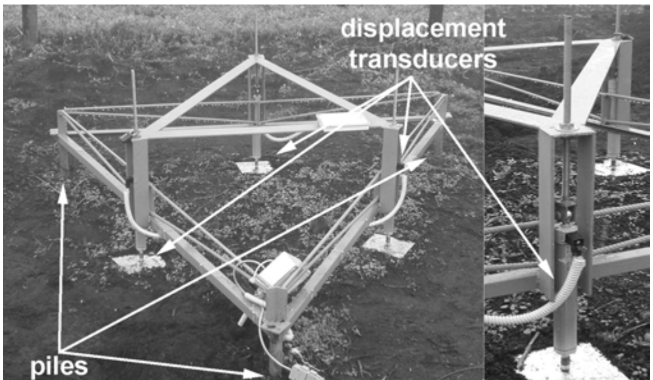

Fig. 2 – Steel tripod constructed to continuously monitor the elevation changes of the peat surface. A zoom of the displacement transducer is shown on the right. The anchoring piles and the displacement transducers are highlighted.

The site has also been permanently equipped with a tilting bucket pluviometer with a 0.2 mm sensitivity and five soil temperature sensors at 1, 5, 20, 30, and 100 cm depth with a measurements range between -15° C and 50° C and accuracy of 0.1° C. Water table depth *h* has been determined by two pressure transducers, with a measuring range of 0-300 mbar and an accuracy of 1.5 mbar, submerged in 3 m deep PVC wells, one located within the field site and the other close to the adjacent drainage ditch.

The site has also been instrumented with an anemometer, five tensiometers and five three-wire time domain reflectometry (TDR) probes for soil moisture content. Methods are described in detail by Fornasiero et al. [2003]. Except for the TDR probes, all sensors are connected to a datalogger and sampled hourly. Problems with the data acquisition occurred in May and July, 2002.

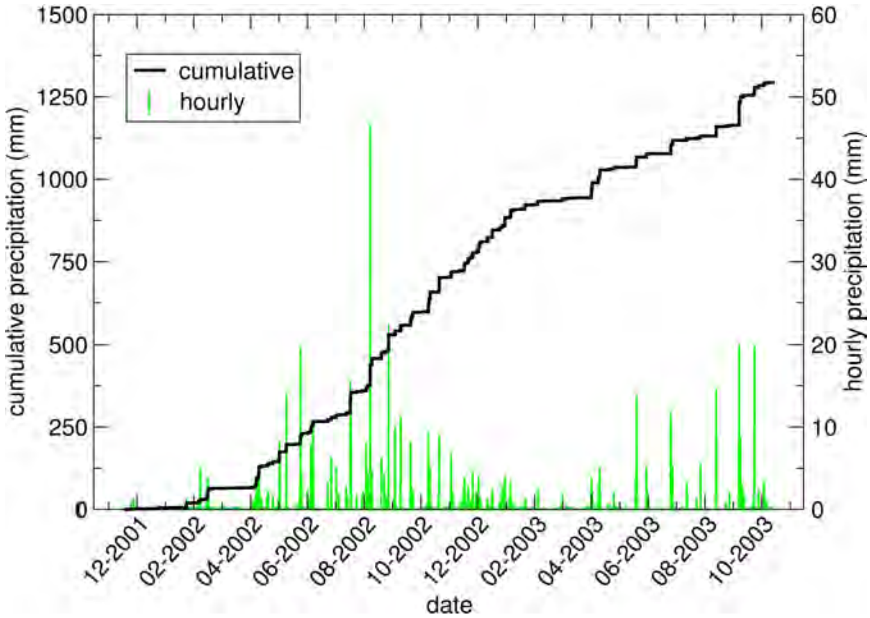

Fig. 3 – Hourly and cumulative precipitation measured at the field site over the last 2 years.

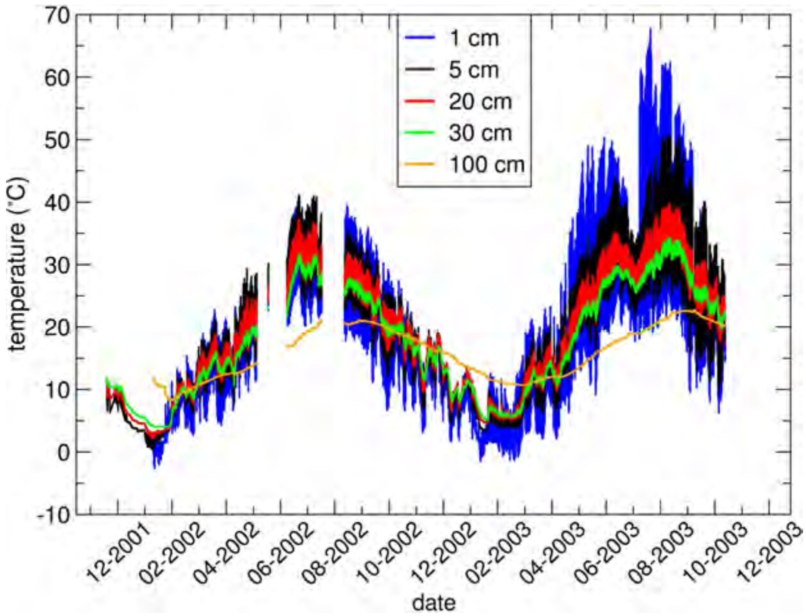

Fig. 4 – Soil temperature recorded at the field site over the last 2 years. Sensors at 5, 20, and 30 cm depth have been established in November 20, 2001, the 1 and 100 cm deep ones in January 11, 2003.

Hourly and cumulative rainfalls, and soil temperature collected over the last two years are shown in Fig. 3 and Fig. 4, respectively. The figures show that the monitored time period is characterized by a very unusual climate features. In fact, a very cold and dry winter 2001-2002, during which the top 10 cm of the peat soil was completely frozen for about 6 weeks and the cumulative precipitation totaled only 70 mm, was followed by a very rainy summer with a 400 mm cumulative rainfall (more than 50% of the overall 2002 rain). The entire area around the test sites was flooded by 10 cm of water during the first two weeks of August. On the contrary, total rainfall from January to September 2003 totaled only 280 mm, with very high summer temperatures that caused the upper 5 cm of peat to be almost permanently above 40°C for three months, with peaks well above the sensor FS (50°C). The extremely dry conditions of summer 2003 are also proven by volumetric water content TDR measurements, that reached values below 30% in the upper 30 cm instead of the usual 50-70% range.

Fig. 4 indicates that daily temperature variations are large for the surface-most probes, small below 20 cm depth, and vanish at the 1 m deep sensor. It is interesting to observe that also the deeper probe shows a seasonal fluctuation of about 10°C. Fig. 5 shows the behavior of the groundwater table at the test site and at the 10 m far ditch. The average depth ranges between 20 and 50 cm and 20 and 80 cm during the previous and the present year, respectively, and experiences significant fluctuations in connection with raining events.

During a precipitation event the water infiltrates through the surface causing an increase in moisture content in the unsaturated zone and a decrease of the water table depth. Since the water elevation in the ditches is kept low by pumping, a groundwater mound forms and seepage from the field to the ditch occurs. Conversely, water level from the ditch recharges the peat layer during dry periods, in particular during the summer season when water levels in the drainage network is maintaned high for irrigation purposes.

The changes of the surface peat elevation are shown in Fig. 6. Note that from the end of December 2001 to the end of January 2002 the surface soil was frozen with the extensimeters showing a net uplift of the bog surface. Except for the large downward movement occurred during and just after the ice melting period, the three displacement transducers display a similar behavior. The 30 mm cumulative land subsidence recorded as of October 2003 develops through a very complex surface peat dynamics, strictly correlated to teh rainfall events and to the water table fluctuations. Throughout the season the surface elevation moved along with the water table, indicating that peat shrank and swelled continuously in connection with changes in moisture content. From late January 2002 to October 2003, when water levels were almost equal, the net loss in land surface elevation approaches 20 mm. Most of the sinking occurred over the last 8 months, whereas a quiescence or even a net uplift was recorded during 2002. Short time-scale peat swelling was measured at each rainfall event in relation to soil moisture increase and water table rise, as can be seen in Fig. 7.

4. Data analysis

Data collected over the last two years have been analyzed to detect the reversible and irreversible components of the recorded peat surface movement. Although the data extend over two complete seasonal cycles, during which the elastic fraction of the movement should be clearly identified, the sequence of extremely dry and wet periods with a 4 to 8 month duration makes it difficult to distinguish the two displacement contributions.

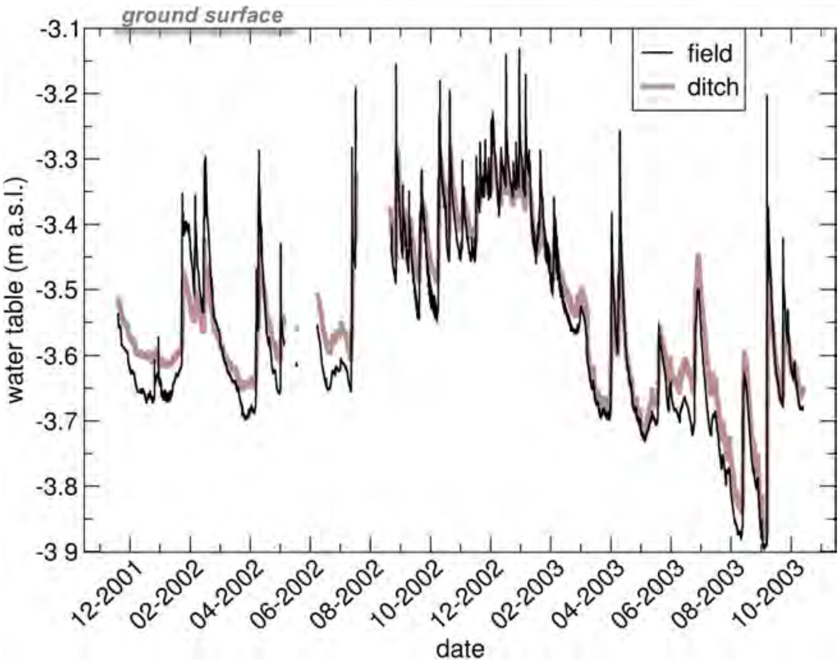

Fig. 5 – Measured water table above the mean sea level at the field site and close to the adjacent ditch. The elevation of the ground surface in also shown.

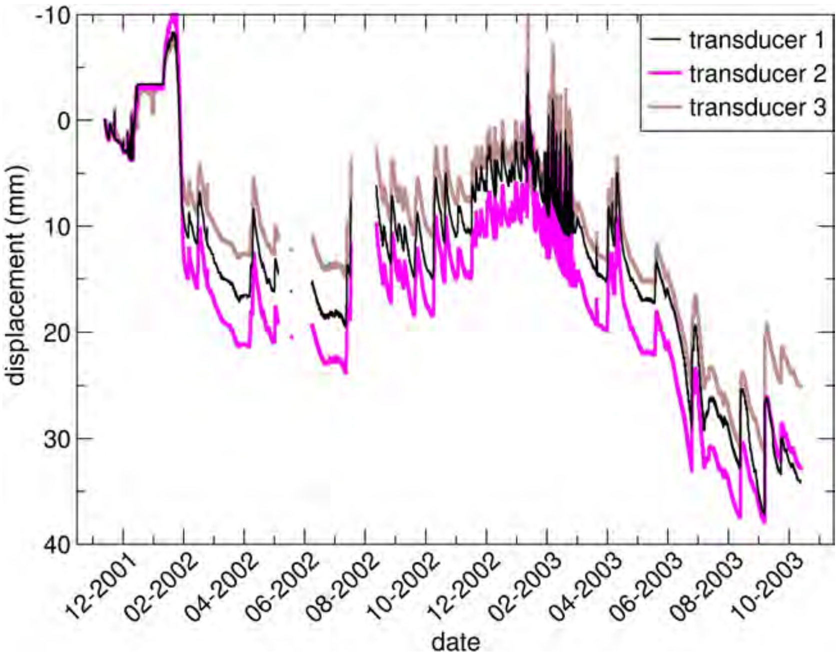

Fig. 6 – Measured changes in peat surface elevation. Positive values represent land subsidence, negative surface uplift.

4.1. Reversible peat displacement

The continuous recording of the ground vertical displacement, soil temperature, precipitation, and depth to the water table reveals significant reversible vertical movements of the land surface. The elastic component of Δd can be easily detected on a short time-scale of a few days or weeks during which the unrecoverable land settlement due to histosols oxidation is negligibly small. Hourly rainfall, depth to the water table, and land subsidence measured at the field site from August 28 to November 11, 2002, are shown in Fig. 7. The figure shows a good correspondence between the rainfall event, and hence the groundwater table depth in the peat, and the movement of the surface soil. Peat expands at each rainfall event. The swelling dynamics progresses very rapidly after a precipitation event in relation to the increase in soil moisture, while decreases slowlier following the water table decline, with time scales ranging from few hours to few weeks, respectively. Moreover, swelling is completely reversible. The ratio between Δd and the water table change Δh is of the order of 0.3 mm/cm.

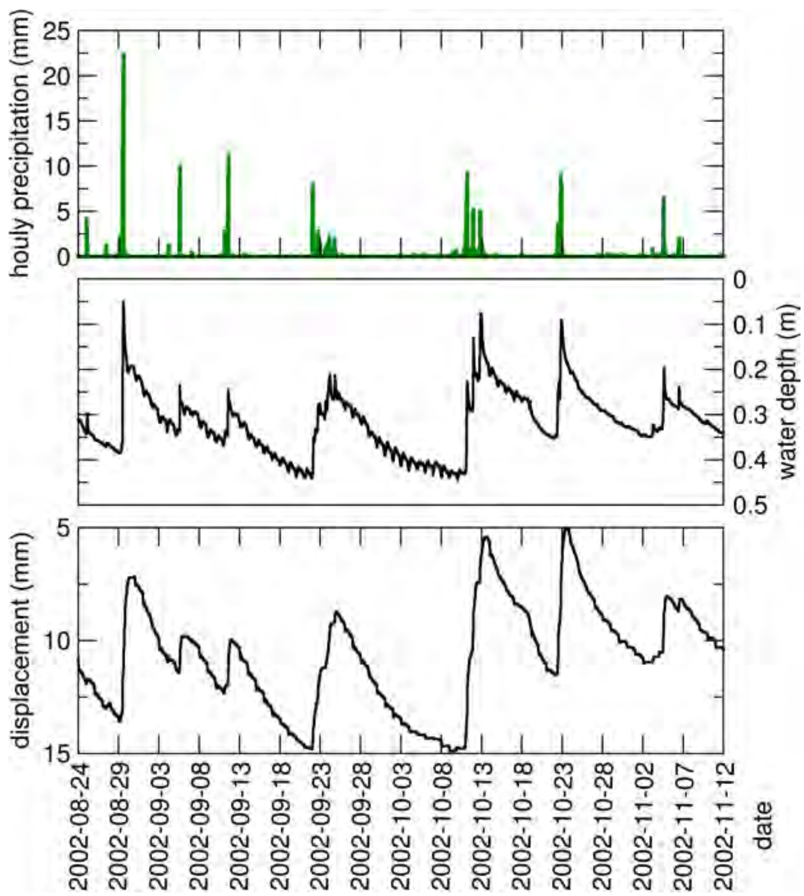

Fig. 7 – Hourly precipitation, depth to the water table, and land subsidence measured between August 24 and November 11, 2002, at the Zennare Basin field site.

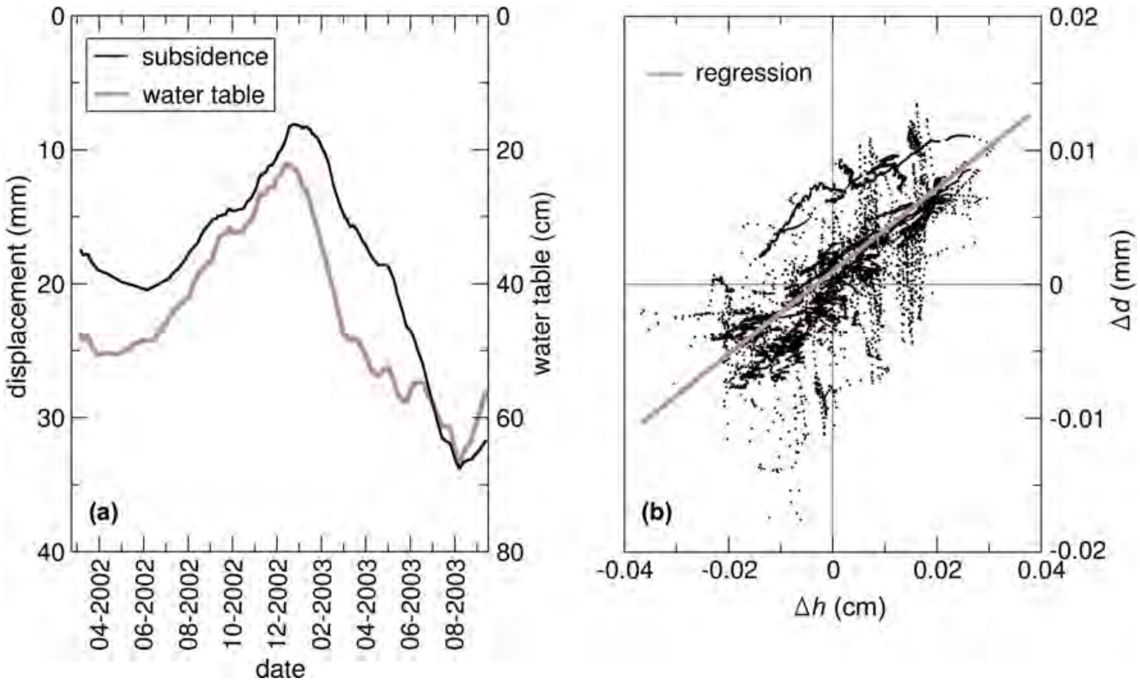

Fig. 8 – (a) Measured surface displacement and water table depth filtered by the moving average method with a window size of 60 days. (b) Hourly displacements versus hourly water table changes obtained with the moving average.

Comparison of Fig. 5 and 6 suggests that Δ*d* depends somehow on *h* also on a time scale larger than that of a single precipitation event. The moving average method has been used for both Δ*d* and *h* to reduce the complexity of the process and extract the main component of the fluctuation. An average window size of 60 days was used.The results of this calculation starts after the ice melting in February 2002 and are displayed in Fig. 8a. The hourly Δ*d* and Δ*h* computed by this approach are linearly regressed in Fig. 8b, obtaining a line with a 0.31 mm/cm slope, consistent with the value obtained over the short time-scale. The large correlation index R^2 = 0.54 indicates, however, that a more complex relationship exists between the two parameters, probably due to the contribution of other important factors such as, e.g., gaseous CO_2 and dissolved organic carbon fluxes, that cannot be neglected in the formation of the measured displacements. Significant daily displacements were observed in winter also in connection with temperature changes. Fig. 9 compares the soil temperature at a 1 cm depth with Δ*d* during February 2003. When the temperature approaches the freezing value at night, down to -2°C at a 1 cm depth, a ground surface uplift up to 1 cm occurs, generally from midnight to 8 a.m. This is entirely reversible and quickly dissipates over 2-3 hours when temperature increases in the morning at a rate between 0.2 and 0.5 cm/hour.

4.2 Irreversible peat subsidence

The data collected in the Zennare Basin allow for the use of the mathematical model proposed by Stephens et al. [1984]. This model, developed for the Everglades marshlands in Florida, links land subsidence due to peat oxidation to depth of drainage and soil temperature.

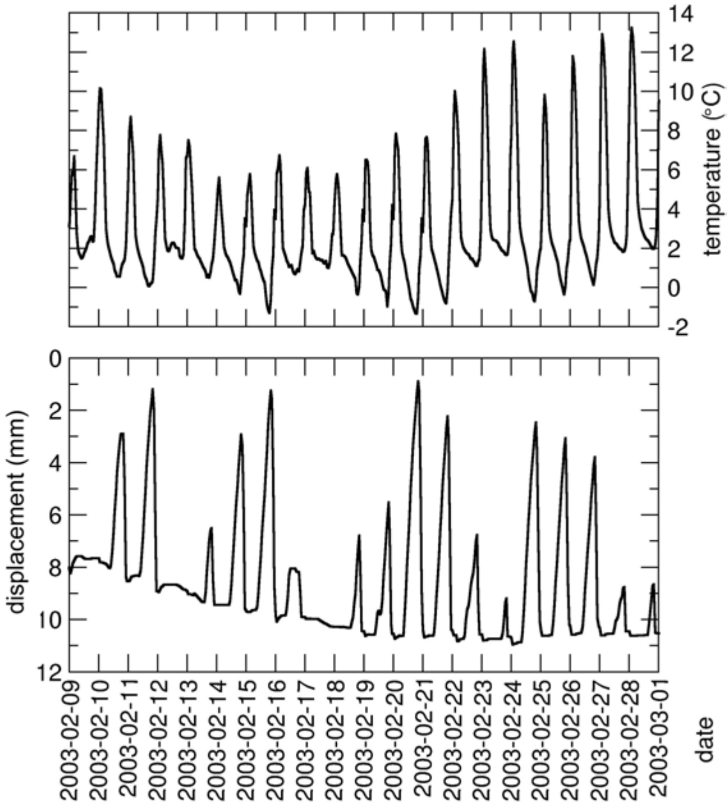

Fig. 9 – Soil temperature at 1 cm depth and surface soil displacement measured from February 9 to March 1, 2003, at the Zennare basin field site.

By the use of Arrhenius's law, stating that the logarithm of a chemical reaction rate is linearly related to the reciprocal of the absolute temperature, the authors provided the following basic subsidence equation:

$$s_T = (a + bh)e^{k(T-T_0)} \tag{1}$$

where:

– s_T is the land subsidence rate at temperature T;
– h is the depth to the water table from the peat surface;
– k is the reaction constant;
– T_0 is the threshold soil temperature where biochemical raction becomes appreciable;
– a and b are constants to be estimated by field or laboratory data.

Denoting by Q_{10} the change of the reaction velocity for each 10°C rise in temperature, k can be written as k=1/10 lnQ_{10} , and Eq. (1) becomes:

$$s_T = (a + bh)Q_{10}^{\frac{T-T_0}{10}} \tag{2}$$

From laboratory study Stephens et al. [1984] derived Q_{10}=2 and T_0=5°C. They calibrated a and b so as to reproduce the yearly subsidence rate s_T [cm/year] at the

Florida Everglades, with *h* [cm] and *T* [°C] the annual average depth to the water table and soil temperature at 10 cm depth. Eq. (2) is used to predict land subsidence due to peat oxidation with the measurements shown in the previous sections. Instead of computing a mean annual value, Eq. (2) has been applied over a hourly time-scale consistent with the sampling of the available hydrological information and the cumulative subsidence is compared to the recorded ground displacement. The soil temperature at 10 cm depth is obtained by linear interpolation from the 5 and 20 cm deep measurements and the gaps in the *h* and *T* time series are filled in by linear interpolation as well. The constants *a* and *b* are calibrated so as to reproduce the overall observed subsidence behavior, starting from February 2002 after ice melting. Using the constraint that all the hourly calculated s_T rates should never be negative (to guarantee the physical meaning of Eq. (2)) and assuming s_T=0 for the periods when soil temperature is less than 5°C, we obtained the values a = -0.025 and b = 0.0085. Fig. 10 compares the measured and predicted land subsidence. Obviously, the model is not capable to capture the dynamics of the process related to the elastic peat shrinkage/swelling, but in general the global long time-scale settlement is satisfactorily reproduced. The model results show that the hydrological conditions occurred between July 2002 and April 2003 have practically precluded the histosols oxidation. About 60% of the irreversible land subsidence took place over the last 6-7 months. The computed subsidence rate ranges from zero during the coldest season to 6 cm/year during the hottest days in August 2003.

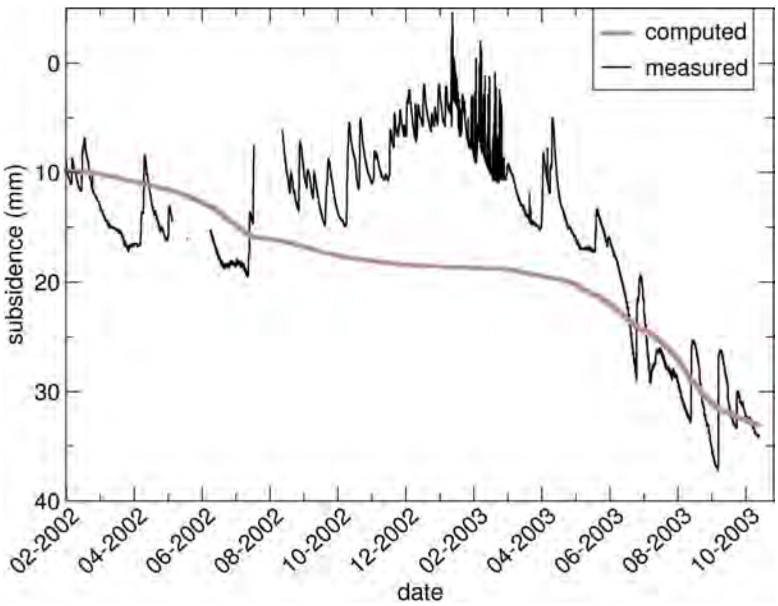

Fig. 10 – Comparison between computed and measured land subsidence since February 2002 after ice melting.

Conclusions

Continuous measurements carried on during the last two years in a cultivated peatland located south of the Venice Lagoon show that the movement of the histosols ground surface is characterized by a fast and complex dynamics. Land displacement is well correlated to the depth of the water table and soil temperature over shorter, seasonal, and longer time-scales. Direct analysis of the collected data shows that the soil water content and water table changes due to each rainfall event produce a significant peat swelling which is fully reversible with a characteristic time-scale from hours to weeks. A more sophisticated statistical approach have indicated that also seasonal oscillations of the water table, typically occurring in continental peatlands during dry and wet periods, influence the ground surface elevation. Low soil temperatures are responsible for very short reversible motions in winter whenever freezing point is approached, with night-daytime oscillations. Water content and groundwater table depth, together with soil temperature, influence the kinetics of the oxidation. A simple model based on Arrhenius's equation shows reasonably accurate predictions of the irreversible land settlement, with values of the order of 1-2 cm/year.

The unusual meteorological conditions occurred since November 2001 do not allow for a conclusive separation between the unrecoverable land subsidence due to carbon oxidation and the seasonal peat shrinkage/swelling due to water table fluctuations. Hopefully, the data to be collected next year and the establishment of a new instrumentation for the continuous monitoring of the soil moisture at different depths will allow for a significant improvement in the understanding and quantification of the two processes.

Nonetheless, the results presented in this communication appear to have important implications for the management of the drainage and agricultural practices of the region. The hydrological regime recorded from mid summer 2002 to spring 2003 has provided evidence that wet conditions drastically reduce the oxidation rates of peat soils, and hence the related land subsidence. In the Zennare Basin, where the productive cycle of corn cultivation begins in April and ends in late August, a careful drainage strategy ensuring very shallow water table during the 7-8 months when land is uncultivated, and whenever agricoltural practices allows it, should yield a significant reduction of the yearly settlement rate.

Acknowledgments

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FEASIBILITY OF HYDROLOGICAL SEASONAL AND INTER-ANNUAL FORECASTS

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Riassunto

E' possibile fare delle affermazioni nell'ambito delle previsioni idrologiche a scala stagionale ed interannuale, quando è difficile prevedere la piovosità della settimana ventura? Contrariamente alle teorie comuni, l'ipotesi che variazioni sia nella temperatura media che nella precipitazione media siano controllate più da forzanti esterne (e soprattutto dalla variabilità solare) che dall'incremento dei gas serra, sta prendendo sempre più piede. La dinamica dell'attività solare è descritta dal momento torcente del suo moto intorno al centro di massa del sistema solare; dal momento che tale momento è calcolabile per il futuro, emerge l'attraente prospettiva della fattibilità di previsioni idrologiche a lungo termine basate sui cicli di attività solare.

Abstract

Is it possible to say anything about hydrological seasonal and inter-annual forecasts while we cannot predict next week's rainfall? Contrary to common theories, the hypothesis that variations in mean temperature and mean precipitation are controlled more by external forcing (solar variability and volcanic) than by the increasing of green-house gases is catching on. The dynamics of Sun's activity is well described by the torque of its motion around the solar system's centre of mass. Because of the fact that we can calculate the solar torque for the future, the attractive prospective of feasibility of long term hydrological forecasting based on solar activity's cycles emerges.

1. Introduction

In our first contribution (Tomasino et al., 2002), we suggested that both global-mean temperature and surface-mean precipitation are controlled by the external natural forcing (solar and volcanic) and so when the latter oscillates (higher or lower intensity) the firsts follow its trend. The most important result pointed out was that the fundamental constraints of the hydrological cycle are the internal energy of the troposphere (the portion of the atmosphere that is strongly coupled to the Earth's surface) and the short-wave heating at the surface resulting from solar activity or scattering aerosols (volcanic fire, etc.). This statement is supported by many scientific works (Landscheidt, 1998; Friis-Christensen & Lassen, 1991; Svensmark & Friis-Christensen, 1997; Hoyt & Schatten, 1997; Allen et al., 2002).

Then, basing on the accord observed between solar activity and hydrological variables (Landscheidt, 2000; Tomasino and Dalla Valle, 2000), and because of the fact that cycles of the solar torque can be calculated for the future (Landscheidt, 1988), once defined the characteristic points in time's axis we can take indications about future trends in hydrological time series, because it is possible to define the probable interval of their critical points.

Given this agreement, predictions are not easy and obvious, because if it is true that solar eruptions can be predicted, their effects on Earth can be more or less effective in function to the position of the Earth as regards to the Sun, on the conditions of the interplanetary state around the Earth and on the climatic conditions in the area of interest. The floods period occurred in 2002 confirms this last statement: the critic state interested Northern Italy in May, Checa Republic and Germany in August and Italy again in November-December. The fact that in this period there was an extra input of energy striking the troposphere is well identified by the enormous number of storms and lightning that stroke Italy (80000 lightning measured in one day in July). This kind of increase had already been pointed out by Bossolasco et al. (1973), who measured an increase in thunderstorms frequency of more than 70% within four days after Sun's flares.

The question that emerges is: what knowledge is necessary to make reliable seasonal and inter-annual forecasts basing on these premises? In the next paragraphs we try to give the premises required to answer this question

2. Description of the data set

A proper set of descriptors is needed to build a model able to guarantee convincing forecasts. Two classes of variables are considered: solar and global climate's indices, to define the main constraints of the system, and regional scale descriptors, to characterize the system's reaction to external forcings.

To characterize the influence of solar activity, a trend indicator and a probability index for extreme events (floods and droughts) are defined. The trend of the discharge is based on the 8.7-year solar cycle: it allows the smoothing of the curve and cutting the effect of higher frequencies. The probability index for extreme events is calculated basing on extrema and zeros in solar torque (Landscheidt, 2000).

Then we looked at the global circulation patterns that are imputed to influence European climate: as the role of each pattern has already been studied, we considered the first three leading modes of variability for Northern Italy climate identified by Quadrelli et al. (2001), that explain respectively 46%, 19% and 12% of the total weather variance in the Mediterranean region during the December-March period. They are the North Atlantic Oscillation (*NAO*), a dominant phenomenon of the Northern Hemisphere's atmospheric circulation whose index provides an expression for the strength of the westerlies over the North Atlantic (Hurrel, 1995), the Eastern Atlantic Pattern (*EATL*) as described by Wallace and Gutzler (1981) and the Euro-Atlantic Blocking, connected with the presence of a high pressure field over the Atlantic coast and the central Europe area respectively (Tibaldi & Molteni, 1990; Pavan et al., 2000).

As regional scale descriptor we used the period-mean temperature at Trieste, a coastal city sited on the Northern Adriatic Sea, referred as well **correlated with both** the patterns of *NAO* and Northern Hemisphere temperature (Tomasino & Dalla Valle, 2000). The complete time series cover the period 1950-2003 (see Fig.1) because meteorological data are not available before 1950. The data of *NAO* and *EATL* indices were taken from the NOAA/National Weather Service NCEP (National Centres for Environmental Prediction) database available at:

ftp://ftp.ncep.noaa.gov/pub/cpc/wd52dg/data/indices/tele_index.nh.

Blocking indices were calculated basing on the method described in Tibaldi & Molteni, (1990); the temperature of Trieste was measured in the meteorological station of the Earth Science Department of the University of Trieste; the Po River discharge was provided by Italian National Technical Services.

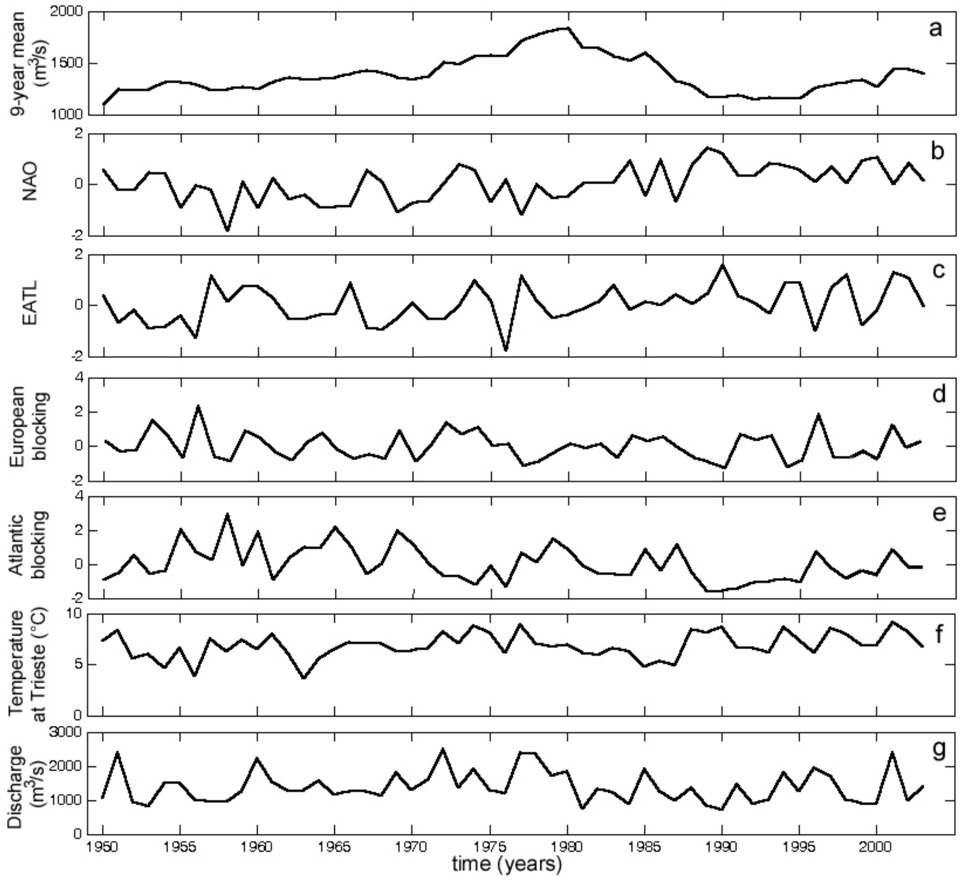

Fig. 1 – Variables considered to describe the Po River Plane climate: 9-years running mean, NAO, EATL, Blocking indices, Trieste temperature and Po River Discharge. All values are January-March mean.

Conclusions

The main problem associated with the making of a prediction system is the choice of the model. In the case of long-term forecasts a deterministic model is not the best choice: even the most complex models, as atmosphere-ocean general circulation models (AOGCMS), fail predictions that go beyond an enough little interval of time in the future. The right one is a 'black box' model, that is able to establish linear or non-linear relations that connects the factors to the phenomenon under observation, whereby the internal workings of the model are not known.

Models available from classic statistics (regressions and time-series analysis techniques) are afflicted with intrinsic restrictions that do not conciliate with this problem. First of all despite the good similarity between solar activity's indices and discharge behaviour, predictions corresponding to critical points of solar activity are quite scarce: because of this, inter-annual but not seasonal forecasts are possible, except in the vicinity of the critical point (maximum or minimum). Moreover, in a black box model the parameters that define the cause-effect relations between forcings and forced variables are fixed and constitute a rigid structure that gives then an invariable output.

The search of the proper model, able to increase the number of predictions up to the desired seasonal scale, is matter of debate for a further contribution.

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HOW COULD A POSSIBLE INCREASE OF MEAN SEA LEVEL MODIFY THE ADRIATIC DYNAMICS

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Riassunto

A fronte di possibili aumenti del livello medio dei mari, si studiano le possibili variazioni della dinamica adriatica (maree, sovralzi mareali e sesse) che ne conseguirebbero. Alcuni risultati dipendono fortemente dalla sorte della linea di costa, se cioè essa viene difesa, o meno, con arginature.

Abstract

Since an increase of the mean sea level seems to be expected, the consequences on the Adriatic dynamics are studied using numerical models. Tides, surges and seiches are going to vary their pattern, but many results strongly depend on the related evolution of the coastline.

1. Introduction

The general concern for the possible rise of the mean ocean level finds one of its focal points in Venice and in the delicate equilibrium of this city with water.

The street level is frequently very close to the usual high tide and frequently an additional wave due to meteorological forcings (a surge) causes a flood in the streets and in the basement of buildings. The most interesting sites, like old palaces and churches, are particularly vulnerable, due to the secular subsidence of Venice and the compression of their foundations. On the other hand, also large areas of north-eastern Italy are at risk of flood [Bondesan et al, 1995].

Since many indications foresee a rise of the global mean sea level, an attempt was done to estimate the possible hydrological modification that would be caused by a similar change. It is understood that the rise in itself would be a disaster, but it is worth estimating the corresponding trend in the sea dynamics.

Keeping in mind that tide, surges and seiches are the characters in the play, how would they change their strength and pattern, should the mean sea level rise?

2. Tide and seiches, a joint problem

By tide is meant the usual oscillation of the sea, due to astronomical forcing: in itself it cannot give origin to floods, even though it can join forces with it. It is interesting that the range of this ordinary tide is very large in the northern Adriatic, compared to most areas in the Mediterranean, and the reason for it will appear very soon.

Seiches are the well-known free oscillations of the sea, that follow a meteorological impulse and that reveal the proper frequencies of the system.

Their investigation gives the reason for the above remark about tides. The periods of the free oscillations (22 and 11 hours) are rather similar to the main periods of the tide (24 and 12 hours): it means that the tidal forced oscillation is close to resonance, and this accounts for the large range that progressively appears along the Adriatic (not mentioning the rotational effects) up to the northern end.

Since the three facts (tides, surges and the following seiches) depend clearly on the morphology of the Adriatic (depth and all geometry), possible changes in the mean sea level can clearly modify the scenario.

Briefly speaking, if the morphology is changed, then the resonant frequency, proper of the Adriatic, will vary. Depending on whether it will get more or less similar to the forcing frequency, the tidal amplitude will increase or decrease. The surge itself will change, since the mechanism of creation will be different.

3. A model and its results

In order to have unambiguous, overemphasized, conclusions, a severe rise of 10 meters was conjectured for the level of the Adriatic: for sure, unrealistic, but not ridiculous, if the variety of hypotheses published so far are considered. Presumably, the most terrific forecast in the literature is, as an increase predicted in 1983 for the year 2100, of 3.45 meters [Hoffman et al., 1983], even though it was an upper limit of possibility.

The tool for the investigation is now a numerical model, a finite-difference scheme, essentially using the Arakawa method, rather simplified since it was intended to be used for an immediate response. Figure 1 shows how the model reproduces the main tidal component, M2, giving also an idea of the number of grid-points.

A bifurcation emerges in the investigation, since two different scenarios can be considered. Indeed, one can think either of the sea invading the coastal plains, or of people building defences to protect their lands. The latter situation, by the way, is already actual for certain areas [Bondesan et al, 1995].

Then, in both cases the sea gets deeper, but in the first case the total surface changes, with the addition of a very shallow area. The Adriatic can either become simply deeper, or deeper and larger.

The case of the "deeper Adriatic" is considered first. A simple concept of oceanography says that long waves travel faster in deeper water. These waves are the ones that some way depend on the depth of the sea, opposite to the usual wind waves, seen on the surface.

Now, the period of a seiche is related to the travel time of the "signals". Hence, if the speed increases, the present 22-hour resonant period will decrease and the distance

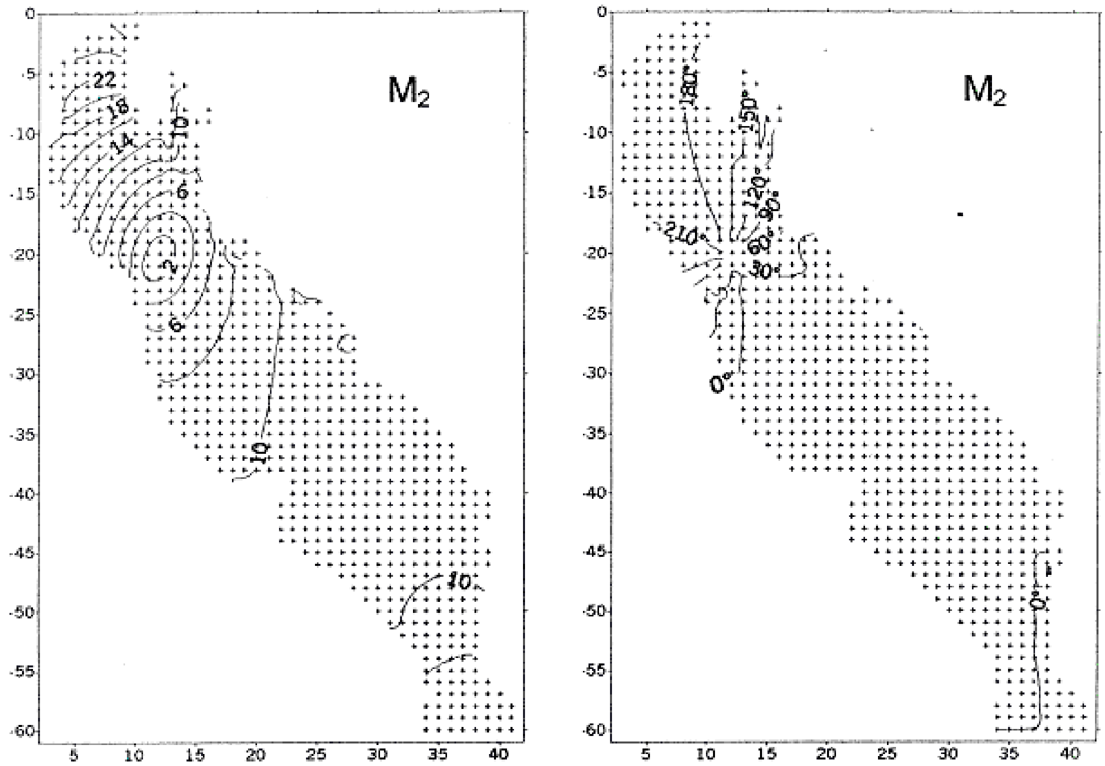

Fig. 1 - Validation of the model in the simulation of the M_2 tidal component. The density of grid-points is clearly shown.

with the tidal forcing will increase. As a result, the observed tidal range will decrease.

Now, the other case, deeper and larger. The above remarks about velocity still hold, but with an additive effect. Assuming a free enlargement of the sea, with a 10-meter increase, it will flood a large area of Venetia (Veneto Region) and the corresponding plains south of Po River (Romagna). Also the northern Friuli-Venezia Giulia Region and Puglia, in the south, would be affected. In total, it was estimated that, for what concerns the Adriatic, 4% of the area of Italy would be submersed. The expansion of the sea requires by itself a longer travel time, and, in addition, the new area is very shallow, with low speed for long waves.This way, an opposite effect takes place, the time required is longer, the seiche period gets closer to the 24 hours, and the tidal range will increase.

As a conclusion, in case of sea level rising, the two possible situations considered have diverging results. Figure 2 refers to K1 (the second important component of tide), whose period remains fixed, with respect to the main seiche. The tide in the Adriatic is stimulated by the Mediterranean, so we are interested in amplifications. The three dots on the axis of K1 show its actual value and how it would change.

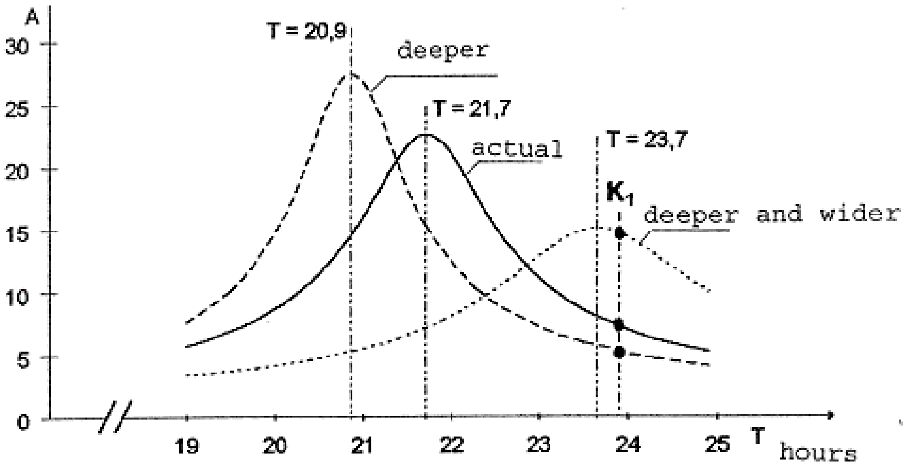

Fig. 2 - The three curves show how the different periodic stimulations from the Mediterranean are (or would be) amplified in the northern Adriatic.

4. *The wind effect*

Another effect of interest concerns the direct consequence of a storm, namely the surge. The best way to understand it is to consider a wind that is suddennly turned on and persists for a long time (a step function).

The effect would be a first strike of level towards the northern end, followed by damped oscillations (the seiches fading away). But due to the wind persistency, the the seiches would develop around a new equilibrium level, obviously higher than usual. Needless to say, it is a dynamic equilibrium, with a "tilted" surface of the Adriatic, and the equations reveal that the its slope depends on depth. There is a linear relation, the tilt increases if the sea is shallow.

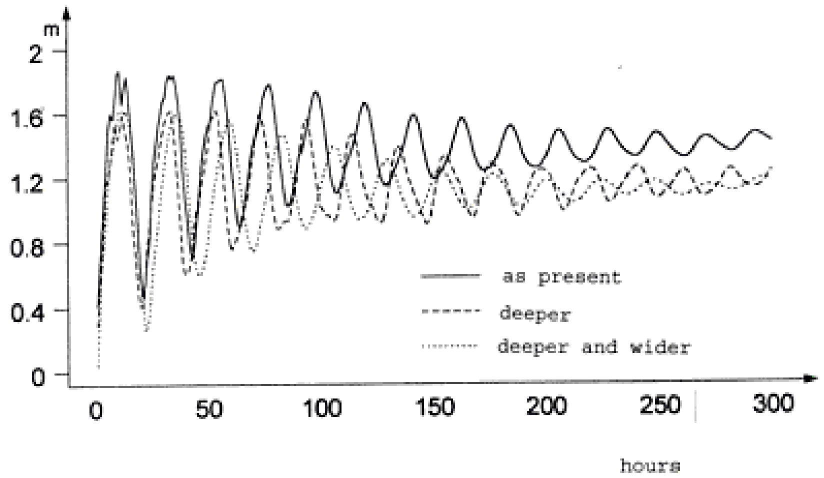

Fig. 3 - Level response, in Venice, to a persisting sirocco wind, chosen to give a surge comparable to the one of Nov. 4, 1966.

This means that if the Adriatic gets deeper, should the sea expand or not on the coastal plains, the overall effect of wind on the present shore, including Venice, would be less severe. This does not refer to wind waves or swell, of course, but to the dynamics that gives origin, even today, to floods.

5. Conclusions

The presumable rise of the mean sea level of the northern Adriatic will create severe problems by itself. It is likely that coastal areas will be protected, as they are now. As a consequence, the only effect will be a deepening of the sea and consequently a decrease in the tidal range. The wind effect also will be slightly more moderate.

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OBSERVATIONS ON THE PRINCIPAL ADRIATIC SEICHE AS INDICATOR OF VARIABILITY AND ON THE PERIOD OF THE SMALLEST ONE

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Riassunto

Le burrasche provocano spesso aumenti anomali del livello marino nel mare Adriatico. Nella ricerca di tendenze della loro frequenza bisogna liberarsi da altre influenze come la marea astronomica o le variazioni a lungo termine del livello medio. A questo scopo si sono esaminate le sesse, oscillazioni libere di livello che seguono le tempeste. Una volta fatto questo, si cercano qui collegamenti con le variazioni di attività solare attraverso il "numero di Wolf" delle macchie che appaiono sulla nostra stella.Attraverso medie annuali si trova un parallelismo tra i due fatti.

Le sesse di alta frequenza, poco rilevanti nella pratica, sono invece utili per la calibrazione dei modelli.

Abstract

Storm surges are frequent in the Adriatic, but for a correct study of possible trends a certain care is required in order to avoid the influence of tides and long-term variations of the sea level. For this reason, a significant indicator of the surge activity has been found in the seiches, the free oscillations that follow the level disturbances given by storms. After this work, a comparison is performed here with the solar activity as expressed by the mean Wolf's number of sunspots and connections are found on a yearly basis. Instead, high-frequency seiche is useful for calibration of numerical schemes.

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1. Introduction

There is a vast literature concerning the surges in the northern Adriatic, particularly since they frequently give origin to floods in the town of Venice. The damages caused to this famous town are such that the concern about them goes much beyond the local borders.

Due to the above consideration, it seems obvious to begin a frequency research from the floods themselves, namely from the extreme levels reached by the northern Adriatic Sea. Records taken in Venice give origin to a plot, frequently seen in the literature, showing the cases when the sea level exceeds 1.10 m over a certain reference in the town (Fig. 1). There are certainly some kinds of clusters of the events, in the time scale, and this to the frequency gives interest for possible periods more or less favorable to their occurrence.

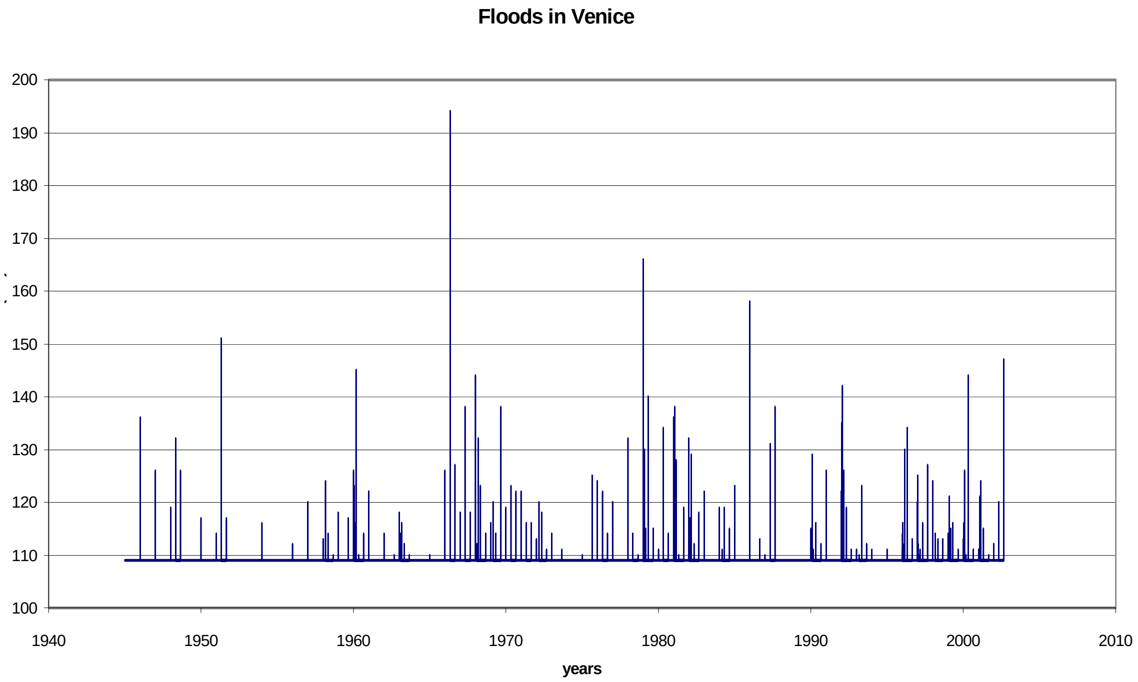

Fig. 1 - Floods in Venice

2. A better approach to the problem of surge frequency

There are many reasons suggesting that this is not the correct sequence to be considered.

First of all, the reference level is not proper, since the town of Venice is well known to suffer subsidence. Much more than the generality of the surrounding district, the areas of the Venice Lagoon lowered in the past for natural compaction, for the weight of the buildings, and, much more, due to the water pumping from the subsoil [Gambolati et al, 1974]. Since the vertical reference used is, in fact, related to the urban structures, the mean sea level is apparently increasing for this reason. The number of floods increase correspondingly, even with a stable frequency of surges.

It is believed also that the sea level is rising, as it appears in other places, like the town of Trieste, whose local subsidence is thought to be negligible.

Even if this belief is taken into account, the occurrence of a flood is certainly relevant for people and maybe for history, but it can have a different evaluation from a scientific point of view. Indeed, the instantaneous sea level is determined by two main factors, to be considered separately, since the ordinary, astronomical tide is active at all times, whilst meteorological forcings are occasional and various.

The ordinary level depends on the Sun-Moon-Earth system, with spring- and neap tides. Also, its magnitude is locally amplified by a kind of resonance involving the whole sea. The Mediterranean has weak tides, order of 0.2 m, but the Adriatic, being a long, almost closed bay, develops oscillations of the order of one meter in the northern part. Astronomical tides are well known, easy to predict, and not sufficient to give any flood to the present human settlements.

3. Surges in the Adriatic Sea

The other face of the story is surge: the word refers to all perturbations of sea level, attributable to meteorology, hence to wind and to pressure, together with other minor effects (like rain or thermal exchange) that will be ignored here.

Generally speaking, the dynamics of surge is clear. Wind pushes water and, in the presence of an obstacle, the liquid will pile up and the sea level will increase. Also the exactly opposite behaviour is sometime observed. A similar effect is given by local decreases of atmospheric pressure: they will raise the sea surface, with an obvious balance with the high-pressure areas.

Considering an observed flood, a large variety of situations can be in the background, high or low tide coupled with a moderate surge or a severe one [Canestrelli et al, 2001]. As it was stressed above, also the mean sea level of that time is relevant. In other words, within the 20th century, for example, this average level changed by more than 0.2 m, and this makes a difference between the case of November 10, 1927, and the flood of December 28, 2000.

Since astronomy, surges and long term variations act separately, the conclusion of the above considerations is that simple statistics of the cases of flood is misleading, when looking for possible climatic changes. The same surge can give an inundation, or not even be seen by the inhabitants of the lagoon, depending on the conditions of tide at that specific time, since surges usually have a duration of a very few hours.

A certain year could be considered more or less plagued depending on the number of floods that were recorded in it. But this is not serious, since the "surge story" that developed in that year could have been merged to a different "tide story", simply moving up or down the time of the surges. A storm system that struck the Adriatic on a certain morning was able to come, instead, in the afternoon, with a completely different effect in the total values of level. So, the year considered would have been more or less "lucky".

4. Seiches as indicators

As a consequence, the study of surges is better done independently, giving a certain attention to the further ambiguity of the long-term mean sea level.

A further step, suggested here, uses seiches. They are relevant as a memory of the sea with respect to storm surges. Since they can be of the same magnitude as the astronomical tide, they have practical relevance.

In the days that follow a storm, weather is usually better and there should be no alarm for flood. But the seiche can come, and since a stronger agreement in phase is possible with ordinary tide, a flood can occur, even heavier than the first one (Fig. 2).

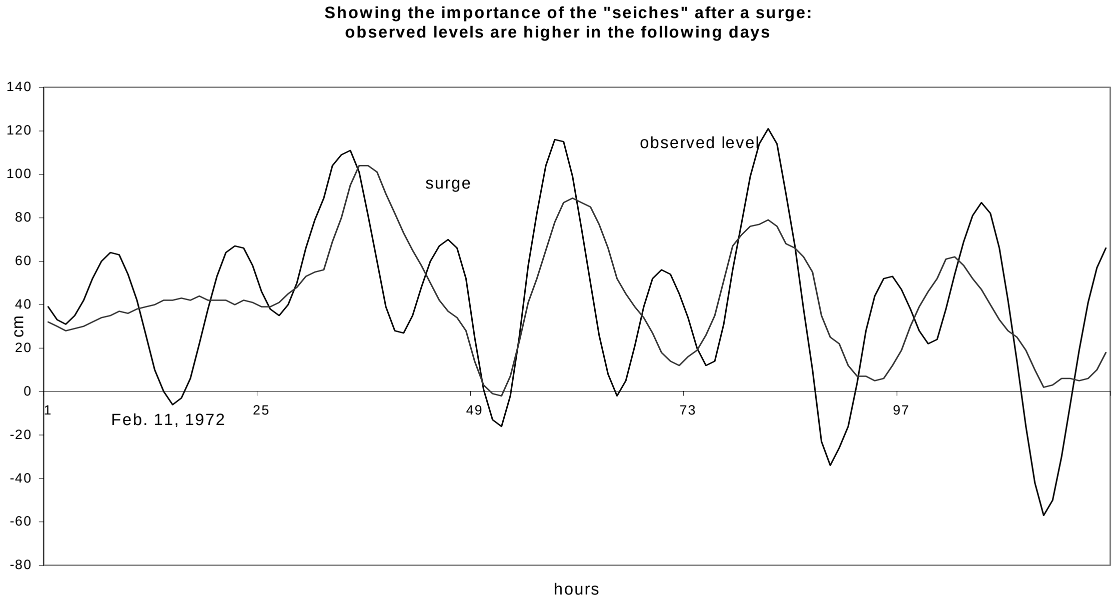

Fig. 2 - Importance of the “seiches” after a surge.

The main seiche has a period of about 22 hours, involves the whole Adriatic in a pattern of a quarter of a wave: it is normally the only interesting oscillation. Due to its persistence, the Adriatic shows in fact a continuous vibration with its frequency. This suggests a new way to identify the time evolution, year to year: a numerical filter on the hourly values, over 60 years of observations, puts the pure 22-hour seiche into evidence.

The simple variance of the hours when the seiche value exceeds a certain threshold, 20 centimers, either positive or negative, gives indeed an interesting history of the seiche activity. It will appear that the time evolution is clearly oscillating, much better than the graph of the floods (Fig. 1), or even of the extreme surges, whose poor number would not give a distribution smooth enough for any processing.

5. Seiches and sunspots

Who is familiar with geophysical processes will easily associate the obtained pattern with the solar cycles [Polli and Vercelli, 1948]. But instead of imposing any fixed periodicity in the histogram (e.g., 11 years), or comparing spectra, since the solar activity itself is less regular and constant than, for example, the orbital motions, a comparison was made here of the activity of seiches considered above with a classical parameter of the solar activity. Wolf's yearly mean of sunspot number [Hoyle, 1955] was used, as introduced by Rudolf Wolf in 1849 (but reconstructed back to 1749). It appears to be the simplest possible index for a correlation. Up-to-date information can be found on line: www.sunspotcycle.com (connected to NASA) can be mentioned.

A three-year moving average was imposed to the two sequences. Now, the direct comparison with the Wolf's sunspots number is sought: for statistical interpretation, the two variables have been standardized (by reducing them to zero mean and unit variance).

Figure 3 shows the result: it clearly appears that there is an interesting similarity in the time development of the mean yearly sunspots number and the yearly variance of "significant seiche hours" in Venice. The value of the linear correlation index is 0.63 if the corresponding numbers (sunspots and surges of the same year) are considered.

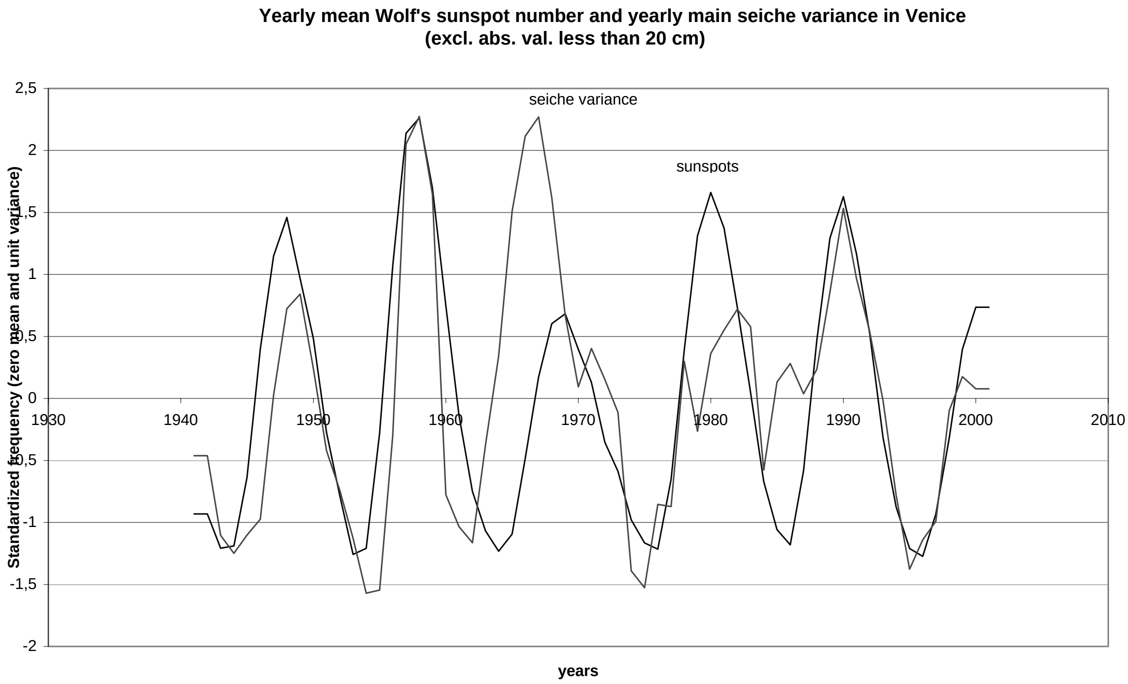

Fig. 3 - Yearly mean Wolf's sunspot number and yearly main seiche variance in Venice.

An obvious curiosity: what is the situation for the future? If the above connection exists, the forecast of the solar activity is some kind of predictor: figure 4 gives this estimate.

6. The smallest observed seiche

The above considerations concern the dominant mode of seiche, the 22-hour one. It is the lowest mode and it is the most frequently observed. Very little will be said here of the next one, 11-hour period, that only exceptionally (like on December 12, 1967) is larger than the main one. Instead, the third one will be considered, relatively unusual and elusive. The reason for this investigation is technical: when models are implemented, the most immediate form of validation is comparison of seiche period in the model and in the observations.

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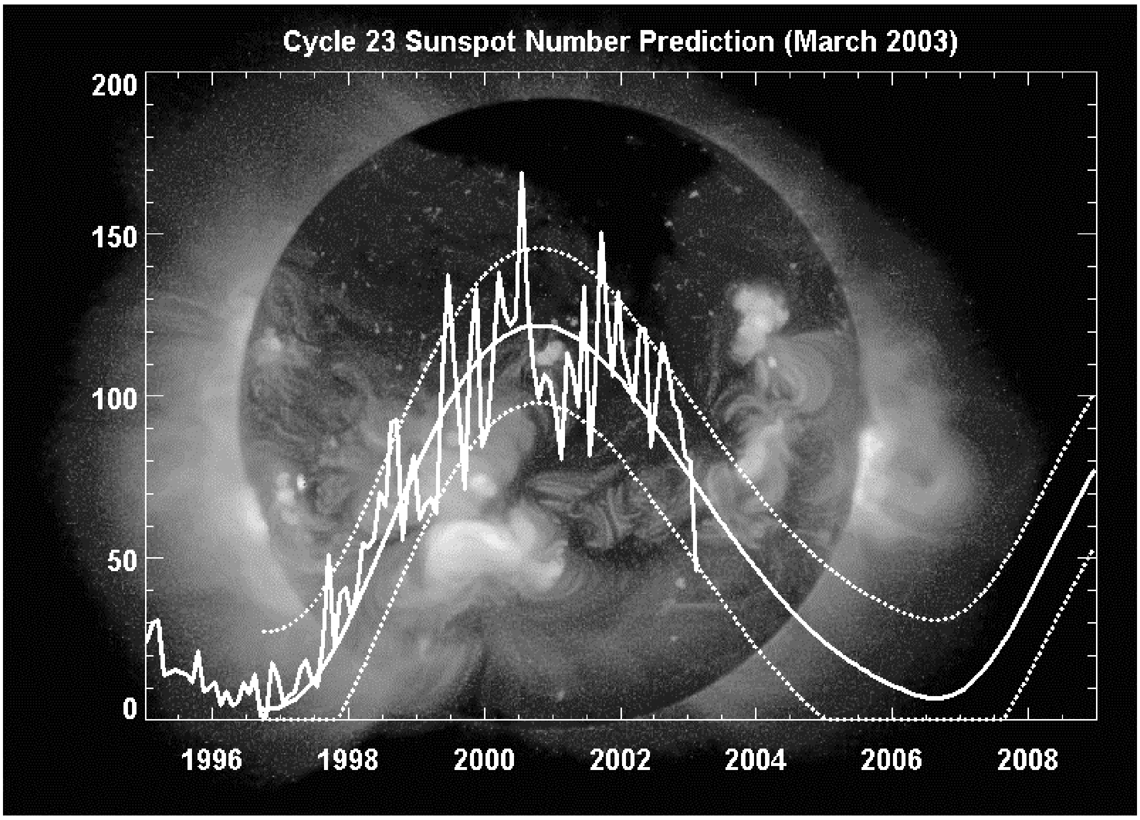

Fig. 4 - Sunspot number prediction

Now, the agreement of high-order seiches appears particularly delicate, and it seems that the literature is not clear, and in most cases suggesting a period over eight hours [Defant, 1960] . But the observed data seem to show the third order oscillation with a period not exceeding six hours. One out of many examples is shown here (Fig. 5), with hourly values of six stations in the Adriatic, after subtraction of astronomical tide and a using a simple filter to remove the dominant seiches. It seems that for the fine structure of models and all numerical simulations this check should not be disregarded.

Conclusions

Studying the frequency of surges requires a certain work on the raw sea-level data.

There is an evident connection between the solar activity and the seiche dynamics observed in the northern Adriatic. For this research, the dominant mode of oscillation has been used, but the other extreme, the third kind of seiche, was also documented, having in mind the optimal validation of numerical models.

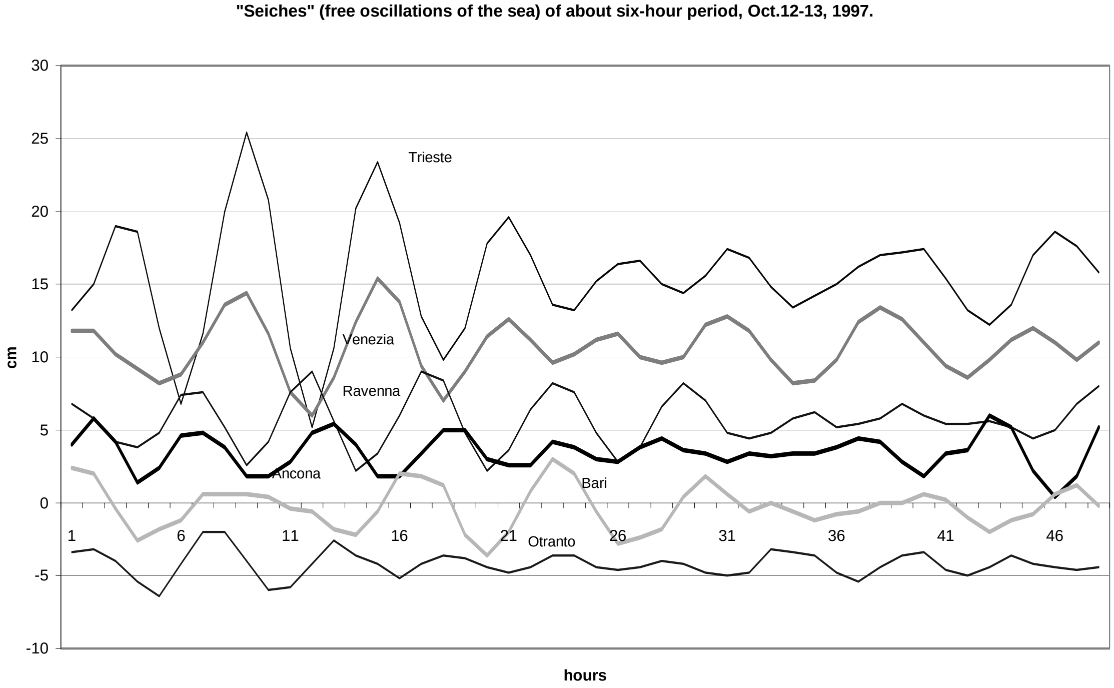

Fig. 5 - “Seiches” of Oct. 12-13, 1997.

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RESEARCH LINE 3.2
Hydrodynamics and morphology

LONG-TERM SEDIMENT CONCENTRATION AND MORPHOLOGICAL CHARACTERISTICS OF A TIDAL LAGOON

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Riassunto

Nel presente articolo viene proposto un modello morfologico per una laguna a marea basato sul concetto di "concentrazione di trasporto" (transport concentration), definita come la concentrazione di sedimenti relativa ad un trasporto netto a lungo termine, somma di un trasporto avvettivo e un trasporto dispersivo. Il coefficiente di dispersione intermareale e il flusso d'acqua residuo si ottengono da un modello idrodinamico. La concentrazione di trasporto nei canali e nei bassofondi di una laguna a marea si ottiene dall'integrazione su un periodo dell'ordine degli anni della concentrazione istantanea. Tale concentrazione è in genere prodotta dall'effetto combinato delle correnti di marea e delle onde di marea. Ma per una laguna a marea (come quella di Venezia) caratterizzata da canali molto incisi che solcano bassofondi non eccessivamente profondi, si può assumere che la concentrazione di sedimenti sui canali dipenda esclusivamente dall'effetto delle correnti, quella sui bassofondi dall'effetto delle onde. Proprio per questo motivo, la concentrazione a lungo termine nei canali a marea (eq. (3)) risulta proporzionale ad un coefficiente di agitazione f_c ed inversamente proporzionale alla potenza *n*-esima ($n \cong 4 \div 5$) della profondità locale. La concentrazione sui bassofondi (eq. (10)), invece, è proporzionale ad un coefficiente di agitazione f_w ed inversamente proporzionale alla profondità locale. I coefficienti di agitazione dipendono rispettivamente dal prisma di marea del canale e dal moto ondoso locale.

Le equazioni semplificate (3) e (10) riassumono le caratteristiche idrodinamiche e batimetriche di questi due comparti lagunari. In particolare, per quanto riguarda il comportamento e l'evoluzione dei canali, lo studio della concentrazione di sedimenti degli stessi ha permesso di valutare le relazioni intercorrenti fra le loro caratteristiche morfologiche. La legge di Jarret, relativa alla proporzionalità fra sezione trasversale e prisma di marea di un canale, è stata indagata e sono stati messi in luce i suoi limiti. Tale legge empirica, infatti, viene analizzata attraverso il modello concettuale proposto (equazioni (30) e (31)), che mette in conto anche l'effetto della concentrazione di sedimenti. Applicando il modello concettuale, si vede come esso confermi la legge di Jarret per quanto riguarda il comportamento dei canali principali. Quando, però, l'analisi si sposta ai canali minori e ai ghebi, caratterizzati da sottobacini relativamente piccoli e ad alta densità di barene, si nota come la legge di Jarret sia via via meno valida. Le barene, infatti, tendono ad assorbire continuamente sedimenti dal canale, per cui il prisma di marea e la cui sezione trasversale non sono più correlabili con una relazione lineare, dipendendo altresì dalla diversa concentrazione presente nei canali. Tale comportamento è confermato dai dati sperimentali raccolti nella laguna di Venezia.

Abstract

In the present paper a long term morphological model of tidal lagoons is proposed based on the concept of "*transport concentration*". This can be defined as the concentration which provides the long-term net transport of sediments in a given location of a lagoon, as the sum of a dispersive and a residual advective flux. The intertidal dispersion coefficient and the residual water flow are provided by a more or less detailed tidal hydrodynamic model. The "transport concentration" is computed as the long-term average concentration produced in a given location by currents and waves. Simple expressions for the transport concentration for the channels and the shoals are developed, as a function of the local depth and the local hydrodynamics.

Moreover, the effects of the long-term concentration along the channel are considered in order to investigate the relationship between cross section area and tidal prism of the channel, known as Jarret law. The "*transport concentration*" model gives reason of this law and shows its limitations.

1. Introduction

In order to study the long-term evolution of lagoons and their possible steady-state configurations, specific morphological models should be developed, capable to put into account all the different driving forces, either natural and anthropogenic. In principle, these models should incorporate a variety of complex processes, as grain size sorting, effects of vegetation, collapse of steep banks, compaction of sediment deposits, etc.

A very useful tool which has been applied since many years to the Venice lagoon [Di Silvio, 1989] and then extended to a number of semi-empirical models [de Vriend, 1998] is the concept of *transport concentration*.

Indeed, morphodynamics of tidal lagoons is controlled by long-term (net) sediment fluxes between littoral and tidal channels as well as between channels and shallows (intertidal shoals and salt marshes). Long-term fluxes can be expressed in advective and/or dispersion form as a function of the local transport concentration, namely long-term averaged concentration of sediments.

In some of the previous models transport concentration was defined by simplified and robust expressions, valid for channels and shoals, where local hydrodynamic effects are accounted for by empirical coefficients to be calibrated against morphological data. In the present paper a justification of these expressions is provided with special attention to transport concentration on the shoals.

Because of the different importance of the physical agents in the lagoonal basin, a distinction has to be made on the different components of the sediments concentration in the various compartments: marshes, shoals and tidal channels. As for the dentritic channel network, it has often been observed that the cross sectional area of the large tidal channels of many lagoons (including the inlet) is more or less proportional to the respective tidal prism. In the present paper the proposed simple model is applied to analyse and show the limitations of this empirical relation, often known as "Jarret law".

2. Transport concentration in channels and shoals

Transport concentration C in a given location is obtained by averaging the instantaneous concentration $c(t)$ over a long period of time. The instantaneous concentration can be computed by any appropriate transport formula, as a function of the local currents (especially active in the channels) and of the local waves (especially active on the shoals).

As far as currents are concerned, let us consider a monomial transport formula for the sediment transport in suspension (e.g. Engelund and Hansen type) and let us call q_s the volumetric sediment discharge per unit width produced by the water flow $q = v \cdot h$, where v is the water velocity averaged over the depth h.

One finds:

$$q_s \propto v^n, \quad \text{where n} \cong 4 \div 6 \tag{1}$$

while the instantaneous sediment concentration (n=5) is:

$$c = \frac{q_s}{q} \propto \frac{v^n}{q} \propto \frac{q^{n-1}}{h^n} \propto \frac{q^4}{h^5} \propto \frac{Q^4}{B^4 h^5} \tag{2}$$

where Q is the water discharge in the channel of width B. Eq. (2) provides in principle the "equilibrium concentration" in a channel. When the falling time of the sediments is reasonably shorter than the tidal period, actual concentration tends to be equal to equilibrium concentration. In a "short" lagoon like Venice, the instantaneous discharge q or Q in a given location (both in flood and ebb conditions) is substantially proportional to the area of the corresponding drainage basin, while the statistical distribution of Q over the year is practically linear. By averaging eq. (2) over the year one finds the long-term average concentration in the section:

$$C_c = \frac{f_c}{h_e^5} \tag{3}$$

where h_e is the local tide-averaged depth and the coefficient f_c is a function of the tidal pism; f_c can therefore be considered rather constant over long periods of time even if the bottom elevation (local water depth h_e) is subject to evolution. Note that eq. (3) has been obtained by introducing simplifications that especially apply to deep tidal channels rather than to shallow shoals. On the other hand, sediment concentration on shoals is almost totally controlled by the waves while the stirring effect by the currents is negligible ($f_c \cong 0$).

An expression similar to eq. (3) can also be obtained for the long-term average concentration produced by waves, by assuming that the proportionality (1) still holds if v is the instantaneous orbital velocity produced by the waves near to the bottom (shallow waters) and that v is proportional to q/h. This assumption implies that the alternate sediment flux q_s during the passage of a wave is in phase with the corresponding depth-integrated water flow q. Note that waves do not transport sediments but just stirr them: long-term sediment transport on the shoals (as well as in the channels) is produced, via the long-term averaged concentration, by intertidal dispersion and residual flow. Under the hypothesis made, the instantaneous concentration on the shoals is:

$$c = \frac{q_s}{q} \propto \frac{v^n}{v \cdot h} \propto \frac{v^{n-1}}{h} \tag{4}$$

By evaluating the value of the maximum orbital velocity v_m by:

$$v_m = \frac{1}{2}\sqrt{\frac{g}{h}} H_w \tag{5}$$

one finds the concentration on the shoals averaged over the wave period:

$$c = k_1 \frac{H_w^{n-1}}{h^{\left(\frac{n-1}{2}+1\right)}} \tag{6}$$

with k_1 including all the constants of proportionality. In order to obtain the long-term average concentration in a given location, eq. (6) should be averaged over, say, a few years.

The height of significant wave H_w in shallow water and within a limited range of length of fetch, Fe, average depth along the fetch, h_s and wind velocity, u_A (Fe =1000÷5000 m, h_s =0.5÷2.0 m, u_A =15÷25 m/s) , can be computed through the monomial formula [Dal Monte & Di Silvio, 2002]:

$$H_w = 3.2 \cdot 10^{-3} \cdot Fe^{0.32} \cdot h_s^{0.5} \cdot u_A^{1.45} \tag{7}$$

By substituting this formula, with $n=5$, one finds, approximately:

$$c = k_3 \frac{h^2 \, F_e^{4/3} \, u_A^6}{h_s^3} \tag{8}$$

By assuming that the average depth along the fetch h_s is proportional to the local depth, *h*, the instantaneous concentration is:

$$c \propto \frac{Fe^{4/3} u_A^6}{h} \tag{9}$$

Eq. (9) indicates that the instantaneous concentration produced by waves depends on the local depth *h* (varying with the tidal level) and on a combination of fetch length and wind velocity. For sake of simplicity we shall consider tidal level and wind velocity, both time-dependent quantities, as mutually independent. The duration of tidal elevation is almost linearly distributed, all over the lagoon, around its average value. Wind and fetch both depend on direction; however, their statistical distributions are again mutually independent [Dal Monte & Di Silvio, 2003]. In conclusion, eq. (9) can be integrated over the time and over directions to get the averaged value:

$$C_w = \frac{f_w}{h_e} \tag{10}$$

of the transport concentration produced by waves, where h_e is the local tide-averaged depth.

The value of the stirring coefficients f_c in eq. (3) and of f_w in eq. (10), depends on the statistics of water flow and, respectively, of wind velocity and fetch length. Moreover, as q_s (eq. (1)) depends on sediment grainsize, the values of f_c and f_w tend to decrease for coarser bottom composition. An appropriate value of f_w can also account for the enhanced resistance of the bottom due to vegetation, either sea weeds (e.g. Zostera marina) on the shoals or aerial alophile species on the salt marshes. Even more, the thick vegetation on salt marshes practically prevents sediments stirring, so that one can put here directly $f_w = 0$.

The total transport concentration C in any location is obtained in principle by summing up expressions (3) and (10):

$$C = C_c + C_w \tag{11}$$

It has been observed above, however, that C is dominated either by waves (on the shallows, where $f_c \cong 0$), or by currents (in the channels, where C_w rapidly decreases as the depth increases).

For predicting the estuary evolution or its equilibrium configuration, eq. (11) should be introduced in the long-term balance equations of sediments (either zero-, one- or two- dimensional), where intertidal dispersion transport and residual advective transport of sediments are expressed in terms of C.

3. Sediment balance equation in a tidal lagoon

A tidal lagoon may be schematised as formed by three main compartments: deep *tidal channel*, with bottom elevation always submerged by water; *shallow shoals*, with bottom elevation below the mean sea level and partially submerged during the tidal cycle; and vegetated *salt marshes*, with elevation slightly above the mean sea level. Tiny tidal channels draining vegetated salt marshes are called marsh *creeks* (fig. 1). The dendritic network of channels is connected with the sea through the inlet and exchanges water and sediments with the sea. Tidal channels, however, exchange water and sediments also with shoals and tidal marshes. For any cross-section of a tidal channel, the following balance equation can be written:

$$T_x = D_x + T_y + I_x \tag{12}$$

where T_x is the long-term net sediment flux towards the sea; D_x is the amount of sediment removed from the bottom of the entire landward part of the channel network with respect to the considered cross section; T_y is the net amount of sediments conveyed from the shallow areas in the channel network; I_x is the external input of sediments in the channel network (positive from the river, negative for dredging).

The sediment removal from the channel network is:

$$D_x = \left(\frac{\partial h_c}{\partial t} - \alpha \right) S_c \tag{13}$$

where $\frac{\partial h_c}{\partial t}$ is the average increase of the channel depth, α is the rate of eustatism and subsidence and S_c is the horizontal surface covered by the channel network.

The net amount of sediments removed from the shallow areas (shoals and marshes) and conveyed into the channel network is:

$$T_y = T_{y,s} + T_{y,m} = \left(\frac{\partial h_s}{\partial t} - \alpha\right)S_s + \left(\frac{\partial h_m}{\partial t} - \alpha\right)S_m \tag{14}$$

where S_s and S_m are the horizontal surface of the inland part of, respectively, shoals and marshes, while $\frac{\partial h_s}{\partial t}$ and $\frac{\partial h_m}{\partial t}$ are the average increase of the corresponding water depth.

The net flux T between shoals and marshes corresponds to the occasional reduction of the marsh surface during the strongest storms, more or less compensated by the slow reconstruction of their surface during the relatively calm periods. Flux T does not affect directly the sediment balance in the channel.

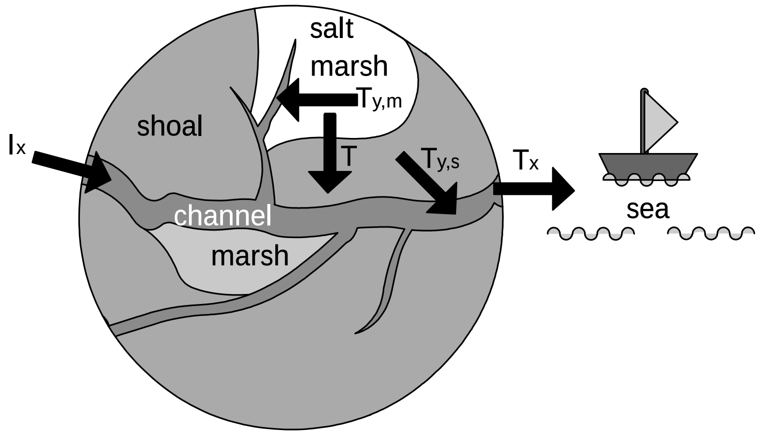

Fig. 1 – Zero-dimensional schematization of a tidal lagoon as a unique basin.

3.1. Long-term sediment transport in tidal channels

The one-dimensional long-term (net) sediment transport through any cross section of a tidal channel can be expressed in terms of long-term averaged concentration $\tilde{c}$ prevailing in the cross section, as the sum of a dispersive component and an advective component (eulerian residual flow):

$$T_x = -D\frac{\partial \tilde{c}}{\partial s}A_c \pm \tilde{c}Q_R \tag{15}$$

where the direction s is assumed to be positive in the ebb direction. The intertidal dispersion coefficient D incorporates different transport mechanisms, somehow related to the residual terms issuing from the averaging operations. For a tidal lagoon formed by a network of deep channels cut in broad and shallow areas, the dominant intertidal transport is due to the alternate “pumping and trapping” between channel and shoals during the tidal cycle [Schijf and Schönfeld, 1953]. An evaluation of the intertidal dispersion coefficient D has been proposed by Dronkers (1978). The numerical results produced by a simple tidal model of a channel/shoal system similar to the Venice lagoon indicated for D values of hundreds $m^2 \cdot s^{-1}$ [Di Silvio & Fiorillo, 1981]. In any case, the dispersive transport produced by tidal pumping is very active and usually much larger than the advective transport due to the net residual flow Q_R (pratically negligible in the venie lagoon).

By neglecting $\tilde{c} \cdot Q_R$ and integrating eq. (15) over the length of the entire tidal basin, one can write the following zero-dimensional expression of the outward net flux of sediment through the inlet:

$$T_x = V(x - z) \tag{16}$$

in which x represents the long-term concentration $\tilde{c}$ averaged along the channels, z the long-term concentration of the sea at the inlet and V an “equivalent exchange discharge” which depends on the spatial distribution of DA_c along the channels. For relatively short lagoons (propagation time shorter than ¼ of the tidal period) the discharge V has the order of magnitude of the tidal prism divided by the tidal period.

For a shallow, short lagoon tidal amplitude is almost uniformly distributed over the entire basin and equal to the amplitude in the sea. The water depth, by contrast, is different in the different locations. Therefore the tidal prism will be written:

$$V = r_c S_c + r_s S_s + r_m S_m = V_c + V_s + V_m \tag{17}$$

where r_c, r_s and r_m represent the averaged tidal excursion in channels, shoals and marshes and depend on the statistics of tidal amplitude and on the respective average local depth (submersion frequency).

The dendritic configuration of the channels (repeatedly branched open network) suggests the possibility of dividing the entire lagoon into smaller and smaller “closed sub-basins” of different rank. For the entire basin (rank 1), the way in which eq. (16) has been obtained by integrating eq. (15) implies that the value x is defined around the middle of the main channel or, more precisely, around the cross section where the tidal prism of the entire basin is divided by 2. We shall define of rank 2, the remaining sub-basin landward of this cross section, as well as any other “closed sub-basin” tributary of the main channel seaward of the same cross section. A dentritic network of tidal channels and basins of different ranks is represented in fig. 2.

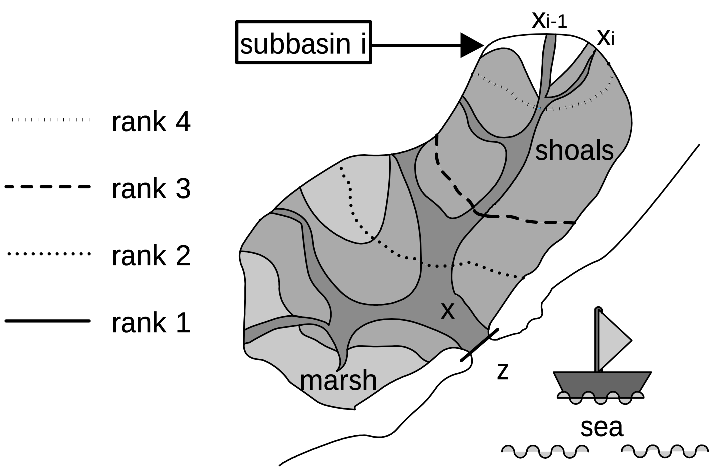

Fig. 2 – Example of a dentritic network of tidal channels and basins of different ranks.

Thus eq. (16) may be written for the net transport T_{xi} through the closure cross section of any sub-basin of the *i*-th rank:

$$T_{xi} = V_i (x_i - x_{i-1}) \tag{18}$$

where x_i is the average concentration in the channels of the sub-basin under consideration; x_{i-1} is the average concentration in the channel of the receiving basin, having (*i-1*)-th rank; V_i is the tidal prism of the sub-basin and Q_{Ri} the residual flow entering the sub-basin. For the first rank basin (entire lagoon) it is $x_i = x$ and $x_{i-1} = z$, as in eq. (16). Eq. (18) can repeatedly be applied along a sequel of smaller and smaller channels, from rank 1 to any higher *N*-th rank.

3.2. Sediments exchange between channels, shoals and marshes

The balance equation (12) includes the sediment exchange between channels and adjacent shallow areas ($T_y = T_{y,s} + T_{y,m}$). The net fluxes $T_{y,s}$ and $T_{y,m}$ are produced by the "pumping and trapping" mechanism mentioned before, associated to the difference of long-term concentration in channels, shoals and marshes. During the flood, sediments are conveyed from the channel network towards shoals and marshes; during the ebb, sediments are conveyed in the opposite direction. As already observed, due to the bottom protection exerted by alophile vegetation, the concentration in the marshes during the ebb phase is practically zero; the channel behaves like a sediment reserve for the marshes and continuosly feeds them with new material.

The long-term (net) flux between channels and shallow areas (fig. 1) can be written as a function of the long-term concentration *x* and *y* respectively in channels and shoals:

$$T_{y,s} = r_s S_s (y - x) \tag{19}$$

$$T_{y,m} = r_m S_m (0 - x) \tag{20}$$

By introducing the expressions (16), (19) and (20) in the sediment balance equation (12), the following relationship can be obtained between the long-term concentration in the channel, x, and the long-term concentration in the sea, z:

$$x = z\left(\frac{1}{1+\frac{V_m}{V}}\right) + \left(\frac{\partial h_c}{\partial t} - \alpha\right)\frac{S_c}{V} + \left(\frac{\partial h_s}{\partial t} - \alpha\right)\frac{S_s}{V} + \frac{I_x}{V} \tag{21}$$

In many lagoons, e.g. Venice, some terms [Dal Monte & Di Silvio, 2003] of the previous expression (21) can be neglected and one can obtain the simpler expression (22):

$$x = z\left(\frac{1}{1+\frac{V_m}{V}}\right) \tag{22}$$

This expression (22) shows that the average concentration in the channels, x, tends to be slightly smaller than the concentration in the sea, z, depending upon the ratio $\frac{V_m}{V}$. In a given lagoon, however, concentration in the channels decreases landward along the channel network. For a sub-basin of i-th rank, one may write:

$$x_i = x_{i-1}\left(\frac{1}{1+\frac{V_{mi}}{V_i}}\right) \tag{23}$$

Proceeding from larger to smaller basins ($i = 1,2...N$) one finds a progressively lower concentration. In the smallest basin of rank N-th one finds a concentration:

$$x_N = z\prod_i^N \left(\frac{1}{1+\frac{V_{mi}}{V_i}} \right) \tag{24}$$

By assuming that the ratio $R = \frac{V_m}{V_i}$ is more or less uniformly distributed over various ranks, eq. (24) becomes approximately:

$$x_N = z\left(\frac{1}{1+R} \right)^N \tag{25}$$

Let us now consider a marsh creek (called in Venice *ghebo*), i.e. a channel draining a totally vegetated watershed (salt marsh, called in Venice *barena*). When one moves from the channel proper towards smaller and smaller creeks, the concentration further decreases. Let x_N be the concentration in the channel of *N*-th rank (where the first creek starts), as given by eq. (25). The concentration in the creek of *M*-th rank will be:

$$x_M = z\left(\frac{1}{1+R} \right)^N \left(\frac{1}{2} \right)^M \tag{26}$$

considering that within a salt marsh it is $R = \frac{V_m}{V} = 1$.

In conclusion, due to the trapping effect by vegetated surfaces, the concentration in the channels decreases from the larger to the smaller branches (eq. 25). However, because of the limited value of *R* (about $0.05 \div 0.15$), this decrease is slow and the long-term concentration in the channels proper keeps very close to the long-term concentration in the sea. By contrast, the decrease of concentration is much faster along the network of creeks in the marshes (eq. 26). We will see later that this effect has consequences on the validity of the Jarret law.

3.3. Long-term concentration in channels and shoals

Let us recall the expressions for the long-term averaged concentration $\tilde{c}$ in any cross section of the channel network as a function of the local hydrodynamic and sedimentological parameters obtained by averaging eq. (3) over a long period of years. These expressions, as a function of tidal prism *V* and a cross sectional area *A* are reported in tab 1.

By combining the concentrations found for any section with eqs. (25) and (26) one finds the ratio between cross-section and tidal prism as a function of rank *N* and ratio

$R = \frac{V_m}{V}$ (for channels proper) and, respectively, a function of ranks *N*, ratio *R* and rank *M* (for marsh creeks).

Tab. 1 – Long-term sediment concentration of the compartments of a lagoon.

Inlet of a lagoon	Channel of N-th rank	Marsh creek of *M*-th rank:
$x = k\frac{V^n}{A_c^n}$	$x_N = k\frac{V_N^n}{A_{cN}^n}$	$x_M = k\frac{V_M^n}{A_{cM}^n}$

3.4. Jarret law in the Venice lagoon

The empirical relationship suggested by Jarret [1976] indicates an almost linear proportionality between cross section and tidal prism of the channel:

$$A_c \propto V^{\alpha} \tag{27}$$

with $\alpha \cong 0.85 \div 1.03$.

In fig. 3 are reported the data about the cross section of channels and marsh creeks (respectively A_{cN} and A_{cM}, although not explicitly distinguished) versus the corresponding tidal prism (V_N), obtained by Rinaldo et al. (1999) for an extremely large number of sub-basins in the northern part of the lagoon of Venice varying between hundreds of square kms and a few hectars. For convenience the data have been made here non-dimensional by scaling them to the size of the largest channel, having a cross section A_c and a tidal prism *V*. In this transformation the maximum tidal flow $Q_{\max,N}$ (Rinaldo et al., 1999) has been assumed proportional to the tidal prism V_N (this paper).

The straight line with a slope 1:1 corresponds to a perfect proportionality between cross section and tidal prism (Jarret law, with $\alpha = 1$). One can observe that this linear proportionality between the cross section and the tidal prism of the channel is reasonably satisfied by the data which pertain the bigger sub-basins. When the sub-basins are smaller (which corresponds to a small cross section and a small tidal prism of the channel), one finds strong relative deviations from the Jarret law, as the cross sections tend to be larger than expected.

The conceptual model proposed in this paper can interpret the different behaviour of channels and creeks depending on the dimension of their corresponding sub-basin. As it appears from tab. 1, the relation between cross section and tidal prism for any tidal channel is provided by:

$$A_c \propto \frac{V}{c^{1/n}} \tag{28}$$

where c represents the local concentration (x in the inlets, x_N in the channel and x_M in the marsh creeks).

This means that (albeit with a relatively small exponent, $1/n \cong 0.2$) also the concentration in the channel plays an important role in the relationship between the cross section and the tidal prism. If we observe the channels proper (cut in the shoals) the following equation can be written from eq. (25) and tab.1 (channel concentration):

$$\left(\frac{A_{cN}}{A_c}\right) = \left(1 + \frac{V_m}{V}\right)^{\frac{N-1}{n}} \left(\frac{V_N}{V}\right) \tag{29}$$

For the inlet and the largest channels (i.e. with a rank N<3 $\div$ 4) the right-hand term of eq. (29) tends to $\frac{V_N}{V}$ that is the largest channels follow the Jarret law (eq. (27) with $\alpha = 1$).

Eq. (29) corresponds to the bold line in fig. 3. In the same figure, the broken lines represent the expression:

$$\left(\frac{A_{cM}}{A_c}\right) = (2)^{\frac{M-1}{n}} \left(1 + \frac{V_m}{V}\right)^{\frac{N-1}{n}} \left(\frac{V_M}{V}\right) \tag{30}$$

following from eq. (26) and tab.1 (marsh creek concentration). Each broken line has been plotted by assuming a different value of *N* and describes the behaviour of a creek of rank *M* connected with a channel proper of different rank *N* (respectively $N = 1$, $N = 4$ and $N = 8$). For all these graphs it has been assumed $R = \frac{V_m}{V} = 0.10$ and $\frac{V_M}{V_{N+1}} = \left(\frac{1}{2}\right)^M$.

The theoretical graphs in fig. 3 seem capable of justifying the deviation from the Jarret law of the smaller channels and even more of the salt-marsh creeks. The dispersion of the experimental points with respect to the theoretical lines is very likely due to the terms of eq. (21) neglected in eq. (22).

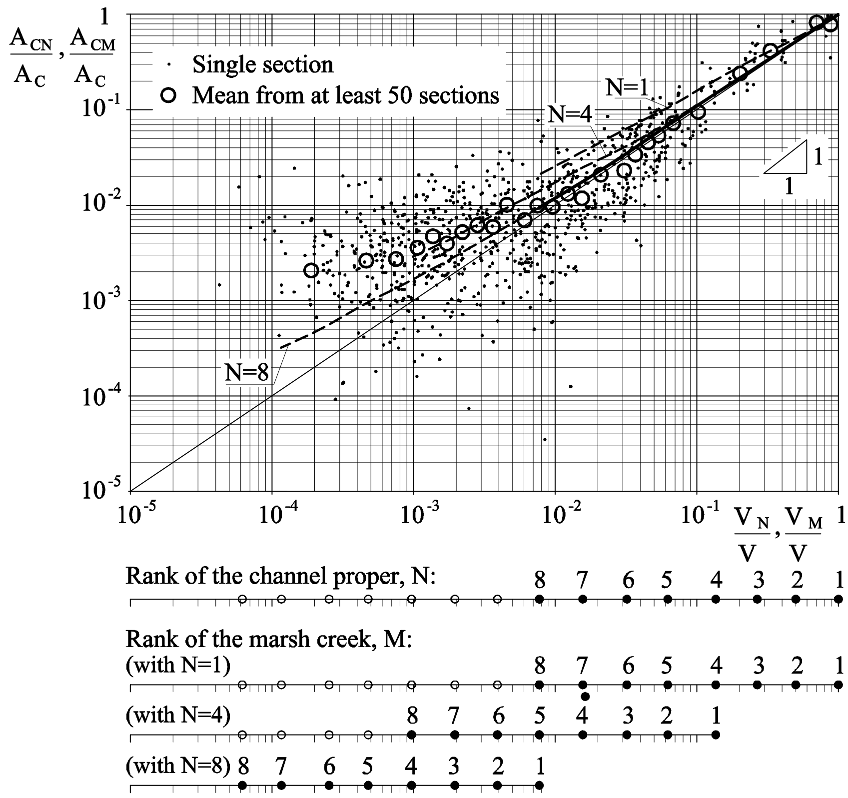

Fig. 3 – Non-dimensional cross sectional area of channels and marsh creeks vs non-dimensional tidal prism. Comparison between field data [Rinaldo et al, 1999] and results of the conceptual model.

Conclusions

Transport concentration in the channels and shoals of a tidal lagoon is obtained by averaging the local instantaneous sediment concentration over a time period of a few years.

Instantaneous sediment concentration is in general produced by both currents and waves, but for a tidal lagoon characterized by deep channels cut on shallow shoals, one may assume that sediments are exclusively stirred by currents in the channels and by waves on the shoals . While the long-term concentration produced by tidal currents results proportional to a local “stirring coefficient” f_c and inversely proportional to the 5-th power of the local channel depth (eq. 3), the local long-term concentration on the shoals results directly proportional to a local “stirring coefficient” f_w, and inversely proportional to the local depth. Hydrodynamics is incorporated in the stirring coefficients and independent from the lagoon bathymetry. This means that the stirring coefficients remain constant during the bathymetric evolution of the lagoon.

The simplified expressions (3) and (10) of the long-term concentration constitute the coupling between hydrodynamics and bathymetry of channels and shoals. In this respect it is to be noted that the inverse of the exponent of the local depth (respectively 1/5 and 1) indicates the different sensitivity of channels and shoals to react to any change of hydrodynamics. It is well known, in fact, that when a perturbation is introduced in a lagoon, the depth of tidal channels is definitely more stable than the depth of the shoals.

From a straightforward application of several monomial transport formulae, the stirring coefficient f_c in a channel (eq.10) results to be proportional to the relevant tidal prism elevated to the exponent $n = 5 \div 6$. The stirring coefficient f_w in the shoals, on the other hand, depends on the local combination of wind velocity and fetch length, as expressed by eq. (9). One should recall, however, that this last expression has been obtained by introducing a number of simplifications which are valid only in a limited range of morphodynamic conditions.

The intertidal dispersion mechanisms (especially the tidal pumping between channel and shoals) tends to make uniform the long-term concentration along the tidal channels. In equilibrium conditions with a complete mixing, the long-term concentration along the channel is equal to the concentration at the sea-end and the net transport tends to zero. In this case the cross section of the channel adapts itself to the tidal prism and to the concentration at the sea-end which, in its turn, is controlled by the wave climate.

Due to the small value of the exponent $1/n$ in eq. (28), the effect of the concentration c is invariably small and the cross-sectional area is more or less proportional to the tidal prism (Jarret law). This is especially true for the largest basins, in which the concentration is uniform and very close to the concentration in the sea. In the peripherical sub-basins characterized by high density of marshes, by contrast, the alophile vegetation strongly reduces the sediment concentration in the tidal channels and even more in the marsh creeks. Thus, the cross-sectional area tends to be progressively larger and larger with respect to the tidal prism, depending upon the rank of the channel and of the creek, as one observe in the Venice lagoon.

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MINERALOGICAL CHARACTERIZATION OF THE VENICE LAGOON TOP SEDIMENTS

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Riassunto

Nell'ambito della Linea 3.2 - *Idrodinamica e morfologia* del Progetto CORILA. è stato completato un dettagliato studio mineralogico dei sedimenti superficiali della Laguna di Venezia, da considerarsi parte complementare di un'indagine multidisciplinare intesa ad evidenziare le variazioni morfologiche recenti ed attuali, in relazione all'idrodinamica lagunare, per un'aggiornata comprensione dei processi erosivo-deposizionali in atto.

L'analisi della distribuzione areale della composizione mineralogica dei sedimenti ha permesso di identificare l'impronta degli antichi apporti fluviali originariamente sversati in laguna, sulla quale si è sovrapposta quella imputabile alle attuali condizioni di circolazione idrodinamica. In generale i risultati ottenuti evidenziano una composizione mineralogica simile, ma con percentuali relative ben distinte nei diversi settori lagunari. In particolare la prevalenza dei carbonati totali nel settore nord e dei silicati totali nel settore sud conferma la diversità litologica degli apporti di Piave, Brenta e Bacchiglione avvenuti in epoca storica, che, come è noto, provengono da bacini idrografici distinti.

Questa indagine mineralogica, basata sull'analisi di oltre 100 campioni, opportunamente selezionati in corrispondenza di siti con strutture morfologiche e condizioni idrodinamiche rappresentative dell'ambiente lagunare, si può ritenere la più esaustiva tra quelle sinora condotte.

Abstract

In the context of the Research Line 3.2 - *Hydrodynamics and morphology* of the CORILA. Project, a detailed mineralogical investigation was carried out on the surficial sediments of the Venice Lagoon, as a part of a multidisciplinary study aimed to point out recent and present morphological changes in relation to hydrodynamic processes.

This paper provides an update overview of the spatial mineralogical variations of the top lagoon sediments. It is based on more than one hundred analyses of samples taken in selected sites, which represent the various morphologies and hydrodynamic conditions of the lagoon system.

As already observed in many previous studies, our investigation indicates an overall similar mineralogical composition with distinct percentage changes from the northern sector of the lagoon, where carbonate-rich sediments prevail, to the southern silicate-rich sector. This distribution mainly corresponds to the ancient fluvial input of the Piave and the Brenta-Bacchiglione river systems, from the north and the south respectively.

In particular, carbonate content shows dominant dolomite and subordinate calcite, whereas within silicates (quartz, k-feldspar and plagioclase) quartz is dominant. Clayey minerals (mica, chlorite, kaolinite, illite, hastingsite) show higher contents within the Brenta river deposits and in low energy areas, particularly landwards.

1. Introduction

The Venice Lagoon is an area featuring strong hydrodynamics and morphological variability, often linked to past and present anthropogenic interventions. Due to these factors, different sub-depositional enviroments exist: in fact they are responsible, at a local scale, for the erosion/sedimentation processes and the transport and redistribution of the sediments in the lagoon itself. Moreover, the presence and the activity of the benthic biosphere can modify the physical, geochemical and mineralogical characteristics at the sediment/water interface and in the topmost sediment layer.

In the context of the Research Line 3.2 - *Hydrodynamics and morphology* of the CORILA. Project, a detailed mineralogical investigation of the top sediments has been carried out over the past three years as part of a multidisciplinary study aimed at obtaining new insights of recent and present morphodynamic processes in the Venice Lagoon [Amos C.L. et al., 2002; Bonardi et al., 2003; Schiozzi et al., 2003; Strozzi et al., 2003; Bonardi et al., 2004].

In addition, within the CORILA. mandate for the coordination of all the research activities carried out in the Venice Lagoon, a few results from the Geological Mapping of Italy Project (Progetto CARG: Fogli “128, Venezia” and “148-149, Chioggia-Malamocco”), financed by the Regione del Veneto and the Agenzia per la Protezione dell'Ambiente e per i servizi Tecnici (APAT), were made available and used to integrate the CORILA. data, in order to fully cover the entire lagoon area (Fig. 1).

The characterization of the sediments is an important tool for the evaluation of the hydrodynamic processes. Hence, the mineralogical composition is related to the ancient fluvial supply to the lagoon, which was different in the north and south lagoon areas; anomalous percentages of the mineral content may be considered a consequence of the hydrodynamic reworking processes. In addition, textural characteristics, here not reported, also give important information about processes responsible for sediment erosion, transport and deposition.

2. Geological setting

In order to better understand present morphological characteristics of the Venice Lagoon, a brief overview of the geological and geomorphological evolutionary processes that took place in it since its formation is presented.

The Lagoon of Venice has a fairly recent origin (about 6,000 years) and it formed during the Holocene marine transgression that followed the Pleistocene last glaciation [Gatto and Carbognin, 1981; Tosi, 1994; Brambati et al., 2003; Bonardi et al., 2004]. The primeval lagoon was smaller than the present one; the water exchange with the Adriatic Sea was possible through eight sea openings against the three it has now and the sediment supply was guaranteed by the main lagoon tributaries, such as Sile and

Piave from the north, Brenta and Bacchiglione from the south. From the geological point of view, the distribution of the surficial sediments has the imprint of the different past fluvial supplies and the reworking caused by the ancient lagoon hydrodynamics. In fact, it is possible to distinguish three main basins: the northern basin, characterized by the presence of the Piave and Sile deposits, the southern basin, characterized by the sedimentation from the Brenta and Bacchiglione supplies, and the central basin with Brenta sediments reworked by the hydrodynamics.

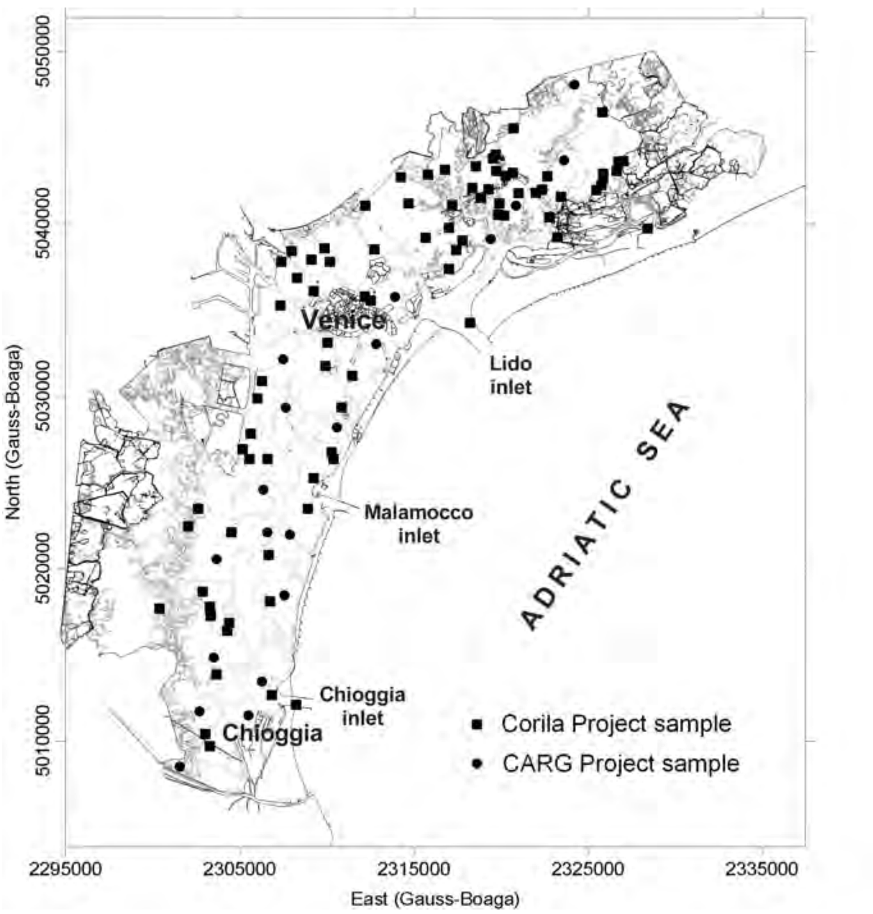

Fig. 1 – Locations of the lagoon sediment samples used for the mineralogical investigation.

During historical times the number of inlets was reduced, the tributaries were diverted into the sea and several other human interventions were carried out with the consequence that the lagoon morphology and hydrodynamics were modified and, in some cases, the sediment distribution changed.

The schematic representations of the lagoon tributaries in the 1300 and 1900 are shown in Figure 2 [Favero et al., 1988].

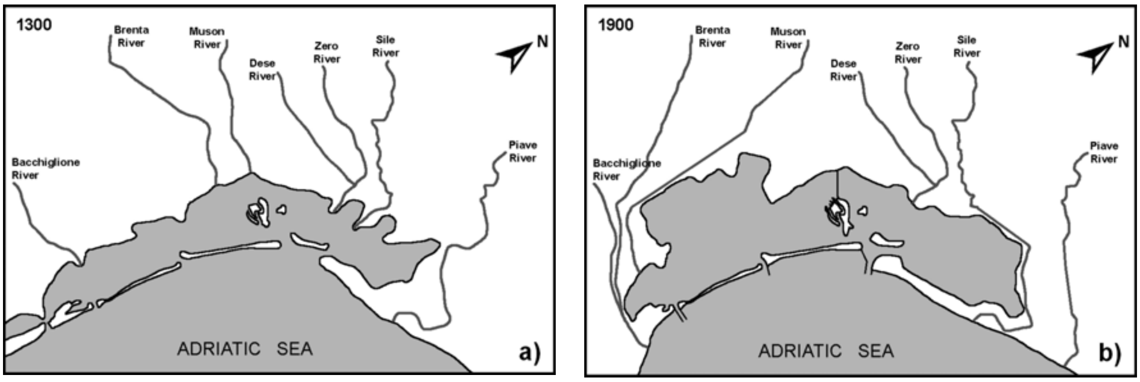

Fig. 2 – Simplified map of the rivers flowing into the Venice Lagoon: (a) at the beginning of the XIV century, (b) in the XX century [Favero et al., 1988, modified].

3. Materials and methods

More than 100 samples of the top sediment were collected within the entire lagoon (Fig. 1), using a Van Veen type grabber and a custom made PVC corer 10 cm in diameter and 100 cm long. Only the first 15 cm of each core, considered to be equivalent to grab, were used for this study.

Even if more than 130 sediment samples (CORILA. and CARG) were available for this study, only 103 samples, 19 of which from the CARG Project, were selected on the basis of their homogeneity; the samples that presented mineralogical composition too diverse from those taken close to their sites were not used. All of the main morphologies of the lagoon bottom were sampled for this purpose.

Textural and geochemical analyses, as well as biotope characterization, although performed on each collected sample, are not reported here.

The mineralogy of bulk material and clay-size components was determined by X-ray powder diffraction analysis (XRD). The clay-size fraction (<2 µm) was separated by centrifugation. Suspensions of the bulk and clay-size samples were pipetted onto glass slides and air-dried overnight to produce oriented mounts. X-ray patterns of the air-dried samples were recorded on a Philips PW1710 automated powder diffractometer equipped with a graphite monochromator, using Cu kα radiation at 50 kV and 30 mA. The samples were also X-rayed following saturation with ethylene glycol and heat treatment (2 hours at 550 ºC). Semi-quantitative analysis was achieved using JADE® software to process digitally acquired XRD data.

The maps of the distribution of the major and minor mineralogical components across the entire lagoon were obtained by the interpolation of experimental data on a 400 m regular grid, using the kriging stochastic method and the had-hoc variograms.

4. Results

The analysis of the mineralogical content and the spatial distribution of the major components (carbonates, silicates and clayey minerals) shows that the lagoon bottom composition is very similar for the entire lagoon: only the relative percentages of the major components vary. The main recognized minerals are: dolomite, calcite, quartz, feldspars (k-feldspar+plagioclase), chlorite, and mica; kaolinite, ankerite, aragonite, and hastingsite are present in low percentages.

In general the total carbonates (dolomite, ankerite, calcite, and aragonite) prevail in the northern sector (60-65%) (Fig. 3), whereas the silicates (quartz+k-feldspar+plagioclase) are more abundant in the southern basin (55-65%) (Fig. 4); in the central sector the relative percentages of carbonates and silicates are very similar. Carbonates and silicates show an opposite trend: carbonates decrease from the north to the south and toward mainland; silicates instead decrease from the south to the north and generally toward the littoral.

Within carbonates (Fig. 3), the dolomite+ankerite content is constantly more abundant (Fig. 5), with values up to 56%, whereas calcite+aragonite content is always less than 25% (Fig. 6).

Quartz is the main component among the silicates and its spatial distribution (Fig. 7) shows a very distinct increase toward the mainland (up to 55%), in particular in the central and southern sectors. The feldspars (Fig. 8) are mainly present in the southern lagoon, especially in the area west of Chioggia with maximum values between 20 and 25%, whereas in the northern basin their content is less than 10%.

The highest concentration of the clay minerals (about 40%) is located in the southern sector toward mainland and in a limited zone of the northern lagoon (Fig. 9). In particular, the areal distribution of chlorite (Fig. 10) and mica (Fig. 11) groups, although very similar, presents an enrichment of the mica content at the Malamocco inlet and on the western side of the southern lagoon.

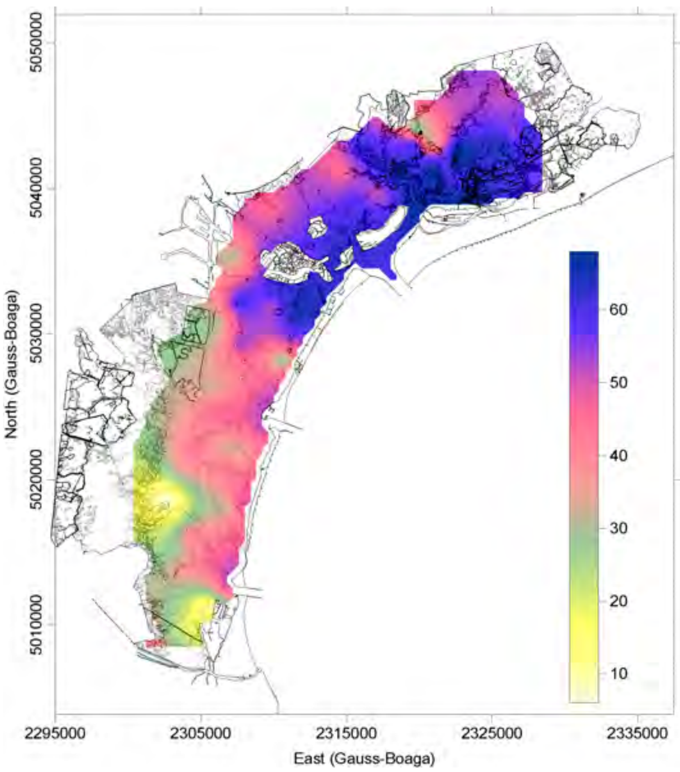

Fig. 3 – Spatial distribution of total carbonates (dolomite+calcite+ankerite+aragonite).

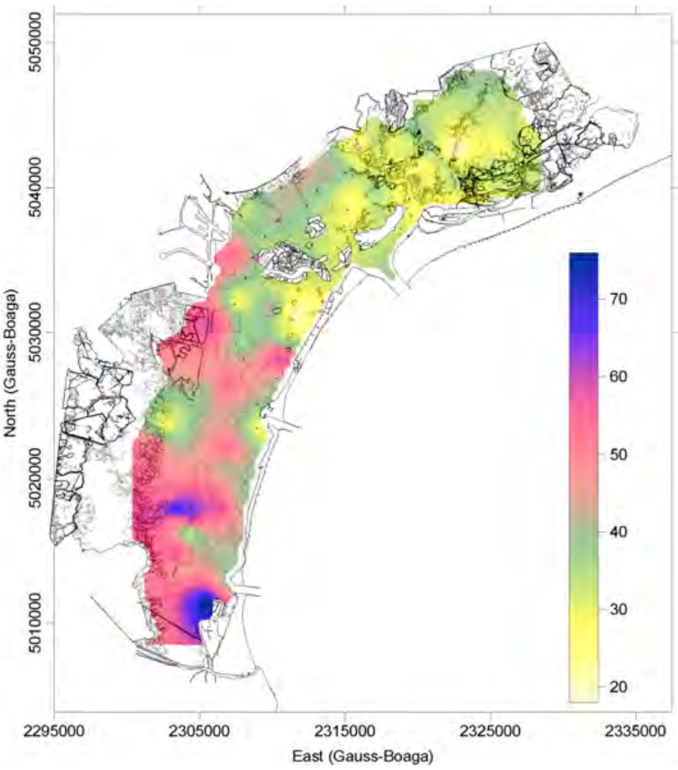

Fig. 4 – Spatial distribution of total silicates (quartz+k-feldspar+plagioclase).

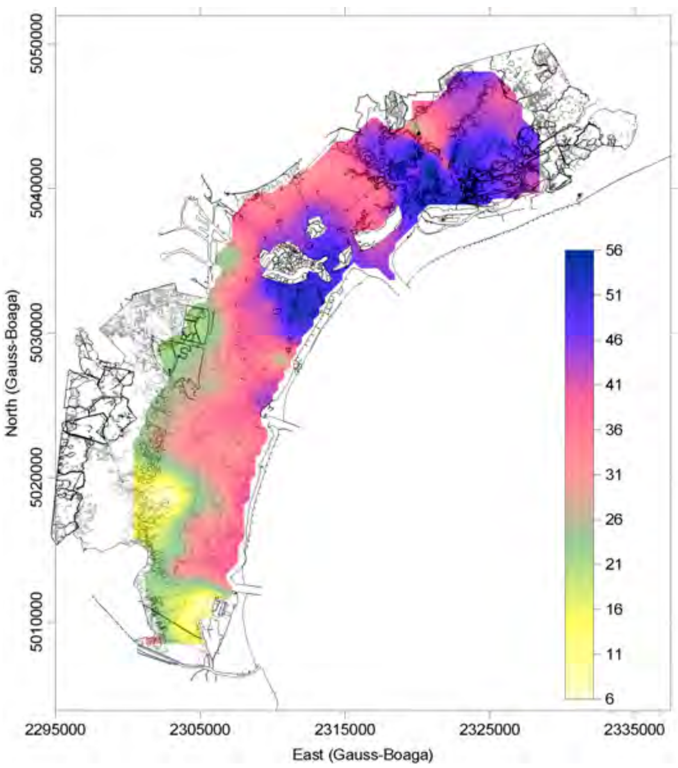

Fig. 5 – Spatial distribution of dolomite+ankerite.

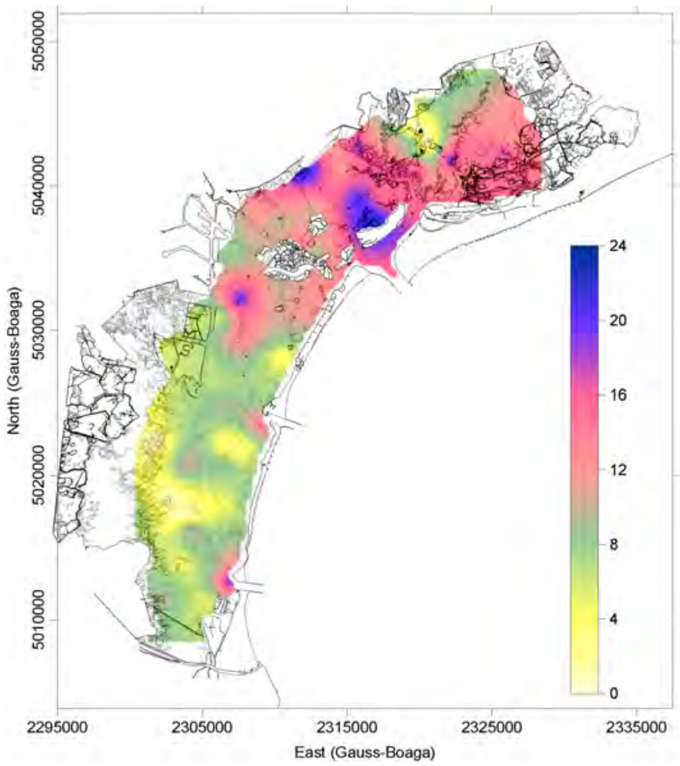

Fig. 6 – Spatial distribution of calcite+aragonite.

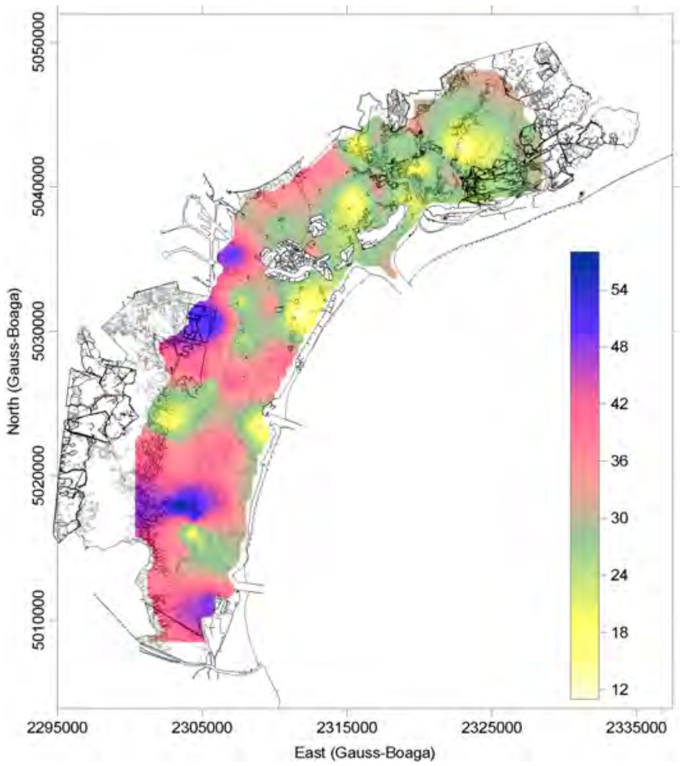

Fig. 7 – Spatial distribution of quartz.

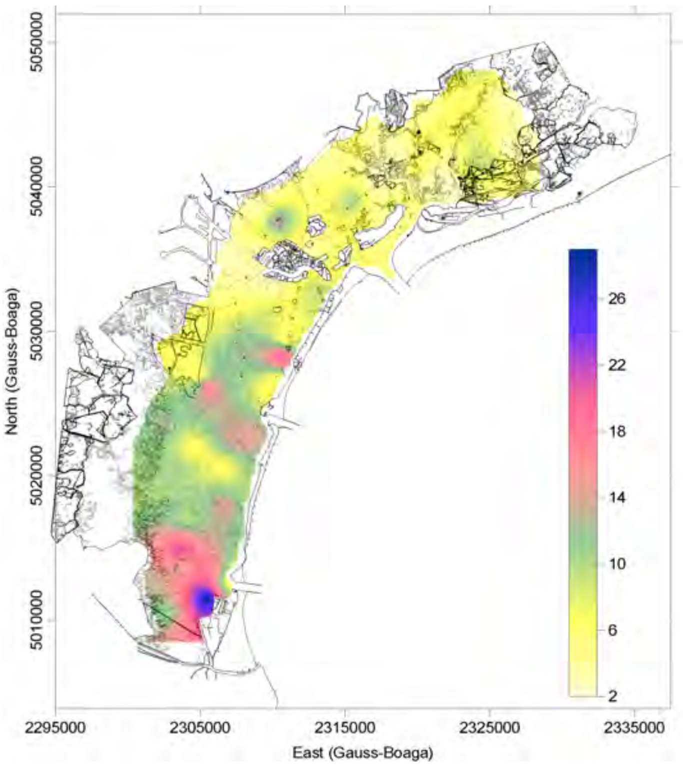

Fig. 8 – Spatial distribution of feldspars (k-feldspar+plagioclase).

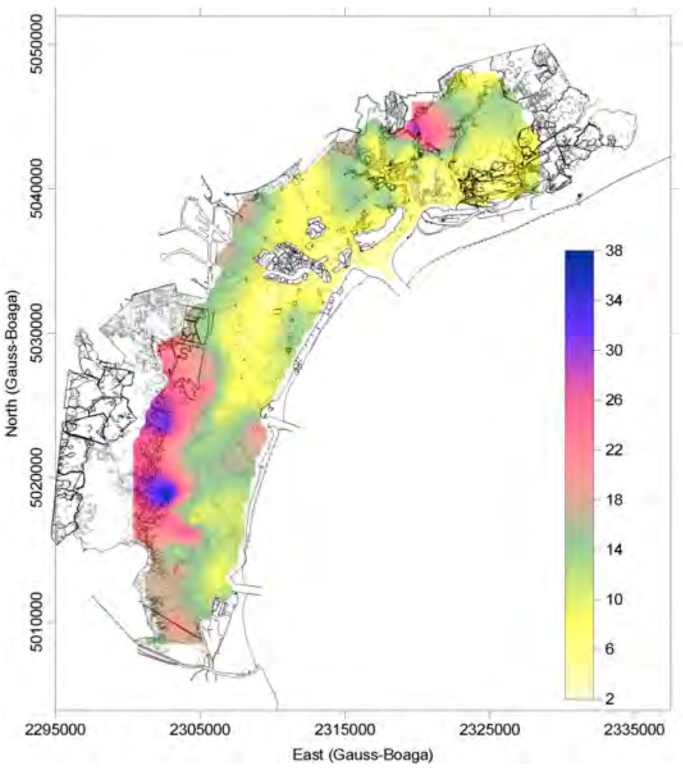

Fig. 9 – Spatial distribution of clay minerals (mica+illite+chlorite+kaolinite+hastingsite).

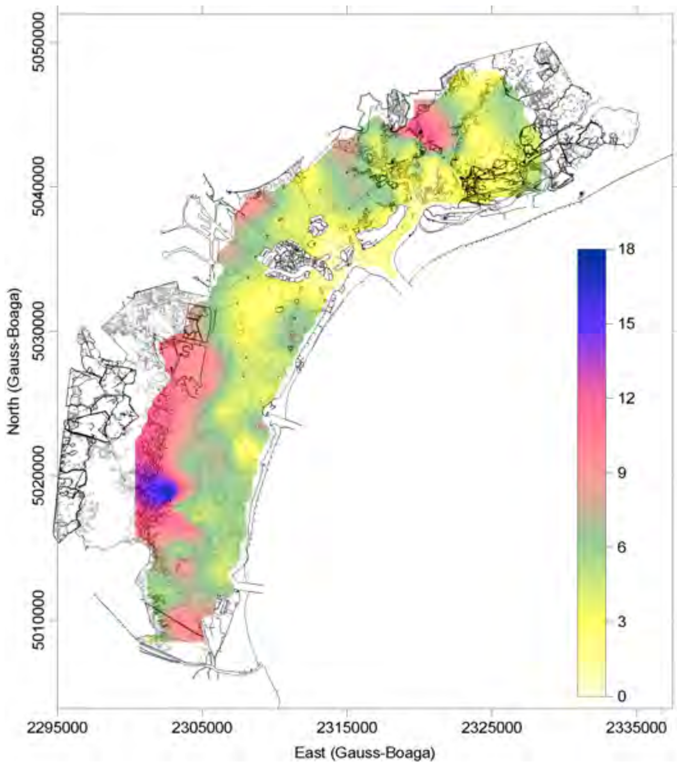

Fig. 10 – Spatial distribution of chlorite+kaolinite+hastingsite.

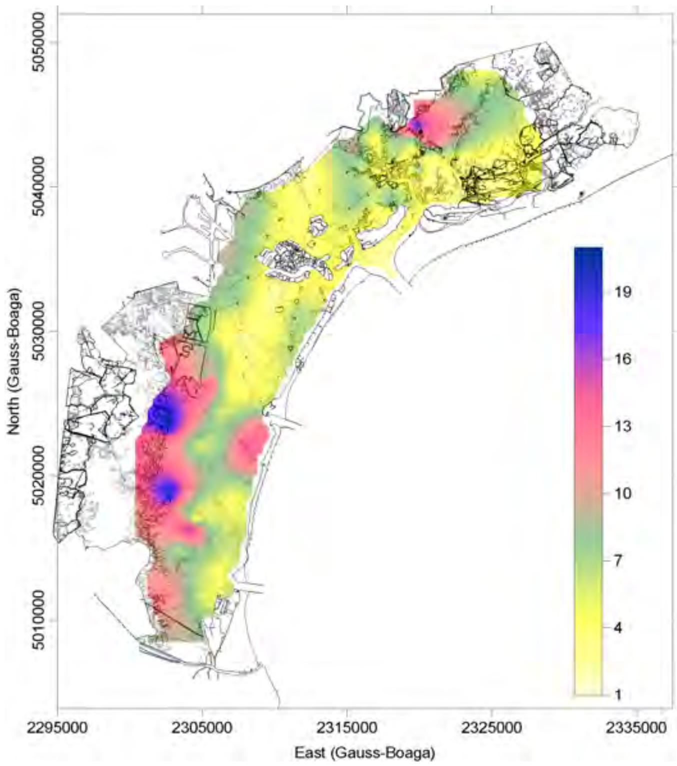

Fig. 11 – Spatial distribution of mica+illite.

5. Conclusions

The areal distribution of the mineralogical concentrations has shown a general decrease of the total carbonate content from north to south, with a parallel increase of the silicates. The central lagoon seems to be a mixing area due to the appreciable amounts of silicates and carbonates inflowing from the southern and the northern sectors respectively.

Carbonates are present across the entire Lagoon of Venice and prevail in the northern and in the central sectors. Their content ranges from 5 to 69%. Silicates prevail in the lower part of the southern lagoon, with a general positive trend toward the mainland. West of the Malamocco inlet low silicate content corresponds to a high mica percentage with small amount of chlorites.

The major mineralogical characteristics of the lagoon top sediments reflect the dominance of deposits mainly related to the Piave river system source area in the northern sector and to the Brenta and Bacchiglione river system provenance area in the southern one. In fact sediments transported by the Piave River are rich in carbonates, with prevailing dolomite on calcite, and have an appreciable content of quartz and basic vulcanites [Gazzi et al., 1973; Jobstraibizer and Malesani, 1973]. In the Brenta river sediments instead, the carbonates are less abundant, with predominant dolomite, whereas quartz and feldspars are higher than those of the Piave River, due to the presence of gneisses and acid vulcanites in the Brenta hydrographic basin. These lithological characteristics are also responsible for the significant contents of phyllosilicates and clay minerals in the sediment supplies by the Brenta River.

The very low quantity of carbonates and the appreciable presence of clay minerals in a restricted zone of the northern lagoon may be due to the local fluvial input of sediment from the spring fed Sile River flowing along the eastern part of the ancient Brenta alluvial fan. This anomalous mineralogical distribution close to the mouth of the Sile River may be attributed to the fluvial reworking and transport of sediments previously deposited by the Brenta River. In addition selective hydrodynamic processes may have contributed to the enrichment in the phyllosilicates, particularly evident in this area.

Other “anomalous” zones are present in various sectors of the lagoon. For example, calcite and aragonite distribution shows a relative enrichment in the southern lagoon, clearly related to the Malamocco and Chioggia tidal inlets. The increase of the phyllosilicates toward the mainland indicates a decrease of energy.

To conclude, the study of the spatial variability of the mineralogical components of the lagoon bottom sediments adds new information to the multidisciplinary investigation (textural, geochemical, microforaminifera, etc.) that will provide new input data for the analysis and the interpretation of the morphodynamic changes and for their simulation by mathematical models.

Acknowledgements

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MODELING SAND TRANSPORT IN THE VENICE LAGOON INLETS

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Riassunto

In questo lavoro viene descritto il trasporto di sedimenti nella Laguna di Venezia allo scopo di valutare gli scambi di sedimento che avvengono tra il mare e la laguna attraverso le tre bocche di porto di Lido, Malamocco e Chioggia. Lo studio è stato condotto applicando un modello di trasporto di sedimenti, Sedtrans96, accoppiato ad un modello idrodinamico, necessario per descrivere le condizioni di flusso.

Considerando che alle tre bocche di porto i sedimenti sono prevalentemente di tipo non coesivo, il modello è stato applicato esclusivamente ad un sedimento di tipo sabbioso.

Per poter valutare l'influenza del vento, che nel caso della Laguna di Venezia si identifica con bora e scirocco, le simulazioni sono state eseguite sia in presenza della sola forzante mareale sia in presenza dell'azione combinata di vento e marea. Inizialmente le simulazioni sono state effettuate su un intervallo temporale di 12 ore e forzando il bacino lagunare con valori ideali di vento e marea; nella fase successiva, l'analisi è stata estesa al periodo di un anno utilizzando come forzanti dei valori di vento e marea misurati in campo.

Il trasporto di sedimento al fondo e in sospensione è stato calcolato attraverso due sezioni su ogni bocca di porto in modo da valutare il bilancio di massa e la variazione dello spessore del fondo dovuta ai fenomeni di erosione e deposizione.

I risultati dell'analisi modellistica hanno evidenziato una tendenza all'erosione alle bocche di porto di Malamocco e Chioggia, confermando i dati sperimentali raccolti negli ultimi 20 anni. Per quanto riguarda la bocca di Lido invece, il confronto con i dati reali non risulta semplice poiché dalle simulazioni non si evidenzia una netta prevalenza di erosione o deposizione.

Abstract

A sediment transport model Sedtrans96 coupled to a hydrodynamic model has been applied to the Venice Lagoon in order to evaluate the sediment exchanges between the sea and the lagoon through the three inlets of Lido, Malamocco and Chioggia. At the three inlets the sediments are mostly non-cohesive and therefore the transport model has been applied uniquely to this sandy sediment type.

To evaluate the influence of the wind (in this case consisting of bora and scirocco) the simulations have been carried out both with the tidal forcing only and with the tide-wind combined action. Two different sets of simulations have been setup. In the first the

models have been applied for 12 hours time and the basin was forced with idealized wind and tide values; in the second set the simulations have been extended to one year and carried out with a real time series of in-situ wind and tide elevation measuraments.

The sediment suspension and transport have been evaluated through two sections per inlet in order to calculate the mass balance and the bottom thickness variation caused by erosion and deposition processes.

From the modeling analysis at the inlets of Malamocco and Chioggia a tendency of erosion has been calculated and this situation shows a good agreement with the empirical data collected during the last 20 years. As far as the Lido inlet is concerned, a clear tendency of erosion or deposition is more difficult to see and further work has to be carried out.

1. Introduction

The Venice Lagoon is the largest lagoon of the North Adriatic Sea. It extends in a wide coastal area parallel to the Adriatic coast in the NE-SW direction for about 50 Km between the Piave mouth and the delta of the Po river. The lagoon is separated from the sea by sandy barrier islands and communicates with the sea through three inlets (Lido, Malamocco and Chioggia) through which the tidal wave enters in the lagoon.

The Venice Lagoon is divided in three principal basins: the northern, Lido, is the widest and it has an extension of 276 Km^2; the central, Malamocco, and the southern, Chioggia, have an extension of 112 and 111 Km^2 respectively.

The lagoons developing along the coast of sedimentary zones are in an unstable situations. If not destroyed by the sea, they tend to be filled up by the sediment flow from the sea or from the rivers ending into the lagoon. Geomorphological variations have been naturally occuring in the Venice Lagoon since its formation. In the past the large sediment discharge from the main lagoon tributaries threatened to transform the lagoon into a marshland. Then the increase in the lagoon depth, due to subsidence and eustatic water level rise, and in recent times the impact of anthropic activities have reversed the lagoon’s natural tendency to silt up transforming it slowly into a more sea-like environment.

To understand the sediment dynamics in the Venice Lagoon it is necessary to analyze the hydrodynamic behaviour of the three inlets. The aim of this paper is to describe the sediment transport in the Venice Lagoon in order to evaluate the sediment exchanges between the sea and the lagoon through the three inlets of Lido, Malamocco and Chioggia.

Up to now numerical models of sediment transport have not been applied estensively in the Venice Lagoon, therefore a lack of knowledge concerning sediment erosion, resuspension, transport and sedimentation remains. This work represents a first attempt to evaluate the role that the hydrodynamics plays in the sediment processes occuring at the three inlets.

2. Methods

2.1 Classification of the sediments

In the past Barillari analized the superficial sediments (6 cm thick) of the Venice Lagoon and carried out a grain size characterization of all the three basins of the lagoon [Barillari et al., 1976; Barillari 1978,1981]. Lately the Water Autority [Magistrato alle acque, 1999] have studied the Venice Lagoon sediments. In this study the superficial layers (15 cm thick) have been sampled in 140 sites from October 1997 to June 1998 mapping the superficial sediment grain size of the whole lagoon (Fig. 1).

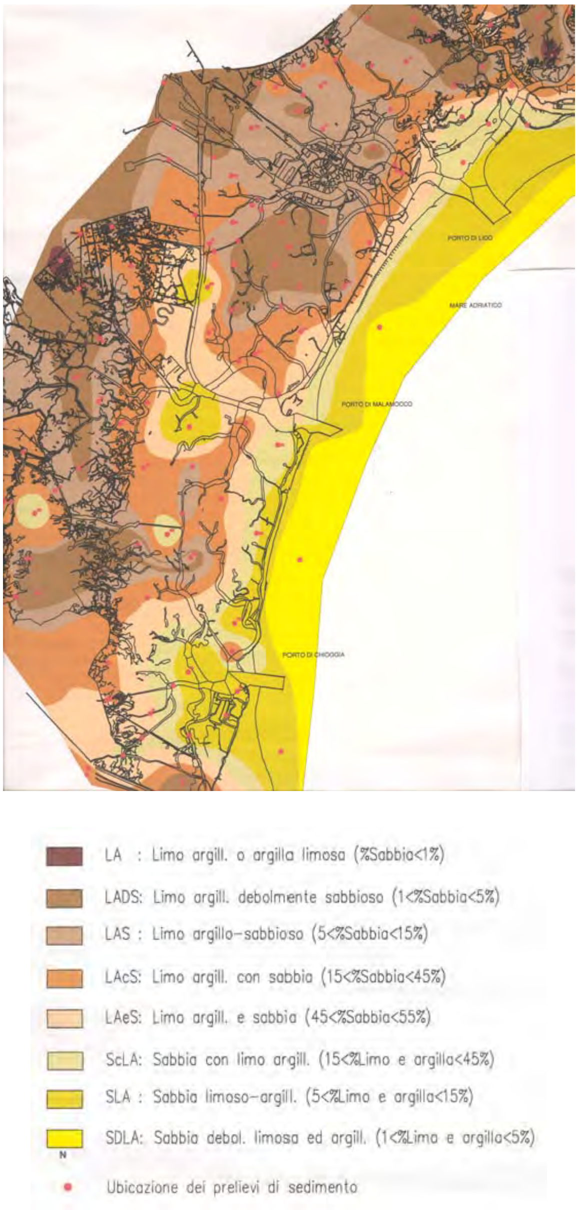


Fig. 1 - Grain size distribuition map of the superficial sediment layer (0-15 cm thick) of the Venice Lagoon [Magistrato alle Acque, 1999].

For the classification the Wentworth scale [Wentworth, 1922] has been used that marks the boundary between sand and mud at 63 μm and between mud and clay at 4 μm. A further division of each grain size class led to the following eight sediment typologies:

- Clay mud or muddy clay (% sand <1)
- Clay mud with very few parts of sand (1<% sand<5)
- Clay-sandy mud (5<%sand<15)
- Clay mud with sand (15<% sand<45)
- Clay mud and sand (45<%sand<55)
- Sand with clay mud (15<%mud and clay<45)
- Clay-muddy sand (5<%mud and clay<15)
- Sand with few parts of mud and clay (1<%mud and clay<5).

The observed sediments distribuition, obtained by sampling and by statistical analysis, is typical of the lagoons, where the grain size becomes finer moving from the inlets towards the inner part. The sand is found to be in front of the coastal belts (Lido, Malamocco and Pellestrina) and at the three inlets, and it represents a homogeneus area in NE-SSW direction. In this area the finer part of sediments increases moving from the sea towards the lagoon in direction E-W. The mud and sand mixture creates a transition zone between coarse (sand) and finer (clayey mud) fraction. This mixture characterizes the area behind the shoreline belts; only in the Malamocco basin these mixed sediments are more inward near the Petroli channel. The cohesive sediment (i.e. finer fraction) is in the central and inner areas of the lagoon and increases moving from east to west. There are some grain size differences not only in this direction (E-W), but also between northern and southern lagoon. The northern one is characterized by clay mud with very few parts of sand (between 1% and 5%) and by clay-sandy mud (between 5% and 15% sand), whereas the southern one is composed of coarse sediments, expecially clay mud with sand (15%-45% sand) and clay mud and sand (45%-55% sand). The overall pattern is that the grain size increases both moving from east to west and from north to south, along the longitudinal axis of the lagoon.

2.2 The sediment transport model

Sedtrans96 [Li et al., 1995, 2001] is a one-dimensional numerical computer model developed at the Geological Survey of Canada-Atlantic (GSCA) to deal with the boundary layer dynamics and sediment transport on continental shelves and in coastal environments. Sedtrans not only gives boundary layer parameters but also predicts bedform development, bedload as well as suspended load transport rates for both sand and cohesive sediments. For given input data of wave, current and seabed conditions (i.e. grainsize, sediment density, bedform dimension), the model applies the Grant and Madsen [1986] continental shelf bottom boundary layer theory to derive near-bed velocity profile and bed shear stress. Then it calculates sediment transport for currents only or combined waves and currents over either cohesive and non-cohesive sediments. The calculations under pure wave, pure current and combined wave-current conditions are treated in separate algorithms. The model calculates the critical shear velocities for three distinctive modes of transport: bedload, suspension and sheet-flow transport. Also an explicit combined-flow ripple predictor is included in the model to provide time-dependent bed roughness.

Five sediment transport formulae are available in the model to integrate the istantaneous sediment transport through a wave cycle in order to obtain the time-averaged net sediment transport rate. Sedtrans also includes the predictions of the velocity and suspended concentration profiles: their product is integrated through depth to derive the suspended-load transport rate.

2.3 The hydrodynamic model

To run the transport model the input data to be inserted are the seabed conditions and the hydrodynamic parameters (current velocity, current direction,…) obtained from the SHYFEM model [Umgiesser et al., 1993; Umgiesser et al., 1995] .
This hydrodynamic model is a two-dimensional finite element model. The finite element method gives the possibility to follow the morphology and the bathymetry of the area and to represeent with a higher resoluytion the zones where hydrodynamic activity is more interesting. The numerical computation has been carried out on a spatial domain that represents the entire Venice lagoon through a finite element grid. The grid contains 4237 nodes and 7666 triangular elements. The grid and a zoom at the inlet areas are shown in figure 2. The bathymetric data necessary for the hydrodynamic model have been provided by CORILA.

The model considers as open boundaries the three inlets of Lido, Malamocco and Chioggia, elsewhere as closed boundary the whole perimeter of the Venice Lagoon.
The model resolves the vertically integrated shallow water equations in their formulations with level and transports. It uses a semi-implicit algorithm for integration in time. The terms treated implicitly are the pressure gradient, the friction term in the momentum equation and the divergence term in the continuity equation, all other terms are treated explicitly.

2.4 The simulations setup

The transitional environment at the inlets is an interesting but complex subject of study as many dynamic processes occur here. The transport model is therefore applied to the three inlets only, Lido, Malamocco and Chioggia, because these areas are characterized mainly by a homogeneus kind of sediment. As can be observed in the map (Fig. 1), the sediments at the three inlets are mainly sand, therefore the modeling analysis is carried out considering a non-cohesive sediment with diameter of 230 μm that represents the mean grain size measured at the Lido inlet [Chick et al., 2001].

The results of this analysis provide the mass balance of deposited and eroded sediments and evaluate the exchanges between the sea and the lagoon. To reach this aim the model Sedtrans96 [Li et al., 2001] has been applied in 27 points at the inlets: here the bedload, suspended and total sediment transport is calculated under varying dynamic conditions. All the simulations are carried out using the Einstein-Brown equation [Brown, 1950] to calculate the sediment transport being the applicable grain size range of this formula is compatible with the sand of the inlets.

Two transects 1000 m far apart at Chioggia and Malamocco inlets and 700 m at Lido (Fig. 2) have been selected on the SHYFEM model grid in order to evaluate the solid transport through the whole inlet section. At each inlet the transect closer to the sea is signed with the number 1, whereas the inner one, closer to the lagoon, is marked with the number 2.

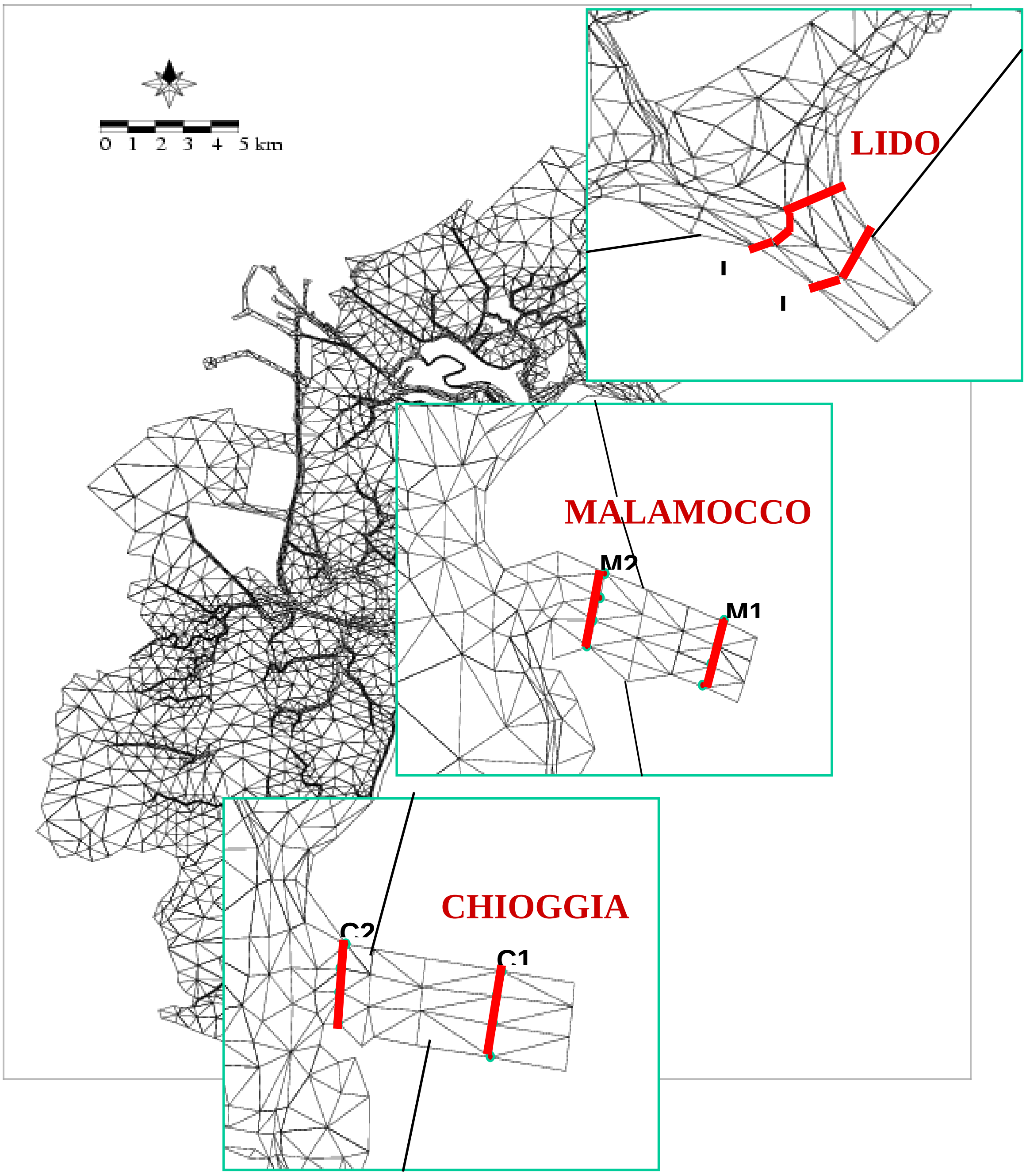


Fig. 2 - Grid of the Venice Lagoon used by the finite element model SHYFEM; in bold the transects at the inlets selected for the sediment transport simulations.

The mass balance has been accomplished at the three inlets. Firstly the sediment discharge and the transport direction are calculated on each transect. The sediment transport has been projected on a direction parallel to the longitudinal axis of each inlet, assigning positive values to incoming fluxes and negative to outgoing fluxes.
Secondly the bottom thickness variation in the area inbetween the two transects is computed from the difference between incoming and outgoing mass through the two sections: in this way a mass balance can be established and the processes of erosion or deposition can be identified.

To evaluate the influence of the wind (in this case consisting of bora and scirocco) the simulations have been carried out both with the tidal forcing only and with the tide-wind combined action. In the first series of simulation a 12 hour period has been chosen that represents a whole tidal cycle. As forcings the tide and the wind have been prescribed. For the wind forcing, two typical wind regimes have been taken into account. The first is the bora, a strong wind from the north-east, the other is the scirocco, a south-easterly wind. These winds have been choosen to be spatially constant over the lagoon, with a wind speed of 15 m/s for the bora and 10 m/s for the scirocco.

Three different scenarios have been considered:

- No-wind (tide forcing only)
- Bora wind event (tide and wind forcing)
- Scirocco wind event (tide and wind forcing).

In the last simulations the time domain has been extended to the whole year**.** The year simulated is 1987, for which a complete tidal record was available at the inlets. As meteorological forcing, real wind data measured during 1987 on the oceanographic platform just outside the lagoon has been used.

3. Results and discussion

In the following the current velocity and the resulting sediment transport at the three inlets of the Venice Lagoon are analyzed. First we describe the situation during a tidal cycle of 12 hours using idealized values of wind and tide as forcings. Second the results of a whole year simulation are presented. In this last experiment real measured water levels and wind speeds have been used.

3.1 Short-term simulations

At the Lido inlet, either without wind or with scirocco, the mean current velocity at the two transects is very similar, conveying slightly higher values in the case of scirocco (Fig. 3). Since the velocity shows similar values in the points belonging to the same transect, the time-averaged velocity representative of the whole transect has been plotted. In the L1 transect the outgoing current velocity (circa 0.8 m/s) is higher than the incoming one (circa 0.7 m/s). The total solid transport reflects this behavior: the transport rate reaches higher peaks in the outgoing direction either with scirocco or in a no-wind condition. In the transect L2, if compared to transect L1, the current velocity has lower intensity and the highest values barely reach 0.6 m/s. The resulting sediment transport is lower than in transect L1 and presents higher outflowing rates.

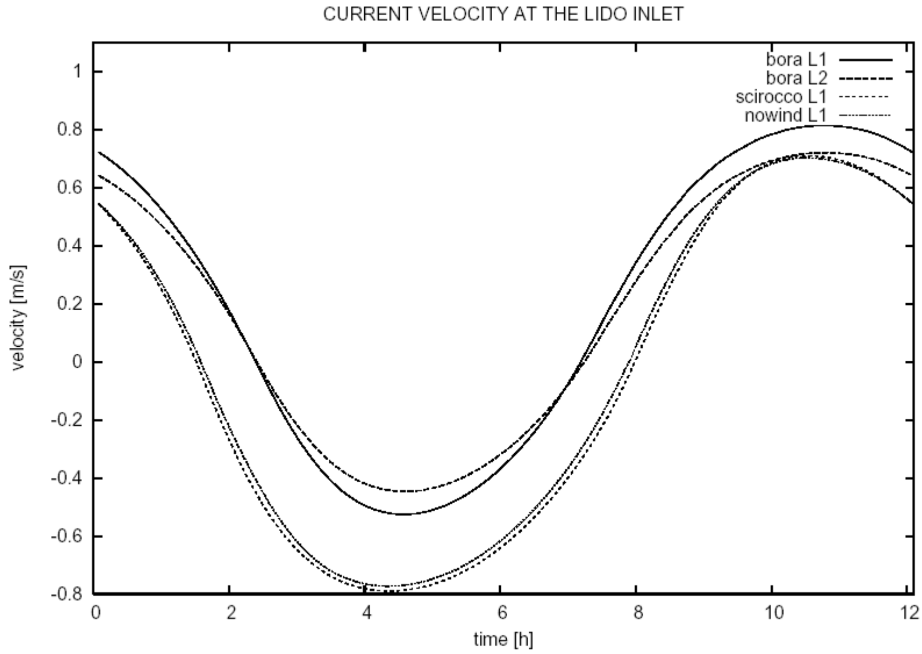


Fig. 3 - Mean current velocity simulated at the Lido inlet with the three wind conditions (bora, scirocco and no wind).

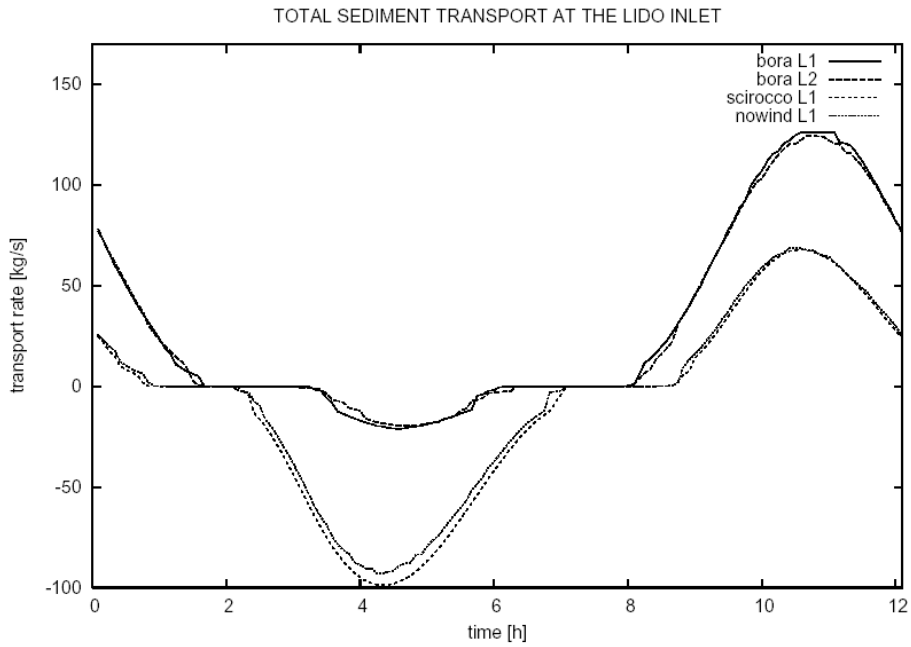


Fig. 4 - Total mean sediment transport simulated at the Lido inlet with the three wind conditions (bora, scirocco and no wind).

It can be noticed how small differences in the maxima, e.g. –0.79 m/s and +0.70 m/s (Fig. 3), bring about evident differences in the transport decreasing from 98 Kg/s in the outflow to 68 Kg/s in the inflow (Fig. 4), which is mainly due to the non-linear relation that links the current velocities to the sediment transport. In the Einstein-Brown equation [Brown, 1950] the transport of the sediment depends on the shear velocity generated by the water flow which is raised to the sixth power. Therefore small differences in velocity generate big differences the transport rates.

When bora blows, the situation changes compared to the two previous cases. In both transects the current velocity is now unsymmetric in the two directions exhibiting higher values during inflow (Fig. 3). The difference in velocity between the two peaks, circa 0.3 m/s, causes incoming sediment transport values six times as high as the outgoing ones (Fig. 4).

In all the three boundary conditions examined, the total transport curve presents two horizontal lines which correspond to zero transport. This happens when the current is weak (between 0 and 0.3 m/s) and the bottom stress is below the critical shear stress for bedload. This situation happens during the directional changes in the tidal flux.

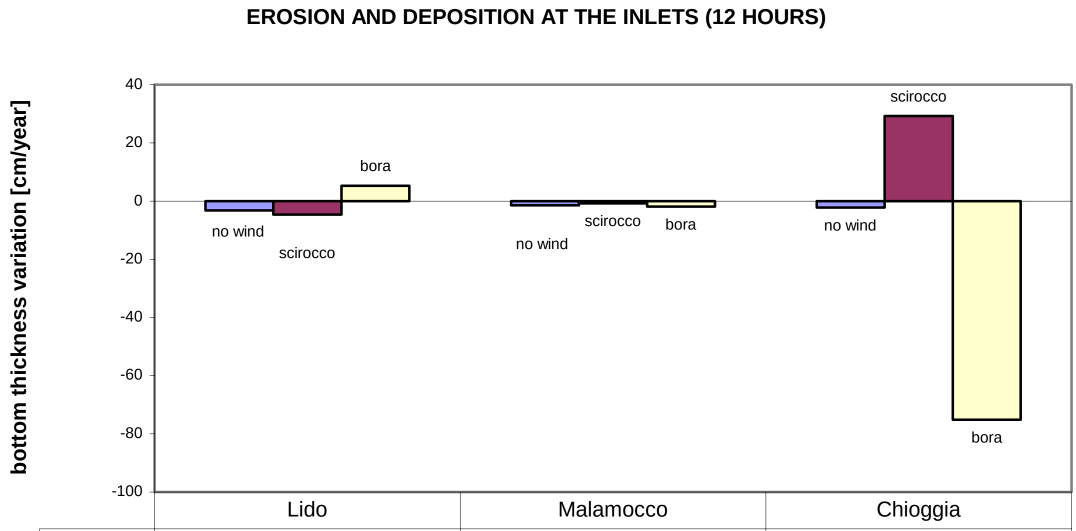
Once having examined the sediment behavior in reaction to the different forcings applied, a wider vision of the exchange processes between the lagoon and the sea can be captured.

During the bora wind events at the Lido inlet the current velocity is stronger in the incoming direction. Consequently the net solid transport occurs nearly along this direction in both transects. At the Chioggia inlet the situation is inverted: the current is much more intense along the outgoing direction and the velocity values are nearly twice as high. From the two transects the sediment is then transported outward to the sea and in the transect C1 the transport rates turn out to be much higher. At Malamocco the situation is halfway between the two other inlets since the current reveals similar values in either directions. As a consequence a certain equilibrium is found in the sediment transport as well. Such an equilibrium does not make it easy to highlight a preferential flow direction.

Everything considered, the results agree well with the residual circulation taking place in the Venice Lagoon when bora is blowing. At the Lido inlet, the incoming water dragged by the wind, transports the sediment from the sea inward into the lagoon; the current then directs itself southward to exit again the lagoon through the Chioggia channel, when a great amount of material is transported.

In presence of scirocco the solid transport in both transects of the Lido inlet displays higher values during the outgoing phase and the velocity is more intense in the transect closer to the sea. In the Malamocco channel the sediment transport is more balanced with regard to both directions, even though a light prevalence of the outgoing flux can be spotted. At Chioggia inlet the solid transport mostly moves from the sea inward to the inner lagoon following the current which reaches higher intensity in the incoming phase. The circulation forced by scirocco wind thus determines the matter exchanges with the sea: the simulations show good agreement between the sediment transport model and the water fluxes from the hydrodynamic model at the three inlet [Umgiesser, 2000; Cucco, 2000].

For each inlet a balance of the mass deposited or eroded at the bottom inbetween the two transects has been calculated. Once the transport direction is known, the bottom thickness variation can be evaluated, relating the moved sediment to the area bounded by the two transects. The values obtained, expressed in cm/year, can be seen in Fig. 5. Positive values refer to deposition and thus to a related increase in the bottom layer, whereas negative values refer to erosion.



	Lido	Malamocco	Chioggia
no wind	-3,2	-1,5	-2,2
scirocco	-4,7	-0,8	29,2
bora	5,2	-1,9	-75,1

Fig. 5 - Bottom thickness variation computed with idealized forcings over 12 hours. The positive values represent deposition and the negative represent the erosion. The values are in cm/year.

At the Lido inlet the sediment deposition calculated with bora wind shows an increase in the bottom thickness of 5.2 cm/year, whereas in the other two wind conditions bottom erosion prevails: higher with scirocco (4.7 cm/year) than in the no wind conditions (3.2 cm/year). At the Malamocco inlet the bottom layer variations are inferior with respect to the other two inlets under all the wind conditions and they always create erosion. In Chioggia the situation differs: the deposition (2.2 cm/year) in absence of wind represents a value that is similar to the other data computed at the Lido and Malamocco inlets. Instead with bora and scirocco the bottom thickness variation turn out to be one order of magnitude bigger than the other values: that is to say a 29.2 cm/year sediment deposition with scirocco and a 75.1 cm/year erosion with bora.

It is important to highlight that these rates can not be considered as representing the real situation: the results calculated by the 12-hour simulations have been transformed into data allegedly meant to represent the bottom variations throughout the whole year. In this way what has been assumed is that the wind blows constantly with the same intensity throughout all the 365 days. Even if these results give a valuable insight into the processes occuring at the inlets during these wind regimes, this scenario cannot be representative for the real situation in the lagoon. So real data of the forcings are needed in order to simulate the sediment transport for a whole year. In the forthcoming experiments this more realistic scenario is going to be analized.

3.2 Long-term simulations

In order to gain a broader view of the sediment transport processes at the three inlets, in the last series of simulations the time domain has been extended to a whole year**.** The simulated year is 1987, for which a complete tidal record was available at the inlets, as well as meteorological forcing (wind data) from a location close to the lagoon in the Adriatic Sea. Unlike the previous scenarios where the atmospheric forcing has been kept constant over the time, here the behavior of the basin has been analized for the whole year, with winds variable in direction and speed.

The sediment transport has been calculated under two different scenarios: first with tidal and atmospheric forcings and then without the wind action. It is important to point out that the tide data have been registered by a tide gauge so that this value inevitably includes also the wind effect in the Adriatic Sea acting at the time of the measurement.

These simulations are always carried out considering a non-cohesive sediment (i.e. sand) with a diameter of 230 μm and a grain density of 2650 kg/m^3. In both transects at the three inlets the trend of the current velocity is closely linked to the tidal forcing: as can be seen from figures 6 and 7 over the year the 14 day tidal cycle is clearly visible. In this period the tidal excursion is higher during spring tide, while neap tide is characterized by lower water levels. The current velocity depends on the velocity gradient, therefore the maxima values have been computed during the spring tide period.

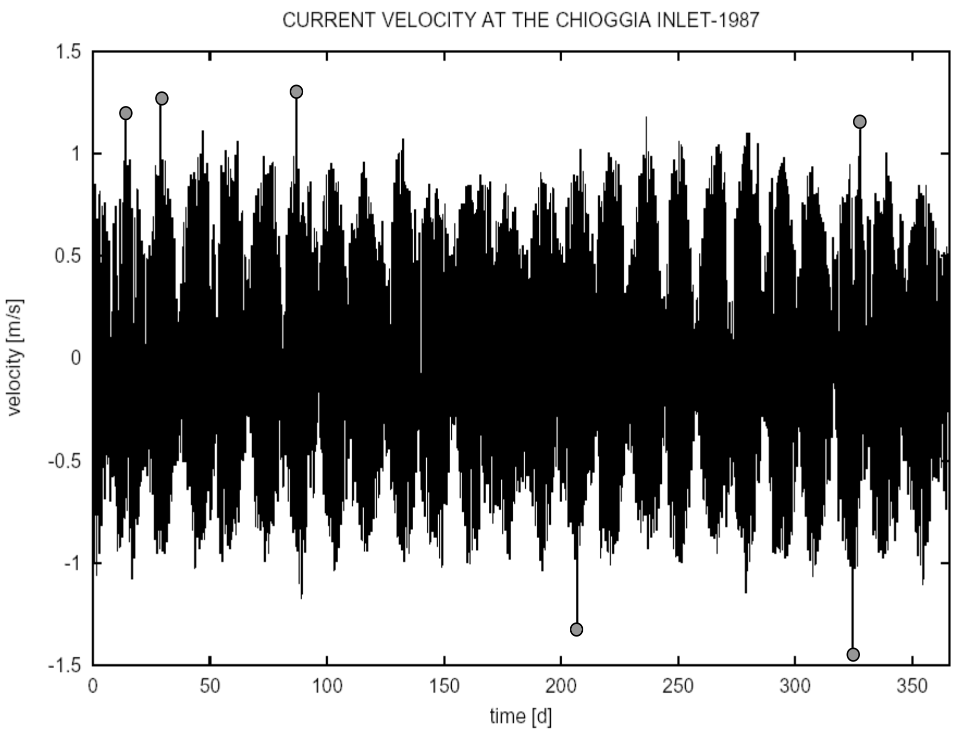


Fig. 6 - Mean current velocity simulated in the transect C1 at Chioggia during the year 1987. The dots evidence the peaks caused by the wind action.

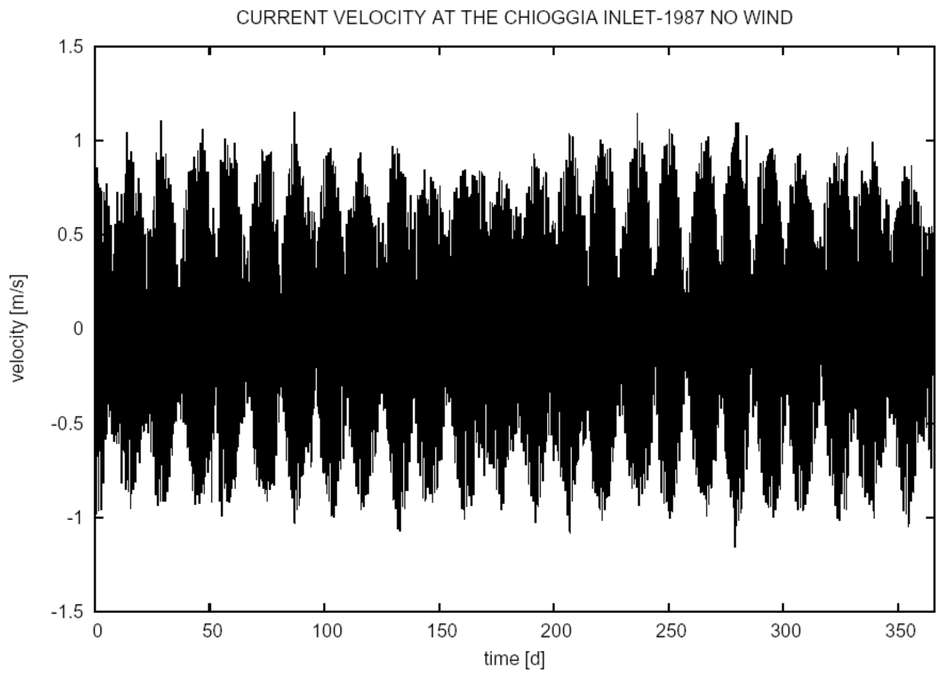


Fig. 7 - Mean current velocity simulated in the transect C1 at Chioggia during the year 1987 in no wind conditions.

During the summer season prounounced peaks are observed less frequently, whereas the strong events are caused by the wind action. Therefore the peaks occur at irregular intervals accounting for the atmospheric variability (Fig. 6). The total transport, obtained by adding the suspended to the bedload transport, is governed by the tidal current. Consequently the lowest rates, are to be found around neap tide period when the current is weak, whereas the highest rates are produced by strong current events (Figs. 8 and 9).

Under tidal forcing only, through both transects at the inlet, the sediment transport does not display the peaks due to the wind action. With this boundary condition the highest intensity in the current is reached at the Malamocco inlet, where a preferential flow direction cannot be easily established; on the contrary at the Lido inlet it is the outgoing flow which turns out to be the strongest. As far as Chioggia inlet is concerned, the current velocity is higher through transect C1 closer to the sea.

In order to understand the sediment transport, also the mass balance has been evaluated over the whole year through the transects at the three inlets. The balance has been established by integrating in time the transport values. The simulation demonstrates that in no wind condition the sediment is transported inward through the Malamocco inlet and seaward through the Lido and the Chioggia inlets. These results agree with the water flow direction through the three inlets: these flows are derived from the time-integrated current velocity multiplied by the area between the two sections. It has been observed that the calculated flow directions do agree well with the distribuition of the residual currents in the Venice Lagoon simulated by the hydrodynamic model under no wind condition [Umgiesser, 2000; Cucco, 2000].

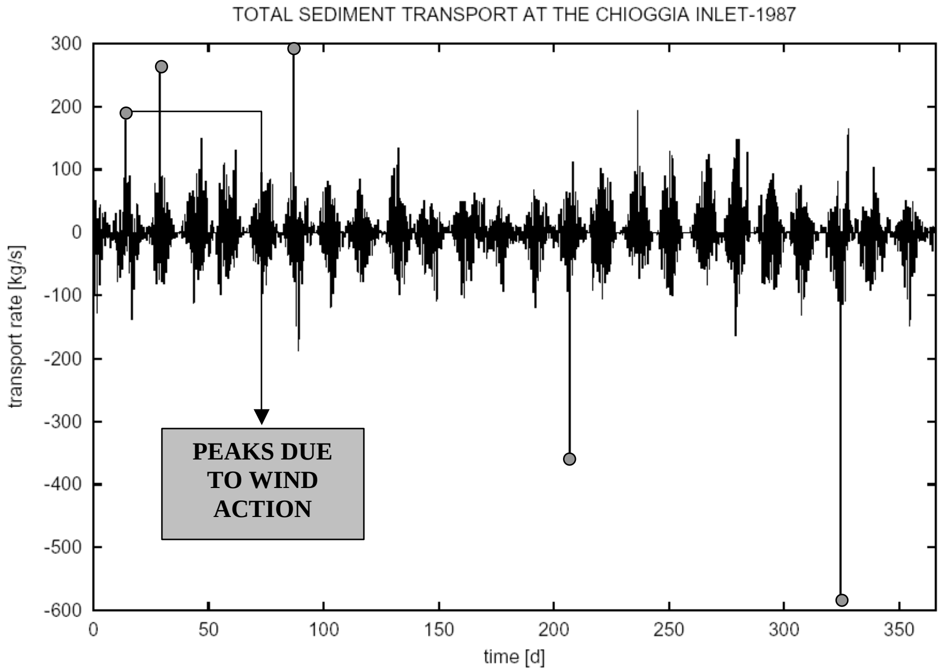


Fig. 8 - Total mean sediment transport simulated in the transect C1 at Chioggia during the year 1987 with wind forcing.

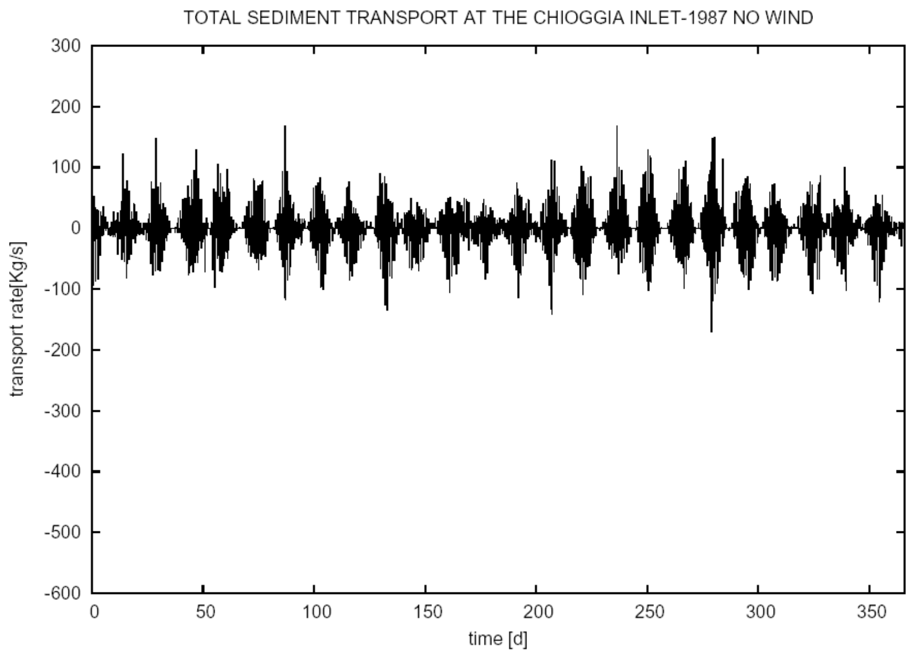
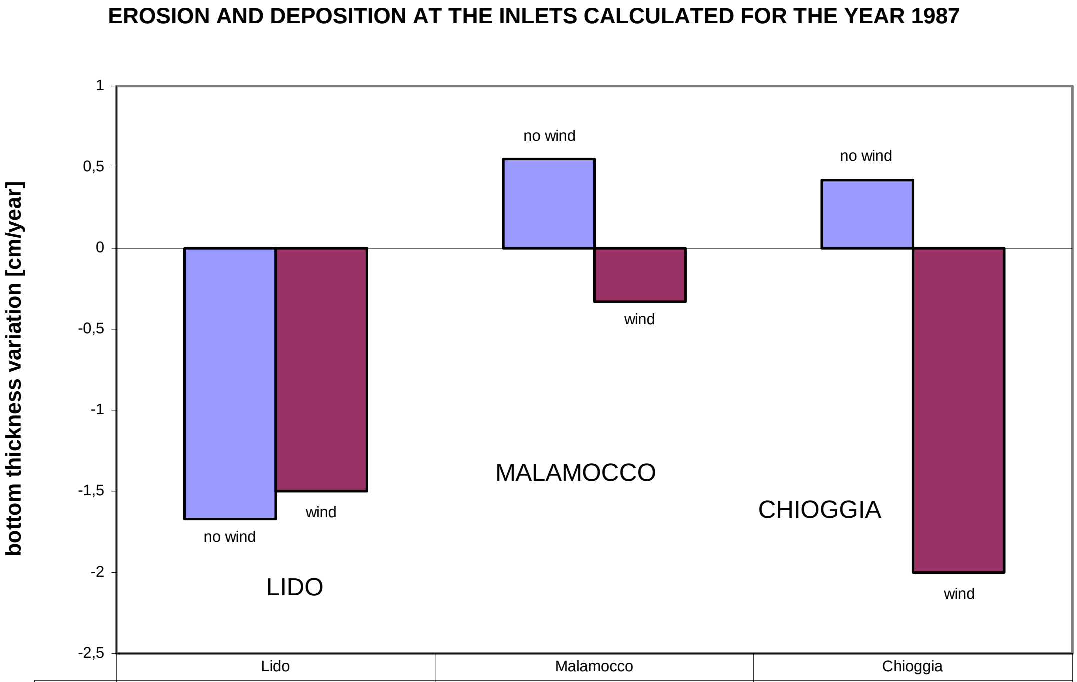


Fig. 9 - Total mean sediment transport simulated in the transect C1 at Chioggia during the year 1987 in no wind conditions.

The bottom thickness variation due to the erosion and deposition in the area inbetween the two transects at each inlet is showed on figure 10. At the Malamocco inlet the sediment deposition calculated in no wind condition shows a deposition of 0.55 cm/year due to the incoming flow, whereas at Lido and Chioggia inlets the mass balance shows an erosion of 1.67 cm/year and 0.42 cm/year respectively.

When the wind action is taken into account, the transport model calculates an erosion at all the three inlets: the sediment is transported inward through Malamocco inlet and since the rate is higher at the inner transect M2, an erosion rate of 0.33 cm/year has been found. At Lido and Chioggia inlets the erosion is derived from the outgoing sediment flux and the bottom thickness variation assumes values of 1.5 cm/year and 2 cm/year respectively (Fig. 10).



	Lido	Malamocco	Chioggia
no wind	-1,67	0,55	0,42
wind	-1,5	-0,33	-2

Fig. 10 - Bottom thickness variation rate calculated by the model in the simulations over the whole year 1987 with real forcing data. The positive values represent the deposition and the negative represent the erosion. The rate is in cm/year.

The results obtained from the transport model have been compared with the “Erosion and deposition map of the Venice Lagoon”, edited by the Water Autority [Magistrato alle acque, 1993]. This work maps the bottom thickness variation due to the sediment erosion and deposition patterns (Fig. 11). Taking into consideration that the period considered in the map (20 years) is much longer than the time simulated in this work, only qualitative considerations about the erosion end deposition processes can be made. What emerges from the map is that erosion is predominant at the Chioggia inlet that grows stronger closer to the sea.

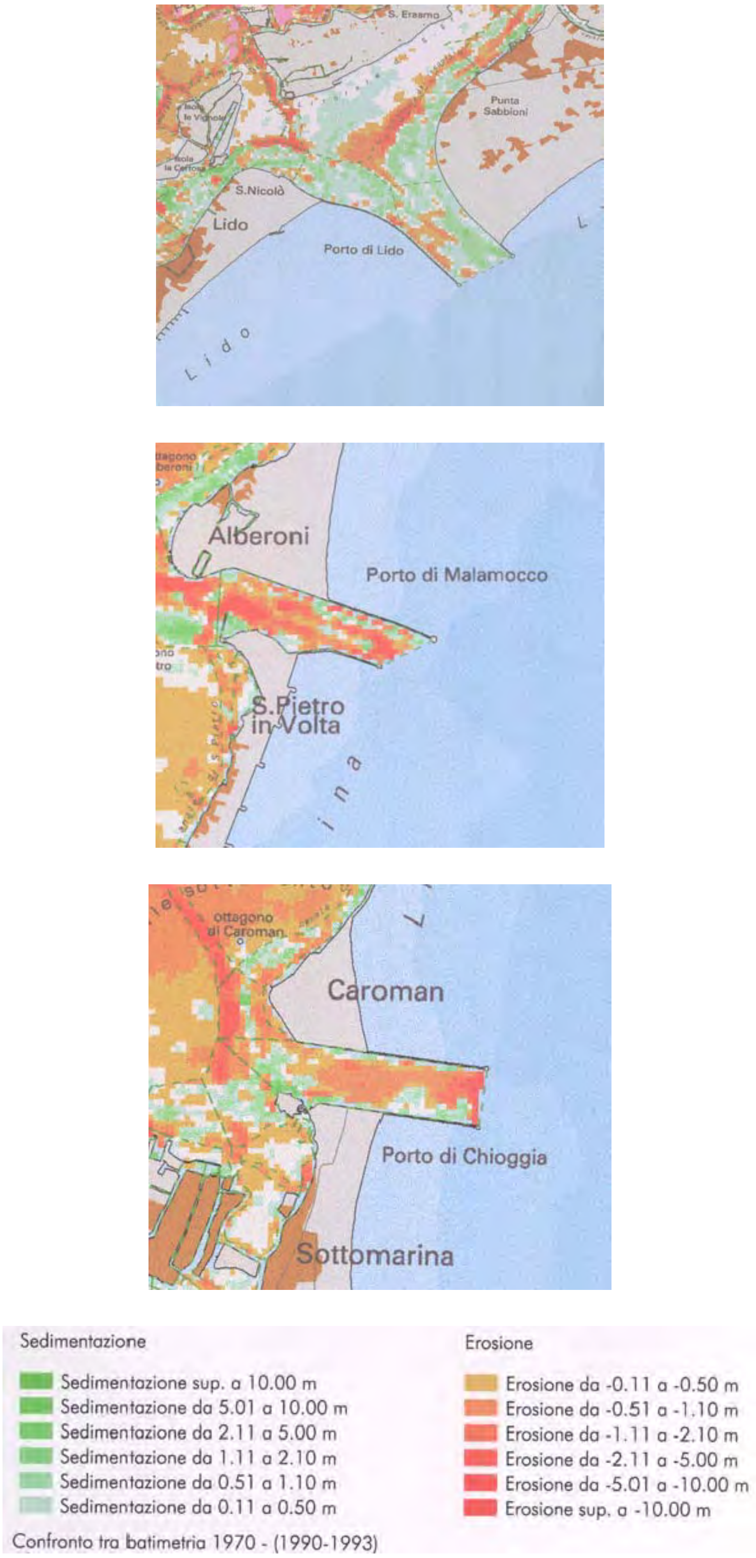


Fig. 11 - Erosion and deposition sediment at the inlets of Venice Lagoon (from the "Erosion and deposition map of the Venice Lagoon" edited by Venice Water Autority). [Magistrato alle Acque, 1993].

This situation well matches even the modeled simulations: the results reveal more intense erosion right in Chioggia where the loss of sediments through transect C1 is higher than through the inner transect C2. What regards the Malamocco inlet, both erosion and deposition can be found in the map even though, overall, the bottom thickness variation is predominantly due to erosion. Modeled data highlight a tendency to erosion leading to bed level variations smaller than those in Chioggia. Therefore, at least qualitatively, the results at Malamocco inlet seem to be in line with the ones in Chioggia.

Finally, at the Lido inlet the tendency is difficult to see. With regard to the map the inlet seems to be divided by a line where erosion prevails on the western side and deposition on the eastern side. The model data represent a balance over the whole transect where both sediment processes take place. Therefore from the numerical values it is not easy to distinguish in the same transect where erosion or deposition only occurs, and no general trend can be identifed.

4. Conclusions

In this paper the sand sediment transport at the inlets of the Venice Lagoon has been investigated with the aid of a one-dimensional numerical sediment transport model coupled to a two-dimensional hydrodynamic model. The influence of the actions of the physical forcings has been investigated.

The results show that the sediment transport depends on the boundary conditions and the highest rate has been observed when the wind forcing is included. In particular bora events increase the sediment transport especially at the Lido and Chioggia inlets. The solid transport calculated by the model through the three inlets is in agreement with the circulation pattern generated by the wind conditions in the Venice Lagoon.

The first part of simulations has been carried out for a short period (one tidal cycle) and the basin forced with idealized wind and tide values. The sediment transport has been evaluated through two sections per inlet in order to calculate the mass balance. Once the balance is known, the eroded and deposited sediments in the area inbetween the two transects has been estimated. These simulations gave an indication of the influence of the wind regimes and the sediment transport through the inlets.

The second part of simulations has been carried out with a long-term real time series of wind and tide-elevation measurements: the derived values of sediment transport appear more realistic with respect to the above analysis with idealized forcings. The inlets of Chioggia and Malamocco show the correct tendency of erosion as indicated by empirical data collected during the last 20 years. At the Lido inlet the tendency is not so clear and no conclusion can be drawn.

This work represents a first attempt to integrate different models in order to explain the sediment transport at the inlets of the Venice Lagoon. The methods applied make it possible to evaluate the direction of the solid transport and the sediment exchanges between the lagoon and the sea under varying external forcings.

Acknowledgements

This work was carr ied out with the financial support of CORILA in the framework of the CORILA Project 3.2 “Hydrodynamics and morphology”.

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FORAMINIFERAL BIOTOPES AS ENVIRONMENTAL MONITORING INDICATORS: A COMPARISON WITH THE 1983 FORAMINIFERAL FAUNAS

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Riassunto

Negli ambienti marini marginali come la Laguna di Venezia, soggetti ad ampi range di variabilità, i foraminiferi bentonici vengono utilizzati come bioindicatori. La comunità a foraminiferi bentonici, con la presenza/ assenza/dominanza dei diversi taxa, fornisce la mappa degli spazi lagunari caratterizzati dalle stesse biofacies e quindi indicativi di condizioni ambientali uniformi. Il campionamento effettuato nel 1983, attraverso l'analisi quantitativa di oltre 600 campioni di fondo, ha fornito la distribuzione delle biofacies nell'intera laguna e indicato i fattori che ne controllano la distribuzione sul territorio: tempo di residenza, livello d'inquinamento, apporti di acqua dolce e la presenza di morfologie intertidali. All'interno delle biofacies note, nel 2001 sono stati raccolti 52 nuovi campioni da confrontare con quelli del 1983 attraverso il test di Kolmogorov-Smirnov.

I risultati indicano condizioni stabili in oltre il 50% delle aree campionate, una diminuzione dell'inquinamento nelle aree lagunari prossime alla zona industriale ed una diminuzione del tempo di residenza nell'area a Nord di Venezia; persistono, invece, le condizioni di inquinamento nei pressi dell'isola di S. Michele e del Tronchetto e alcune aree a Nord di Venezia segnalano il recente instaurarsi di locali condizioni di stress.

Abstract

In coastal lagoonal environments such as the Lagoon of Venice, which daily are subject to wide range of variability, benthic foraminifera are used as bioindicators. These organisms, through their presence-absence-dominance, define the extent of similar environmental conditions (biotopes). The sampling carried out in 1983, based on the quantitative analysis of well over 600 bottom samples, have delineated the extent of the various biofacies for the complete Lagoon and have indicated the parameters that control their distribution: residence time, pollution, fresh water input and the presence of intertidal morphologies. Within the 1983 biotopes 52 new samples were collected in 2001 and compared with the previous faunas using the same methodology of 1983 and the Kolmogorov-Smirnov index.

The results indicate stable conditions for more than 50% of the area, a decrease of pollution in the areas closest to the industrial zone and a decrease of the residence time in the northern portion of the Lagoon. Pollution conditions persist, however, near the

island of S. Michele and of Tronchetto, while some areas north of the city indicate a local pollution.

1. Introduction

Benthic foraminifera (Kingdom Protozoa, Phylum Foraminifera) have been often used to assess the level of environmental stress and pollution in coastal zones. They offer an effective and integrated view of the prevailing environmental conditions. For this purpose the total assemblage is considered, both biocenosis and tanatocenosis, as only the totality of the species present reflects the physical-chemical parameters prevailing, and is capable to recognize subtle but permanent changes in the environmental condition [Albani, 1993; Alve, 1995].

This methodology is of great value in a coastal setting such as the Lagoon where the level and direction of environmental stress can be determined and evaluated.

Benthic foraminifera are affected by physical and chemical parameters of the water masses and because of their presence in all lagoonal environments, from brackish to marine, are here considered as bioindicators.

The distribution of benthic foraminifera is mainly affected by the residence time of the water masses [Guelorget and Parthuisot, 1983]; some taxa reflect a relationship with the water level [Albani et al., 1984; Petrucci et al., 1983; Scott e Medioli, 1980; Hayward & Hollis, 1994] others the presence of fresh water [Donnici and Serandrei Barbero, --]. Changes in the level of abundance reflect the morphological evolution of the lagoon, as clearly shown by the study of palaeoenvironments [Reinhard et al., 1994; Serandrei Barbero et al., 1997].

A complex sampling (733 samples) of the Lagoon and the Gulf of Venice during the ‘80s has provided a baseline study of the distribution of benthic foraminifera (biotopes) [Albani et al., 1984, 1991, 1998; Donnici et al., 1997; Serandrei Barbero et al., 1989, 1999], recent sediments and their geochemical characteristics [Albani et al., 1995]. In particular foraminiferal biotopes identify, on the basis of the faunal similarities, the areas characterized by similar environmental conditions.

The foraminiferal fauna of the Lagoon of Venice is composed by 67 species; the areas close to the lagoon’s entrances reach 37 species per sample while those with reduced exchange show an assemblage with 5-6 species only. *Ammonia beccarii* Linnaeus is the dominant taxon representing at time up to 90% of the assemblage, particularly in areas with high antropic influence [Alve, 1995].

The baseline sampling of 1983 has also identified the degree of confinement and the level of pollution linked to the industrial activities and antropic impacts, the two major stress components, which also are interacting with the lagoon’s morphology.

The sampling carried out in 2001 was designed to offer an understanding of the environmental changes that have occurred twenty years after the original survey.

While the present report deals with the northern and central sectors of the Lagoon, the same methodology is being applied to the southern sector of the Lagoon to determine the portions that, on a twenty years interval, have shown the significant changes.

2. Method of Study

Within the Lagoon, characterized by wide ranging environmental parameters, foraminiferal individuals appear to reach reproductive maturity later than in the marine environment. The full development is reached by individuals of greater dimensions than those of the marine environment. Therefore in all the foraminiferal studies, carried out in the Lagoon of Venice since the ‘60s, only the fraction with a diameter greater than 0.125 mm has been considered. The examination of the smaller fraction, between 63 microns and 0.125 mm has confirmed the presence of a very large number of juvenile individuals of doubtful identification.

During 2001 a set of 52 sampling sites, selected within the already identified biotopes, have been analyzed using the same methodology adopted in the 1983 survey; the new quantitative data set was based on at least 300 individuals [Buzas, 1990; Serandrei Barbero et al., 1997] of the fraction >0.125 mm. The location of the new samples within the various biotopes defines their environmental association. The 2001 numerical data set was added to the data from the 1983 study and the combined set was analyzed using cluster analysis (Pearson coefficient); this phase of the analytical process allowed the establishment of the level of similarity within the existing biotopes and establish the cluster links.

In addition, to assess the degree of environmental change, the quantitative data have been used for a comparative study between the 2001 and the nearby 1983 samples using the Kolmogorov-Smirnov statistical test, [Sokal and Rohlf, 1969]. This non-parametric test compares the cumulative frequency values of two samples and records the value of the level of difference; the smaller the value the smaller is the difference and thus greater is the similarity of the two samples. The combination of the Kolmogorov-Smirnov test, which determines the level of similarity between each pair [Albani et al., 1998], and the cluster links determines not only the degree, but also the direction of the change, if any.

The interpretation of the results were based not only on the direct observations and on the local morphological factors, but also on the experimental work of five years carried out through monthly measurements of the physical and chemical parameters. These measurements were taken along a section of the lagoon characterized by a gradient in the degree of pollution and in the residence time [Ramasco, 1991]. This study appears to reflect the terminology previously adopted as descriptors of the various biotopes (Fig. 1).

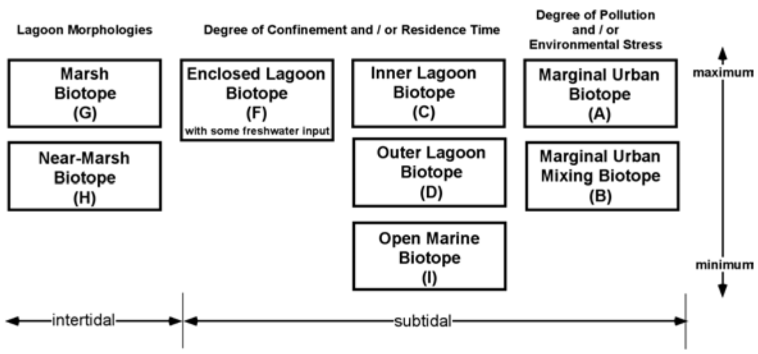

Fig. 1 – Biotopes terminology and their relationship with the Lagoon morphology and environmental conditions.

Tab. 1 – Foraminiferal fauna of the 2001 sampling program

Foraminiferal species	range	average	occurrence
Acostata mariae *(Acosta)*	0.25 - 0.26	0.26	4
Haplophragmoides canariensis *d'Orbigny*	0.26 - 0.88	0.45	7
Ammobaculites agglutinans *(d'Orbigny)*	0.19 - 5.96	0.84	30
Trochammina inflata *(Montagu)*	0.25 - 66.45	5.91	22
Gaudryina silvestrii (*Bronniman, Whittaker and Valleri*)	0.29 - 0.61	0.45	2
Eggerella scabra *(Williamson)*	0.26 - 18.26	2.95	16
Textularia agglutinans *d'Orbigny*	0.61 - 2.33	1.47	2
Spirillina vivipara *Ehrenberg*	0.26 - 2.45	0.99	6
Spiroloculina excavata *d'Orbigny*	0.61 - 0.61	0.61	1
Spiroloculina lucida *Cushman and Todd*	1.22 - 1.22	1.22	1
Massilina disciformis *(Wiliamson)*	0.25 - 0.25	0.25	1
Quinqueloculina agglutinata *Cushman*	0.26 - 0.52	0.36	3
Quinqueloculina candeiana *d'Orbigny*	0.25 - 1.34	0.66	7
Quinqueloculina cultrata *(Brady)*	0.92 - 0.92	0.92	1
Quinqueloculina elegans *(Williamson)*	0.19 - 1.78	0.73	12
Quinqueloculina ferussacii *d'Orbigny*	0.24 - 0.26	0.25	2
Quinqueloculina laevigata *d'Orbigny*	0.22 - 1.89	0.71	5
Quinqueloculina seminulum *(Linné)*	0.18 - 22.94	3.27	42
Quinqueloculina subpolygona *Parr*	0.51 - 0.92	0.65	3
Miliolinella subrotunda *(Montagu)*	0.36 - 0.36	0.36	1
Triloculina trigonula *(Lamarck)*	0.25 - 2.67	0.83	5
Sigmoilina grata *(Terquem)*	0.36 - 0.36	0.36	1
Procerolagena semistriata dorbignyi *(Jones)*	0.26 - 0.26	0.26	1
Fissurina lucida *(Williamson)*	0.19 - 0.25	0.23	3
Brizalina striatula *(Cushman)*	0.23 - 0.89	0.46	6
Cassidulina laevigata *(d'Orbigny)*	0.26 - 0.26	0.26	1
Bulimina gibba *Fornasini*	0.60 - 0.60	0.60	1
Valvulineria perlucida (*Heron-Allen and Earland*)	0.32 - 16.24	5.75	51
Poroeponides lateralis *(Terquem)*	0.36 - 6.57	3.46	2
Helenina anderseni *(Warren)*	0.25 - 0.33	0.30	4
Rosalina bradyi *(Cushman)*	0.24 - 0.52	0.37	5
Rosalina candeiana *d'Orbigny*	0.77 - 2.15	1.46	2
Discorbis mirus *(Cushman)*	0.26 - 0.26	0.26	1
Cibicides lobatulus (*Walker and Jacob*)	0.26 - 0.26	0.26	1
Planorbulina mediterranensis *d'Orbigny*	0.61 - 0.61	0.61	1
Asterigerinata adriatica *Haake*	0.24 - 0.24	0.24	1
Haynesina paucilocula *(Cushman)*	1.29 - 61.54	11.01	52
Haynesina simplex *Cushman*	0.19 - 0.57	0.33	10
Buccella frigida granulata (*Di Napoli Alliata*)	0.24 - 2.62	0.75	12
Buccella pustulosa *Albani and Serandrei Barbero*	0.26 - 0.32	0.29	3
Trichohyalus lacunae *(Silvestri)*	0.24 - 0.36	0.28	3
Ammonia beccarii *(Linné)*	5.00 - 86.62	53.12	52
Cribrononion granosum *(d'Orbigny)*	0.26 - 45.74	11.77	52
Cribrononion lagunensis *Albani, Favero and Serandrei*	0.23 - 3.22	0.86	46
Cribrononion translucens *(Natland)*	0.19 - 3.33	0.83	45
Cribrononion venetum *Albani, Favero and Serandrei*	0.19 - 1.19	0.59	11
Elphidium advenum *(Cushman)*	0.26 - 0.52	0.43	3
Elphidium crispum *(Linné)*	0.26 - 0.26	0.26	1
Elphidium depressulum *(Cushman)*	0.18 - 3.27	0.80	34
Elphidium discoidale multiloculum (*Cushman and Ellisor*)	0.24 - 0.51	0.34	4
Elphidium macellum *(Silvestri)*	0.26 - 0.51	0.39	2
Elphidium macellum aculeatum *(Silvestri)*	0.26 - 0.26	0.26	1

Tab. 2 – Foraminiferal assemblages of the 1983 and 2001 studies. Only the presence or absence of the various species is shown.

foraminiferal species	1983	2001
Acostata mariae *(Acosta)*		XX
Haplophragmoides australensis *Albani*	XX	
Haplophragmoides canariensis *d'Orbigny*	XX	XX
Ammobaculites agglutinans *(d'Orbigny)*	XX	XX
Trochammina inflata *(Montagu)*	XX	XX
Gaudryina silvestrii (*Bronniman, Whittaker and Valleri*)		XX
Eggerella scabra *(Williamson)*	XX	XX
Textularia agglutinans *d'Orbigny*	XX	XX
Textularia conica *d'Orbigny*	XX	
Spirillina vivipara *Ehrenberg*	XX	XX
Vertebralina striata *d'Orbigny*	XX	
Spiroloculina antillarum *d'Orbigny*	XX	
Spiroloculina excavata *d'Orbigny*	XX	XX
Spiroloculina lucida *Cushman and Todd*	XX	XX
Spiroloculina soldanii *Fornasini*	XX	
Massilina disciformis *(Wiliamson)*	XX	XX
Quinqueloculina agglutinata *Cushman*	XX	XX
Quinqueloculina anguina arenata *Said*	XX	
Quinqueloculina bicornis (*Walker and Jacob*)	XX	
Quinqueloculina candeiana *d'Orbigny*	XX	XX
Quinqueloculina costata *d'Orbigny*	XX	
Quinqueloculina cultrata *(Brady)*	XX	XX
Quinqueloculina elegans *(Williamson)*	XX	XX
Quinqueloculina ferussacii *d'Orbigny*	XX	XX
Quinqueloculina laevigata *d'Orbigny*	XX	XX
Quinqueloculina lamarckiana *d'Orbigny*	XX	
Quinqueloculina pseudoreticulata *Parr*	XX	
Quinqueloculina seminulum *(Linné)*	XX	XX
Quinqueloculina squamosa *(Terquem)*	XX	
Quinqueloculina subpolygona *Parr*	XX	XX
Miliolinella subrotunda *(Montagu)*	XX	XX
Triloculina trigonula *(Lamarck)*	XX	XX
Sigmoilina grata *(Terquem)*	XX	XX
Nodosaria perversa *(Schwager)*	XX	
Lenticulina limbosa *(Reuss)*	XX	
Marginulina bacheii *(Bailey)*	XX	
Lagena laevis *(Montagu)*	XX	
Lagena striata *(d'Orbigny)*	XX	
Lagena striata strumosa *Reuss*	XX	
Procerolagena clavata *(d'Orbigny)*	XX	
Procerolagena semistriata dorbignyi *(Jones)*	XX	XX
Globulina gibba myristiformis *(Williamson)*	XX	
Guttulina problema *d'Orbigny*	XX	
Oolina costata *(Williamson)*	XX	
Oolina hexagona *(Williamson)*	XX	

foraminiferal species	1983	2001
Fissurina laevigata *Reuss*	XX	
Fissurina lucida *(Williamson)*	XX	XX
Fissurina orbignyana caribaea *(Cushman)*	XX	
Brizalina catanensis *(Seguenza)*	XX	
Brizalina laevigata *(Williamson)*	XX	
Brizalina spathulata *(Williamson)*	XX	
Brizalina striatula *(Cushman)*	XX	XX
Cassidulina laevigata *(d'Orbigny)*	XX	XX
Bulimina gibba *Fornasini*	XX	XX
Bulimina marginata *d'Orbigny*	XX	
Buliminella elegantissima *(d'Orbigny)*	XX	
Uvigerina bassensis *Parr*	XX	
Trifarina angulosa *(Williamson)*	XX	
Reussella spinulosa *(Reuss)*	XX	
Valvulineria perlucida (*Heron-Allen and Earland*)	XX	XX
Poroeponides lateralis *(Terquem)*	XX	XX
Helenina anderseni *(Warren)*		XX
Neoconorbina terquemi *(Rzehak)*	XX	
Rosalina bradyi *(Cushman)*	XX	XX
Rosalina candeiana *d'Orbigny*		XX
Discorbis mirus *(Cushman)*	XX	XX
Cibicides lobatulus (*Walker and Jacob*)		XX
Cicbicides refulgens *de Montfort*	XX	
Cibicidella variabilis *(d'Orbigny)*	XX	
Planorbulina mediterranensis *d'Orbigny*	XX	XX
Asterigerinata adriatica *Haake*		XX
Haynesina paucilocula *(Cushman)*	XX	XX
Haynesina simplex *Cushman*	XX	XX
Nonion politum *(d'Orbigny)*	XX	
Nonionella auris *(d'Orbigny)*	XX	
Nonionella opima *Cushman*	XX	
Buccella frigida granulata (*Di Napoli Alliata*)	XX	XX
Buccella pustulosa *Albani and Serandrei Barbero*	XX	XX
Trichohyalus lacunae *(Silvestri)*	XX	XX
Ammonia beccarii *(Linné)*	XX	XX
Cribrononion granosum *(d'Orbigny)*	XX	XX
Cribrononion lagunensis *Albani, Favero and Serandrei Barbero*	XX	XX
Cribrononion translucens *(Natland)*	XX	XX
Cribrononion venetum *Albani, Favero and Serandrei Barbero*	XX	XX
Elphidium advenum *(Cushman)*	XX	XX
Elphidium complanatum *(d'Orbigny)*	XX	
Elphidium crispum *(Linné)*	XX	XX
Elphidium depressulum *(Cushman)*	XX	XX
Elphidium discoidale multiloculum (*Cushman and Ellisor*)	XX	XX
Elphidium macellum *(Silvestri)*	XX	XX
Elphidium macellum aculeatum *(Silvestri)*	XX	XX
XX = present		

3. Results

The foraminiferal taxa identified in the 52 stations are listed in Tab. 1 together with their range and average value. The total number of species is less then those of the 1983 study due to the limited sampling. In Tab. 2 the 1983 and 2001 faunal records are shown as presence/absence only.

In figures 2 and 3 the extent of the 1983 biotopes are shown together with the 2001 sampling sites, while figures 6 and 7 summarize the environmental changes noted.

Selected locations are illustrated in figure 4, for stable conditions, and figure 5 with the most noticeable changes. In these figures the cluster links and the Kolmogorov-Smirnov index are shown.

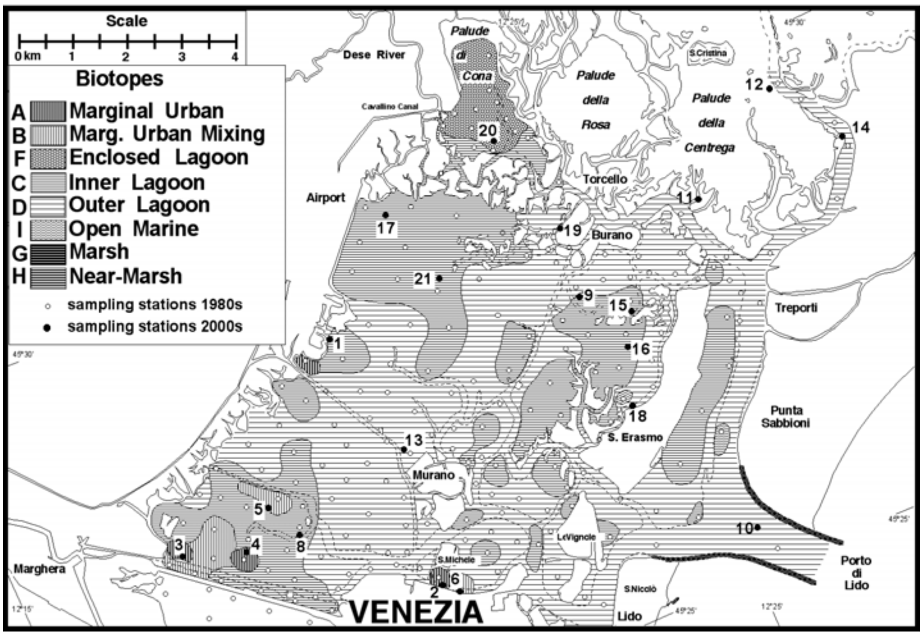

Fig. 2 – Northern sector of the Lagoon of Venice with the 1983 biotopes distributions and the locations of the 2001 samples.

In the northern and central hydrographic basins of the Lagoon the results indicate a stationary situation in more than 50% of the cases (Figs. 4 and 6). Stable conditions are present up to the northern extremity (stns 11, 12, 14, 15, 16, 19 and 20) as well as near the inland margin (stn. 1) similarly on the south of the City (Figs. 4 and 7) at stations 30, 32, 35, 36, 37 and 38).

Along the Canale dei Petroli, in the central hydrographic basin, the conditions typical of the open lagoon extend from the central basin to the northern basin creating relatively stable conditions (stns 25, 26, 27, 29 and 34). These conditions, stabilised during the last 20 years, have produced the local disappearance of the some intertital morphologies, clearly shown by the disappearance of the faunas of the Marsh Biotope at stations 28 and 33 (Figs. 5 and 7).

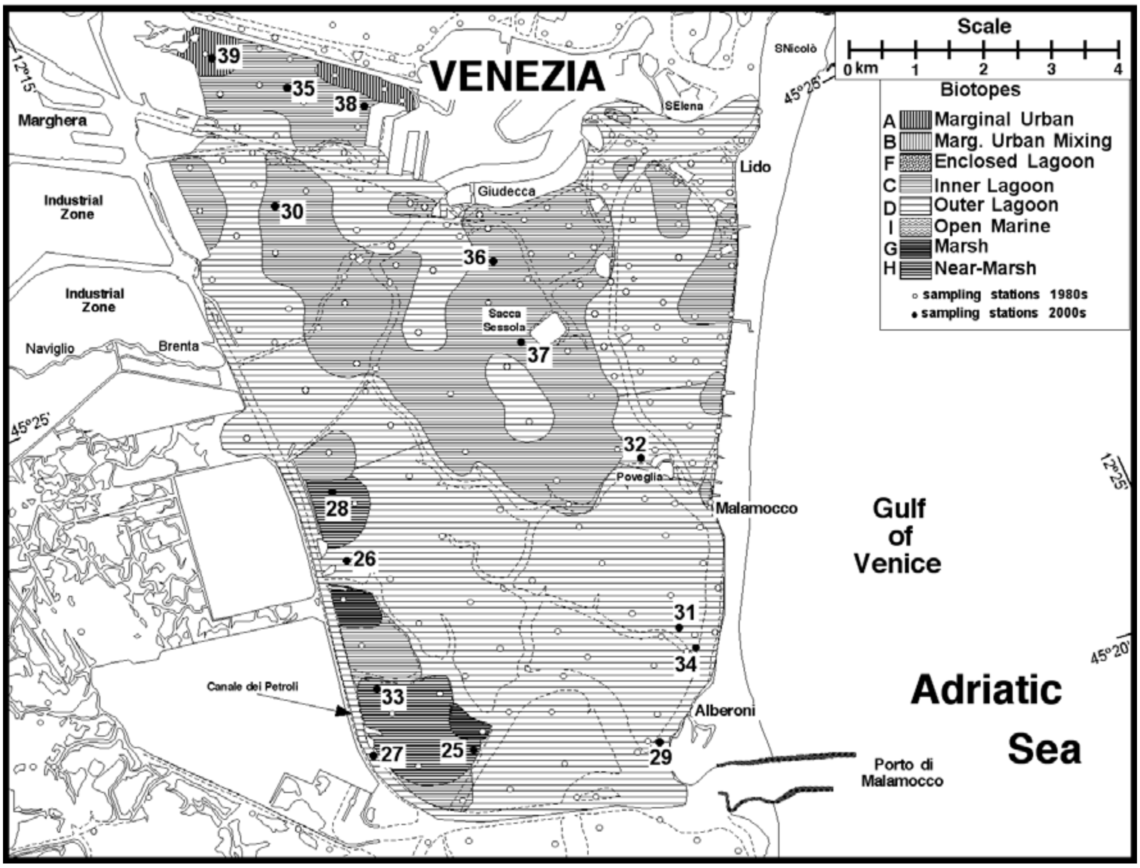

Fig. 3 – Central sector of the Lagoon of Venice with the 1983 biotopes distributions and the locations of the 2001 samples.

In the area south of the City of Venice, affected by the Canale dei Petroli for several decades, the marine influence can be considered to be in near equilibrium.

On the northern sector, however the marine influence has slightly increased from 1983 (stns 8, 9 and 18) (Figs. 5 and 6).

In respect to pollution levels, the foraminiferal biotope of 1983 had identified and delineated areas with high environmental stress, in good agreement with the areas within the central sector where ammonia, phosphorous and nitrates were the main polluting parameters [Ramasco, 1991]. In 1986 purification plants of the Consorzio Comunale came on-line between Mestre/Marghera and Venice; the consequent decrease of the pollution levels is shown at stations 3, 4, 5 and 39 (Figs. 5, 6 and 7). However the environmental stress has increased at stations 13, 21 (Figs. 5 and 6) and 31 (Fig. 7) where it appears related to local factors. The same local parameters affect station 6 (Fig. 6) between Venice and the island of S. Michele as well as station 38 (Fig. 7) near Tronchetto where the level of pollution appears unaltered.

Tab. 3 – Comparison between the1983 biotopes and the 2001 samples. For the symbols used, please refer to Figure 1.

location	Biotope 1983	Biotope 2001	environmental conditions
1	C	C	Unchanged conditions
2	-	-	not comparable
3	A	C	Decrease in pollution levels
4	A	F	Decrease in pollution levels
5	C	D	Decrease in pollution levels
6	B	B	Unchanged conditions
8	C	D	Decrease in residence time
9	C	D	Decrease in residence time
10	I	I	Unchanged conditions
11	D	D	Unchanged conditions
12	D	D	Unchanged conditions
13	D	C	Increase in pollution levels
14	D	D	Unchanged conditions
15	D	D	Unchanged conditions
16	D	D	Unchanged conditions
17	-	-	not comparable
18	C	D	Decrease in residence time
19	C	C	Unchanged conditions
20	F	F	Unchanged conditions
21	C	F	Increase in pollution levels
25	H	H	Unchanged conditions
26	D	D	Unchanged conditions
27	H	H	Unchanged conditions
28	H	C	change in morphology
29	D	D	Unchanged conditions
30	D	D	Unchanged conditions
31	D	C	Increase in pollution levels
32	D	D	Unchanged conditions
33	H	C	change in morphology
34	D	D	Unchanged conditions
35	C	C	Unchanged conditions
36	C	C	Unchanged conditions
37	C	C	Unchanged conditions
38	A	A	Unchanged conditions
39	A	C	Decrease in pollution levels

Stations 2 and 17 (Fig. 6) do not contribute to the environmental change assessment as they belong to different subtidal morphologies, not previously sampled. Station 2 (2001), in contrast to the 1983 sampling, is located in the channel, which explains the decreased residence time as shown by the foraminiferal fauna. On the contrary, station 17, in which the foraminiferal fauna indicates an increase in residence time, is further away from the channel sampled in 1983.

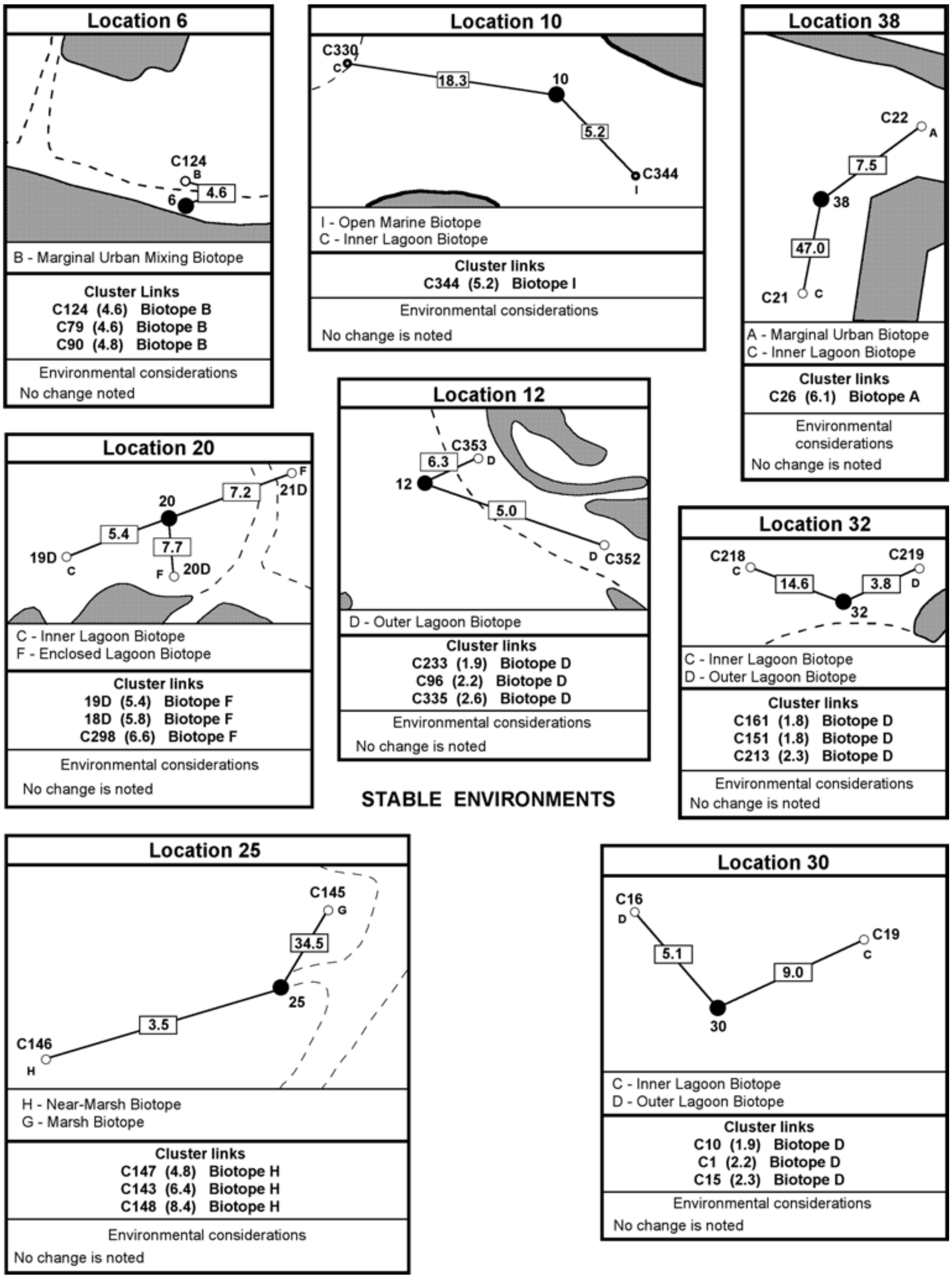

Fig. 4 – Relationships between the 2001 faunas (solid dots) and the 1983 faunas (open dots) for the stable environments. The Kolmogorov-Smirnov indices are also shown (smaller the value, smaller the difference or higher the similarity). The cluster links are derived from the combined cluster analysis of the total fauna.

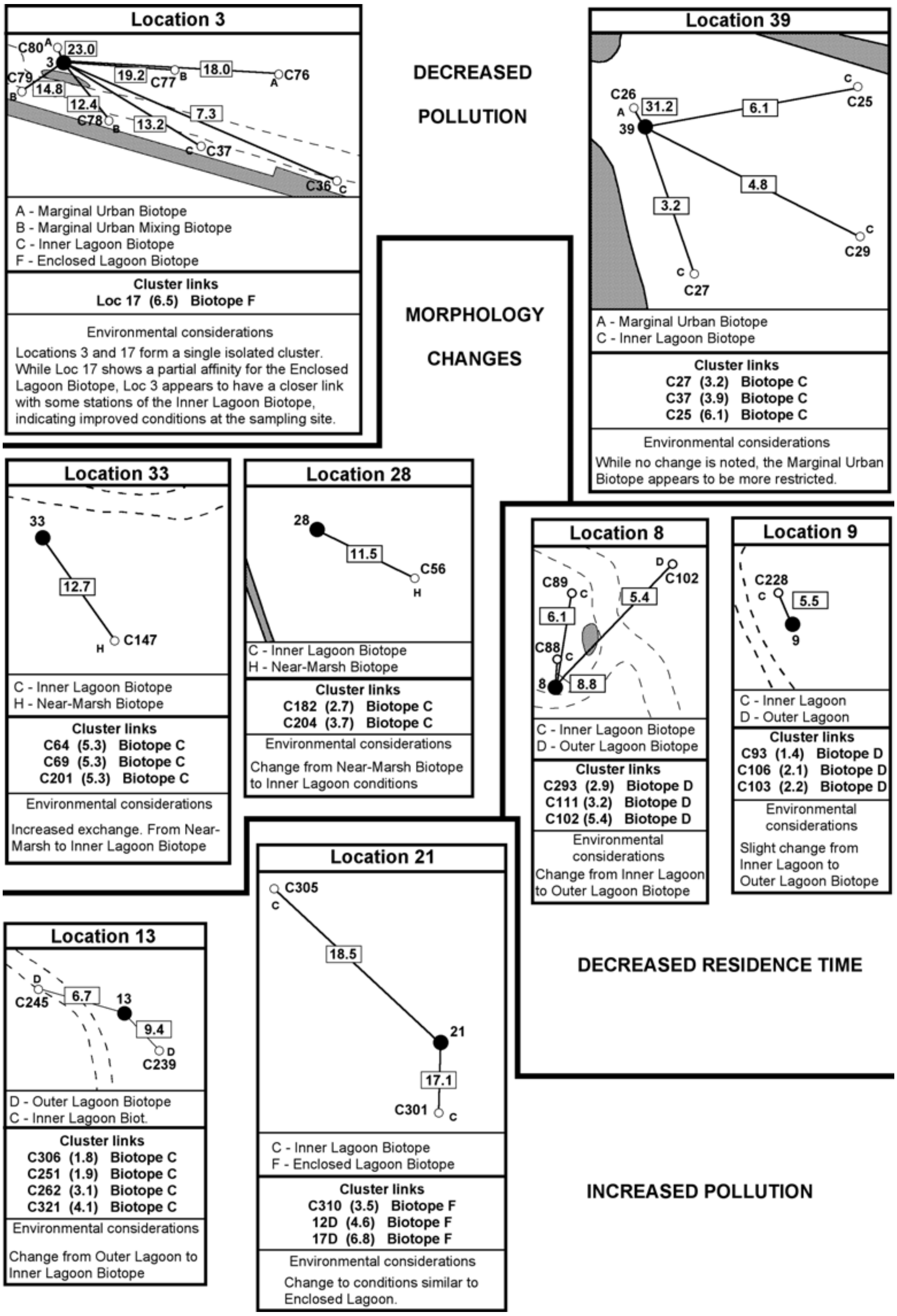

Fig. 5 – Relationships between the 2001 faunas (solid dots) and the 1983 faunas (open dots) for the changed environments. (See fig. 4 for details)

4. Conclusions

In biological investigations a species is considered an environmental indicator when its presence-absence-abundance relates to processes that are not directly measurable or are subject to wide range of variability of the physical and chemical parameters within 24 hours such as in the lagoonal environment. However the species as indicator is less efficient and reliable than the whole assemblage.

The whole foraminiferal assemblage responds to the predominant conditions, as the totality of the species present reflects the physical-chemical parameters prevailing, and thus capable to recognise subtle but permanent changes in the environmental conditions.

Each assemblage is composed by species characterized by relative abundance related to the predominant physical and chemical parameters; thus similar assemblages reflect similar environmental conditions.

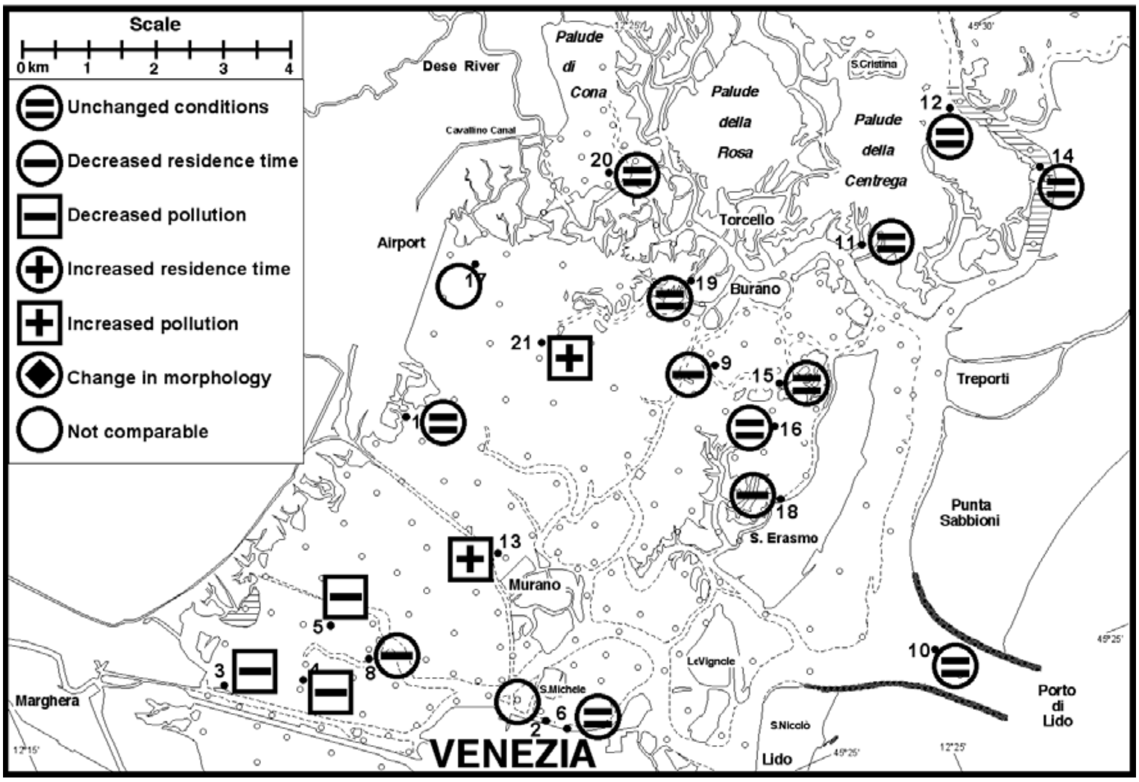

Fig. 6 – Summary view of the changes in the northern sector of the Lagoon of Venice.

The comparative study between the faunal distributions of the base-line 1983 and the 2001 samples, using the cluster analysis and the Kolmogorov-Smirnov indices, shows areas of environmental stability, although with a slight decrease of the residence times.

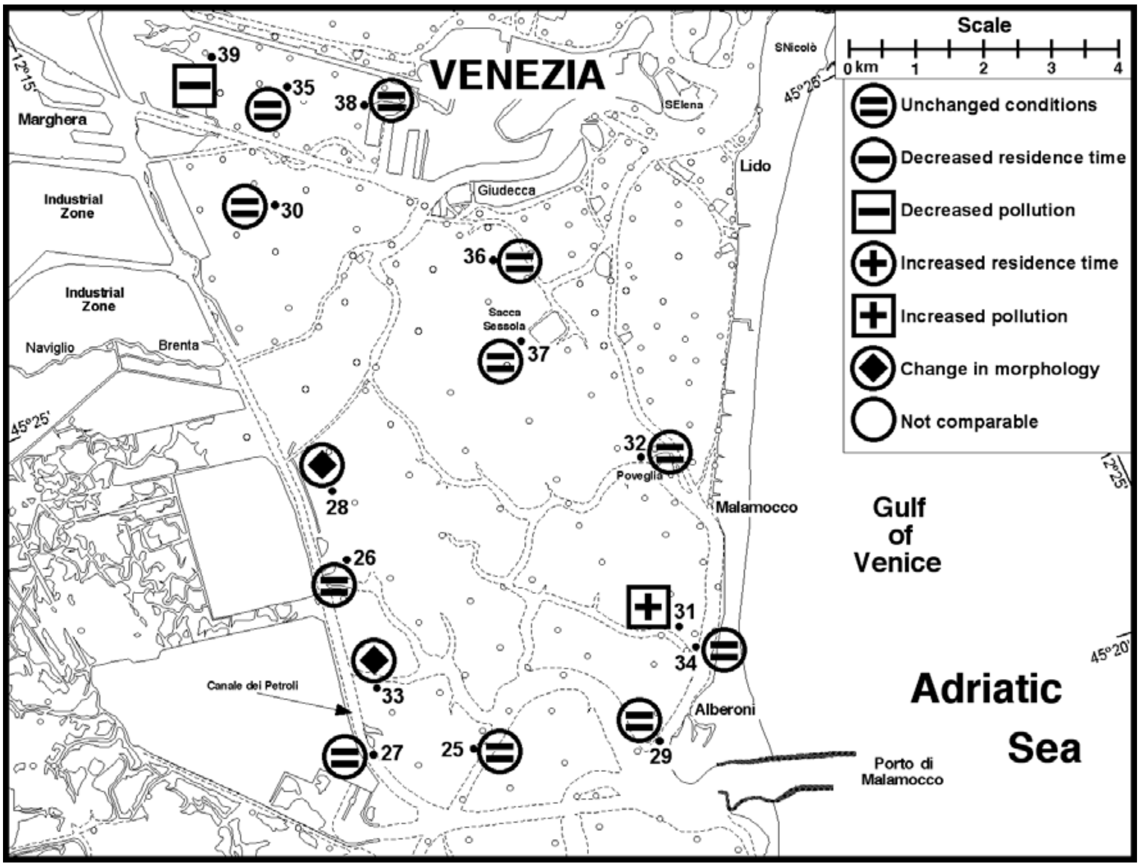

Fig. 7 – Summary view of the changes in the central sector of the Lagoon of Venice.

These are linked to the maintenance dredging of the channel in response to the navigational needs. The purification plant, operating since 1986, has improved the conditions in areas where industrial and urban stress predominated, shown by the decrease of faunas tolerant of such conditions, whereas no improvement is recorded in areas with local pollution sources such as at Tronchetto and off the island of S. Michele (stns 6 and 38). In addition, new areas with high environmental stress are noted in the northern sector of the Lagoon.

Along the Canale dei Petroli the collapse of some intertidal morphologies appears to be related to the local predominance of more marine conditions.

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THE RESIDUAL TIDAL CIRCULATION OF WATER, SEDIMENT AND ORGANICS IN NORTHERN VENICE LAGOON, ITALY

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Abstract

This paper is a description of a series of studies undertaken along the Treporti-Burano canal and its tributaries within the CORILA project 3.2 (Hydrodynamics and Morphology of Venice Lagoon). Three main activities are described: (1) frontal development at canal triple-junctions and the impact on scouring; (2) turbid plumes and the impact on residual sediment movement; and (3) the nature and effectiveness of submerged beaches on marsh protection. The over-arching purpose of the study was to measure the mass transport and residual motion of water, inorganic suspended particulate matter, and organic carbon within what is considered to be a key region of northern Venice Lagoon from the perspective of numerical simulation. The region is unique because tidal marshes on Palude della Rosa are accreting at 1.54 cm/a whereas, elsewhere in the Lagoon, erosion prevails. It is proposed that understanding the mechanisms at play in the northern Lagoon is vital to remediation or reversal of habitat destruction in the central and southern parts. Three important conclusions have been reached within the framework of this study: (1) enhanced shearing, peak flows, and vorticity are the mechanisms for scouring deep holes at triple-junctions, and evidence for significant resuspension at peak flows have been found; (2) strong residual flows were found, which enhance the export of material through Scanello and Palude Burano canals; and (3) submerged beaches formed of shelly sand appear widespread, and provide an effective barrier to wave erosion.

1. Introduction

Schubel and Kennedy (1984) recognised that tidal estuaries, such as Venice Lagoon, behave as filters to material entering at the head or the mouth. That is, material may be trapped within the estuary as it passes through it: this does not appear to be the case for Venice Lagoon. The efficiency of lagoonal filtering is strongly dependent on the non-tidal residual circulation, turbulent activity, and degree of stratification (Bowden, 1984). The residual currents vary in magnitude and direction within Venice Lagoon (Umgiesser, 2000) and hence the filtering efficiency may be expected to vary. The manifestation of this appears evident in the differing evolutionary trends of *paludi* north and south of Venice. To the north, Cappucci (2002) detected a mean upward growth of Palude della Rosa. This is in contrast to widespread erosion that is taking place on the adjacent Palude Burano: Yet both are within the catchment area of the

Treporti-Burano canal system. Given the general trends of erosion within Venice Lagoon, the question is asked: what factors lead to the accretion of Palude della Rosa, and equally important, why is Palude Burano not also undergoing accretion? Possible controls on the patterns of growth are: high local sediment supply from rivers, high sediment supply from the erosion of adjacent tidal flats, biological effects, local changes in wave exposure, changes in residual flows in the adjacent canals which favour import of sediment over export, or some combination of these mechanisms. The main objectives of this study were thus to: (1) determine the residual flows within the Treporti-Burano canal and two of its tributaries: Scanello canal which drains Palude della Rosa, and Palude Burano canal, which drains Palude Burano; (2) determine the mass balance of suspended particulate matter through the canals and (3) suggest sources and sinks of the suspended particulate matter. Other factors, unique to the region, have also been investigated. Specifically, to examine the role of canal triple junctions to enhance bed scour through frontal development and enhanced shear, and finally, to examine the serendipitous discovery of submerged beaches on the preservation of *paludi* through wave attenuance.

2. The study region and background relevant research

Venice Lagoon may be divided into four main physiographic regions, each with differing hydrodynamic and ecological characteristics. These are: permanently submerged channels and mudflats; intertidal mudflats (*paludi)* which are exposed during low tides; high intertidal salt marshes (*barene*) and tidal creeks which are

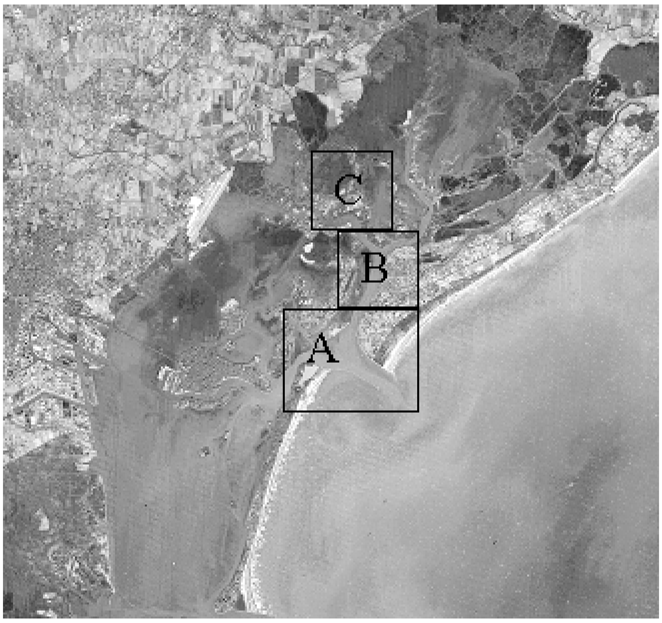

Fig. 1 - The location of surveys undertaken within the Lido-Treporti-Burano canal system, Venice Lagoon.

submerged only during extreme high tides; and the permanently subaerial islands and reclaimed regions. The study region of the Lido-Treporti-Burano canal system exhibits all four physiographic regions and is thus a valuable setting to examine the linkages between them, and in particular to examine factors leading to the accumulation of mudflats and salt marshes within the study area. It is part of a system of canals that starts at the Lido Entrance and passes into the northern Lagoon via the first-order canal of Treporti. This canal branches into the second-order canals of Burano and S. Felice, and thence into many third-order canals which feed and drain the *Paludi* of the northern Lagoon. In 2003, approximately 200 line km. of digital sidescan and bathymetric surveying were carried out along the Lido-Treporti-Burano-Dese system, in order to provide baseline information for process-oriented studies. As well, bottom sampling and vertical CTD profiles were collected from Lido to the Dese river, and headwards into S. Felice canal. These data are being processed to map the distribution of scour holes, sandy substrates, muddy substrates, submerged beaches, and seagrasses, and to identify key areas that merit further study.

Chick (2002) studied the evolution of large-scale bedforms in the Lido entrance (Figure 1, region A), and was able to demonstrate a flood-dominance to sand transport as bedload. She presented ADCP transects across Lido which were used to interpret the mechanisms leading to the sand transport, and concluded that this transport is ongoing and largely controlled by peak tidal flows. This was corroborated by trends in grain size of bottom sand which showed a consistent fining landwards. Further landward, Reed (2001) studied in detail the flow character and water mass transport in Treporti canal (Figure 1, region B). He mapped and described a 20 m-deep scour hole at the triple-junction of Treporti with Burano and S. Felice canals, and postulated peak flows, frontal turbulence, and vorticity as mechanisms of scour. As Chick (*ibid*), Reed found clear evidence for sediment mobility albeit through a different mechanism. In Reed's case, frontal turbulence during ebbing tides caused bed scour and resuspension. Reed also found a strong flood-oriented residual mass movement of water into S. Felice canal. In his opinion, the residual mass movement in the northern Lagoon is extremely complex and shows strong residuals and frontal shearing that cause scour. In 2003, synoptic flow measurements were made at several triple junctions known to have scours holes in order to see if a general pattern of flow emerged.

Recent bottom samples collected within the Treporti-Burano system within this study were largely composed of shelly sand. The source of this sand appears to be through reworking of the ancient sandy barrier islands which crop out within the Burano region. Much of this sand has been reworked into submerged beaches that border large parts of Palude della Centrega and Palude Burano, and which appear to provide a natural defence against erosion (Munford, 2002). Recent measurements undertaken in Burano canal demonstrate strong attenuance of boat wakes across the submerged beach due to the presence of *Cymadocea sp.* This work is also ongoing and further measurements of wave attenuance, sand resuspension, and beach texture are expected. CTD profiles along the canal system show vertical variations in temperature and salinity: the cooler, more saline water floods beneath warmer, fresher water creating a typical estuarine circulation (inflow at depth; outflow near the surface). An evaluation of the mass transport of water/sediment in the Palude della Rosa region (Figure 1, region C) was undertaken by Lea (2003) who demonstrated the complexity of residual flows in the region.

3. Inner canal system residual transport

Region C (Figure 1) is known for the presence of turbid plumes that appear to emanate from third-order canals. Two canals (Palude Burano and Scanello) were examined in order to determine the net transport patterns and how the material entering Burano canal is transported. Four transects (A-D) were established for hourly surveying across: (A) the mouth of Scanello; (B) northern Burano canal; (C) Palude Burano canal; and (4) southern Burano Canal (Fig.2).

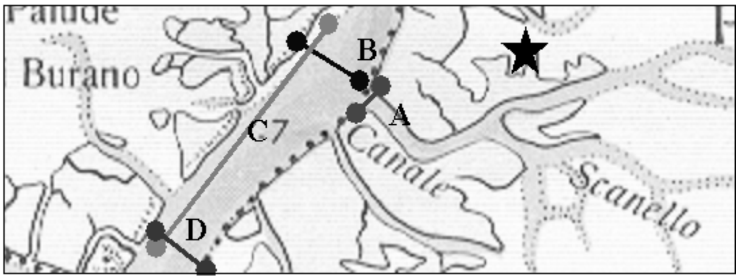

Fig. 2 - The transects occupied during this survey: (A) Scanello; (B) Burano north; (C) Palude Burano; and (D) Burano south. The star shows the site where accretion of 1.54 cm/a was measured by Cappucci (2002).

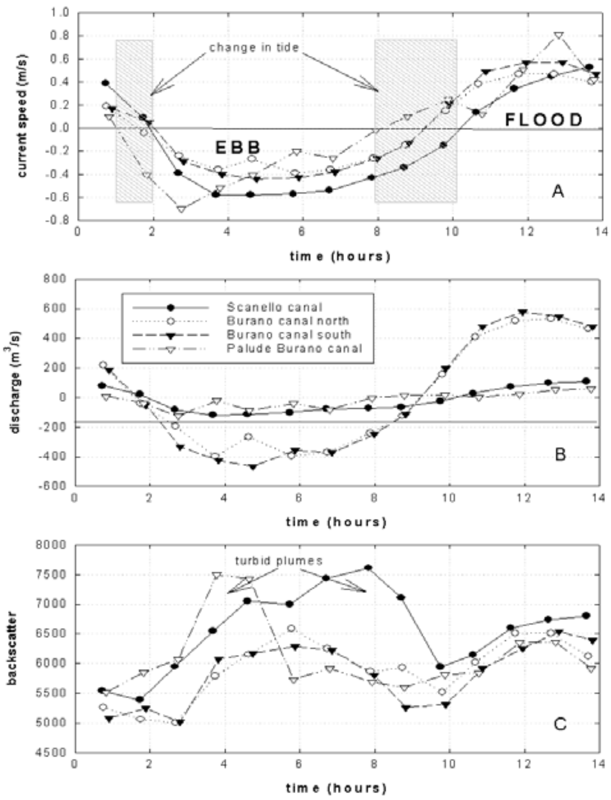

Fig. 3 - A time-series of ADCP data collected within the Burano-Scanello canal system; (A) current speed; (B) discharge; and (C) backscatter intensity.

The fieldwork for this study was carried out during August, 2001. The survey lasted a complete tidal cycle (13 hours) at hourly intervals. An *RDI Workhorse*[R] 1200 kHz Acoustic Doppler Current Profiler (ADCP) was used, which was interfaced to a Garmin[R] Global Positioning System. The detailed system configuration is described by Reed (2001) and by Lea (2003). 3-D current velocity and backscatter were measured in depth bins of 0.50 m to within 1 m of the bed. Surface water samples were collected mid-way along each transect hourly. These samples were filtered from suspended particulate matter, chlorophyll and organic content (through loss on ignition) in order to calibrate backscatter recorder by the ADCP in the water column.

The time-series of measurements for the four transects surveyed in the Burano-Scanello canal system are shown in Figure 3. It comprises a complete tidal cycle from high water to the subsequent high water. Burano north and south are very similar in current speeds and are significantly less than those monitored to the south. Volumetric discharges are flood dominant and similar to those evident from Treporti. By contrast, Scanello and Palude Burano canals are strongly ebb dominant; the ebb tide which flows into Burano canal lasts about 8.5 hours creating clearly visible turbid plumes in the relatively-clear waters of Burano canal (Figure 3C).

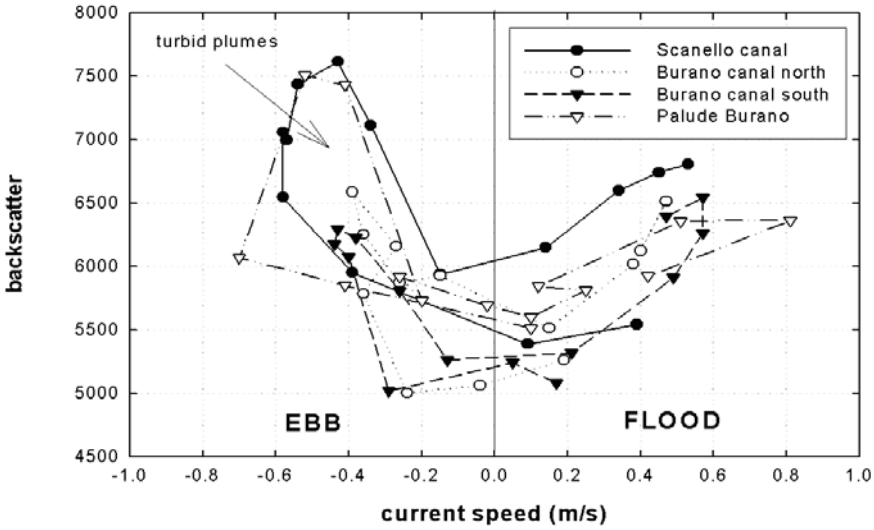

Fig. 4 - A bivariate plot of current speed versus backscatter intensity showing the dominance of turbid plumes during ebb tides.

The elevated turbidity is due to material entrained by flow over Palude Burano and Palude della Centrega and does not come from the flood waters of Burano or S. Felice canals which are the sources of the system. Flood waters entering Scanello and Palude Burano have similar levels of particulate matter to that of Burano indicating that material discharged on the ebb is dispersed and does not return on the subsequent flood. This is evident in Figure 4, which illustrates the relationship between backscatter and current speed. The turbid plumes (high backscatter) are evident only during mid-ebb stages and are synoptic with peak tidal flows (> 0.4 m/s). The plumes are considered to be due mainly to advection as no equivalent increase in turbidity is seen on the equally strong flood tide. Also note that below mean current speeds of 0.2 m/s, the backscatter remains evenly low. Whereas at higher speeds, there is a trend of increasing backscatter (resuspension) as speed increases. The inference is that bed scouring by tidal action is also taking place.

Burano S and N are remarkably similar in tidal pattern, volume discharge, and phase. The flood tide is 50% shorter in duration (5 hours) than the ebb (7.5 hours). Burano N has a lower flood discharge than Burano S as approximately 100 m^3/s of the flooding waters are directed into the two tributaries of Palude Burano (Burano W) and Scanello: Thus continuity mass is preserved (Table 1). The ebb is more complex as the sum of ebb discharges from Scanello, Burano W. and Burano N is greater than Burano S by approximately 100 m^3/s. We suspect that the extremely shallow waters in some parts of Burano W, which are bisected by several small channels from the Palude Burano, mask a complex 3-D flow structure. High tide flow reversal appears first in Palude Burano canal and is about 60 minutes ahead of flow reversals in Burano and Scanello canals. Low tide flow reversal is again first in Palude Burano whereas Scanello ebbs for a further 1.5 hours before slack water is encountered. During this time, waters enters Scanello from the north due to a westerly discharge from Palude della Centrega. The turbid nature of this ebbing flow is clear indication of erosion of the tidal flats to the east that exports sediment to the Burano canal system. In summary, Burano canal is weakly flood dominant whereas Scanello and Palude Burano are strongly ebb dominant: the latter having the greatest asymmetry (253%).

Tab. 1 - Volumetric estimates of discharge (m^3) for the Burano-Scanello canal system (+ is flood residual, - is ebb residual), and estimated X-sectional area (m^2).

SITE	*EBB*	*FLOOD*	*RESIDUAL*	*AREA*
SCANELLO	2.33×10^6	1.49×10^6	$- 0.84 \times 10^6$	194
BURANO N	7.59×10^6	8.77×10^6	$+ 1.38 \times 10^6$	1064
PALUDE BURANO	1.46×10^6	5.76×10^5	$- 0.88 \times 10^6$	987
BURANO S	8.61×10^6	8.87×10^6	$+ 0.26 \times 10^6$	108

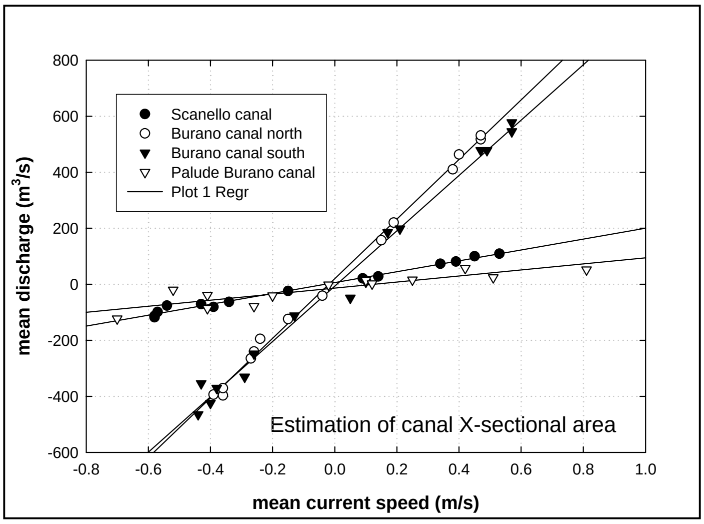

Fig. 5 - The estimated volume discharge rate plotted against mean current speed - used to derive the X-sectional area of the canals

The discharge-speed relationship may be used to derive a robust estimate of X-sectional area of the canal over the survey line. In Figure 5, these relationships are straight lines passing through the origin in all cases. The area is simply the slope of the lines, which is derived from linear regression. These estimates are presented in Table 1 and form a base-line for comparisons in the future from which changes may be evaluated. The trend lines (which span a full tidal cycle) are to mean water level; the changes in area due to the tide are evident as departures from the lines and, as seen, are small.

The ADCP transects show a distinct lack of vertical structure in velocity and direction diagnostic of fully turbulent flow conditions. The benthic boundary layer appears masked within the bottom bin and is thus order 1 m thick. The flow direction also appears constant with depth at all stages of the tide. A weak horizontal gradient in velocity is evident; fastest flows are centre canal, while the weakest are near the margins.

In Scanello, the strongest backscatter is noted in the deeper section of the channel. Backscatter increases across the channel throughout the ebb phase until at maximum ebb the whole channel returns high levels. At the slack low water stage, the backscatter decreases and shows stratification within the water column diagnostic of settling.

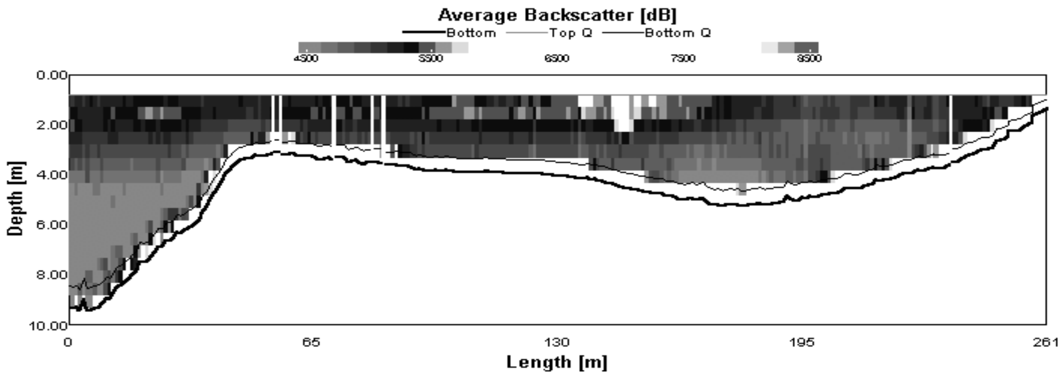

Fig. 6 - An E-W transect of Burano canal north showing the turbid waters in the Scanello scour hole and clearer flooding waters above

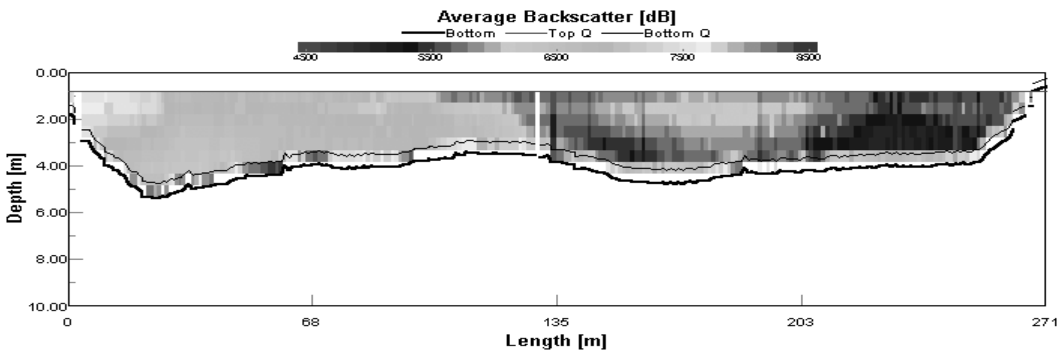

Fig. 7 - An E-W transect of Burano canal north showing the turbid plume from Scanello canal during mid ebb

Two profiles of backscatter, taken along section B (Fig. 2) from east to west, are shown in Figures 6 and 7. Figure 6 illustrates conditions near high tide and shows the relatively clear surface waters entering Burano canal over turbid bottom waters of the scour hole at the Scanello-Burano junction. This contrasts sharply with Figure 7, which shows the turbid plume of Scanello entering Burano canal in the east on an ebbing tide, creating a distinct sloping turbid front with the clearer waters in the west.

Tab. 2 - A summary of the analyses of surface water samples collected mid-way along the Burano transects throughout the survey period. SPM is suspended particulate matter; LOI is loss on ignition (at 450^0C) which yields the inorganic (sediment) concentration.

BURANO N				BURANO S			
Sample time	SPM (mg l^{-1})	LOI (mg l^{-1})	Inorganic (mg l^{-1})	Sample time	SPM (mg l^{-1})	LOI (mg l^{-1})	Inorganic (mg l^{-1})
18:45	187	85	102	18:53	131	76	55
19:44	120	45	75	19:52	137	78	59
20:41	165	99	66	20:48	120	75	45
21:43	180	74	106	21:49	168	71	97
22:38	141	81	60	22:44	148	94	54
23:46	183	90	93	23:52	132	122	10
00:43	215	90	125	00:50	123	85	38
01:52	107	61	46	01:58	100	61	39
02:44	146	94	52	02:50	145	90	55
03:53	133	78	55	03:59	145	86	59
04:43	158	78	80	04:48	136	71	65
05:41	149	90	59	05:57	194	80	114

SPM data were collected for surface samples mid-way along Burano canal north and south. The results of the analyses of these samples are presented in Table 2. Note the relatively constant values of all constituents within the surface layer. The range in SPM values is typical of tidal estuaries and does not influence either the settling character of material, nor the viscous behaviour of the flow. The ratio of organics:inorganics is about equal: inorganics are expected to increase in magnitude towards the bed.

4. Flow character at the Treporti triple junction

An ADCP survey similar to that at Burano was undertaken at the Treporti-S.Felice-Burano triple junction. Transects of the three canals were made hourly for thirteen hours.

Tab. 3 - Volumetric estimates of discharge (m^3) for the Treporti-S. Felice-Burano canal system (+ is flood residual, - is ebb residual), and estimated X-sectional area (m^2).

SITE	*EBB*	*FLOOD*	*RESIDUAL*	*AREA*
TREPORTI	2.38×10^7	3.65×10^7	$+ 1.27 \times 10^7$	2696
BURANO	4.40×10^6	1.05×10^7	$+ 0.61 \times 10^7$	757
S. FELICE	1.74×10^7	2.64×10^7	$+ 0.90 \times 10^7$	1171

The estimates of residual discharge is summarised in Table 3. All canals are strongly flood dominant with a mass influx of 1.27 x 10^7 m^3/tidal cycle, 72% of which enters S. Felice; the remainder entering Burano canal. The flood dominance of Burano is similar to that observed further landwards however the magnitude of the residual is a factor of 10 larger and is about 58% of the total flooding water mass.

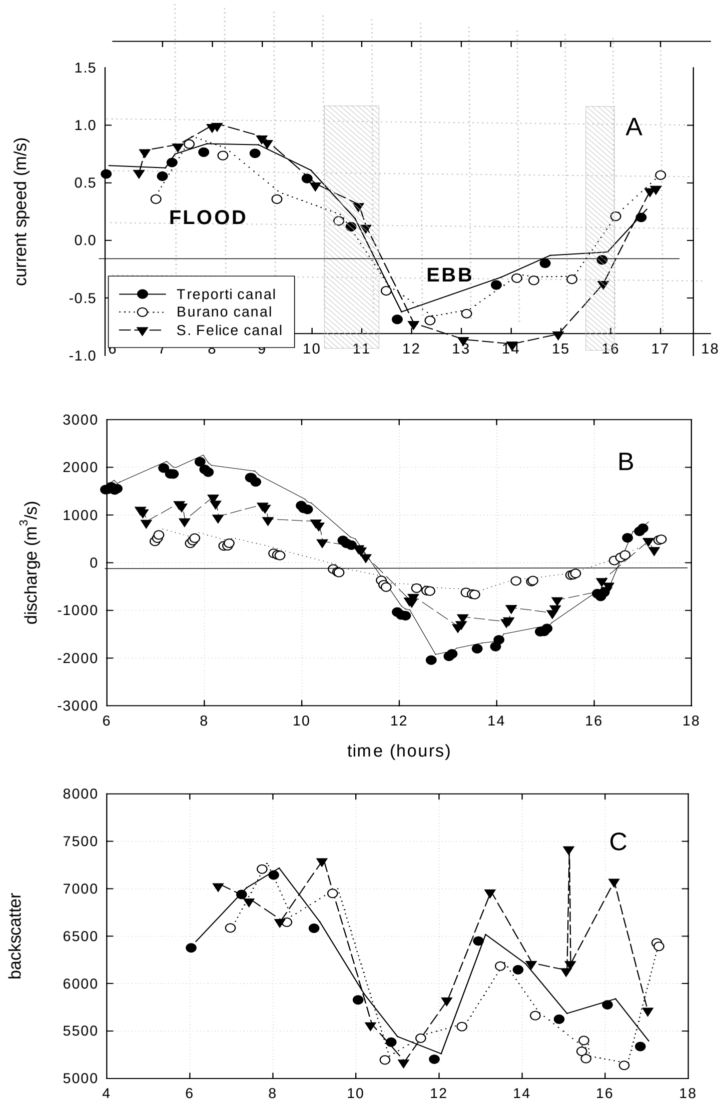

Fig. 8 - Time-series measurements of (A) mean current speed; (B) discharge; and (C) backscatter intensity within the Treporti-S. Felice-Burano triple junction

The time-series from the Treporti region is shown in Figure 8A. It demonstrates peak tidal flows in excess of 1 m/s and a slightly stronger flood current speed over the ebb. Tidal flows in S. Felice and Treporti are similar in magnitude, whereas the flows are much reduced in Burano canal. The consequence of this is seen in the discharge (Table 3). The backscatter is high on both flood and ebb tides. It is equal in magnitude in all three canals during the flood, but highest in S. Felice and Treporti on the ebb: Burano canal, by contrast, shows much clearer waters on the ebb tide reflecting a strong flood residual in suspended matter over the tidal cycle. The backscatter is greatest during peak tidal flows (Figure 8B). The inference of this is that SPM is largely due to resuspension (in Treporti and S. Felice), not advection. The time-series of backscatter during the ebb is erratic reflecting the passage of water masses of varying turbidities. The tide turns first to ebb in Burano. This is evident as a strong front at the triple junction of Treporti-Burano-S. Felice separating the ebbing waters of Burano (in the north-eastern part) from the still-flooding waters of Treporti. Vortices and shear are evident at the front with evidence of strong resuspension were these vortices reach the bed (Figure 9). This phenomenon lasts about 30 minutes only. The water depth beneath the region of scour can exceed 20 m and is evidence of active and ongoing morphological responses to tidal flow. Similarly, it is Burano that is first to experience flooding tides followed after 30 minutes by the remainder of the system.

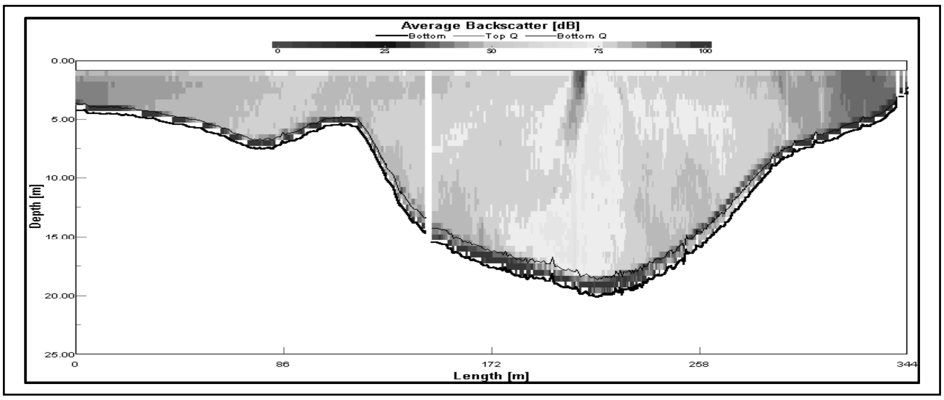

Fig. 9 - A section across Treporti canal from W-E. Burano at peak ebb. A front can be seen in the centre of the image with evidence for resuspension at the bed either side. Also, high turbidity and resuspension is evident at the mouth of Burano canal (left).

The suspended particulate matter of surface waters is generally higher on the ebb than on the flood. Approximately 50% of SPM is organic matter (through loss on ignition); the remainder is sediment. By contrast, chlorophyll is greatest on the flood tide and least on the ebbing tide. It is lowest at mid ebb, perhaps reflecting the highest turbidity levels associated with discharge from Palude Burano and Scanello.

5. Submerged beaches of Palude del Tralo

Shelly fine sand borders many of the marshes of northern Venice Lagoon. The sand is well sorted and has been found to extend to depths of 2 m. The sand sits on an eroded shoulder produced (in all probability) by marsh cliff recession through wave attack.

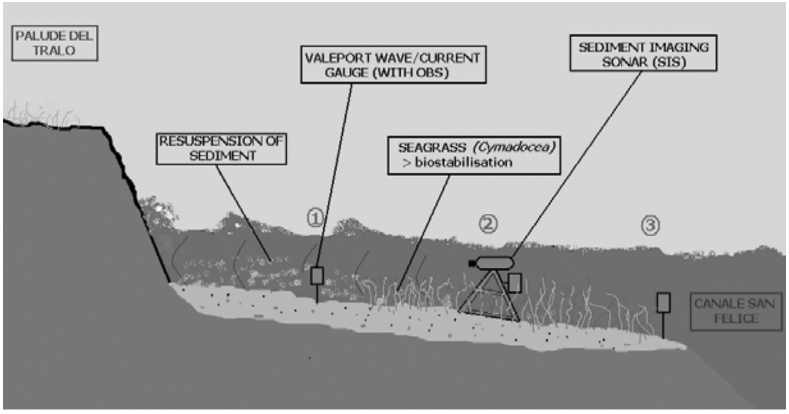

Fig. 10 - A schematic diagram of the eroded "shoulder " of Palude del Tralo on the north bank of S. Felice canal. The diagram illustrates the submerged beach with *Cymadocea* sp. growing on it. Also shown is the instrument array used in the study of wave attenuance.

A schematic representation of the submerged beach is shown in Figure 10. A survey undertaken with sidescan sonar shows strong evidence that such beaches are prevalent throughout the Burano canal system, if not elsewhere. The instrumentation array used to study wave attenuance and sand resuspension across the beach is shown in Figure 10, and is described by Munford (2002). Palude della Centrega has been studied by Ciavola *et al*, (2002). The sediments of this marsh are compact and consist of silts to fine silts and cannot, therefore, be the source of the sand found on the submerged beaches.

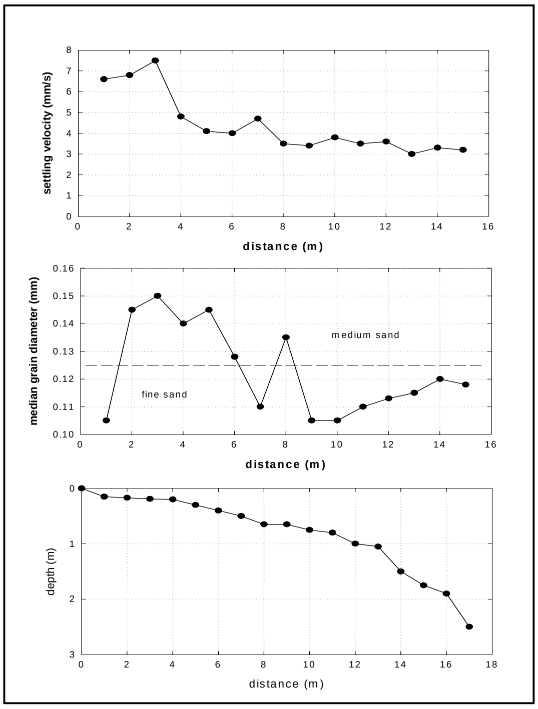

Fig. 11 - The profile of the submerged beach off Palude del Tralo showing (A) the settling velocity of bed material; (B) the mean grain size of the bed material; and (C) the beach profile to the canal edge which has a slope of 8^{o}.

Sediments, collected along the submerged beach, are composed of fine to medium sized shelly sand (Fig. 11). The sediment is well-sorted, which is diagnostic of regular reworking, and is often moulded into wave-formed ripples. The coarsest material is situated in the shallowest water closest to shore, and is associated with the region of wave breaking and sand resuspension. The still water settling velocity of the sand shows a systematic decrease seawards diagnostic of decreased reworking. This trend is reversed at the canal edge where the first line of wave breaking takes place.

The effect of wave breaking is seen in the time-series of synoptic hydrostatic pressure and turbidity measurements made at site 1 (Fig. 10) during the passage of a boat bow-wave train. The peak in turbidity, shown in Figure 12, clearly coincides with the passage of the wave train (E2). In this example, the maximum wave height is about 10 cm. A total of about 15 similar wave trains have been examined from two sites (the second in Burano canal). Unfortunately the wave trains are all from boat wakes, and as a consequence, are very small. Further work using a series of pressure/turbidity transducers across the beach during storm events would be required to evaluate fully the role of submerged beaches in marsh protection.

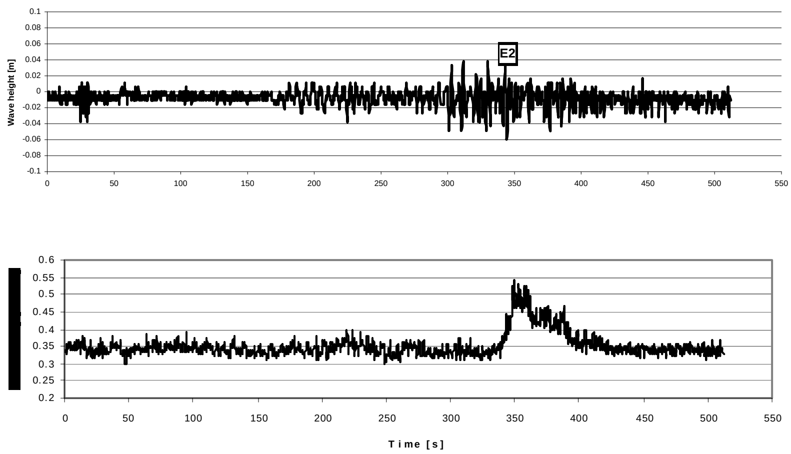

Fig. 12 - (A) a time-series of hydrostatic pressure illustrating the passage of a small wave train due to a boat wake (S3); (B) attenuance of the nearbed waters due to wave resuspension of sand due to the wave passage.

The role of coastal marsh plants in shear stress and turbulence reduction has been presented by Numeier and Amos (in press). This work shows the efficacy of intertidal plants in stress suppression and presents an effective method of analysis for evaluation of the turbulence spectra that might be used to examine the contribution of small waves to resuspension.

Finally, the analyses of systematic, digital bathymetry and sidescan sonar measurements made in the Lido-Treporti-Burano system are approaching completion. We anticipate a further field programme during spring, 2004 in order to complete this work. The sidescan imagery is effective in revealing the complexity of bottom character within the canal system and especially in mapping the distribution and extent of submerged beaches. As well, work is underway to develop an ultrasonic, narrow-beam sounder capable of measuring bed roughness at cm scales for purposes of defining bed roughness. This type of measurement is essential if bed shear stresses under waves are to be determined accurately, and is aniticipated to undergo trials in Venice Lagoon during Spring, 2004.

Conclusions

This paper reports on a linked series of studies undertaken within the Lido-Treporti-Burano canal system in an attempt to understand and define the links between hydrodynamic forcing and morphological character. The site chosen has been considered key to understanding the long-term evolution of *paludi* in Venice Lagoon as there are sites where growth is taking place and others where recession dominates: one purpose is to understand the differences in setting of these two contrasting regions. As well, the hydrodynamic measurements provide valuable calibration data for a hydrodynamic/sedimentation numerical model of the region.

The highlights of this study have been the identification of the mechanism leading to the genesis and growth of scour holes (which are up to 20 m deep). Frontal turbulence and vorticity together with strong tidal flows enhance scouring and resuspension. Resuspension under peak flows is prevalent in all regions monitored and illustrates the dynamic nature of Venice Lagoon and the high mobility of sediments. It appears that the canal system under study is continuing to enlarge and deepen.

Submerged beaches were found to be widespread. They border the marshes and provide an effective and natural mechanism of marsh protection. The source of the and of these beaches is unkown.

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RESEARCH LINE 3.3
Efficiency of lagoon metabolism

SEDIMENT QUALITY ASSESSMENT IN THE LAGOON OF VENICE USING A BATTERY OF TOXICITY BIOASSAYS

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Riassunto

Una batteria, composta da quattro test tossicologici, spermiotossicità ed embriotossicità con *Paracentrotus lividus*, embriotossicità con *Crassostrea gigas* e Microtox® Solid-Phase test, è stata impiegata per indagare la presenza di effetti tossici in campioni di sedimento superficiale raccolti mediante carotaggio dei primi 20 cm e provenienti da quattro siti della Laguna di Venezia aventi caratteristiche fisiche e grado di contaminazione diversi. I risultati dei test di spermiotossicità con *P. lividus* hanno mostrato una irrilevante tossicità acuta per gli elutriati provenienti da tutti e quattro i siti; i test di embriotossicità con *P. lividus* evidenziano un gradiente di tossicità sub cronica per gli elutriati, in generale accordo con i risultati del Microtox® Solid-Phase e con quelli ottenuti con *C. gigas*. I risultati ottenuti sono stati comparati con dati precedenti, ottenuti utilizzando la stessa batteria su numerose aree della laguna ed hanno evidenziato come il sito scelto come potenzialmente di "riferimento" presenti valori di tossicità superiori a quelli incontrati precedentemente in siti "puliti" nella Laguna di Venezia.

Un altro obiettivo della ricerca è stato quello di mettere in evidenza come i fenomeni di risospensione possano essere fattori che influenzano la distribuzione della tossicità. A questo scopo sono effettuati test di embriotossicità con *P. lividus* sugli elutriati ottenuti da campioni di sedimento da carote relative ai primi 5 cm e provenienti dalle stesse stazioni di campionamento. Gli elutriati dei primi 5 cm di sedimento hanno rivelato un gradiente di tossicità completamente invertito rispetto a quello trovato per i campioni di sedimento dei primi 20 cm e la presenza di "hot spot" di contaminazione nel sito scelto come possibile area di riferimento (S.Erasmo). I risultati hanno evidenziato come la risospensione di sedimenti contaminati e la rideposizione in aree diverse possano essere un possibile fattore in grado di influenzare la tossicità sub cronica in zone particolarmente disturbate della Laguna aperta.

Abstract

A battery of four toxicity bioassays, the sperm cell toxicity test and the embryotoxicity with sea urchin *Paracentrotus lividus*, the embryotoxicity with bivalve *Crassostrea gigas* and Microtox® Solid-Phase test, has been provided to investigate the toxic effect in surficial sediment samples (20 cm) from sites of the Lagoon of Venice covering different physical typologies and levels of contamination .

Sperm cell toxicity test results showed negligible acute toxicity of elutriates from all investigated sites; the embryo toxicity test with *P. lividus* evidenced a sub-chronic toxicity gradient for elutriates, in general agreement both with the expected contamination gradient and with results of the Microtox® Solid-Phase test the *C. gigas* test. Toxicity results were compared with previous data obtained using the same battery covering numerous areas of the Lagoon. All tests evidenced that the sediment toxicity values in the potential reference site (S.Erasmo) were higher than previous data from “clean” sites in the Lagoon of Venice.

1. Introduction

Toxic level in core-top 20 cm deep surface sediments of four sites (Tresse, Celestia, Foce Dese, S. Erasmo) covering different typologies and level of contamination in the Lagoon of Venice was estimated by means of a battery of bioassays: Microtox® solid-phase test, sperm cell and embryo toxicity tests using the autochthonous sea urchin *Paracentrotus lividus*, embryotoxicity test using the oyster *Crassostrea gigas*. Elutriate was chosen as matrix for tests using sea urchin and oyster, due to its ability to highlight potential toxic effects towards sensitive biological components of the water column as early life stages of lagoonal species, whereas Microtox® Solid-Phase test was used to evaluate toxic effects in whole sediment due to contaminants which were bound to grain surface or were soluble in interstitial fluids.

Another aim of the research was to put in evidence if the sediment resuspension phenomena, well known in the central basin of Lagoon, could be possible factors influencing the distribution of the toxicity. In the same sites a screening investigation on more superficial sediment (core-top 5 cm deep) was contemporaneously carried out using *P. lividus* tests.

2. Materials and methods

2.1. Sediment sampling and characterization

Four sampling sites, were selected in co-ordination with other research groups (Co.Ri.La. Project, Line 3.3 . “Efficiency of the lagoon metabolism”) and based on previous data. Three sites (SE, CEL, TR) were located in zones influenced by anthropogenic activities, in shallows characterized by bare substrates. A fourth sampling site (DE) was located in an estuarine area. One station (SE) was close to Sant’Erasmo island , in an area characterized by fast water turnover [Melaku Canu et al., 2001] due to the proximity of the Lido sea inlet, and presumably also by a minimum degree of contamination. This site was classified as a high-quality site (class A for both organic and inorganic micropollutants) [Venice Water Authority, 1999, Volpi Ghirardini et al., 2003a] according to current quality criteria used to classify dredged sediments in the Lagoon of Venice [Volpi Ghirardini et al., 2001]. For this reason, this site was chosen as a possible reference. The second site, Celestia (CEL), was located between the island of Murano and the north-eastern side of the city of Venice. The site receives untreated municipal wastewater (from Venice city centre) and may also be affected by contamination from industrial sources, due to the vicinity of Murano, where several glass factories are located. The contamination level of the area near the site is medium for heavy metals (class B) and higher for organic micropollutants (class C) [Volpi Ghirardini et al., 2003a]. The third station (TR) was located off Tresse, an artificial island composed of rubble dredged from the Industrial Zone channels near Porto Marghera. This site had already been investigated from a chemical point of view, and had revealed high contamination levels of both heavy metals and organic micropollutants (class C) [Volpi Ghirardini et al., 2003a]. The fourth station (DE), located in the estuary of the river Dese, is affected by pollution from agricultural drainage. It had been studied by our research group and showed a medium contamination level (class B) for both organic and inorganic micropollutants and moderate toxicity [Volpi Ghirardini et al., 2003a].

Core sediment samples were collected in an area (a circle approximately 30 metres across, with a central point fixed by geographical co-ordinates) in order to carrying out an integrated sampling [Volpi Ghirardini et al. 2003b]. In the text, the numbers 5 and 20 after the site identification labels indicate the core-top 5-cm sediment samples and the core 20-cm sediments samples, respectively. Samples, stored at 4°C, were homogenized within 24 hours of sediment collection in nitrogen atmosphere. Several sub-samples were prepared for sediment characterization and processing, to obtain elutriates for toxicity bioassays and chemical analyses.

Analyses of grain size, volatile organic matter and water content were carried out for sediment characterization. Sediment cores were thoroughly washed with distilled water to remove residual sea salts. The sediments were treated with H_2O_2 to remove organic matter and then oven-dried at 45°C. The dry samples were sieved through a 62 µm sieve in order to separate sand from the pelitic fraction (< 62 µm). The sample fraction < 62 µm was dispersed in a 6‰ Na-hexametaphosphate solution for 24 hours and ultrasonically treated (bath) for a time not exceeding 10 min. The grain size distribution in < 62 µm fraction was determined by Micromeritics SediGraph 5000D (Mönchemgladbach, Germany). The percentage of water content was calculated as the weight difference between wet and dried sediments (dried overnight at 105°C) (ASTM, 1990), in three replicates for each sediment sample. Volatile organic matter content was determined by subtracting the weight of a sediment aliquot burned at 450°C from the weight of the same aliquot dried at 105°C (Loss-on-ignition), in three replicates for each sediment sample.

2.2. Elutriation and chemical analyses of elutriates

Elutriates were prepared according to the method reported in Volpi Ghirardini et al. [2003a, 2003b]. Briefly, the elutriation steps were the following: addition of artificial seawater (Ocean Fish, Prodac International, Cittadella, PD, Italy) to sediment samples at a sample dilution of 1:4 w'/v (w'= sediment dry-weight; v = dilution water volume); stirring of the sediment-water mixture for 24 hours at 230 rpm at 4°C using a Jar test (mod. ISCO, Vittadini, Milan, Italy); settling of the mixture for 60 minutes at 4°C; centrifuging of the supernatant at 7,700g at 4°C for 15 minutes using a refrigerated ultracentrifuge (mod. L7-35, Beckmann, Milan, Italy); storing the supernatant, without filtering, in 100-mL PE containers, and then freezing it at –18°C for later toxicological analyses. Only 100 mL of each elutriate sample were filtered through Whatman GF/F 0.7-µm filters, for total ammonia and sulphide analyses.

Concentrations of sulphides and total ammonia in elutriates were measured with a spectrophotometer (mod.DR/2010, HACH, Loveland, CO, USA) using the methylene blue method (USEPA SM 4500-S2 D) for sulphides and the salicylate method (Reardon et al., 1966) for total ammonia. These analyses were performed to evaluate the possible influence of these chemical compounds on elutriate toxicity.

2.3. Toxicity bioassays

Microtox solid-phase test was performed according to Large Sample Solid-Phase protocol, provided by Azur Environmental [Microbics Corporation, 1992], but following modifications introduced by Volpi Ghirardini et al [1998; 1999] to adapt the test to sediment features of the Venice Lagoon.

Bioassays with *P. lividus* were performed according to Volpi Ghirardini and Arizzi Novelli [2001] and Arizzi Novelli et al. [2002], using adults collected from an unpolluted site in the northern Adriatic (Italy) and stored at mean temperature, salinity and pH of 18.00±1.35°C, 34.85±0.49 ‰ and 7.80±0.19, respectively.

Bioassays with *Crassostrea gigas* were performed according to His et al. [1997]. Mature animals from a conditioning sea-farm (Guernsey Sea Farms Limited, UK), were induced to spawn by thermal stimulation. Spawners were individually transferred to sterile beakers with artificial sea water. Gametes from three females and three males were sieved through sterile 100 µm and 32 µm (respectively) sieves to remove tissue debris. About 10 mL of sperm solution was added to 500 mL eggs suspension; fertilisation success was verified by microscopic examination. Fifteen minutes after fertilisation, volumes corresponding to 200 eggs were exposed to 3 mL test solution and incubated for 24 h at 24°C. After the incubation period buffered formalin was added and the percentage of anomalies was determined counting 100 larvae.

Bioassays using early life stages of sea urchin and oyster were performed on differing elutriate dilutions (25%, 50%, 75%, 100%), using sterile polystyrene micro-plates with lids (Iwaki Brand, Tokyo, Japan) as test chambers. Three experimental replicates were used for each dilution and for control tests. At the same time, tests were carried out on positive controls (with copper as reference toxicant).

Data are expressed as EC50 and UT50 (=100/EC50) values. The percentage of effect was considered to discriminate fewer toxic samples [Volpi Ghirardini et al., 2003a]. Responses to each treatment (% of fertilized eggs, % of normal plutei) were corrected for effects in control tests by applying Abbott’s formula. The EC50 values with 95% confidence limits were calculated using the Trimmed Spearman-Karber statistical method [Volpi Ghirardini and Arizzi Novelli, 2001]. The EC50 values for Microtox® Solid-Phase test were calculated using MicrotoxOmni™ Software by mean of regression statistics of logarithm of concentrations on logarithm of gamma values function, a ratio of light output of the control at time t to the light output for a given sample concentration at the same test time.

3. Results and discussion

3.1. Sediment characterisation

Results of grain size, organic matter and water content analyses highlight different sedimentological environments for the four sites (Tab. 1). Samples from site SE show very similar percentages of sand, silt and clay. Sample CEL-5 shows a larger amount of sandy fraction compared with sample CEL-20, taking into account that CEL-20 is a homogenized sample, containing also the 5-cm surficial sediment, and that the deeper layers of the cores should have lower sandy fractions. The same case is demonstrated in samples from site TR, where TR-5 is sandier than TR-20. Samples from site DE show a completely different particle size distribution with respect to the other three sites, confirming the difference in sedimentological environment, where specific physico-chemical processes take place. As regards organic matter, sample DE-20 exhibited the highest volatile organic matter content coming from decay of plant debris (several vegetal fragments deriving from riverine vegetation were found during sample homogenization). Results on organic matter highlighted that low concentrations were associated with sandy sediments and high concentrations with mud, in agreement with Mayer (1994a,b). As regards water content, percentages in sediments from site DE were from 2 to 3 times higher than in the other samples; water content differences among the sites were closely related with the different grain size composition of sediments, particularly clay.

Tab. 1 – Geographical co-ordinates of the stations and results of grain size and organic matter analyses, and water content for the two core sediment samples (5 cm and 20 cm deep).

Samples	Station Co-ordinates		***Grain size %***			OM	**Water content**
	Latitude	Longitude	Sand	Silt	Clay	%	%
SE-5	45°27'25''	12°25'31''	75	23	2	1.4	24
SE-20			76	22	2	0.9	20
CEL-5	45°26'25''	12°21'13''	65	33	2	1	26
CEL-20			51	45	4	2.5	23
DE-5	45°32'16''	12°23'14''	2	56	42	3.7	60
DE-20			4	52	44	6.5	58
TR-5	45°26'16''	12°15'60''	84	14	2	1	22
TR-20			57	33	10	4.1	32

3.2. Toxicity bioassays

The Microtox solid-phase test, performed on the sample cores of 20 cm, revealed the following gradient in toxicity (Fig. 1): TR-20 > DE-20 > CEL-20 > SE-20. The sediment toxicity value in the potential reference site (SE-20) was higher with respect to other low impacted sites previously investigated in the Lagoon of Venice. The value for TR-20 was the highest found in the open Lagoon [Volpi Ghirardini et al., 1998, 1999].

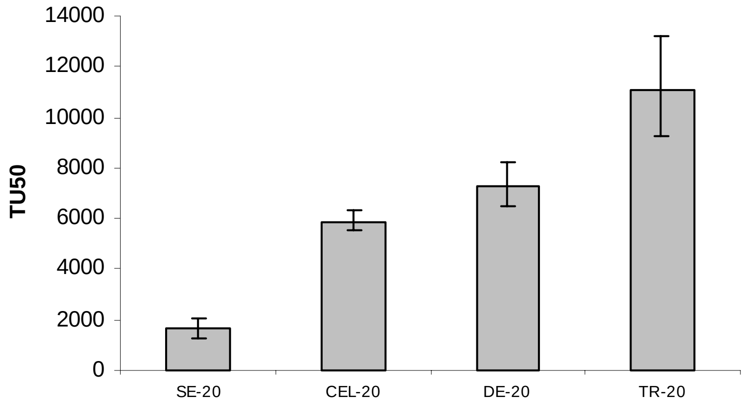

Fig. 1 – Results of Microtox solid-phase test on the core-top 20 cm sediments.

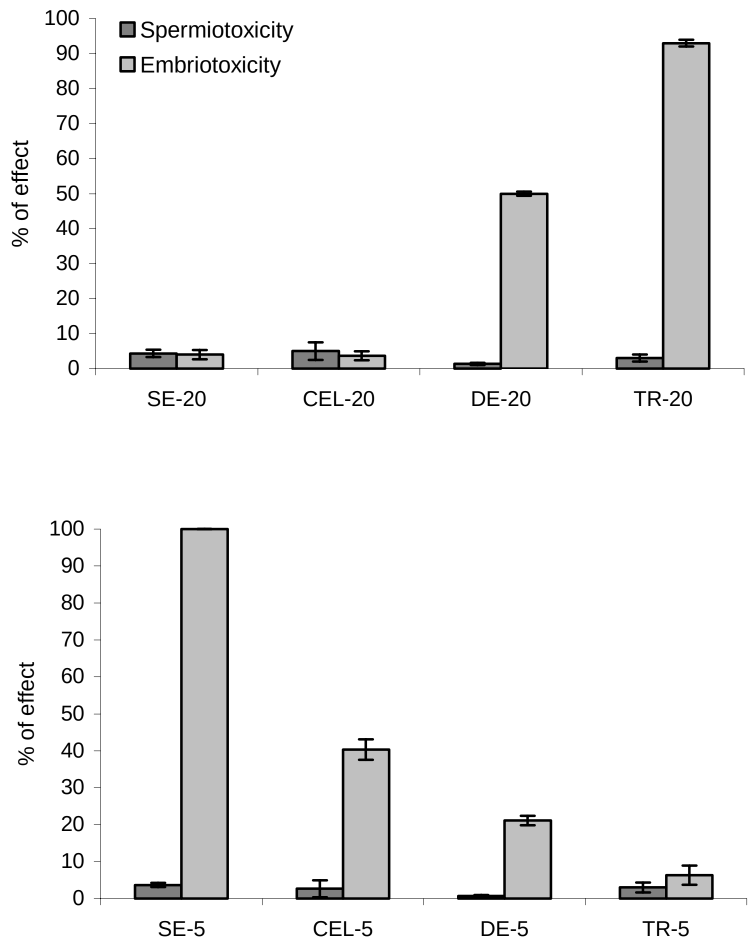

Fig. 2 – Results of spermiotoxicity and embryotoxicity tests with *P. lividus* on the elutriates obtained from the core-top 20 cm (top) and core-top 5 cm (bottom) sediments.

About tests with *P. lividus*, controls showed, during the experimental period, 87±5 % of fertilized eggs (C.V. = 6.2 %, n = 58) and 80±5 % of normally developed plutei (C.V. = 5.9 %, n = 52). Experiments using copper as reference toxicant produced toxicity data well within the acceptability range of both tests [Volpi Ghirardini and Arizzi Novelli, 2001; Arizzi Novelli et al. 2002]. The results of both tests for elutriates are shown in Fig. 2. The data of sperm cell test (sensitivity similar to that of an acute test) revealed extremely low toxicity of all elutriate samples (5 and 20 cm sediments); indeed, the most spermiotoxic sample was CEL-20, with only 5% of unfertilized eggs in treatment with undiluted elutriate. Instead, the embryo toxicity assay (considered a short-term chronic test) was able to distinguish the various toxicity responses. It was possible to calculate the EC50 only for the most toxic samples SE-5 and TR-20, which had a percentage of effect >50%; SE-5 (elutriate extracted from the chosen reference site) showed a mean EC50 ± SD of 39.7 ± 1.8% and TR-20 a mean EC50 ± SD of 72.8 ± 0.9%. As Fig. 2 clearly shows, samples CEL-5, DE-5 and DE-20 had abnormal pluteus percentages of 40.3%, 21.1% and 50.0% respectively, whereas SE-20, CEL-20 and TR-5 had extremely low embryo toxicity. Different trends at the two investigated depths were evidenced, with an unexpected "hot spot" of toxicity in sample SE-5.

Tab. 2 – Elutriates pH, total sulphides and total ammonia concentrations.

Sample	pH	Total sulphides (mg/L)	Total ammonia (mg/L)
SE-5	8.1	0.005	2.07
SE-20	8.2	0.015	1.52
CEL-5	8.3	0.012	1.67
CEL-20	8.0	0.004	1.40
DE-5	8.2	0.007	4.40
DE-20	8.0	0.048	4.97
TR-5	8.1	0.014	1.63
TR-20	8.2	n.d.[1]	4.50

[1] Not detectable. Under instrumental detection limits

About tests with *C. gigas*, controls showed 83±4 % of normally developed plutei, that means an accettable level of malformation and mortality (His et al., 1997). The samples investigated with *C. gigas* are elutriates from sites CEL and SE. CEL-20 and CEL-5 showed low toxicity, with a percentage of effects of 2% and 34%, respectively. The difference in toxicity in the site SE was highlighted also by this test: SE-20 showed 39% of effect while SE-5 100% of effect, with a calculable EC50 of 31% of elutriate (UT50 = 3.2). Also the sample SE-20 data were compared. The sulphide concentrations found in elutriates (Tab. 2) do not represent a possible confounding factor in sea urchin and oyster bioassays: the EC50 and the NOEC values for *P. lividus* are respectively 1.20 mg/L and 0.11 mg/L (total sulphide) for the sperm cell test and 0.43 mg/L and 0.10 mg/L for the embryotoxicity test (Losso et al., 2003); the EC50 and the NOEC values for the embryotoxicity test with *C. gigas* are respectively 0.34 mg/L and 0.10 mg/L (ASTM, 1998). For ammonia (Tab. 2), only in the case of the samples DE-20, TR-20 and DE-5 could ammonia greatly contribute to the embryotoxicity with *P. lividus*, exceeding the EC50 value (4.2 mg/L as total ammonia at pH 8.0) (Arizzi Novelli et al., 2003). We can exclude the influence of ammonia in toxicity data obtained with oysters for SE and CEL sites because total ammonia of elutriates are below the threshold values

(4.7 mg/L for total ammonia) reported by ASTM (1998) for embryotoxicity test with *C. gigas*. In conclusion, this study of confounding factors allows us to confirm that the "hot spot" of SE-5 showed high toxicity not attributable to ammonia but produced by an unidentified mixture of pollutants.

Conclusions

This work aimed at providing evidences of sediment toxicity using a battery of acute and short-term chronic tests on elutriates, identifying possible confounding factors of toxicity (such as ammonia and sulphides) and taking into account the physico-chemical characteristics of sediments (particle size, organic matter and water content). Integrated physico-chemical and toxicity results on sediments at different depths demonstrated the presence of disturbed sediments in the central basin of the Lagoon of Venice.

The toxicity gradient (embryotoxicity bioassay with *P. lividus*) for 20-cm sediment cores generally fitted data concerning chemical contamination and Microtox® Solid-Phase test, whereas a completely unexpected and inverted trend of toxicity was found in the core-top 5-cm surficial sediment, with respect to that of 20 cm. At the same time, particle size data showed coarser sediment composition in some surficial sediments, with great differences in composition from top 5 and top 20 cm. Moreover, an unexpected "hot spot" of toxicity was found in the more surficial layer of the site chosen as a possible reference, also confirmed by embryotoxicity test with the mussel *Mytilus galloprovincialis* (Losso, unpublished data).

These results suggest that, in the central basin of the Lagoon of Venice, resuspension phenomena remove pollutants from polluted area redepositing them according to the tidal currents. In this context, effects on resident water column organisms cannot be excluded and should be closely investigate (Losso et al., 2004). d.

Environmental matrices used for toxicity bioassays thus turn out to be suitable for investigating sediment quality. In particular, elutriate toxicity did not seem to be greatly affected by confounding factors such as sulphide and ammonia contents in the studiedsites.

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EVALUATION OF BENTHIC SECONDARY PRODUCTION IN THE VENETIAN LAGOON USING EMPIRICAL EQUATIONS

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Riassunto

È stato condotto un primo tentativo di valutare indirettamente la produzione secondaria dei macroinvertebrati bentonici in alcuni bassofondali della Laguna di Venezia usando alcune equazioni empiriche rinvenibili in letteratura. Le stime hanno fornito valori di produzione secondaria compresi tra i 40 ed i 60 g AFDW m-2 yr-1, mentre, ai siti che avevano subito recenti crisi distrofiche, si può attribuire una produzione secondaria che va dai 5 ai 25 g AFDW m-2 yr-1. Tuttavia, risulta fondamentale mantenere una grande attenzione nell'applicazione delle equazioni empiriche, in quanto esse risentono sia dei parametri ambientali, quali la temperatura, che dei parametri biologici, quali il metodo scelto per la misura della biomassa.

Abstract

A first attempt to evaluate Secondary production of macrobenthos from the Venetian Lagoon using empirical equations is proposed. Mud flats belonging to the lower intertidal showed a secondary production of 40 ed i 60 g AFDW m-2 yr-1. In sites that were affected by summer dystrophic crises, the secondary production was estimated to be between 5 and 25 g AFDW m-2 yr-1. Caution should be used in the application of empirical equations because of their sensitivity to environmental parameters, such as temperature, and to the biological parameters used, such as the way biomass is measured.

1. Introduction

Benthic secondary production can be evaluated using direct measurements or indirect estimations.

Direct methods give a "real" measurement of secondary production. One of the most accurate direct methods consists in measuring the biomass variations of each cohort of a given population [the “*Increment Summation Method*”, Allen, 1950, 1971], whereas cohorts are not clearly separable a method called " size-frequency method" [Hynes and Coleman,1968; Krueger and Martin. 1980]. Anyway, these methods require long and accurate dedicated studies, supported by adequate sampling design and strategies.

Indirect methods or regression methods [e.g. Robertson, 1979; Banse and Mosher, 1980; Schwinghamer et al. 1986; Plante and Downing, 1989; Brey 1990, 1999, 2001; Edgar, 1990; Morin and Bourassa, 1992; Sprung, 1993; Tumbiolo and Downing, 1994] differ from direct methods because they infer just an estimation of secondary production (and/or secondary productivity) from other biological and environmental parameters. These empirical models are based on the correlation, observed in a certain number of studies, between secondary production and some measured population features (e.g. average lifespan, average biomass, individual weight at the sexual maturity etc.) often combined with observed correlations with some environmental parameter (e.g. temperature, depth).

2. Material and methods

To perform any indirect estimation of Secondary Production for the whole Venetian Lagoon, long term studies are needed. The dataset used for this first evaluation of the indirect methods for the estimation of secondary production, consists of annual studies on macrobenthic communities carried out in the Venetian Lagoon by the authors during the 1990s.

On the basis of our set of variables i.e. abundance, biomass, number of species, temperature and depth, only three of the above mentioned methods could be used in this study,: Edgar's (1990), Morin and Bourassa's (1992), and Brey's (1999; 2001) models.

Other empirical models needed more detailed information, such as lifespan as for Robertson, (1979) or individual weight at the first sexual maturity as for Banse and Mosher (1980) and therefore they were not applied here. Since the Morin and Bourassa's model was produced for fresh waters, in this study it was applied just in an explorative way.

Tumbiolo and Downing's model (1994) require the measurements of “Maximum Individual Body Mass” calculated for each population in a sample, metric that seldom is considered. From our data we could calculate in place of the “Maximum Individual Body Mass” the highest value of the “Mean Individual Body Mass” but, in the frequent case of high presence of juveniles, the “Mean Individual Body Mass” will be very different from the “Maximum Individual Body Mass”. Therefore, we preferred not to use, for the moment, this model.

When models used dry weight instead of ash-free-dry-weight, we adopted the Brey’s conversion factors afdw/dw (ash-free dry weight/ dry weight).

Other models refers to the dry weight of molluscs or without shell [Morin & Bourassa, 1992] or with shell dissolved in Chloridric Acid [Tumbiolo & Downing, 1994], in these cases we used a conversion factor between dw and afdw.

During the application of Edgar's model, in order to calculate the production in the interval between the sampling dates, figures from samples taken at the beginning and at the end of the period, were averaged. Individual daily production was then multiplied by the inter-sampling mean population abundance and by the number of inter-sampling days. “Infauna” coefficient was used mostly for polychaetes and the “General” coefficient was used when taxa did not fit other categories.

Temperature averaged form meteorological reports were preferred to in situ water bottom temperatures, because the latter were measured just during the samplings so that they does not constitute a continuous time series. In situ measured average air temperatures were very close to the bottom water temperatures (some Celsius degree warmer in summer and some Celsius degree colder in winter) due to the shallowness of the Venetian lagoon. Water and air temperatures measured in situ were compared with air temperature measured at the two meteorological station in Venice at the same time, data from Istituto Cavanis resulted closer to the field temperature.

For the Edgar's model the average temperature of the inter-sampling period was used. Average water temperatures, required by the models, were then obtained from meteorological reports of two stations located in Venice City. One meteorological station is managed by the Istituto di Scienze del Mare, Consiglio Nazionale delle Ricerche, (latitude 45° 25' 50" N, longitude 12° 21' 15" E station elevation on msl m 16) the second stations in managed by the Istituto Cavanis (Latitudine: 45°25'48'' N Longitude: 12°19'25''E, station elevation on msl m. 18,08).

Detailed meteorological bulletins are downloadable from the web (Istituto Cavanis http://www.istitutoveneto.it/venezia/dati/atmosfera/dati_cavanis/cavanis.asp; Istituto di Scienze del Mare CNR, http://www.ibm.ve.cnr.it/meteo/intro.htm).

The equations used in the empirical models are reported below.

Edgar (1990)

log P =a + b * log W +c* log T

Faunistic group	coefficients		
	a	b	c
General	-2,31	0,80	0,89
Infauna	-2,46	0,79	1,05
Crustacea	-2,86	0,81	1,32
Mollusca	-2,18	0,87	0,46

Where :

P= Individual daily production [micrograms AFDW $m^{-2} day^{-1}$]

W= Mean individual body mass [micrograms AFDW]

T = Mean daily temperature for the considered period [°C]

Morin and Bourassa

Log P= -0,75+ 1,01 log B-0,34 log W + 0,037 T

Where :

P = Population annual production [g m^{-2} DW $year^{-1}$]

B = Population average annual biomass [g m^{-2} DW]

W = Mean individual body mass [g DW]

T = Average annual temperature [°C]

Brey

Log (P/B) = 7,979 –2,5022 * log W –2370,984 * 1/(Tb 273) + 0,171 * 1/D + 641,559* log W*1/(Tb+273) + (Dummy Variables)

Where:

Depth = 1 for the intertidal

P= Population annual production [kJ m^{-2} $year^{-1}$]
W= Mean individual body mass [kJ]
Ts = Bottom Water Temperature [°C]
D = Water Depth [m]
"Dummy" variables are discrete, i.e. they are either 1 (=true) or 0 (0 false), all "true" dummies are added up during calculation:

Faunistic group	coefficients
Infauna	+ 0.191
Motile Epifauna	+ 0.284
Mollusca	– 0.174
Echinodermata	– 0.352
Insecta	– 0.058

Conversion factors were obtained form Bray's "Virtual Handbook" (Brey, 2001).

Results and conclusions

Only two studies (five stations each) could be analysed using all the three methods; production estimates resulted from the three methods gave highly correlated results.

Morin and Bourassa's model gave higher values in comparison with the other two models.

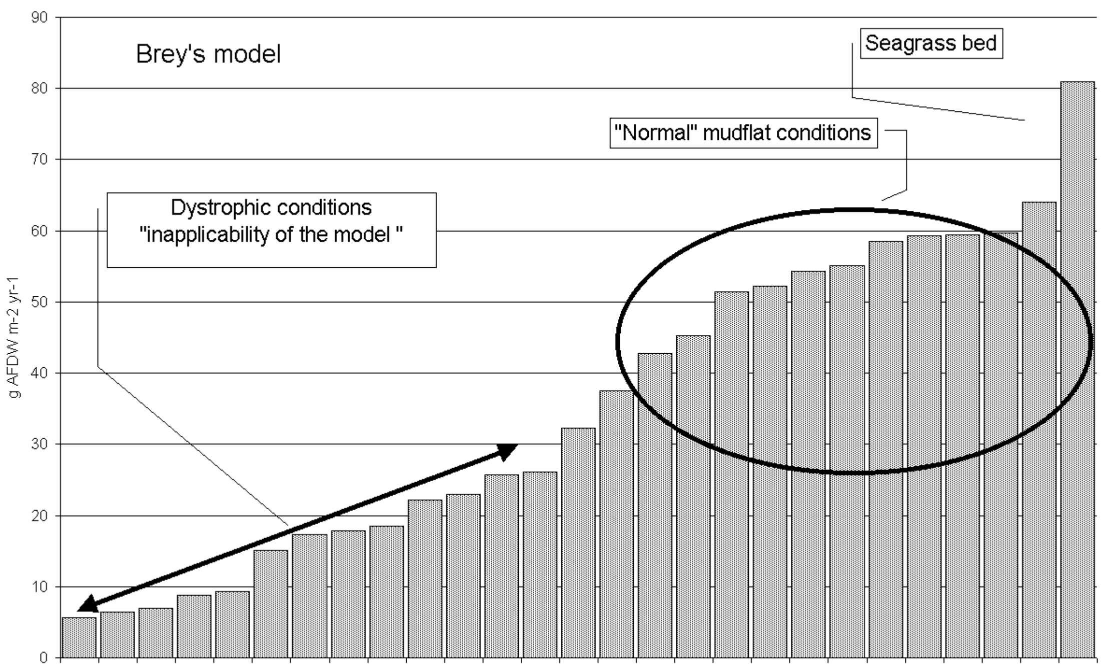

Fig. 1 – Secondary productions as estimate using Brey's empirical model.

Secondary production was then calculated using the Brey's method at 27 stations, results are reported in figure 1.

Since dystrophic condition occurred at least during two of the considered studies, some of the estimates should be considered very carefully or even ignored; in fact every empirical model was built on data resulting from studies conducted on "normal" situations (i.e. non dystrophic) and have to be applied only within that (normal) environmental parameters range.

On the basis of these considerations, we can conclude that our estimates for the inner Lagoon habitats fell within the range 10-70 g afdw m-2 yr-1.

More precisely, mud flats belonging to the lower intertidal showed a secondary production between 40 and 60 g afdw m-2 yr-1.

In sites affected by summer dystrophic crises, the secondary production could be estimated between 5 and 25 g AFDW m-2 yr-1, but this last estimation should be used with an extreme prudence.

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FUNCTIONAL DISTRIBUTION OF ORGANIC MATTER IN LAGOONAL ENVIRONMENTS

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Riassunto

La quantità di sostanza organica nei sedimenti, valutata come tale o come carbonio organico, rappresenta uno dei parametri guida, proposto a livello internazionale, nella scelta dei siti di riferimento utili alla messa a punto di criteri biologici di qualità per gli ecosistemi estuarini e alla loro applicazione. Tuttavia il suo ruolo e il suo significato metabolico, nei diversi ambiti dell'ecosistema alle diverse scale di paesaggio, sono aspetti ancora sorprendentemente poco indagati. Una particolare attenzione è stata rivolta anche alla qualità della sostanza organica, intesa come sua labilità/refrattarietà. Vengono quindi chiariti sia il quadro concettuale sia i risultati preliminari di un indagine volta alla stima della distribuzione della sostanza organica nei sedimenti lagunari, nei diversi habitat, e alla valutazione della sua labilità. In questo contesto è stata avviato lo studio e l'applicazione di protocolli metodologici speditivi che consentano valutazioni a scala di bacino, rapide, efficaci e a basso costo.

Abstract

The amount of organic matter in sediments represents one of the main discriminants, proposed at international level, in the choice of reference sites for the application of bioassesment methods for estuarine ecosystems. However, the role and metabolic significance of organic matter at different landscape levels, are still poorly investigated aspects. A particular attention has been turned also toward the quality of the organic substance, i.e. its lability/refractority. In this paper are therefore presented both the conceptual framework and the preliminary evaluations of organic matter content in lagoonal sediments and the assessment of its lability through the application of expeditious protocols.

1. Introduction

The starting point for the present research was a careful analysis of Bioassessment (Biological Assessment) protocols for coastal and estuarine environments that have been proposed at international level by US-EPA [US-EPA, 2002].

Besides the traditional approaches of chemical, physical and toxicological assessments, based on predefined quality standards, the biocriteria approach would represent an strategic method useful for the management of transitional aquatic ecosystems. This approach aims to establish series of measures and indices of local validity for the characterisation of the state of health of a complex ecosystem. Bioassessment is an evaluation of the "state of health" of an aquatic environment based on its "Biological Integrity". The evaluation of the Biological Integrity of a site is achieved comparing the investigated site with a "reference site", being the latter assumed to be a "pristine" or, at least, a "minimally impaired" site. Compared sites have to belong to the same class of habitats. Our attempt to apply this procedure to the Lagoon of Venice evidenced some intrinsic limits in the methodology used for the choice of reference sites: habitats whose sediments present high organic matter content, a very frequent situation in lagoons and estuaries, were unquestionably considered by the US Biocriteria as "low quality" environments, considering neither the functional distribution or the nature of organic matter. Our research is focused on these points. The "quality" of the organic matter, its degree of lability, represent a fundamental property guiding the metabolic responses of an estuarine system: confined lagoonal structures, characterised by the pulsing energy of the tides, seem to have a functional role in sinking labile organic matter from the lagoon and sourcing refractory materials [Boorman L.A., 1999]. If this functional role and distribution among different estuarine habitats can be established, then the definition of environmental quality founded on the organic content, should be revised. Our research is therefore addressed both to the functional distribution of the organic matter in different lagoonal habitats and to the development of an expeditious protocol for the evaluation of organic matter content in the sediments and its degree of lability. Preliminary results show that the lability of the organic matter in the lagoonal sediments follow both local and topographic gradients suggesting a functional interdependence between different districts of the lagoon.

2. Functional role of sediment organic matter: a conceptual framework for this research

In the Lagoon of Venice, like other transitional aquatic ecosystems, sedimentation of both inorganic and organic suspended material is guided by tide cycles and hydrodynamic processes, developing specific morphological structures, such as channels, mudflats, salt marshes, salt-pans; whatever the source of sediments, their deposition within an estuarine environment is controlled principally by the speed of the currents, the particle size of the sediments and, for clays, the “salt flocculation” phenomenon. [Pethick J., 1984; Mc Lusky D.S., 1989].

The organic matter carried into the lagoon, consists of various materials resulting from the excretion and decomposition of estuarine animals and plants, supplemented by fragmented, particulated and dissolved organic material derived from both natural or anthropogenic sources. Incorporation and mineralisation of organic matter in sediments, may be important processes in the nutrient economy of the whole estuary ecosystem, but not only. The distribution of organic and inorganic pollutants in estuaries is controlled mainly by the distribution and transport of suspended particulate matter. Human modification of estuarine processes may have considerable impact upon patterns of matters accumulation or dispersion. "*However in many marsh systems, the greatest bulk of material eventually accumulates in a narrow zone of the high marsh*" [Adam P., 1990]. Various physical and chemical properties (such as mean fragment size and degree of lignification of detritus) vary between litter types and this would influence rates of mineralisation. All tide-borne material including plants and animal debris tends to accumulate in particular parts of a marsh, litter deposits are thus likely to be sinks for various pollutants. In this sense, various studies attempted to understand the equilibrium partitioning models of pollutants in sediments and the significance of bioavailabily referred to organic carbon [Di Toro et al. 1991, Mahony et al., 1996]. The rates of breakdown, the role and the composition of the often abundant invertebrate fauna in degradation processes and the fate of mineralised nutrients remain poorly studied topics.

Considering that different habitats, within the same lagoonal ecosystem, vary in their efficiency to retain organic matter, and the quality and the quantity of the organic matter determine their metabolic response, ones could wander why in environmental monitoring programs, organic matter quality (at least as lability) is not considered as a core metric as it is organic matter content . Labile organic matter, that is easily broken down through biochemical and microbiological pathways, is potentially a major source of nutrients returned to the water column.

3. Materials and methods

During the summer 2002, surficial (5 cm) sediment samples from different habitat of the Lagoon of Venice were collected. In details, sediment cores were taken from salt marshes and from shallow bottom sediments from the Northern basin of the Lagoon. (Figure 136). The organic matter content and lability content was estimate using a modified loss on ignition (loi) method. loi provides a fast and inexpensive means of determining carbonate and organic contents of sediments and rocks with precision and accuracy comparable to other, more sophisticated geochemical methods. For the study purposes, the traditional procedure [Dean W.E. Jr, 1974; Craft C.B. et al., 1991; Sutherland R.A., 1998; Heiri O. et al., 2001;]., based on two ignition temperature, was transformed in a sequence of 5 increasing ignition temperatures, in order to determine the loss of weight referred to each step; each sample was sequentially ignited at 105°C (dry weight), 250°C, 350°C, 450°C, 550°C, the ignition was maintained 16 hours every step.

Sediment samples were wet sieved through 1mm mesh size, dried at 60°C overnight and then manually homogenised before applying the ignition sequence.

After each overnight ignition, the sample weight was registered, using a calibrated analytical balance. The assumption of this sequential modification of the usual loi method (in some way similar to Thermal Gravimetric Analysis) is that thermal lability of sedimentary organic matter (som) relates to its degree of degradability [Otero et al., 2002]. Mineralisation of organic matter by decomposers and detritivorous species represent only one metabolic aspect of the wider and much more complex biogeochemical cycle of carbon, nitrogen and phosphorous. In this sense, quantity and quality of organic matter is strictly related with the capacity of habitats to sustain metabolic mineralisation.

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[36] Part of the figures are taken from ortophotographic pictures of the Venetian Lagoon (1996) by courtesy of CORILA.

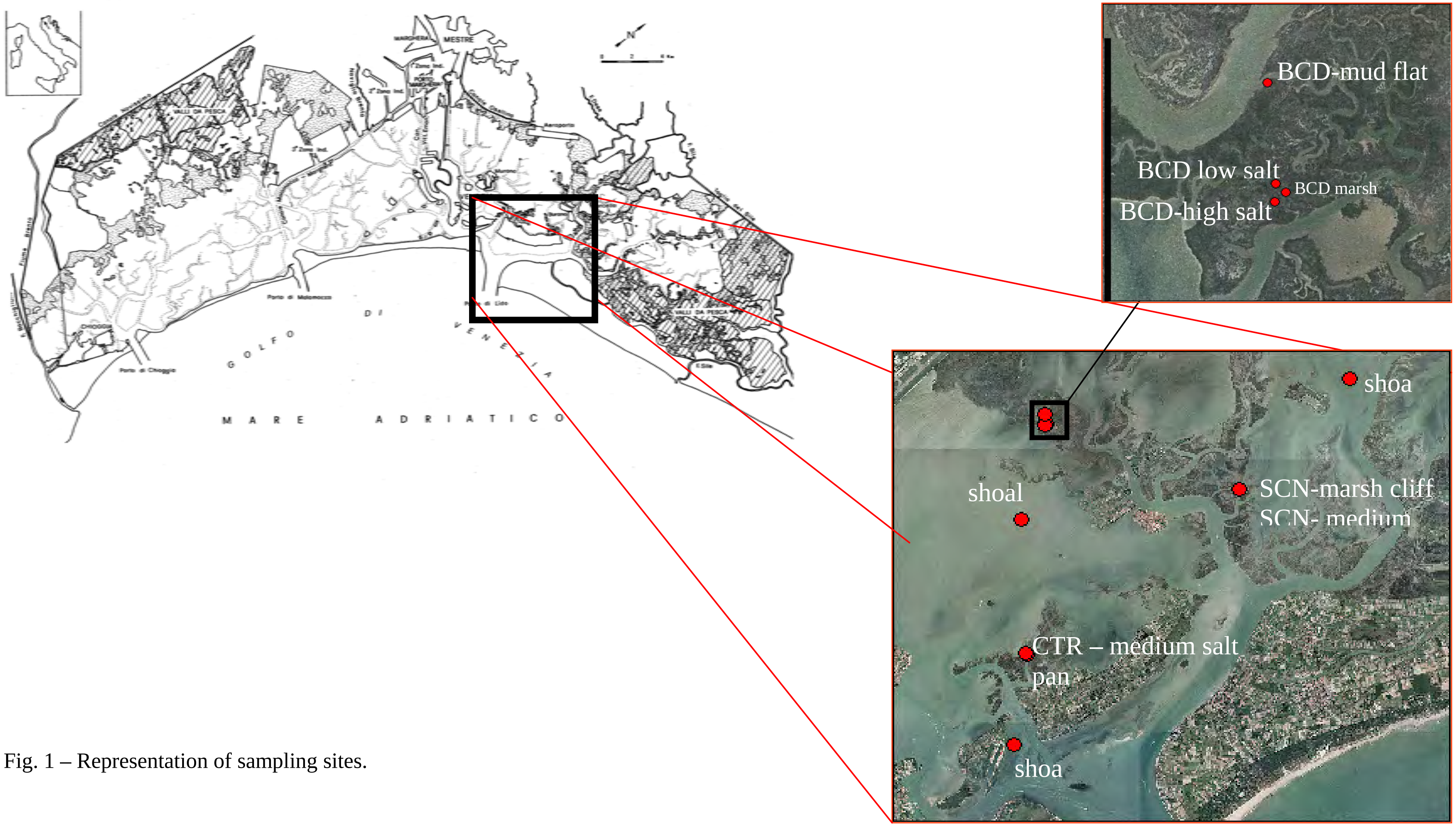

Fig. 1 – Representation of sampling sites.

The obtained data set was integrated with previous data (1991) referred to Palude della Rosa, a swamp with intermediate confinement degree compared to shallow bottom sediments and salt marshes.(Figure 1).

4. Results and Discussion

The distribution of organic content in the sediment samples follow a confinement gradient [sensu Guelorget and Perthuisot , 1983], being lower in open lagoon areas and higher in the salt pans microenviroment (Fig. 2). Moreover, the distribution patter of som in Palude della Rosa samples, confirm this evidence.

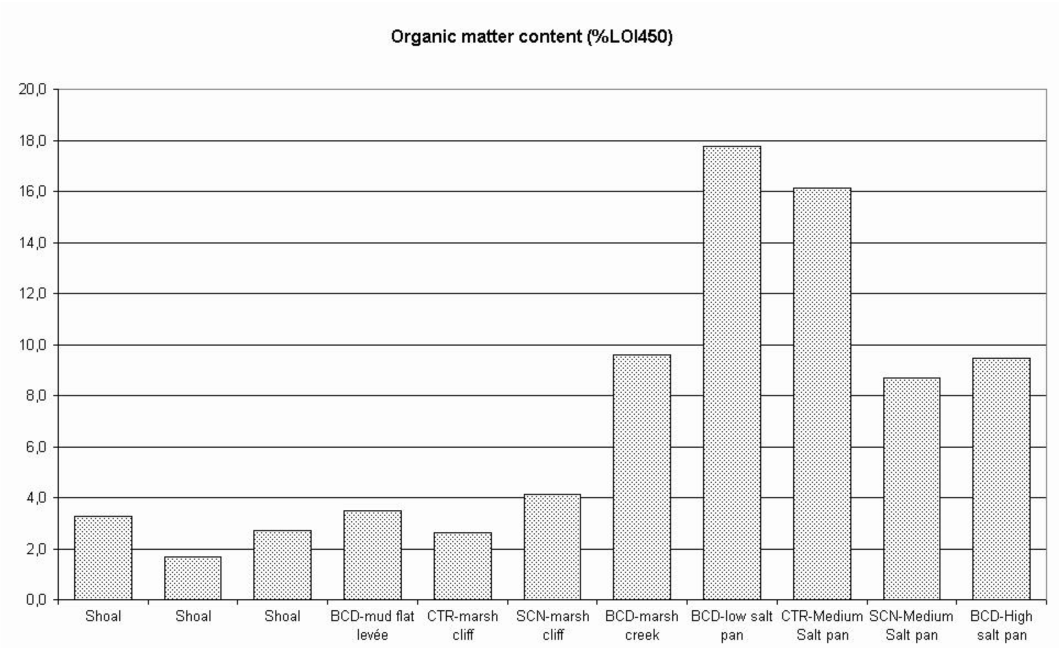

Fig. 2 - Histogram representing organic matter content, as %LOI450, along a transect from the shoals, mud flat, marsh cliff, marsh creek, and marsh salt pans.

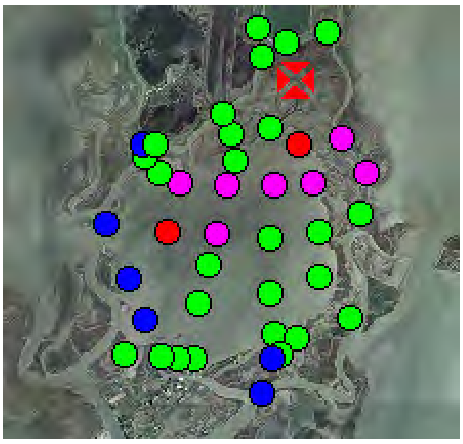

Fig. 3 - Organic matter distribution in Palude della Rosa. Different colours represent different levels of organic matter content expressed as %LOI-550°C: blue=0-6%; green=6%-12%; pink=12%-18%; red=18%-24%; red cross >24%.

In figure 4 quality (thermo-lability as %LOI350) and quantity (as %LOI450)of organic matter are contrasted. The assumption is that the most thermo-labile fraction of the organic matter could be associated with the 250°C and 350°C combustion temperatures. Loss of weight on ignition at different temperatures was normalised to total om content, for a correct comparison between samples.

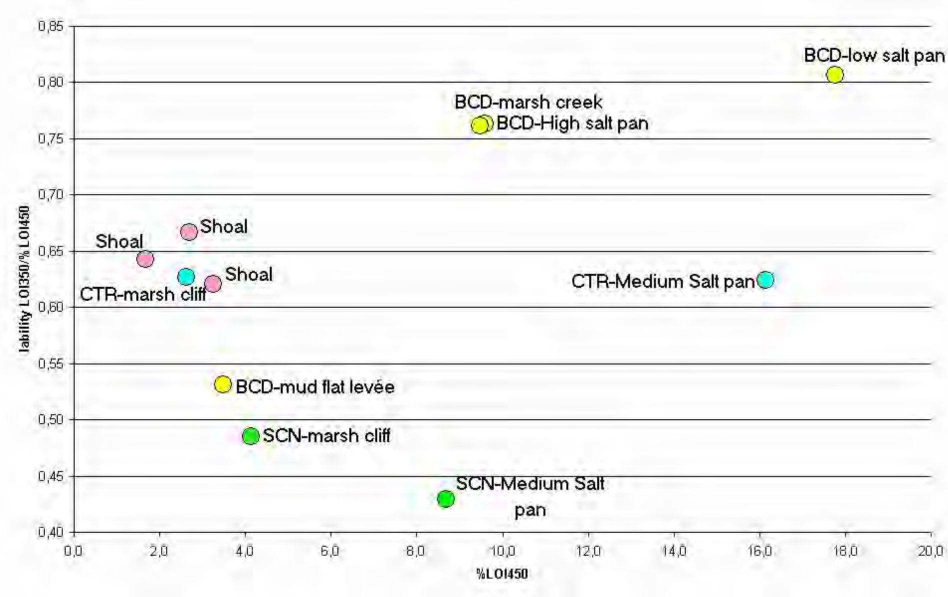

Fig. 4 - Relatioship between organic matter content and lability related to sediment samples. Colours refer to samples collected from the same area. Lability is expressed as (%LOI350/%LOI450) ratio.

In the obtained picture samples are well separate accordingly with their microenvironment of origin: open lagoon environments lye on the lower left quadrant of the graph showing not only a lower content in organic matter but also a more refractory

quality of the substance. Shallow bottom samples (pink dots) exhibit similar content and lability som levels even though they are some located kilometre apart indicating an high degree of homogeneity of the organic matter contained in their sediments. The thermo-refractivity was particularly evident for the two station of SCN and for the station of Barena Canal Dese located on the edge between an high flow channel and a little tidal flat (BCD-mud flat levée). Salt pans are located mostly at the upper right corner of the graph indicating an accumulation of thermo-labile organic matter. Peculiar is the position of SCN salt pan that seems to accumulate a discrete amount of organic matter but this organic matter is the most thermo-refractory as if it came from lignified phanerogams more than algae.

With reference to the confinement (see fig.1), BCD sediments show the greatest differentiation: as more pronounced the confinement is, as higher som content and thermo-lability levels are. For CTR and SCN sites (respectively blue and green dots), the pattern is evident only considering quantity of som and not quality, further investigation on the source of their organic matter is needed.

Conclusions and perspectives for further research

Results indicate a direct relationship between som accumulation, its thermal lability and confinement of natural lagoonal habitats. This evidence could seem fairly obvious, but it has deep implications on the metabolic role of the different micro-environments on the eco-physiology of the whole estuarine system.

A systemic view of the role of the different miocroenvironments in the estuarine metabolic processes is often disregarded; for instance some index of biotic quality for estuarine environments [e.g. Wiesberg et al., 1997] fix a treshold limit for organic carbon, between reference sites and impacted sites, independently from their metabolic performance.

The ecosystemic implication of som distribution in lagoon habitats, must be interpreted at proper spatial scale, like any other property of a landscape in a specific domain [Farina A., 2001].

The sequential- loi method proposed, make possible to appreciate the different contribution of the thermal-labile som fraction (250 -350 °C) compared to the refractory one (450°C). To calibrate the procedure next steps of the method will be to process a large set of sediments samples, in order to verify if the suggestion obtained from these preliminary results are correct. Biological samples will be processed as well in order to extend interpretation of lability to various pools of biodegradable matrices that can be source of organic matter for the different micro-environments.

Research efforts will be, then extended in two different directions: first, to find experimentally regression equations and conversion factors between, on one hand, organic matter and organic carbon contents (quantitative) and, on the other hand, between thermal lability and elemental composition of organic matter, whose great variability is truly dependent on local features, [Nelson D.W. & Sommers L.E., 1996; Swift R.S., 1996]; second, to assess how functional and landscape relationships between sedimentary micro-environments and the open lagoon, could influence the carrying capacity of the whole ecosystem, in terms of accumulation, export and transformation of different quantity and quality of organic matter.

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GROWTH AND PRODUCTION OF *CYMODOCEA NODOSA* (UCRIA) ASCHERSON IN THE VENICE LAGOON

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Riassunto

L'accrescimento e la produzione di *Cymodocea nodosa* (Ucria) Asher. sono stati studiati con frequenza mensile e bimensile in una stazione posta nella bocca di Lido allo scopo di quantificare le variazioni di biomassa e la produzione primaria su base annuale.

La biomassa media totale (3.01±1.09 kg WW m^{-2}), composta da getti fogliari (37%), rizomi/radici (53%) e parti morte (10%) è variata tra 1.96 (aprile) e 5.27 (agosto) kg WW m^{-2}. Il minimo numero di getti fogliari (747 germogli m^{-2}) è stato campionato in dicembre e il massimo (1860 germogli m^{-2}) in giugno mentre la loro altezza è variata tra 13.9 cm in aprile e 98.4 cm in agosto. Ogni germoglio mediamente presentava 2.2±0.9 foglie con un massimo di 3.6 in agosto e un minimo di 1.1 in febbraio-marzo. Di conseguenza l'indice di area fogliare (LAI) è variato tra ca. 0.5 m m^{-2} (marzo) e 14.4 m m^{-2} (settembre), mentre il valore medio è stato di 4.4±5.2 m m^{-2}.

L'accrescimento di ogni germoglio su base annuale è stato di ca. 1.95 cm d^{-1} con un massimo di 7.87 cm d^{-1} in luglio. L'accrescimento annuale delle foglie corrispondeva a ca. 10554 m m^{-2} e a una biomassa di ca. 13.7 kg WW m^{-2}. A questa deve essere aggiunta la produzione annuale dei rizomi valutata in ca. 1.6 kg WW m^{-2}. Pertanto la produzione totale netta di *Cymodocea* è stata di ca. 15.3 kg WW m^{-2}.

L'analisi delle concentrazioni di azoto è fosforo nei tessuti di *Cymodocea* hanno evidenziato che il fosforo presentava valori potenzialmente limitanti la crescita (<2 mg g^{-1}) durante il massimo accrescimento delle piante, tra luglio e settembre. Tuttavia l'analisi dei nutrienti condotta separatamente dalla 1^{a} (più giovane) alla 4^{a} (più vecchia) foglia ha evidenziato che nelle prime due foglie non c'era mai alcuna limitazione. Invece le altre due foglie, ormai completamente sviluppate e prossime alla caduta, presentavano concentrazioni di nutrienti progressivamente minori. Sia l'azoto che il fosforo, prima della perdita delle foglie vengono infatti translocati nelle parti in crescita.

Abstract

Results of monthly samplings during one year (July 2001-July 2002) have shown that the biomass of *Cymodocea nodosa* (Ucria) Asher. ranged from ca. 1.96 (April) to 5.27 (August) kg WW m^{-2} with a mean biomass of 3.01± 1.09 kg WW m^{-2}. On average the total biomass was composed by shoots (37%), roots-rhizomes (53%) and dead parts (10%). The mean shoot number ranged from 747 shoots m^{-2} in December to 1860 shoots m^{-2} in June while the mean shoot height was 13.9 cm in April and 98.4 cm in August. The number of leaves ranged between 3.6 (August) and 1.1 (February-

March) with a mean of 2.2±0.9 per shoot. It means that the mean number of lives per square meter was 2564±1715. As a consequence the leaf area index (LAI) measured in one face ranged between 14.4 m m^{-2} in September and 0.5 m m^{-2} in March, displaying a mean value of 4.4±5.2 m m^{-2}.

On a yearly basis each shoot increased ca. 1.95 cm d^{-1}, peaking in July with 7.87 cm d^{-1}. That growth corresponded to a leaf growth of ca. 10554 m m^{-2} y^{-1}, accounting for ca. 13720 g WW m^{-2}. The roots-rhizomes production was ca. 1.6 kg WW m^{-2}. On the whole the net production of *Cymodocea* was ca. 15.3 kg WW m^{-2}.

By considering the nutrient quota in the seagrass tissues only phosphorus was slightly below the critical value (ca. 2 mg g^{-1}) in both roots-rhizomes and shoots in July and September, during the highest biomass growth. However, the nutrient analyses performed separately, proceeding from the 1th (the youngest) to the 4th (the oldest) leaf showed that also phosphorus in the first two leaves was never below the critical value. In contrast the 3rd and possibly the 4th leaf showed decreasing nutrient concentrations. That was explained by the translocation of nutrients to the growing parts of the shoots after the oldest leaves had reached their maximum height.

1. Introduction

Seagrasses together with macroalgae are the main primary producers of the Venice lagoon (Sfriso and Marcomini, 1996). With reference to macroalgae, both by considering the standing crop, the biomass production and the ecological implications a rich literature is already available (Sfriso et al., 2003a). But as far as the knowledge on the lagoon seagrasses is concerning (*Zostera marina* L., *Zostera noltii* Hornem., *Cymodocea nodosa*), although distribution maps are available, information on the biomass production is scarce and attention is prevalently drown to *Zostera marina* (Sfriso & Ghetti, 1998).

After the strong reduction of macroalgae monitored since the early ‘90s (Sfriso et al., 2003a), the bottoms of the Venice lagoon started to be colonized both by seagrasses and by the clam *Tapes philippinarum* Adams and Reeve, an exotic bivalve introduced in the lagoon for aquaculture purposes (Orel *et al.*, 2000). In a fairly short time the development of intense clam-fishing activities stopped the spreading of seagrasses, but later both *Zostera marina* and *Cymodocea nodosa* extended their coverage and at present seagrasses are by far the main primary producers of the lagoon.

This work aims at examining closely changes occurred in the biomass and the production of the seagrass *Cymodocea nodosa* in an area of the central part of the Venice lagoon (station of San Nicolò) selected as reference area to update data on the trophic state of the Venice lagoon.

2. Methods

2.1. Study area

The sampling site (S. Nicolò: 45° 26’ 047” N, 12° 23’ 345” E) is placed north of the Lido island in the Lido inlet. Sediments are prevalently sandy (93.9% <63 µm) and colonised by a dense population of *Cymodocea nodosa*.

2.2. Biomass determination

The biomass of *Cymodocea* was sampled monthly in agreement with the sampling procedure proposed by Sfriso & Ghetti (1998). Six sub-samples collected by a frame of 20 x 25 cm (0.05 m^{-2}) of an area measuring 15 x 15 m according to a predetermined sampling grid guaranteed a sampling accuracy >95%. During each sub-sampling, plants were washed through a 3mm mesh sieve to remove sediment and epiphytes and transported to the laboratory for the material examination. There the number of shoots, leaves and the shoot length was determined after careful washing in tap water in order to remove salts and the remaining epiphytes. Then plants were sorted in three fractions: shoots, roots-rhizomes and dead parts (i.e. leaf and rhizome black parts mixed together) and weighed by using an electronic balance (precision: 0.1 g) after drying with blotting-paper. Aliquots of samples were frozen and lyophilised to determine the dry/wet weight ratio and the concentrations of nutrients in the tissues.

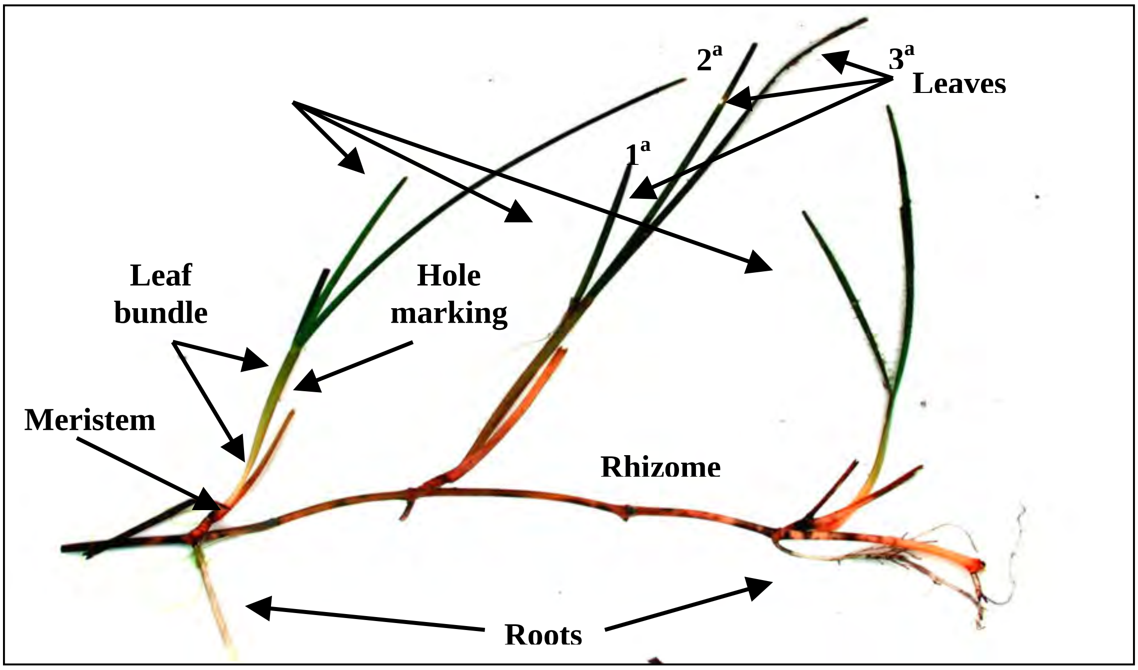

Fig. 1 – *Cymodocea nodosa* features.

2.3. Nutrients concentrations

The nitrogen and carbon concentrations in shoots, roots-rhizomes and dead parts of *Cymodocea* were determined by analysing ca. 3 mg of dry material by means of a Carlo Erba 1500 CNS Autoanalyser. The concentration of phosphorus was obtained by hot-digesting 3 mg dry material with a mixture of HNO_3 (3 ml), $HClO_4$ (3 ml) and be-distilled water (4 ml) and the spectrometric determination according to Strickland and Parsons(1972).

2.4. Biomass production and growth rates

The shoot apical leaf bundle, above the leaf meristem (Fig. 1), were marked *in situ* with a hole and the leaf increase was measured on ca. 10 plants by twice a month frequency. The total shoot production was estimated by adding up the mean shoot increase during one year for the mean shoot number per square meter.

The production of rhizomes and roots was estimated by adding up the root-rhizome increases recorded on an yearly basis. In fact, it is not possible to measure the rhizome increase by tagging the rhizome meristems such as for *Zostera* because of the complexity of the root-rhizome net of this species.

3. Results

The study area showed a dense and homogenous population of *C. nodosa* which colonised bottoms from the lower mid-littoral (ca. –20, -30cm on the mean tidal level) up to a depth of 3-4 m. The sampling area was selected at ca. 1 m depth. On the whole, between July 2001-July 2002 the total biomass ranged between ca. 1.96 kg WW m^{-2} in April and ca 5.27 kg WW m^{-2} in August with a mean of 3010±1085g WW m^{-2} (Fig. 2). On average the root-rhizome apparatus accounted for ca. 53% of the total biomass whereas shoots were only 37%. The remaining biomass (ca. 10%) was composed by dead parts. In April the roots-rhizomes were up to 84% of the total biomass and shoots 61-64% in August and September, when the above-ground part showed the highest increase. The mean dry/wet weight ratio was ca. 21.5% for shoots and ca. 17.5% for roots-rhizomes.

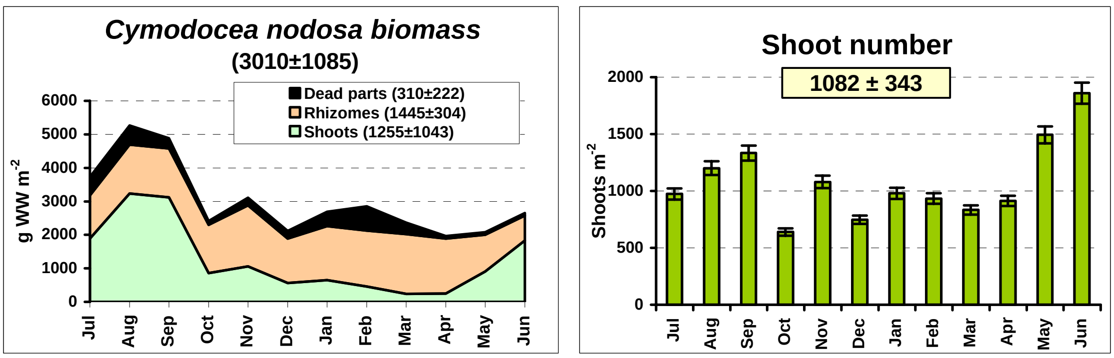

Fig. 2 – Annual trend of the *Cymodocea nodosa* biomass and shoot number.

The number of shoots per square meter was 1082±343, ranging from 640 shoots m^{-2} in October to 1860 shoots m^{-2} in June (Fig. 2).

The mean shoot height was 45.4±31.6 cm (Fig. 3). The minimum value was recorded in April (13.9 cm) and the maximum in August (98.4 cm). The mean number of leaves per shoot was 2.2±0.9 while on average 2564±1715 leaves m^{-2} were recorded.

The leaf area index (LAI) ranged between 0.5 m m^{-2} in March and 14.4 m m^{-2} in September (Fig. 3). The average value was 4.8±5.2 m m^{-2}.

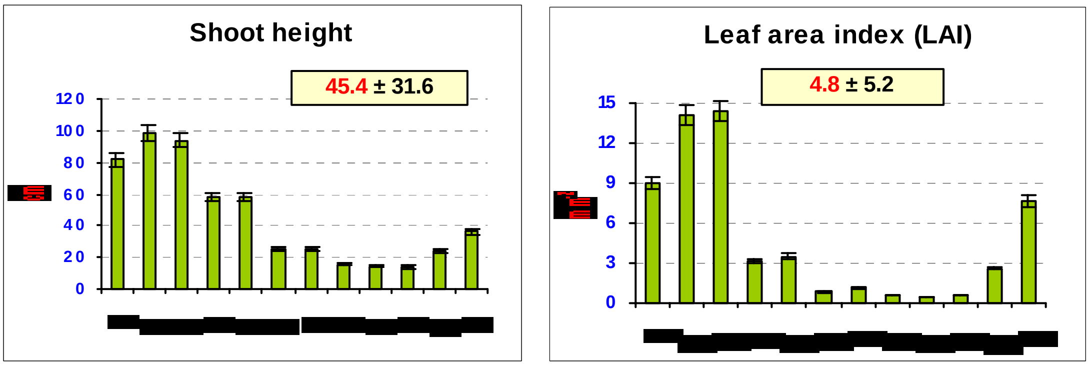

Fig. 3 – Annual trend of the shoot height and LAI of *Cymodocea nodosa*.

The shoot growth was very high in June-August (5.0-7.9 cm d^{-1}), but it was negligible in January-March with a mean value of ca. 1.95 cm d^{-1} (Fig. 4). As a result each shoot produced ca. 7.2 m y^{-1} of leaves accounting for a total leaf production of ca. 10554 m m^{-2} y^{-1} and a biomass production of ca. 13.7 kg WW m^{-2}.

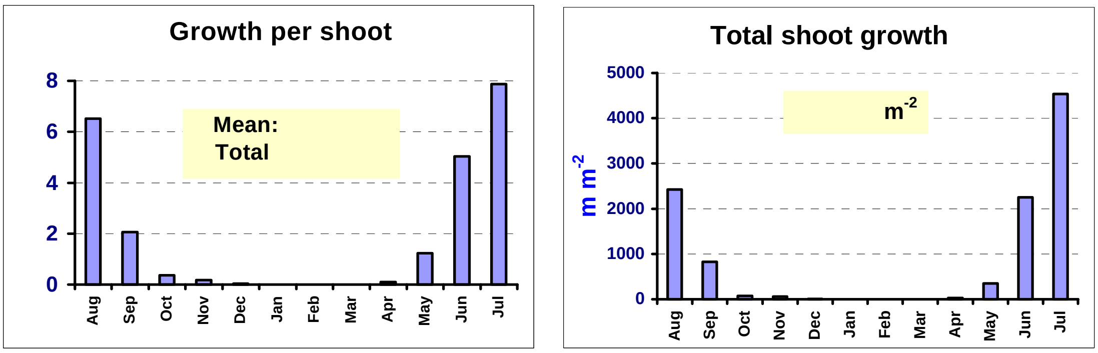

Fig. 4 – Mean growth of shoots on one year basis.

The relative growth rate (RGR), by considering also the loss of leaves, ranged from 5.6% in June and –4.0% in November (Fig. 5).

The root-rhizome production was much lower than the shoot production (1.6 versus 13.7 kg WW m^{-2}) but the under-ground apparatus produced a dense and intricate net that survived winter without significant biomass loss. In fact, in winter, the shoot biomass was lower than the root-rhizome one because of a significant loss of leaves.

By analysing the nutrient concentrations in the plant tissues (Fig. 6), marked differences were found for nitrogen and phosphorus concentrations in shoots, roots-rhizomes and dead parts, while carbon displayed values quite similar. In particular phosphorus and nitrogen were significantly higher in the shoots than in the roots-rhizomes but much higher than in the dead parts of the plants.

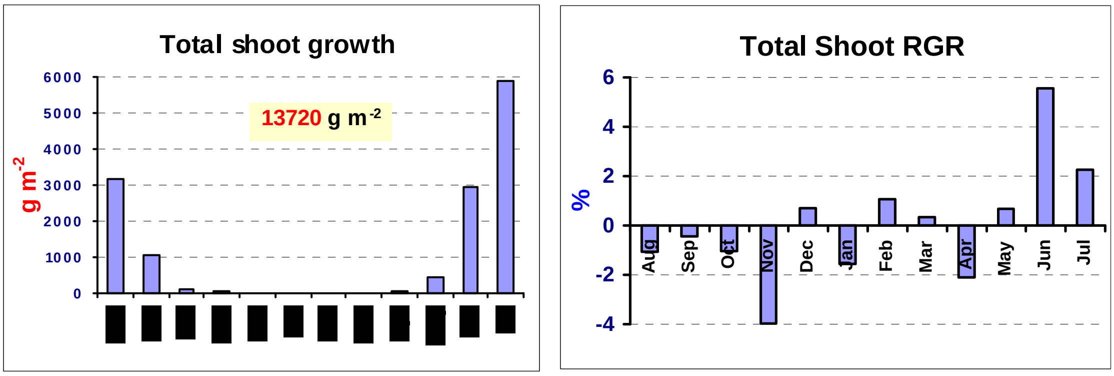

Fig. 5 – Annual growth of shoots and relative growth rate (RGR).

Moreover shoots and rhizomes never showed nitrogen concentrations below the critical growth value (ca. 18 mg g^{-1}, Duarte, 1990) while phosphorus was below the critical value (ca. 2 mg g^{-1}) in shoots during June-October, the period of the highest shoot growth.

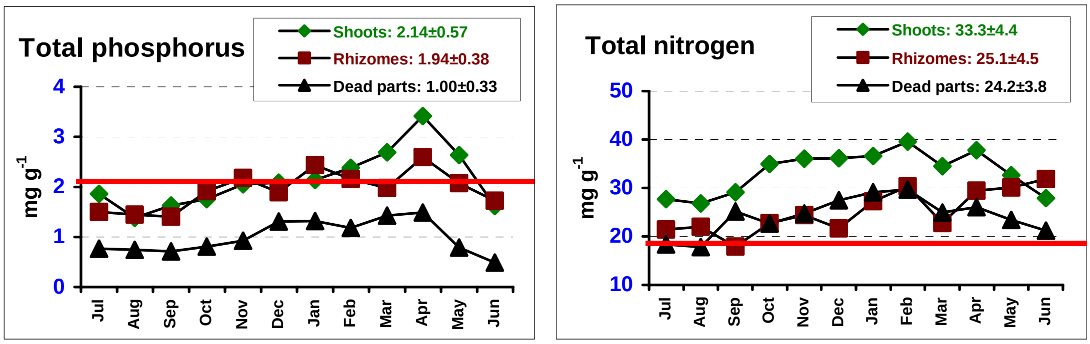

Fig. 6 – Annual trends of nutrients in *Cymodocea* tissues.

However, nutrient analysis showed that in the youngest leaves (1th and 2nd), which are the growing ones, there was no nutrient limitation (Table 1), while in the oldest ones (3rd and 4th), which show a negligible or no growth at all and are close to fall the nutrient concentration was low because of the nutrient dilution during the plant growth and nutrient translocation to the growing parts.

4. Discussion and Conclusions

Cymodocea nodosa is the seagrass species that is undergoing the greatest spread in the Venice lagoon, possibly because of the increase of the environment oxidizing conditions and the loss of fine material from surface sediments. In fact, the marked macroalgal biomass decrease recorded in the early '90s (Sfriso et al., 2003a) allowed the spread of both seagrasses and the clam *Tapes philippinarum* Adams & Reeve. The lack of anoxic crises and the sediment mixing which oxidized and changed the grain-size of surface sediments (Sfriso et al., 2003b) favoured that species. The mapping of *Cymodocea* in the whole lagoon carried out in summer 2003 shows that, although that species rarely produces seeds and the reproduction occurs mainly by rhizome growth and propagation, it has increased remarkably colonising also some inner lagoon areas where it had never seen before.

Tab. 1 – Nutrient concentrations in *Cymodocea* leaves.

Leaf	Phosphorus	Nitrogen	Carbon
	mg g^{-1}		
1th	2.43	34.6	372
2nd	1.99	28.5	366
3rd	1.35	26.8	336
4th	0.78	18.1	265

This paper investigates on the growth and production of *Cymodocea* in order to add knowledge on the role played by that species in the sediment colonisation by a deep (up to 30-40 cm) and dense root-rhizome apparatus which, differently from *Zostera*, lives many years compacting surface sediments. In general, in Europe *C. nodosa* is less spread than *Zostera* and studies are less numerous because of its subtropical origin which asks for warm waters and its need of well oxidised and coarse sediments. Oxidised and coarse sediments are mainly characteristic of the sea coastlines but there temperatures are usually not enough high. Lagoons and estuaries have warmer temperature, but frequently show fine and anoxic sediments which favour the presence of *Zostera marina* and *Zostera noltii*. That is also the case of higher latitudes such as the north of Europe where the spread of *Cymodocea* is hampered by low water temperatures.

In contrast many areas of the Venice lagoon which are near the sea inlets or are affected by a high water renewal exhibit the best environmental conditions for that species which is rapidly increasing. The station of San Nicolò at the Lido inlet has a very dense *Cymodocea* population which, along the borders of the main canals, in August-October is ca. 1.0-1.2 m high with shoots up to 130-140 cm long. In summer the shoot growth rapidly reaches ca. 8 cm d^{-1} and accounts for a biomass increase up to ca. 6 kg WW m^{-2} in July. In winter and in spring that species is temperature-limited and loses great part of leaves. The growth is temporarily suspended but the under-ground part keeps the dense and intricate root-rhizome net which contributes to consolidate sediments better than the other seagrasses.

As a results the spread of *Cymodocea* monitored in these last years is an important index of the good environmental conditions of the Venice lagoon, although the many anthropic disturbances that affects this basin. In addition it can actively contrasting the erosive processes caused by the water renewals through the sea inlets and the loss of fine material mainly caused by clam-fishing activities.

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ORGANOTIN CONTAMINATION IN THE GASTROPOD HEXAPLEX TRUNCULUS OF THE LAGOON OF VENICE

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Riassunto

Il grado di contaminazione da composti organostannici è stato valutato nei tessuti del gasteropode *H. trunculus* campionati in tre stazioni della laguna di Venezia e in una stazione in mare. Inoltre, è stata determinata la presenza del fenomeno imposex in questa specie e l'effetto biologico è stato messo in relazione con il contenuto di xenobioti ottenendo una buona correlazione.

Abstract

The contamination deriving from organotin compounds in tissues of the gastropod *H. trunculus* collected from three stations inside the Lagoon of Venice and one station at sea has been evaluated. The occurrence of the imposex phenomenon in this species was also assessed and related to the content in xenobiotic compounds achieving a good correlation.

1. Introduction

To assess the environmental quality of an ecosystem, the sole determination of the concentrations of specific pollutants in different environmental compartments is not sufficient. In fact, the biological effects induced by those chemicals on the organisms have to be analysed as well. The organism response to the exposure to a contaminant can be assessed at different levels of the biological structure (molecular, cellular or individual), but in the long term effects at the popolutation, community or ecosystem level can also occur. A wide variety of xenobiotic compounds, introduced in the environment from different human applications, are known to be responsible for disruption of the endocrine system of different organisms, with a consequent reduction in the reproduction capability. Among them, particularly important are the Organotin compounds (OTCs), Polychlorinated biphenyls (PCBs), organochlorine pesticides and polycyclic aromatic hydrocarbons (PAHs)[Sonnenschein and Soto, 1998; Santodonato, 1998]. The most sensitive species are threatened to disappear. For example the superimposition of male sexual characters (namely a *penis* and a *vas deferens*) on females in some species of gastropods, a phenomenon known as imposex [Smith, 1971], in response to tributyltin (TBT) contamination led to the decline of population of the whelk *Nucella lapillus* on the south west coasts of England [Gibbs and Bryan, 1986;

Bryan et al., 1986]. Imposex is now a world-wide bioindicator of the exposure to organotin compounds [Ellis and Pattisina, 1990] and it is reported to affect more than 150 species of gastropods [Schulte-Oehlmann et al., 2000].

The aim of this research is to study the contamination from organotin compounds in relation to the appearance of the imposex effects in the common gastropods *Hexaplex trunculus* (Neogastropoda: Muricidae) in different sites in the Lagoon of Venice. The role of the contamination by POPs (Persistent Organic Pollutants) namely PCBs, organochlorine pesticides and PAHs is also investigated.

2. Materials and methods

Sediments samples were collected from the stations at Tresse, S. Nicolò del Lido and Celestia to quantify the contamination by OTCs, PCBs, PAHs and organochlorine pesticides. Specimens of *H. trunculus* (at least 40 individuals) were collected from stations at S. Nicolò del Lido, S. Maria del Mare and Malamocco, whereas no individuals could be collected in Tresse and Celestia stations. An additional station was located at sea, 5 miles away from Chioggia (Fig. 1).

The determination of the imposex degree was performed by inspecting the animals to determine the presence and degree of development of a penis and/or a vas deferens on the females according to the Vas Deference Sequence Index (VDSI) reported by Axiak et al. [1995]. This index quantifies the intensity of the biological effect with 8 stages (from 0 to 5). In the ultimate stage females are considered to be sterile.

The OTCs determination was performed both in the visceral coil and in the rest of the soft tissue of pooled organisms with the same imposex degree, according to the analytical procedure reported in Bortoli et al. [2003]. It consists of an acid-methanol extraction assisted by the complexation with tropolone, a liquid-liquid extraction with dichloromethane, a derivatization step performed with Pentylmagnesiumbromide, an extraction of the derivatised organotins in hexane, a purification of the extract with Florisil and a final analysis with GC-MS.

The determination of the other POPs was performed at the same time with the procedure reported in Raccanelli et al. [1994] based on an ultrasonic extraction, a separation of the analytes, purification with a multilayer chromatographic column and the determination with GC-MS and GC-ECD.

3. Results and discussion

In Tab. 1 the concentrations of the four classes of organic compounds in the sediment samples are reported. These data allow to define the level of contamination of the sampling sites. Celestia station appears the most contaminated by organotins, polychlorinated biphenyls and polycyclic aromatic hydrocarbons. Tresse and Celestia seem to be equally contaminated by organotin compounds, while in the station S. Nicolò del Lido a lower content in butyltins compounds was found. In all the considered station phenyltin compounds are lower than the detection limit of the analytical procedure.

Unfortunately, no gastropods were sampled in the stations of Celestia and Tresse where, in fact, habitat conditions are unfavourable for *H. trunculus*, who prefers a more salted water, and therefore thrives near the port entrances.

The results of the biological monitoring are reported in Fig. 2. No stage of imposex lower than 3 was found in any of the stations sampled. This shows the high sensitiveness of the species and the high level of imposex in this gastropod in the Lagoon of Venice. The least affected population seems the one in Chioggia station, located at sea. Nevertheless, imposex degrees are unexpectedly relatively high also for this station which, before sampling, was regarded as a reference site. The most affected population in term of the VDS is the one in S. Nicolò del Lido station where most of the females are at the stage 5 with a splitted capsule gland and therefore are in a condition of probable sterility.

In Tab. 2 the concentrations of organotin compounds in pooled tissues of *H. trunculus* at the same degree of imposex are reported. It appears clear that butyltins concentrations are much higher in the biota tissues than in the sediments. Preliminary data on concentrations in the gastropods of PCBs, organochlorine pesticides and PAHs confirm this observation. Among phenyltins derivatives, only the parent compound triphenyltin was found and at concentrations two order of magnitude lower than butyltins (data not shown).

A good agreement was found between the biological and the chemical data in differentiating the examined stations, confirming the effective role of this species as a bioindicator of organotin contamination. In fact, the highest concentrations of organotin compounds were found in S. Nicolò del Lido where also the most imposex affected population was detected, the lowest concentrations were found in the station at sea.

A relationship between the biological effect (imposex) and the disrupting agent (cause) is clear in S. Nicolò del Lido and S. Maria del Mare stations, where at higher degree of imposex correspond higher organotin content in the entire organism. Such a correlation is not so evident in the other two stations.

4. Conclusions

The number of samples so far analysed does not justify any conclusion concerning a possible decline of the population in the stations considered. Repeated sampling campaigns in the same sites are necessary to evaluate the time trend of organotin contamination, especially in relation to the ban for TBT containing paints started on January 1st 2003, and to assess the existence of a potential risk for the population caused by the damage to its individuals.

The same samples analysed for organotins are now being processed for determining the content of PCBs, PAHs and organochlorine pesticides in order to establish a possible contribution, agonistic or antagonistic, of these compounds to explain the level of imposex and the morphological modification related to it. In fact, these classes of compounds have been reported by many authors as potential endocrine disruptors being able to interfere with the reproductive capability of different organisms.

Fig. 1 - Location of the sampling sites for the sediments and for *H. trunculus* population: Station 1: S. Nicolò del Lido; Station 2: Celestia; Station 3: Tresse; Station 4: S. Maria del Mare; Station 5: Malamocco; Station 6: Chioggia

Tab. 1 - Concentrations of the different organic compounds in the sediment of Tresse, S. Nicolò del Lido and Celestia stations (all values are reported as ng g^{-1}; for OTCs as ng Sn g^{-1})
Lod = limit of detection (calculated as 3σ of the blanks)
DBT, MBT=3 ng Sn g^{-1}; TPhT= 0.1 ng Sn g^{-1}; DPhT, MPhT= 0.4 ng Sn g^{-1}

	TRESSE	**Dev std**	**S. NICOLO' DEL LIDO**	**Dev std**	**CELESTIA**	**Dev std**
TBT	33	3	10	2	33	1
DBT	19	2	< lod		21	9
MBT	28	4	< lod		21	1
TPhT	< lod		< lod		< lod	
DPhT	< lod		< lod		< lod	
MPhT	< lod		< lod		< lod	
ΣPCB	5.3	0.3	0.79	0.08	16	1
ΣPEST	1.32	0.05	0.189	0.002	6.3	0.4
ΣPAH	133	24	33	7	1977	458

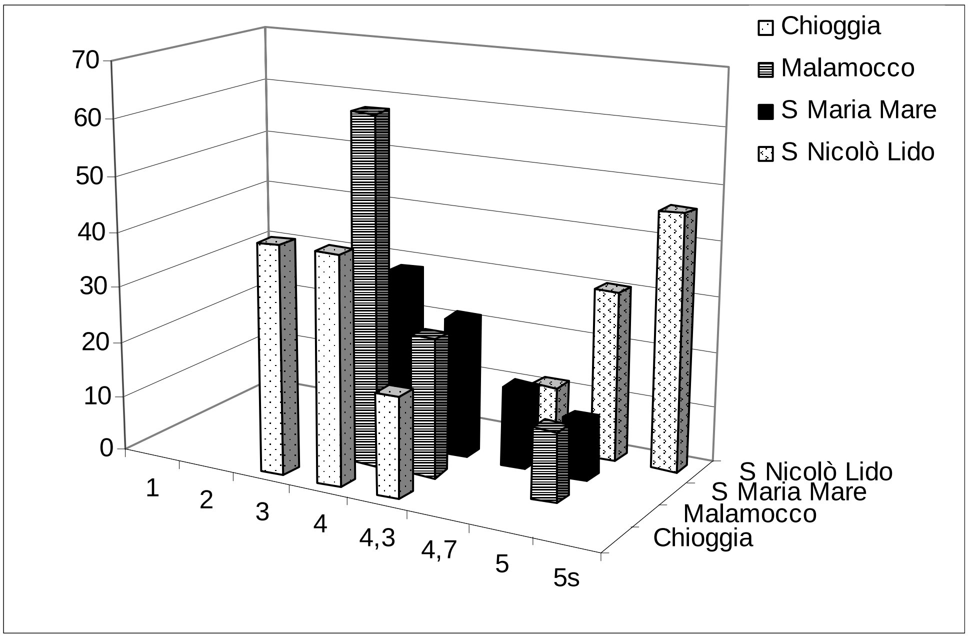

Fig. 2 - Stages of imposex according to the Vas Deferens Sequence (VDS) developed by Axiak et al. (1995) in the four sampling stations.

Tab. 2 - Concentration of the organotin compounds in the entire organism of *H. trunculus* in the four sampling stations (all values are reported as ng Sn g^{-1}).

		ΣBT	DEV STD	ΣPhT	DEV STD
S. NICOLO' DEL LIDO	**males**	216	5	8	1
	females 4	218	13	13	1
	females 4.7-5	262	14	15	2
	females 5s	342	105	29	9
S. MARIA DEL MARE	**males**	178	28	4	2
	females 3	149	21	2,4	0,3
	females 4-4.3	164	38	7	1
	females 4.7-5	163	30	7	3
CHIOGGIA	**males**	158	70	3,3	0,10
	females 3	115	15	6	1
	females 4	111	10	7	2
	females 4-4.3	114	16	7,4	0,2
MALAMOCCO	**males**	166	19	4	1
	females 4	125	25	5	1
	females 4.3-5	114	15	8	2

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EVALUATION OF BIOMARKER RESPONSES IN BIVALVES FROM THE VENICE LAGOON: SEASONAL STUDY AND TRANSPLANTATION EXPERIMENT

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Riassunto

Questa ricerca è stata condotta allo scopo di valutare la qualità ambientale della Laguna di Venezia attraverso lo studio delle risposte biologiche di organismi bioindicatori, quali i molluschi bivalvi. Una batteria di biomarker è stata applicata a diversi livelli di complessità biologica (dal molecolare al comportamentale) su due bivalvi marini (*Mytilus galloprovincialis* e *Tapes philippinarum*) quali organismi indicatori di due comparti ambientali (rispettivamente la colonna d'acqua e l'interfaccia acqua sedimento).

Lo studio stagionale effettuato su *M. galloprovincialis* ha permesso di discriminare le variazioni della risposta biologica attribuibili agli stress naturali da quelle indotte da fattori antropici. L'esperimento di trapianto condotto con *T. philippinarum* ha evidenziato i diversi tempi di risposta degli indici biologici nelle vongole trasferite in due zone della Laguna caratterizzate da diverso grado di contaminazione chimica.

Abstract

The present study was carried out in the lagoon of Venice to evaluate the biological responses of mussel, *Mytilus galloprovincialis,* and clam, *Tapes philippinarum,* to stress factors, both natural and anthropogenic, and to assess the effects due to spatial and temporal variations.

M. galloprovincialis were seasonally sampled (2001-2002) in areas of the lagoon of Venice affected by different kinds and degree of pollution. *T. philippinarum* was transplanted from a reference site outside the lagoon to two different areas inside the lagoon.

The biological response was evaluated at biochemical (aldehyde dehydrogenase and catalase activities), cellular (neutral red retention time), physiological (survival in air and condition index) and behavioural (reburrowing rate) levels.

Mussel responses varied among the different site, mainly in relation with temperature. The difference between reference and polluted stations was clearly distinguishable only in spring and summer, underlining the heavy influence of natural factors such as temperature, food availability and the reproductive cycle on the biological response of mussels in the lagoon of Venice.

Biochemical biomarkers and condition index showed spring values mostly far apart between polluted and reference samples, indicating a lesser influence, at least in this season, by natural and endogenous factors. As for survival in air, a marked difference

was observed only during winter time, whereas the values of neutral red retention time ranged similarly in all seasons.

The results of the transplantation experiment showed different although not significant biological responses in the clams deployed in the two lagoon sites.

1. Introduction

The Lagoon of Venice receives pollutants from a vast surrounding area, which is deeply urbanised, industrialised and subjected to a strong agricultural exploitation.

Domestic and industrial waste waters and agricultural drainage reach the lagoon by means of the Fusina and Campalto waste depurators, of the industrial plant of Porto Marghera, of stream outlets and from the canals.

The high variations of the environmental parameters increase the complexity of this ecosystem, making it difficult to define clearly the impact due to anthropogenic activities.

In the last years, several research campaigns were carried out with the aim to evaluate the environmental health of the Lagoon by means of the biomarker approach applied on marine bivalves (Livingstone et al, 1995; Livingstone & Nasci, 2000, Lowe & Da Ros, 2000; Marin et al., 2001; Nasci et al., 2002; Da Ros et al., 2002).

One of the main problems in the use of this approach is to establish what range of variations in the biological response can be considered "normal" rather than "pathological" (Ringwood et al., 1998). Several studies have showed how the biological response can be affected not only by chemical pollutants but also by a number of natural stressors such as temperature, salinity, hypoxia, food availability and the reproductive cycle of the sentinel organism (Depledge & Lundenbye, 1996; Ringwood et al., 1998; Nasci et al., 2000).

In this study, mussels (*Mytilus galloprovincialis)*, well-known as bioindicators of the water column quality (Goldberg et al., 1978; Bayne et al., 1979), were collected from differently polluted areas of the Venice Lagoon. Moreover, a transplantation experiment using clam (*Tapes philippinarum)* was carried out for the biological evaluation of the interface water-sediment (Da Ros et al., 1998; Nasci et al., 2000; Marin et al., 2001).

The suite of biomarkers applied in this study evaluated the biological responses at different degrees of biological organisation. As for biochemical parameters, catalase and aldheyde dehydrogenase activities were determined both in mussels and clams. The catalase is an antioxidant enzyme, detoxifying oxyradicals, which can be increased by stress conditions (Livingstone et al., 1993). The aldheyde dehydrogenase is involved in the oxydative biotransformation of endogenous and xenobiotic compounds in more soluble and excretable products, and it is inducible by exposure to pollutants (Forlin et al., 1995).

The neutral red retention time was measured in the mussel hemocytes. This assay has been widely employed to evaluate the condition of the lysosomal membranes, by considering the retention time of neutral red dye into the lysosomal compartment before it leaches into the cytoplasm, the elapsing time being a measure of the membrane stability (Lowe et al., 1995).

As for the physiological parameters, condition index and survival in air were determined both in mussels and clams. The condition index gives an indication of the animal physiological activity (growth, reproduction and secretion, etc.), and it is used to describe the fitness of the organisms (Lucas & Beninger, 1985). Survival in air is a simple but effective test to determine pre-existing stress in the bivalve population normally adapted to periodical aerial exposure (Eertman et al., 1993).

The behavioural response was evaluated in clams measuring their recessing ability by the reburrowing test, recognised able to provide a rapid response (from minutes to hours) to the introduction of environmental or chemical stresses (Phelps, 1989).

2. Materials and Methods

Samples of *M. galloprovincialis* were seasonally collected during the years 2001-2002 in four differently contaminated sites of the lagoon of Venice: Tresse, located close to the industrial area of Marghera, Celestia which receives urban sewage from the city of Venice, and S. Nicolò and S. Erasmo, both considered as reference sites.
The transplantation experiment with *T. philippinarum* was performed in March – April 2002. As in the last years this species was subjected to an heavy fishing pressure which has impoverished the clam bed in the Venice Lagoon (IMPACTO, 2003), clams to be transplanted were obtained from a rearing farm in the Sacca di Goro, and subsequently transferred in two lagoon areas: Tresse and S. Erasmo. The animals were kept for about one month in plastic hampers on sediment, and sampled at days 0, 2, 7, 14 and 30.

After each sampling, mussels (lenght 4-5 cm), and clams (length 3-4 cm) were kept in refrigerated box until arrival at the laboratory, where the organisms were processed for the different analyses.

Temperature and salinity of water were also recorded at each site.

As for biochemical parameters, activities of aldehyde dehydrogenase (ADH) and catalase (CAT) were measured on S9 fraction of 5 pooled samples, each made up of 4 digestive glands.

Aldehyde dehydrogenase activity (ADH) was determined by measuring the increase of absorbance at 340 nm, due to the NAD reduction (Förlin et al., 1995).

The catalase activity was measured at 240 nm, by the decreasing of the absorbance due to the H_2O_2 consumption (Aebi, 1974).

The neutral red retention time (NRR) was evaluated individually on the hemocytes of 10 animals, according to Lowe et al. (1995).

After the incubation with the neutral red staining, the hemocytes were inspected under a microscope at time 15 minutes and then every 30 minutes to determine when loss from the lysosomes to the cytosol was evident. The test was terminated when the dye loss was observed in 50 % of the small granular haemocytes (Lowe & Pipe, 1994; Ringwood et al., 1998).

The condition index (CI) was calculated on 30 individuals after dehydratation in oven at 90°C for 48 hours, using the following ratio CI = dry weight of the wet meat/dry well of the shell (Lucas & Beninger, 1985).
The survival in air was determined on samples of 30 individuals. They were damp dried with paper tissue and the tray was placed in a constant temperature room of 18°C (Eertmann et al, 1993). Daily recordings were made of the number of the animals alive.

Animals were considered dead when shell-gape occurred and an external stimulus (prodding tissues with a probe and/or squeezing of the valves) didn't generate any response. Dead animals were removed immediately.

The LT50 (lethal time for the 50% of the sample) was calculated according to the method of Kaplan & Meier (1958), and the resulting survival curves were compared using the Gehan & Wilcoxon test (Gehan, 1965), both included in the software STATISTICA.

On *T. philippinarum,* the reburrowing rate was calculated according to the method suggested by Phelps (1989): twenty individuals were placed in aquaria (42x24x26 cm) with a fine sediment obtained by sieving natural beach sediment (Phelps, 1989). The aquaria were kept in a thermostatic chamber simulating original water temperatures. A web cam was employed for the continuous observation of the reburrowing time. The camera was set to take a photo every 30 minutes over a time period 24 hours long. Subsequently the RT50 (the time requested for the reburrowing of the 50% of the sample) was calculated according to the method of Kaplan & Meier (1958), and the reburrowing curves were compared using the Gehan & Wilcoxon test (Gehan, 1965), both included in the software STATISTICA.

In the seasonal study, the averaged values of biomarkers measured in each site, and the salinity and temperature recordings, were used in the subsequent principal component analysis (PCA).

The not normally distributed data of biochemical and cellular parameters and the condition index were statistically compared using the non-parametric Kruskall – Wallis test. The Gehan & Wilcoxon test was used for survival in air and reburrowing rate.

3. Results

3.1. Seasonal study

Temporal variations recorded for each biomarker revealed similar seasonal trends for all the considered studied area, both in the reference and the contaminated sites.

The ADH activity showed values generally higher in the samples from Tresse and Celestia than in control sites considered as unique reference point (REF), except for Tresse in October and for Celestia in July (Fig. 1).

The values of CAT activity were significantly higher in REF samples than in mussels from polluted sites in May and July, in October they were similar, and significantly depressed at Celestia in February (Fig. 2).

The NRR test revealed similar values in polluted and reference samples throughout the year, although the median value of REF samples resulted slightly higher than in the polluted mussel, especially in October and May (Fig. 3).

The CI showed significantly higher values in samples from Tresse than in the REF and Celestia mussels, except in February, whereas REF is significantly higher than Celestia in all seasons (Fig. 4). The SOS analysis presented similar values among samples in October, higher values in polluted samples than in REF in February and May, whereas higher resistance values were recorded in REF samples in comparison with Tresse and Celestia only in July (Fig. 5).

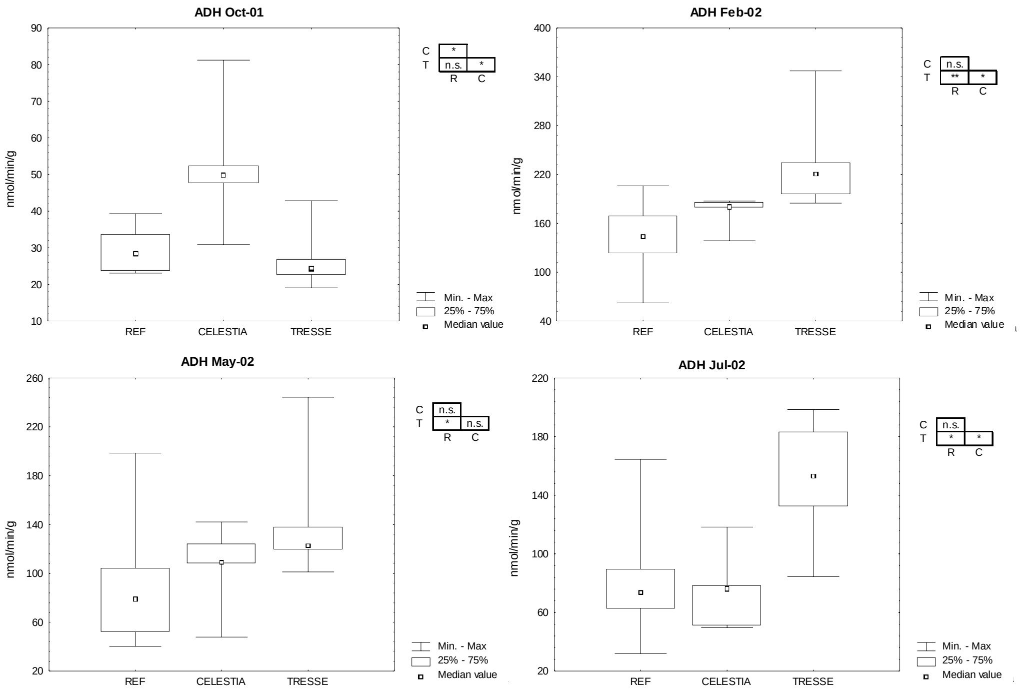

Fig. 1 – Aldehyde dehydrogenase activity (ADH) (nmol/min/g) in *M. galloprovincialis* seasonally collected in different sites of the Venice Lagoon. REF = reference obtained averaging the median values calculated in S. Nicolò and S. Erasmo.
Statistical comparison (Kruskall – Wallis test): * = $p < 0.05$; ** = $p < 0.01$; n.s. = not significant.

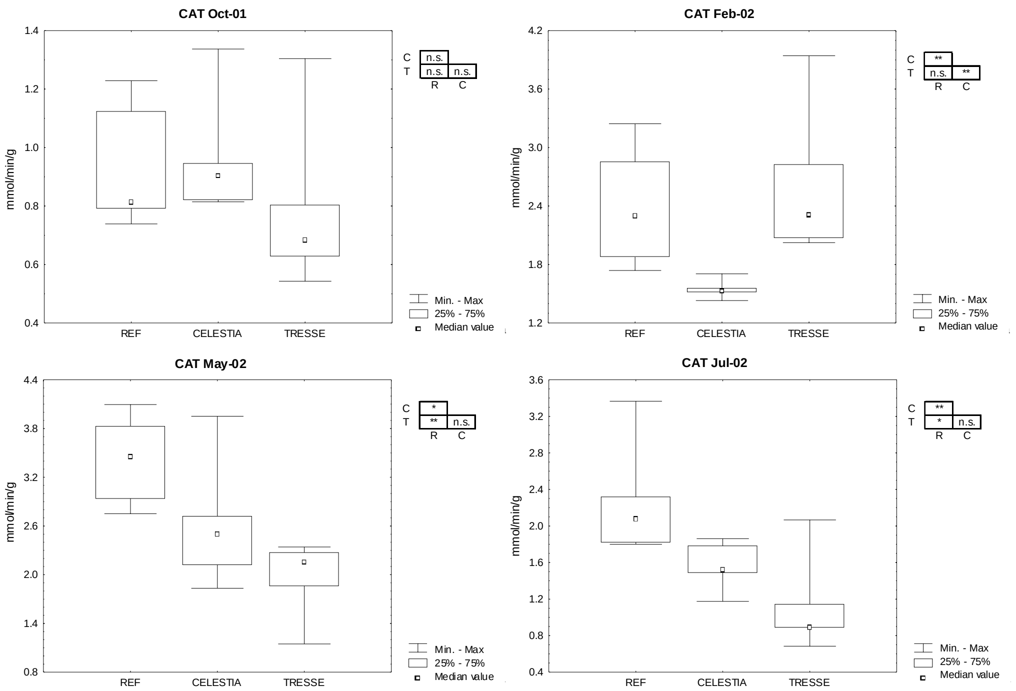

Fig. 2 – Catalase activity (CAT) (mmol/min/g) in *M. galloprovincialis* seasonally collected in different sites of the Venice Lagoon. REF = reference obtained averaging the median values calculated in S. Nicolò and S. Erasmo.
Statistical comparison (Kruskall – Wallis test): * = $p < 0.05$; ** = $p < 0.01$; n.s. = not significant.

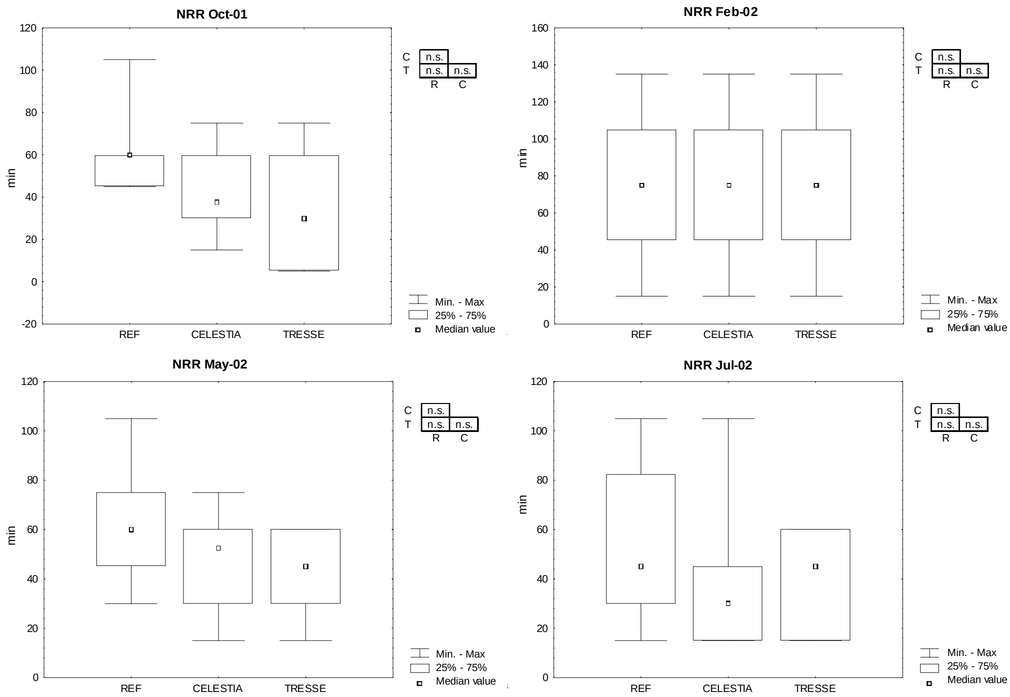

Fig. 3 – Neutral red retention time (NRR) (min) in *M. galloprovincialis* seasonally collected in different sites of the Venice Lagoon. REF = reference obtained averaging the median values calculated in S. Nicolò and S. Erasmo.
Statistical comparison (Kruskall – Wallis test): n.s. = not significant.

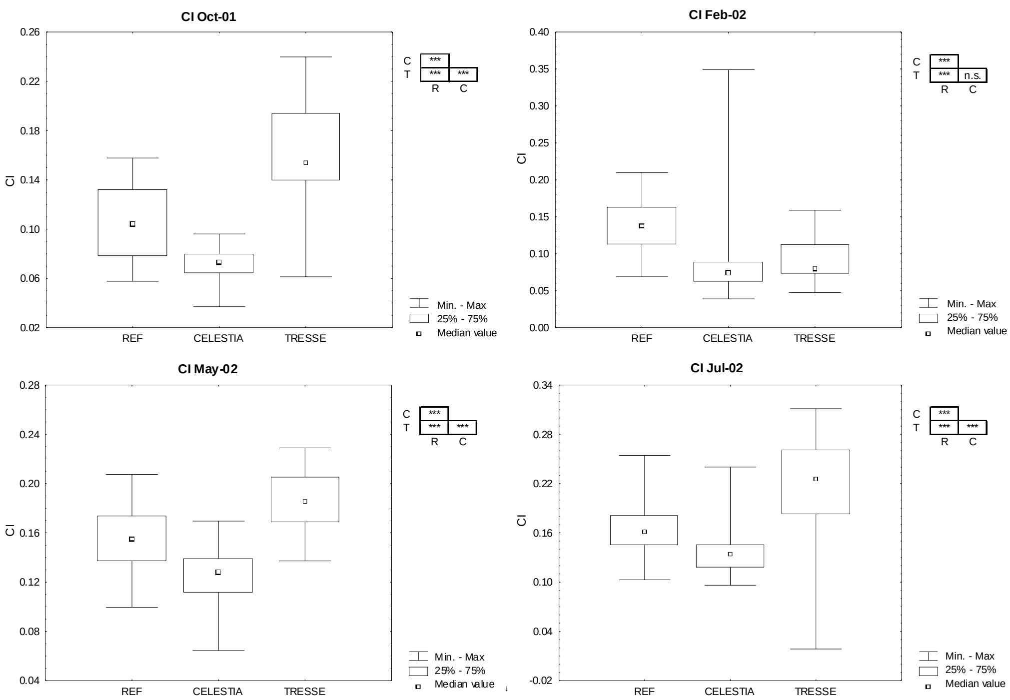

Fig. 4 – Condition index (CI) in *M. galloprovincialis* seasonally collected in different sites of the Venice Lagoon. REF = reference obtained averaging the median values calculated in S. Nicolò and S. Erasmo.
Statistical comparison (Kruskall – Wallis test): *** = p < 0.001; n.s. = not significant.

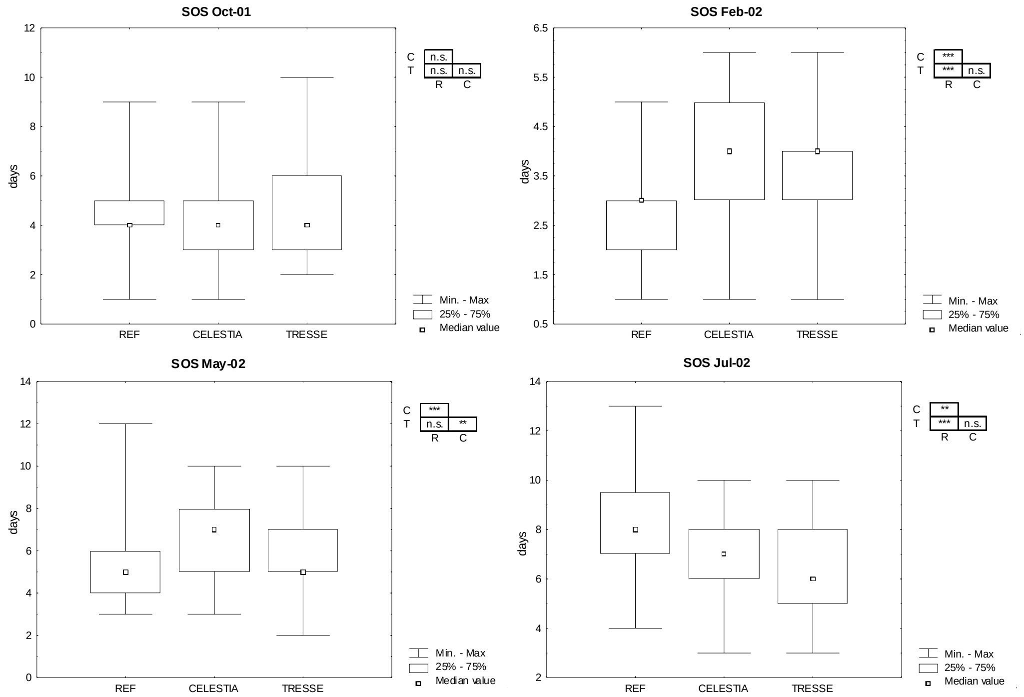

Fig. 5 – Survival in air (SOS) (days) in *M. galloprovincialis* seasonally collected in different sites of the Venice Lagoon. REF = reference obtained averaging the median values calculated in S. Nicolò and S. Erasmo.
Statistical comparison (Gehan & Wilcoxon test): ** = $p < 0.01$; *** = $p < 0.001$; n.s. = not significant.

The principal component analysis performed on data of Tab. 1 showed a distribution of the stations mainly according with temperature. This variable characterises factor 1, which explain the 43% of the total data variance, whereas the variable CAT and NRR characterise factor 2 (23% of the variance explained). Four seasonal groups were identified and a greater separation between polluted and reference stations was present mainly within the spring and summer groups (Fig. 6).

3.2. Transplantation experiment

All the applied biomarkers revealed the presence of stress condition in the clams from the rearing farm , which resulted to be not a good control.

The results of ADH activity are shown in figure 7. Higher values were recorded in Tresse samples than in S. Erasmo after 2 and 7 days of exposure, whereas after 14 days, the opposite trend was highlighted (Fig. 7).

The CAT activity revealed a slight but not significant increase in Tresse in comparison with S. Erasmo after 7 days of transplantation (Fig. 8).

The NRR test showed higher values in clams transplanted to S. Erasmo than to Tresse after 2 day exposure. The differences between stations, although not significant, increased during the whole exposure period (Fig. 9).

The reburrowing test, determined after 14 days, indicated a greater reburrowing ability in clams transferred to S. Erasmo, in comparison both with the time 0 and the Tresse sample (Fig. 10).

Tab. 1 - Mean values of biochemical, cellular, physiological and environmental parameters measured in *M. galloprovincialis* from different sites in the Venice Lagoon (SE = S. Erasmo, SN = S. Nicolò, C = Celestia, T = Tresse).

	ADH (nmol/min/g p.u.)	**CAT (mmol/min/g p.u.)**	**NR (min)**	**IC -**	**LT50 (giorni)**	**T (°C)**	**SAL (‰)**
SE Feb02	115.562	2.462	63	0.122	3	4.9	36
SE May02	107.723	3.491	61.5	0.151	5	19	32
SE Jul02	60.588	2.143	51	0.15	8	25	35
SN Oct01	29.624	0.939	58.5	0.106	4	19.5	34
SN Feb02	171.422	2.318	93	0.155	3	6.2	38
SN May02	79.602	3.361	64.5	0.161	5	18.6	35
SN Jul02	110.323	2.303	58.5	0.175	8	25	34
C Oct01	52.364	0.964	42	0.071	4	19.5	33
C Feb02	174.328	1.545	69	0.084	4	4.2	24
C May02	106.293	2.623	48	0.123	7	20.3	31
C Julg02	74.721	1.564	40.5	0.136	7	24.8	31
T Oct01	27.132	0.792	33	0.16	4	20.2	30
T Feb02	236.468	2.636	78	0.088	4	5	35
T May02	145.088	1.952	42	0.187	5	20.7	33
T Jul02	150.38	1.134	42	0.213	6	25.9	30

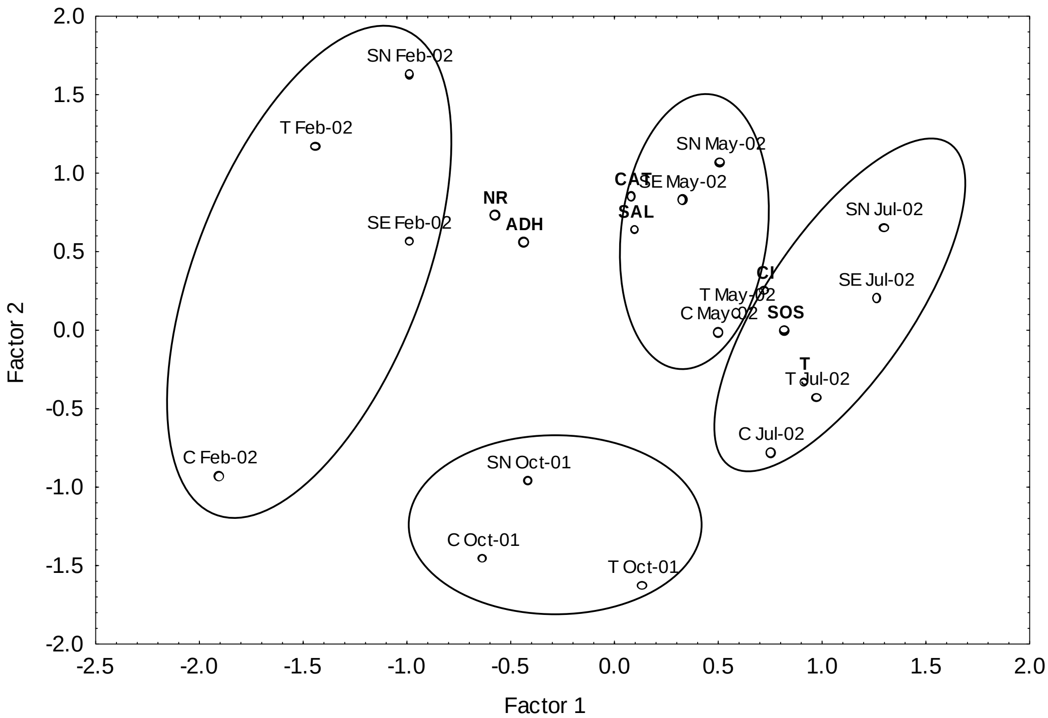

Fig. 6 - Principal component analysis (PCA), obtained by biplot technique, applied to average data of various biomarkers and environmental parameters measured in Tresse (T), Celestia (C), S. Nicolò (SN) and S. Erasmo (SE) during the four sampling periods.

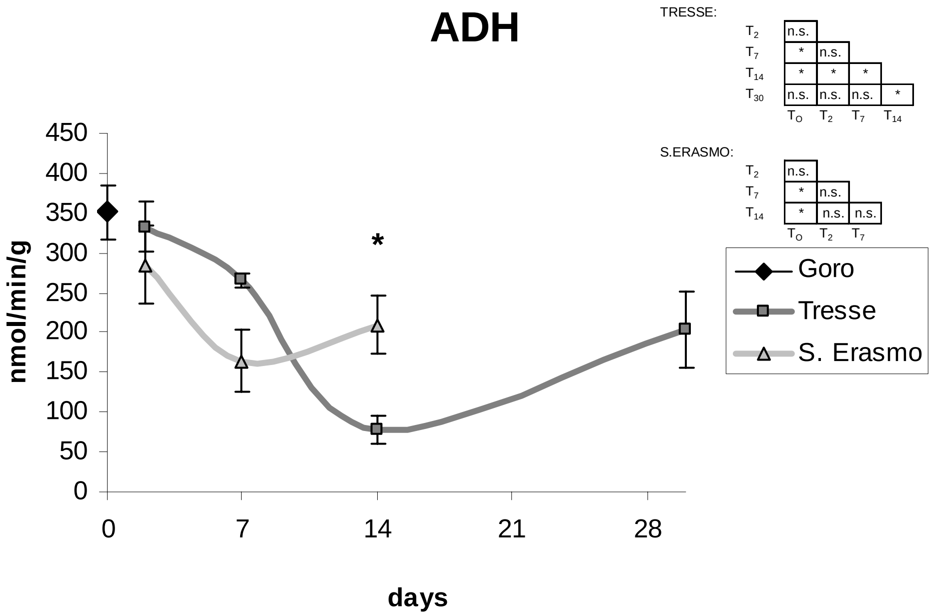

Fig. 7 – Aldehyde dehydrogenase activity (ADH) (nmol/min/g) (mean ± SE) in *T. philippinarum* sampled at time 0 (T0) at Goro and transferred for 2 days (T2), 14 days (T14) and 30 days (T30) at Tresse and S. Erasmo.
Statistical comparison (Kruskall-Wallis test): * = p < 0.05; n.s. = not significant.

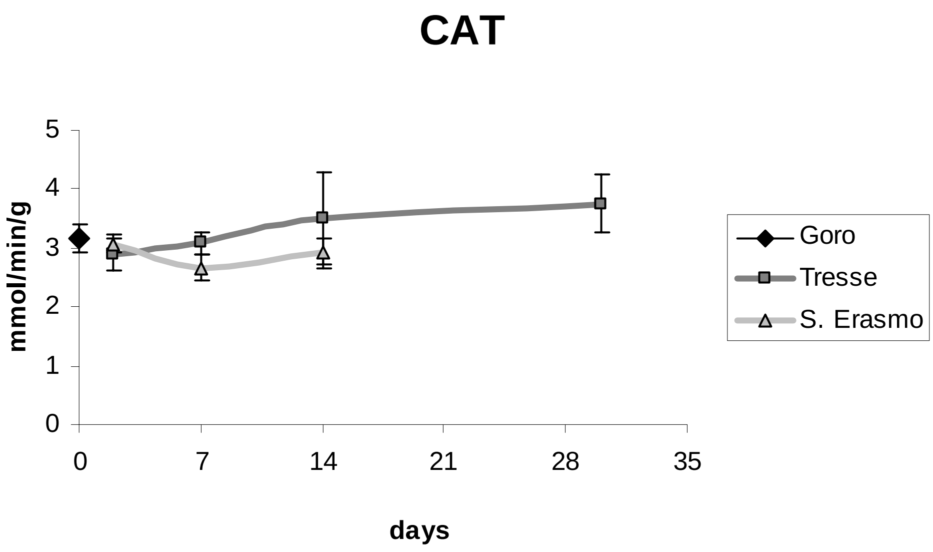

Fig. 8 – Catalase activity (CAT) (mmol/min/g) (mean ± SE) in *T. philippinarum* sampled at time 0 (T0) at Goro and transferred for 2 days (T2), 14 days (T14) and 30 days (T30) at Tresse and S. Erasmo.
Statistical comparison (Kruskall-Wallis test) between sites at the same time and among times at the same site: n..s. = not significant.

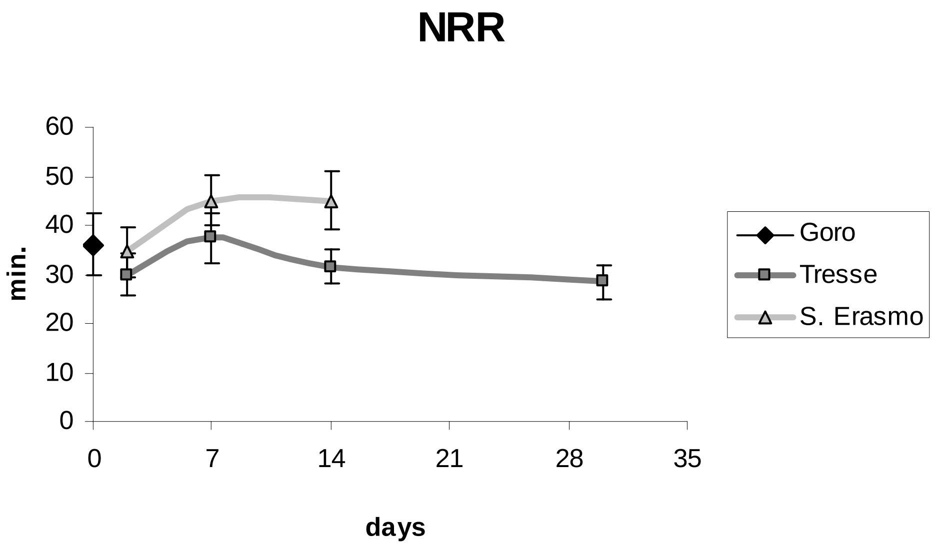

Fig. 9 – Neutral red retention time (NRR) (min) (mean ± SE) in *T. philippinarum* sampled at time 0 (T0) at Goro and transferred for 2 days (T2), 14 days (T14) and 30 days (T30) at Tresse and S. Erasmo. Statistical comparison (Kruskall-Wallis test) between sites at the same time and among times at the same site: n..s. = not significant.

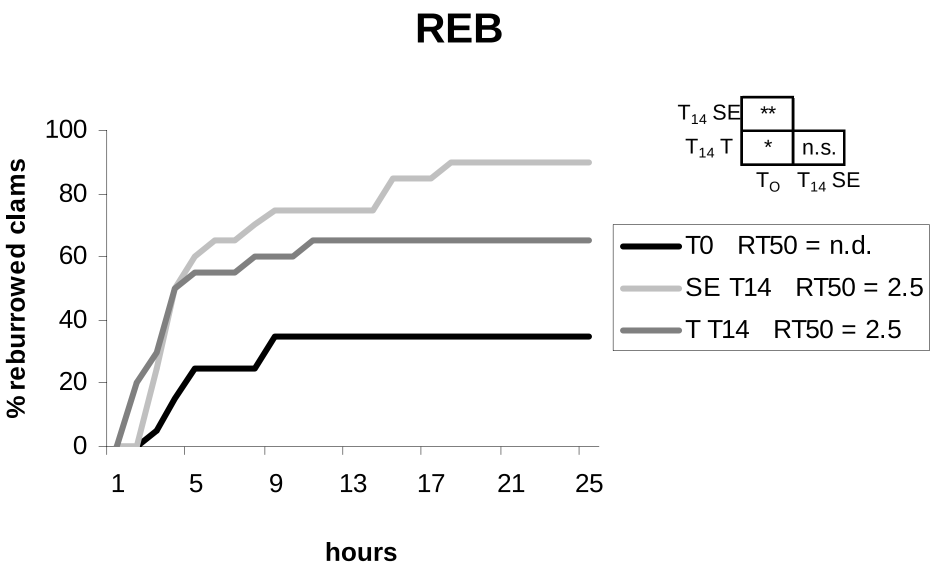

Fig. 10 - Reburrowing curves (REB) (% reburrowed clams) calculated in *T. philippinarum* sampled at time 0 (T0) at Goro and transferred for 14 days (T14) at Tresse and S. Erasmo.
Statistical comparison (Gehan & Wilcoxon test): * = p < 0.05; ** = p < 0.01; n..s. = not significant.

4. Discussion

4.1. Seasonal study

The overall results highlighted a seasonal variability in the biological responses. Temporal variations recorded for each biomarker revealed similar seasonal trends for all the studied areas, both in the reference and contaminated sites.

The combination of spatial and temporal information allowed us to distinguish the physiological variations due to natural from those ones due to anthropic stress and to identify the sampling period when biomarkers result less influenced by both natural and endogenous factors.

Comparing the seasonal variations by the median and the data range (including the 25% and the 75% of the values of each biomarker) (Da Ros et al., in press), the ADH activity showed in the February and May values of polluted samples clearly outside the reference range. These results revealed that this parameter is generally suitable to highlight the presence of chemical pollutants, and that its capability to discriminate among differently impacted areas appears higher in winter and spring.

As for the CAT activity, the values of the reference sites were well separated from those of the polluted areas in May and July, months in which it resulted to be severely depressed. It is known that several endogenous and environmental factors can influence the response of this enzyme, as observed in many field studies (Sheehan & Power, 1999; Livingstone, 2001). The peculiar environmental conditions at Tresse and Celestia (e.g. high food availability as Particulate Organic Carbon) (Sfriso, unpubl. data), could have interfered with enzyme induction more than in the reference sites, located by the sea inlet, where the water is less enriched with suspended particulate food. These results are in agreement with the data reported by Nasci et al. (2002), in a study on the biochemical responses of *M. galloprovincialis* in the Venice Lagoon, indicating a significant decrease of antioxidant enzyme activities in the urban and industrial areas. The values of neutral red retention test failed to reveal a clear pollution response, having proved similar among the sites throughout the year. In our opinion, this may depend on the peculiar environmental conditions of the polluted sites, that could have masked the negative effects of contamination (Ringwood et al.,1998; Nicholson, 2001).

As for the condition index (CI), the data range of the reference sites, was completely separated from those of the contaminated areas in every season, with values always higher at Tresse, except in February. These results might be partially due to the large amount of nutrients at Tresse (Sfriso, unpubl.data), a condition which turned into an higher body mass in the native mussels. In February, when the concentration of nutrients resulted similar for all the sites, this index was higher in REF mussels, highlighting the worse conditions of the animals from Celestia and Tresse.

The survival in air (SOS) is considered a physiological biomarker very sensitive for the identification of generic environmental stress conditions (Eertman et al., 1993; Viarengo et al., 1995). Only for the month of July the survival curves and the related LT50 showed a greater stress condition in the contaminated mussels than in the ones from the reference sites, whereas an opposite situation was observed during the other sampling periods. Again, the high levels of particulate organic matter and nutrients levels in the water of the more contaminated sites (Sfriso, pers. comm.) could have determined particularly favourable conditions for the indigenous mussels, making them more resistant to air exposure. Under anaerobic condition, the metabolism of the mussel turns into anaerobic pathways, and the glycogen becomes its only or main source of energy (de Zwaan and Wijsman, 1976). Therefore, in a high trophic environment, the energetic resources of these organisms could be such as to increase their fitness, despite the higher chemical contamination affecting those areas.

4.2. Transplantation experiment

The transplantation of sentinel organism has been proposed as an useful tool in environmental biomonitoring, ensuring comparable biological samples and reducing their natural variability (de Kock & Kramer, 1994).

The experiment carried out in this study with *T. philippinarum* highlighted differences, although not significant, between the biological responses of the clams deployed in the two lagoon sites. On the other hand, some technical problems have arisen in applying this approach to the Venice lagoon. All biomarkers revealed the presence of stress condition in clams from the rearing farm , which resulted to be not a good control.

Moreover the loss of the hampers transferred to S. Erasmo made it impossible for us to compare the biological responses of the organisms after 30 days of exposure .

Nevertheless, the ADH activity showed higher values in the sample transferred to Tresse than in the REF one of S. Erasmo just after 2 exposure days. This difference increased after 7 days, while an opposite trend appeared in 14 days. This behaviour could be due to the beginning of adaptation phenomena in the animals, or to the presence of environmental factors that could have masked the effects of the chemical contamination.

A previous transplantation experiment was performed during 1998 transferring samples of *T. philippinarum* from a rearing farm located in the northern part of the Venice Lagoon (Val Dogà) to Marghera (close to Tresse) and to Palude della Rosa a reference area) for 4 weeks. In comparison the sample transferred to Marghera in 1998 showed lower ADH activity levels than the one deployed to Tresse for 30 days in the present study. Moreover in the 1998 experiment, a positive correlation among ADH activity, PCB and PAH animal contents was recorded (Nasci et al., 2000).

The CAT activity evidenced an increasing trend (although not statistically significant) in the samples transferred to Tresse in comparison with the S. Erasmo ones, after 7 days of exposure. After 30 days, the values were lower than the levels measured in Marghera sample in the previous transplantation experiment (Nasci et al., 2000). Similarly, in 1998 study no statistical difference was observed between the enzymatic activities of the samples transplanted in Marghera and Palude della Rosa.

The neutral red retention test showed a higher lysosomal stability in the sample transplanted to S. Erasmo than in the Tresse one just after two days, with an increasing trend during all the exposure period, although never significant. This biomarker probably requires a longer period to discriminate among the selected stations. These results are in agreement with the data reported by Marin et al. (2001) regarding a transplantation experiment of *T. philippinarum* performed in the Venice Lagoon in 1998 where a better condition, though not statistically significant, was recorded in the sample transferred to the less contaminated site.

Also the reburrowing test didn't show significant differences between the two sites, although the sample transplanted for 14 days to S. Erasmo presented an higher reburrowing capacity than that one transplanted to Tresse. This rapid assay was developed and widely used in toxicity tests of sediment (Phelps et al., 1985; Phelps, 1989). The reburrowing rate recorded in this study (RT50 = 2.5 hours) resulted higher than the value registered for the same species in a field survey carried out in the Venice Lagoon in 2001 (0.66 – 0.95 hours) (IMPACTO, 2003). The RT50 values were also higher than the ones calculated for *Mya arenaria*, which is considered a suitable organism for rapid reburrowing assays in estuarine sediments (mean RT50 = 0.45 in controls) (Phelps, 1989).

5. Conclusions

The results of the seasonal study with *M. galloprovincialis* indicated the strong influence of environmental parameters (mainly temperature) on biological responses, as evidenced by PCA analysis .

The combination of spatial and temporal information allowed us to recognise the natural vs anthropic stress-induced physiological variations, and to identify the most suitable sampling periods, in which the several biomarkers are less influenced by both natural and endogenous factors.

The biochemical biomarkers and condition index showed the most relevant differences between polluted and reference samples in spring, when natural and endogenous factors appear to be less impacting. Survival in air was able to separate polluted from reference sites in winter, whereas the values of neutral red retention time ranged likewise in all sites throughout the year.

As regards to the transplantation experiment of *T. philippinarum,* the results generally revealed a worse condition for samples transplanted to the most impacted area. However, due to problems in getting good controls and in the field managing of organisms, further studies are advisable to validate the use of this procedure for assessing the environmental quality in the Venice Lagoon.

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EXPOSURE LEVELS TO ESTROGENIC COMPOUNDS IN THE VENICE LAGOON

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Riassunto

E' stata valutata l'esposizione della laguna di Venezia (Italia) a sostanze estrogeniche di origine naturale (estradiolo, estrone, estriolo) e sintetica (etinilestradiolo, mestranolo, nonilfenolo, ottilfenolo, nonilfenolo monoetossilato carbossilato, benzofenone, bisfenolo-A, dietilstilbestrolo) analizzate mediante metodi avanzati (cromatografia liquida/spettrometria di massa, HPLC-MS). Il dato di concentrazione per ciascuna sostanza è stato convertito in concentrazione equivalente di estradiolo, EEQ, mediante i fattori di equivalenza dell'estradiolo, EEF, in modo da determinare la potenza estrogenica totale nelle matrici ambientali acqua e sedimento. Da dati di letteratura, i valori di EEQ ottenuti per i campioni acquosi (2.8-191 ng/L, media: 28 ng/L) e per i sedimenti (4.7-190 µg/Kg, media: 69 µg/kg), con il preponderante contributo delle sostanze naturali e di sintesi steroidee (> 99.9%) per le acque, e quello delle sostanze di sintesi steroidee e non (> 99%) per i sedimenti, possono causare effetti negativi sugli organismi acquatici.

Abstract

The exposure to estrogenic substances both natural (estradiol, estrone and estriol) and synthetic (ethinylestradiol, mestranol, nonylphenol, octylphenol, nonylphenol monoethoxylate carboxylate, benzophenone, bisphenol-A, diethylstilbestrol) in the Venice lagoon (Italy) was assessed by means of Solid Phase Extraction followed by High Performance Liquid Chromatography separation coupled with Ion Trap – Mass Spectrometry detection via Electrospray Interface (SPE-HPLC-ESI-IT-MS). The individual compound concentrations were converted into estradiol equivalent concentration (EEQ), by means of estradiol equivalency factors (EEF), in order to estimate the estrogenic potency of Venice lagoon water and sediment. According to literature, EEQ found for the aqueous samples (2.8-191 ng/L, average: 28 ng/L) and for the sediment samples (4.7-190 µg/Kg, media: 69 µg/kg), are likely to pose adverse effects on the Venice aquatic wildlife.

1. Introduction

During the past decade, scientists took growing interest in so-called "endocrine disruptors". These exogenous substances are able to interfere with the hormonal system, thus causing adverse effects on the intact physiology of organisms [Bögi, 2003]. Both field and laboratory studies have provided evidence that exposure to these chemicals can lead to the modulation or disruption of development and reproduction in aquatic life and wild life [Wen Li, 2003]. We define estrogenicity as the property of producing biologic responses qualitatively similar to those produced by the endogenous hormone, estradiol-17β [Daston, 1997].

Chemicals with hormonal activity, i.e. potential endocrine disrupters, include natural hormones from any animal, released into the environment, natural chemicals including toxins produced by components of plants (the so-called phytoestrogens, such as genistein or coumestrol) and certain fungi, synthetically produced pharmaceuticals that are intended to be highly hormonally active, e.g. the contraceptive pill and treatments for hormone-responsive cancers, and finally, man-made chemicals and by-products released into the environment, that include some pesticides (e.g. DDT and other chlorinated compounds), chemicals in some consumer and medical products (e.g. some plastic additives), and a number of industrial chemicals (e.g. PCBs, dioxins) [http://europa.eu.int/comm/environment/endocrine/definitions/endodis_en.htm].

In wildlife, endocrine disrupters have been clearly shown to cause abnormalities and impaired reproductive performance in some species, and to be associated with changes in immunity and behaviour and skeletal deformities. Experimental studies indicate that EDCs are particularly active during the early developmental stages of the male reproductive system [Petrelli, 2002]. Reduced fecundity and/or fertility, abnormally elevated levels of plasma vitellogenin and intersex gonads are the most commonly observed effects produced by EDCs on aquatic wildlife species [Jobling, 1998; Solè, 2000; Ternes, 1999]. All these effects can cause an increase in the feminization process that is very dangerous for the survival of species and ecosystems, as they necessarily lead to a loss of biodiversity. Most of the effects observed up to now are related to disturbances of the reproductive biology of aquatic vertebrates, because aquatic vertebrates are directly exposed to potential endocrine disruptors in their habitats [Bögi, 2003].

In humans, endocrine disrupters have been suggested as being responsible for apparent changes seen in human health patterns over recent decades. These include declining sperm counts in some geographical regions, increased incidences in numbers of male children born with genital malformations, and increases in incidences of certain types of cancer that are known to be sensitive to hormones. More controversially, links have been suggested with impairment in neural development and sexual behaviour [http://europa.eu.int/comm/environment/endocrine/definitions/endodis_en.htm]. Men exposed to estrogenic compounds may have reduced fertility and may develop female secondary sex characteristics, such as enlarged breasts (gynecomastia). Prolonged exposure to estrogens is thought to promote breast cancer in women [Daston, 1997]. Table 1 reports the potential reproductive endpoints altered following exposure to estrogenic and antiestrogenic chemicals.

As new evidence has been obtained that could associate potential problems and endocrine disruption and public concern increased the European Commission established a legislative-based strategy for endocrine disrupters. In 1999, the Commission's Scientific Committee for Toxicity and Ecotoxicity and the Environment (SCTEE) published a report 'Human and wildlife health effects of endocrine disrupting chemicals with emphasis on wildlife and ecotoxicology test methods'. In order to respond quickly and effectively to the concerns and recommendations highlighted in these reports, the Commission, in 1999, adopted a strategy that was in line with the precautionary principle COM(1999)706 [http://europa.eu.int/comm/environment/endocrine/strategy/index_en.htm].

In the United States, the *U.S. Food Quality Protection Act* (1996) [The Food Quality Protection Act of 1996] requires Environmental Protection Agency (EPA) to test all pesticide chemicals for endocrine-disrupting effects, while the *Safe Drinking Water Act Amendments* (1996) [Safe Drinking Water Act Amendments of 1996] authorizes EPA to develop and to implement a program for identifying and regulating substances that may have effects on humans similar to those produced by naturally occurring estrogens or other endocrine effects.

Tab. 1 – Potential reproductive endpoints altered following exposure to estrogenic and antiestrogenic chemicals [Daston, 1997]

Sexual differentiation
Offspring sex ratio
Gonad development (size, morphology, weight)
Accessory sex organ development (size, morphology, weight)
Accessory sex organ function (secretory products production)
Secondary sexual characteristics (muscle and body mass, hair/fur, etc.)
Sexual development and maturation (vaginal opening, testes descent, preputial separation, anogenital distance, nipple development)
Fertility
Fecundity (litter size and the number of litters)
Time to mating
Mating and sexual behavior
Ovulation
Estrous cyclicity
Gestation length
Abortion
Premature delivery
Dystocia
Spermatogenesis
Sperm count and production
LH and FSH levels
Androgen and estrogen levels
Gross pathology of reproductive tissue
Histopathology of reproductive tissue
Anomalies of the genital tract
Malformation of the genital tract
Viability of the conceptus and offspring (post- and preimplantation loss, gestation, and neonatal survival)
Growth of the conceptus and offspring (body weight)

The chemicals examined in this work were both of natural and synthetic origin. Among the natural hormones, estrogens are a group of chemicals of similar structure mainly responsible for female sexual differentiation, reproduction, somatic cell function, development of secondary sex characteristics, ovulation, regulation of mating and breeding behaviours, and regulation of calcium and water homeostasis [Jobling, 2003]. They are produced mainly by the ovaries but also by the adrenal glands and fat tissue. The principal human estrogen is 17β-estradiol (E2) [http://europa.eu.int/comm/environment/endocrine/definitions/endodis_en.htm], while E1 is its main degradation product originated in the liver. Natural estrogens such as those regulating the female reproductive cycle are excreted both by women and men in the population and occur in sewage [Svenson, 2003]. The synthetic derivatives of natural estrogens, such as ethinylestradiol (EE2) and mestranol, are used extensively in oral contraceptives for treating both pre- and post-menopausal disorders. Furthermore, EE2 is used in human medicine to treat conditions such as amenorrhea, breast carcinoma, hypogonadism, postpartum breast engorgement and prostatic carcinoma [Environmental Health Perspectives official web-site: http://ehp.niehs.nih.gov]. Estrogens used as contraceptives and pharmaceuticals are also excreted and have been found in municipal wastewater [Svenson, 2003]. Selected synthetic non-steroidal estrogens exhibit estrogenic activity regardless structural similarity with steroidal EDCs. Diethylstilbestrol (DES) is a synthetic estrogen prescribed in the 1950s and 1960s to five million pregnant women for the prevention of spontaneous abortion. It was banned in the 1970s, but it is still used as a growth-promoting agent in livestock [http://europa.eu.int/comm/environment/endocrine/definitions/endodis_en.htm].

Bisphenol-A (BPA) is an industrial product used as a monomer of polycarbonate plastics present in food cans and dental resins; benzophenone (BP) is used as photoinitiator, fragrance enhancer, ultraviolet curing agent and as additive in insecticides, pharmaceuticals and plastics, coatings and adhesives. Nonylphenol polyethoxylates (NPE) are nonionic industrial surfactants used worldwide in detergents, paints, herbicides and cosmetics; their environmental and sanitary relevance is due to the considerable amount that can be pour into the water receiver [Ferrara, 2001, Ann. ISS]. Nonylphenol monoethoxylate carboxylate (NP1EC), nonylphenol (NP) and octylphenol (OP) are the main microbial degradation products of NPE.

Many biological experiments have been performed in order to evaluate potential effects of EDCs. Estrogenic potency of an endocrine disrupter is commonly related to E2 by means of estradiol equivalency factors (EEFs). The EEF is the quotient of values $EC50_{,E2}$ / $EC50_{,\text{test compound}}$ and it is conventionally set to 1 for E2. These factors cover a very wide range of values (see Fig. 1). EE2, E1 and mestranol are the most potent steroidal EDCs: their EEFs are 1.5, 5.8×10^{-2} and 1.3×10^{-2}, respectively [Gutendorf, 2001; Körner, 1999, 1999 (PUG), 2001]. The synthetic EDCs are indeed much less potent than E2 (EEFs: 5.7×10^{-4}, 1.0×10^{-4}, 2.0×10^{-5}, 6.1×10^{-7} for BPA, NP, NP1EC and BP, respectively), apart from DES which is 2.6 times more potent than E2 (EEF = 2.6) [EPA/630/R-96/012, 1997; Gutendorf, 2001; Körner, 1999, 2001; Lagler, 2002; Routledge, 1996; Thomas, 2001].

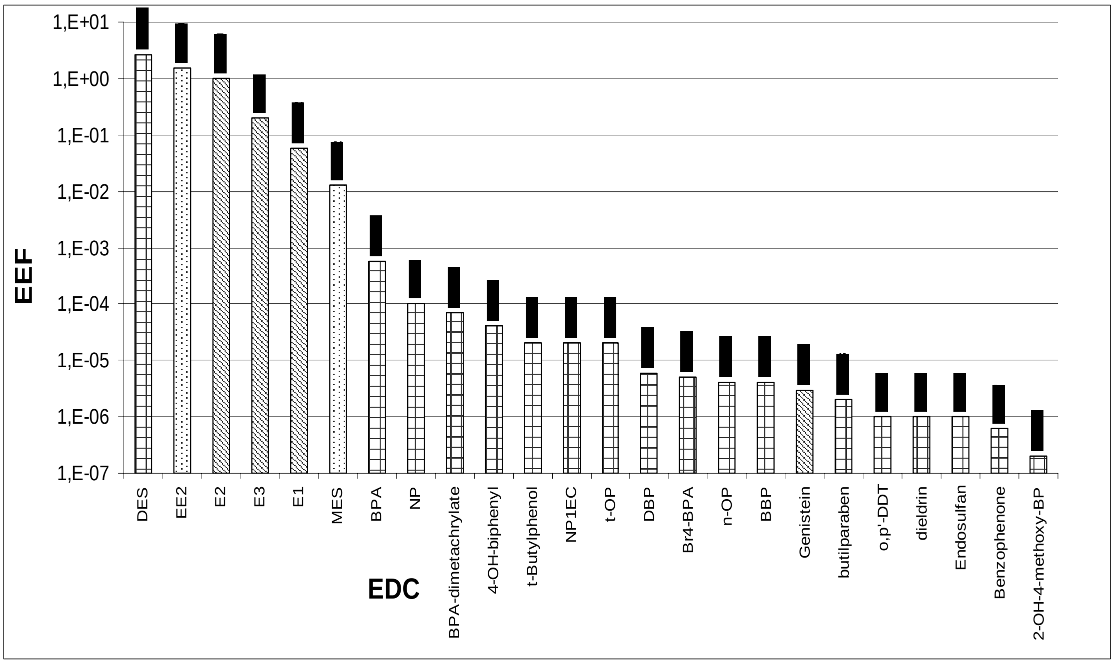


Fig.1 - Average EEF values from *in vitro* biological assays (▧: natural non-steroidal estrogens; ⊡: synthetic non-steroidal estrogens; ⊞: synthetic steroidal estrogens)

In order to determine the potential exposure from estrogens in environmental samples, chemical analysis is usually essential for determining the concentrations of estrogens [Wen Li, 2003]. Since the additive behaviour of the estrogenic activity of EDCs mixtures has been recently proved [Körner, 1999], the total estrogenic activity of environmental samples contaminated by EDCs can be quantitatively evaluated in terms of EEQ (estradiol equivalent concentration), provided that individual concentrations of all active compounds are known. EEQ, expressed typically as ng/L or μg/kg, is the total amount of estrogenic compounds contained in a sample normalized to E2. Literature reports show that when EEQ values of water samples, obtained from both laboratory studies or field investigations, are > 2.5 ng/L, an increase of plasma vitellogenin levels, a decrease in the gonad development and difficulty in the sexual differentiation, can occur in surface waters fish [Schwaiger, 2002; Seki, 2003; Tilton, 2002], while for EEQs ranging between 10 ng/L to 50 ng/L, ermaphroditic gonads development can be observed [Harries, 1997; Seki, 2003]. When EEQs >50 ng/L are determined, interrupted egg production can be noticed [Folmar, 2000; Giesy, 2000; Seki, 2002]. A recent study indicated, for the sediments samples, that when EEQs > 1 μg/kg abnormal embryo development can be observed [Duft, 2003]. Until now, to the best of our knowledge, no EEQ thresholds values over which a contaminated aquatic environment can cause a real damage to exposed organisms, have been proposed. To the best of our knowledge, effects were observed only on fish and few species of *Gasteropoda*.

2. Materials and Methods

2.1. Locations of the sampling stations

The Venice lagoon appears quite suitable for investigating occurrence and effects of EDCs. It is a shallow coastal lagoon ecosystem (average depth: approx. 1m ± 0.3m, average salinity: 31 ± 4 ‰), connected with the Adriatic Sea by three inlets (Fig. 2). The lagoon is subjected to heavy anthropogenic pressure (e.g. inputs of nutrients and pollutants) which increased greatly during the last century, following urban, industrial and agricultural development. The four sampling stations were selected in order to estimate the main potential sources of EDCs: Station 1, Isola delle Tresse, is affected by treated industrial effluents from the large industrial district of Porto Marghera and by the final effluents from municipal sewage treatment plants (approx. 400,000 equivalent inhabitants); Station 2, S.Nicolò, and Station 3, Celestia, receive municipal untreated sewage from Lido island and the historical centre of Venice, respectively, and Station 4, S.Erasmo, located near a harbour mouth, is the one less affected by EDCs contamination and so it should give the environmental background EDC level.

Water and sediment samples togheter with organisms (*Mytilus galloprovincialis)* were analysed in the selected stations from October 2001 to October 2002. The sediment samples were collected at two different depths (0-5 cm and 5-20 cm) in order to evaluate the potential effect of the aerobic degradation on the surface sediment in contact with the lagoon water and the effect of the anaerobic degradation on the deeper sediment. Mussels were selected since they are filterer representative organisms, which can exhibit a great ability in bioaccumulating persistent pollutants.

Fig. 2 – Sampling stations in the Venice lagoon: **1**. Isola della Tresse; **2**. S. Nicolò; **3**. Celestia; **4**. S.Erasmo.

2.2. Chromatographic conditions

Analytes were simultaneously separated by reversed-column with an acetonitrile (A) / water (B) linear gradient and then were simultaneously detected and quantificated by Ion-Trap Mass Spectrometry via electrospray interface (ESI-IT-MS) operating under both negative (NI) and positive (PI) ionization conditions. Structural confirmation of the selected analytes obtained by MS-MS (MRM mode) [Pojana, 2003].

The Extraction/enrichment/clean-up of the examined analytes was performed by solid phase extraction (SPE) for aqueous samples, by sonication with an Acetone/Methanol mixture for sediments and by sonication and purification on Florisil® for biota, which resulted necessary to remove the lipidic component which would decrease the s/n ratio of the instrument. The sonication/extraction of the examined organisms were performed with a Hexane/Acetone mixture and the subsequent extraction from Florisil® was obtained with a Hexane/iso-Propanol mixture. QA/QCs were applied throughout the whole analytical procedures [Pojana, 2003].

3. Results and Discussions

3.1. Occurrence and spatial distribution of EDCs in lagoon samples

All average concentrations for the four sampling stations are reported in Fig. 3-5. A preliminary spatial evaluation of the distribution of EDCs showed the systematic occurrence of estrogens both natural and synthetic in all the selected stations, with concentrations of 1.6÷175 ng/L for estradiol (E2), 1.4÷10 ng/L for estrone (E1), 1.0÷6.7 ng/L for estriol (E3), 4.6÷34 ng/L for ethinylestradiol (EE2) and < MQL for mestranol, respectively. While E2 showed concentrations significatively higher than those previously found (0.05÷88 ng/L), recorded levels for the other EDCs were in the typical concentration range previously reported for treated and untreated sewage effluents, as well as for fresh waters (0.1÷132 ng/L, 0.05÷220 ng/L, 0.05÷31 ng/L and 1÷3 ng/L for E1, E3, EE2 and mestranol, respectively) [Baronti, 2000; Belfroid, 1999; Danish EPA, 2002; Desbrow, 1998; Ferguson, 2001; Spengler, 2001; Tashiro, 2003].

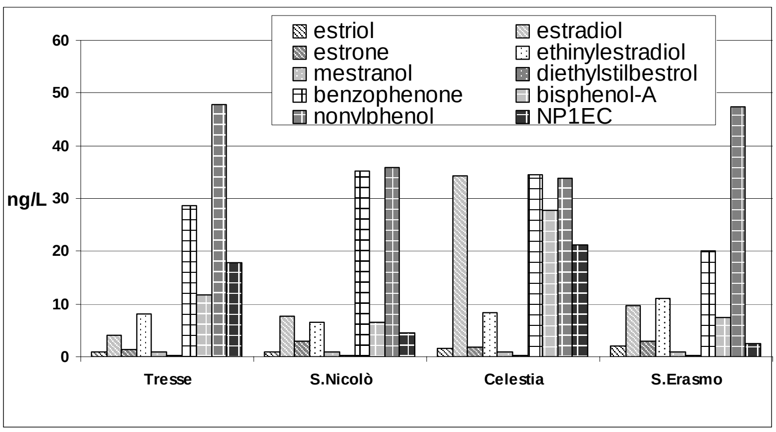


Fig. 3. - Dissolved concentration of estrogenic compounds analyzed in grab water lagoon samples (1000 mL) collected in the 4 sampling stations

Among the non-steroidal EDCs, bisphenol-A (BPA), a typical industrial by-product, was recorded in all the monitored stations, although at concentrations lower (1.7÷145 ng/L) than those previously recorded in surface waters and sewage effluents (10÷37,000 ng/L) [Danish EPA, 2002; Ferguson, 2001; Fürhacker, 2000; Körner, 1999], while benzophenone (BP), used as flavor ingredient and as additive, exhibited concentrations (1.9÷136 ng/L) in the typical environmental range (1.3÷190 ng/L) [Little, 1991]. Diethylstilbestrol (DES), still used for chemical castration and animal growth promotion, was always < MQL. The two biodegradation products of nonylphenol polyethoxylate NPE, i.e. nonylphenol (NP) and nonylphenol monoethoxylate carboxylate (NP1EC), were found at concentration levels significatively lower (1.2÷211 ng/L and 2.3÷82 ng/L, respectively) than those reported elsewhere (250÷644,000 ng/L) [Danish EPA, 2002; Körner, 2000; Little, 1991; Marcomini, 2000; Solé, 2000; Spengler, 2001]. The non steroidal EDCs concentration levels resulted generally higher than the steroidal ones.

In some more detail, at station 1 (located near the large industrial district of Porto Marghera) the non-steroidal EDCs were higher than steroidal estrogens, according to the characteristic industrial sewage impacting this station; however, the closeness of a mechanical-biological sewage treatment plant, resulted in EE2 and E2 relevant concentrations (1.0÷28 ng/L and 0.5÷15 ng/L, respectively). At station 2, mainly affected by municipal raw sewage, NP and BP were still more abundant than steroidal EDCs (1.0÷146 ng/L and 3.4÷136 ng/L, respectively). At station 3, affected by municipal raw sewage, non-steroidal EDCs were as abundant as E2, with average concentration: 34 ng/L for NP, 21 ng/L for NP1EC, 34 ng/L for BP and 28 ng/L for BPA, respectively vs. 34 ng/L for E2. Such evidence indicates that station 3 is actually affected by both domestic and industrial sewage. At station 4, i.e. the environmental background, NP reached concentration levels of 211 ng/L, BP of 87 ng/L and also E2 and EE2 were present at relevant levels (36 ng/L and 38 ng/L, respectively), thus indicating contaminants redistribution inside the central lagoon by hydrodynamics.

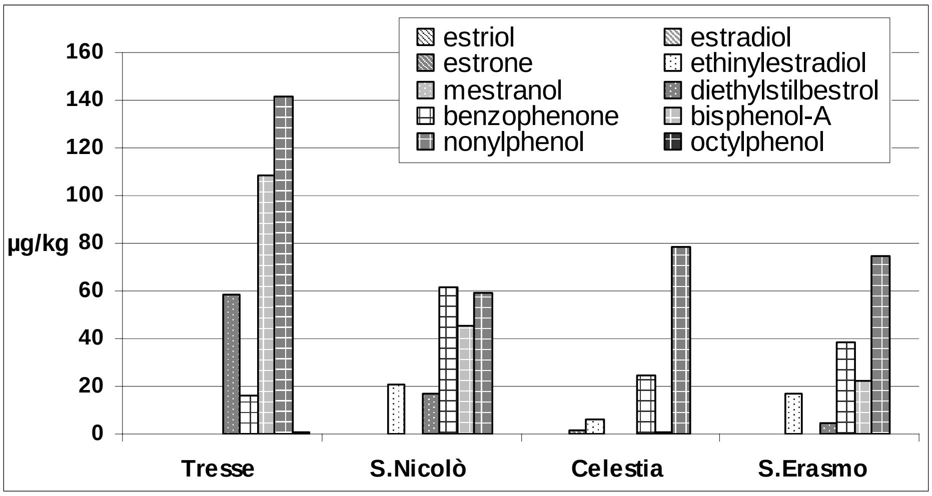


Fig. 4. - Concentration of estrogenic compounds analyzed in lagoon sediment samples (0-20 cm) collected in the 4 sampling stations

The average concentrations of the selected EDCs in the sediment samples from the four sampling stations is reported in figure 3. NP resulted the most abundant analyte in all the sampling stations (8.0÷289 µg/kg): this compound is generally characterized by a high bioconcentration factor (BCF) and elevated Kow (4.0) [Ferrara, 2001] and accumulates both in sediments and aquatic organisms. Notwithstanding this, the reported concentrations were lower than those previously recorded in lake and fluvial environments (4÷24,000 µg/kg) [Duft, 2003]. Conversely, OP was always < MQL. BPA was found in the 3.1÷161 µg/kg concentration range, similar to that previously reported for German and Korean streams (54÷343 µg/kg), while DES was recorded in three of the monitored stations in the 0.9÷73 µg/kg range, similar to the typical environmental levels (10÷250 µg/kg). Eventually, BP exhibited concentrations higher (12÷154 µg/kg) than the typical environmental levels (10÷100 µg/kg) [Baronti, 2000; Desbrow, 1998; Ferguson, 2001; Johnson, 2000; Korner, 1999; Marcomini, 2000; Spengler, 2001; Ternes, 1999]. EE2 was the only steroidal EDC detected at relevant concentrations (3.1÷80 µg/kg).

In some more detail, station 1 (Tresse) resulted the most contaminated sediment station; the fast environmental degradation rate of natural estrogens (half lives: 2.8÷3.0 days) [Danish EPA, 2002] can explain their almost total absence in the sediment samples.

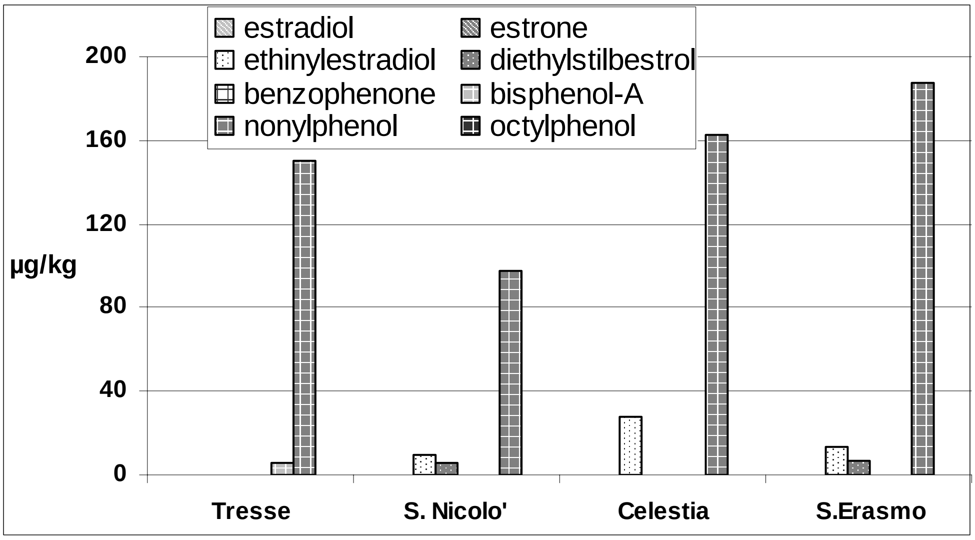


Fig. 5. - Concentration of estrogenic compounds analyzed in grab lagoon mussels samples (30 g) collected in the 4 sampling stations

The average concentrations of the selected EDCs in the mussels (*Mytilus galloprovincialis*) samples in the four sampling stations is reported in Figure 5. In the anlysed organisms, only NP was detected at relevant concentrations in all the four stations (24÷211 µg/kg, d.w.), while EE2 resulted the only steroidal estrogen detected in three sampling stations (7.2÷38.3 µg/kg, d.w.). These levels are lower than those previously reported for mussels in the Adriatic sea (243÷265 µg/kg, w.w.) [Ferrara, 2001].

3.2. Estimation of estrogenic potential

The measured individual EDC concentrations allowed to assess the EDCs environmental exposure in the waters of the Venice lagoon, in terms of known endocrine effects. In order to obtain a cumulative evaluation of the estrogenic potential, the estradiol equivalents (EEQs) were calculated with the following equation:

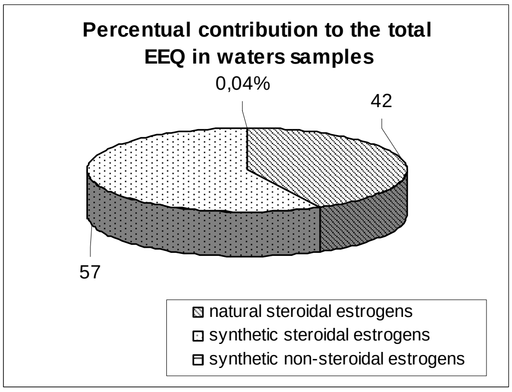
$$\textbf{EEQ, ng/L (µg/kg) (analyte) = ng/L (µg/kg) (analyte) x EEF (analyte)}$$
$$\textbf{EEQ (sample)} = \sum \textbf{EEQ (analyte)}$$

Since many different bioassays have been developed to determine EEF (Estradiol Equivalency Factor) values, except for BP, EEFs values reported by literature were averaged and applied for the calculation of the EEQ of each sample (see Fig. 1) [Legler, 2002; Korner, 1999, 2001; Thomas, 2001]. The determined water EEQ values ranged between 2.8 ng/L and 191 ng/L, with no marked seasonability. The higher levels were recorded for station 3 (average: 48 ng/L) while the lower for station 1 (average: 17 ng/L) situated near the industrial area of Porto Marghera. In the sediment samples the EEQ ranged between 4.7 µg/kg and 190 µg/kg while it resulted zero for 4 samples. The higher levels were recorded for station 1 (average: 153 µg/kg) while the lower were recorded for station 3 (8.7 µg/kg), in contrast to the water EEQ results. Both waters and sediments EEQs resulted quite high if compared to the EEQs values reported for other ecosystems, in surface waters and sediment as well as in sewage treatment plants effluens and sediments (2.0÷7.4 ng/L; $3.3 \times 10^{-3} \div 11 \times 10^{-3}$ µg/kg) [Behnisch, 2001; Oh, 2000]. The 22 water samples were divided into four groups according to the literature EEQ data:

EEQ < 10 ng/L:	**9 samples**
10 ng/L < EEQ < 50 ng/L:	**9 samples**
50 ng/L < EEQ < 100 ng/L:	**3 samples**
EEQ > 100 ng/L:	**1 sample**

Most of the samples resulted > 50 ng/L, while only 1 sample resulted > 100 ng/L. In the case of the sediment samples, only four samples were < 0.05 ng/L; the remaining 12 samples were all > 1 µg/kg.

The EEQs estimation allowed also to identify the compounds most contributing to the total estrogenic potential of the lagoon waters. In Figure 6, the comparison between the percent contribution of the analysed compounds to the total EEQ of lagoon warters and sediments is shown. The analytes were divided in 3 groups: ▧ natural steroidal estrogens, ⊡ synthetic steroidal estrogens, ⊞ synthetic non steroidal estrogens.



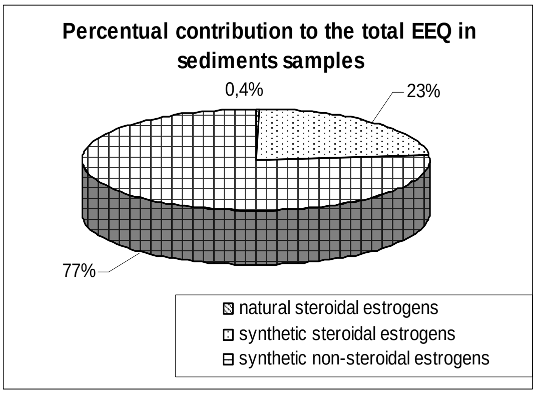


Fig. 6. - Relative contribution of the three EDC groups to the total estrogenicity (EEQs) of the lagoon waters and sediments.

Steroidal EDCs contributed almost totally (> 99.9%) to the water EEQs, while steroidal and non-steroidal synthetic EDCs contributed mostly (> 99%) to the sediment EEQs levels.

3.3. Estimation of the possible estrogenic effects on the lagoon biota from literature data

EEQ thresholds values over which a contaminated aquatic environment can cause an observed damage to exposed organisms are not yet available. In adult fish, for example, exposure to xenoestrogens, or to synthetic or natural estrogens, has been reported to result in altered fecundity in female fish, reduced testicular development and fertility in male fish, and in increased or decreased vitellogenin (Vtg) production (the precursor of egg yolk protein) in both male and female fish (Jobling, 2003). However, laboratory biological tests, usually performed with one or two EDCs, reported that EEQ values in the 0.1÷5 ng/L (as nominal concentration range) can already induce a pronounced effect in fish [Danish EPA, 2002; Folmar, 2000, 2002; Körner, 2001; Seki, 2002; Solé, 2000]. Based on the comparison between literature effect concentrations [Harries, 1997; Seki, 2002 ; Solé, 2000] and determined EEQs, biological effects are strongly expected to be observed for the aquatic organisms of the Venice lagoon. Taking into account that all water samples exhibited EEQ values >2.5 ng/L, an increase of plasma vitellogenin levels together with difficulty in the sexual differentiation (oocytes in the male gonads) [Schwaiger, 2002; Seki, 2003], is likely to occur in male rainbow trout (*Oncorhynchus mykiss*); at the same level, a decrease in gonadal development has been noticed in other surface water fish (*Oryzias latipes*) [Tilton , 2002]. In the samples exibiting EEQ value between 10 and 50 ng/L, the development of ermafroditic gonads resulted the most observed effects on the aquatic biota [Seki, 2003]. A great increase in Vtg levels was observed in *Cyprinodon variegatus* at exposure levels ranging from 50 ng/L to 100 ng/L [Folmar, 2000]. Finally, when EEQ > 100 ng/L, an interrupted egg production in female fish (*Pimephales promelas)* was observed [Giesy, 2000]. Since recorded EEQs for lagoon waters were almost (82%) < 50 ng/L, an increase in Vtg levels and the presence of testis-ova are the most expected effects on the lagoon biota, which indicate a first step towards the feminization process.

As for sediment samples, a recent study investigated the effects of EDCs on the freshwater mudsnail *Potamopyrgus antipodarum* [Duft, 2003]. A distinct increase in the number of sheltered embryos was observed already at 1 µg/kg EEQ level. Since most of the sediment samples (75%) exhibited EEQ > 1 µg/kg, the lagoon sediments resulted an other EDCs exposure source for the aquatic biota.

This results suggest that the Venice lagoon waters and sediments show a significant capability to induce effects on the endocrine system of aquatic organisms.

Conclusions

Based on these results, biological effects are strongly expected to occur in the Venice lagoon organisms, even if a critical analysis of the obtained data is needed, since most studies on EDCs effects were carried out on freshwater organisms, particularly on fish, while few data are so far available on salt water biota. Investigations are scheduled to elucidate this important issue.

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SPATIAL AND TEMPORAL DISTRIBUTION OF PHYTOPLANKTON COMMUNITIES IN THE VENICE LAGOON CENTRAL AREA

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Riassunto

Campioni rappresentativi di tutta la colonna d'acqua sono stati raccolti per lo studio delle comunità planctoniche microalgali da luglio 2001 a giugno 2002 (tre stazioni campionate con cadenza mensile) e durante l'estate 2002 (65 stazioni). L'analisi quantitativa e qualitativa è stata fatta allo spettrofotometro e al microscopio ottico invertito.

L'abbondanza annuale minore ($1.23\pm0.97 \times 10^6$ cells dm^{-3}) è stata registrata in prossimità della bocca di porto di Lido. Valori sensibilmente maggiori sono stati osservati nei pressi del centro storico di Venezia ($8.60\pm14.1 \times 10^6$ cells dm^{-3}) e della terraferma ($18.3\pm19.9 \times 10^6$ cells dm^{-3}) a sud del ponte translagunare. I risultati della mappatura hanno confermato la distribuzione delineata dal campionamento stagionale nelle tre stazioni mostrando un gradiente d'abbondanza crescente dal mare verso la gronda lagunare. I valori medi di clorofilla *a* (2.2 ± 2.0 µg dm^{-3}) e di abbondanza cellulare ($1.7\pm2.4 \times 10^6$ cells dm^{-3}), sono risultati più bassi di quelli osservati durante campagne precedenti condotte nella stessa zona e stagione.

Abstract

Water samples were collected from July 2001 to June 2002 (one sampling campaign per month on three sites) and during summer 2002 (65 sites) to investigate the phytoplankton community. Quantitative and qualitative analyses were performed by means of a spectrophotometer and a inverted light microscope.

The lowest annual abundance ($1.23\pm0.97 \times 10^6$ cells dm^{-3}) was recorded close to the Lido inlet. Higher values were observed near Venice historical centre ($8.60\pm14.1 \times 10^6$ cells dm^{-3}) and in front of Porto Marghera industrial zone ($18.3\pm19.9 \times 10^6$ cells dm^{-3}). The chlorophyll *a* and cell abundance map confirmed the spatial distribution recorded during the seasonal sampling in the three sites showing an increasing gradient from the sea towards the mainland. The average values, of both chlorophyll *a* (2.2 ± 2.0 µg dm^{-3}) and cell abundance ($1.7\pm2.4 \times 10^6$ cell. dm^{-3}), were lower than those recorded during previous sampling campaigns in the same area and period.

1. Introduction

Since the beginning of the '90s, in the central part of the Venice lagoon, phytoplankton has progressively decreased: the decrease considers both chlorophyll *a* concentrations [Facca et al., 2002a; Sfriso et al., 2003] and cell abundance [Facca et al., 2002b]. In some stations, in 1990, the mean chlorophyll *a* concentration was up to one order of magnitude as high as in 1998 [Sfriso et al., 2003]. Socal et al. [1999] described a spring (February-May 1986) *Skeletonema costatum* Cleve bloom (60 x 10^6 cells dm^{-3}), which was one order of magnitude higher than in 1999 and in 2001 [Facca et al., 2002a; Facca et al., 2003]. Similar results were observed by comparing two maps which show the phytoplankton distribution in June 1993 and in June 1998 [Facca et al., 2002b].

The main cause of the mentioned general reduction seemed to be related to the increase of the water column turbidity. At the beginning of the '90s, the huge macroalgal biomass which has characterised the central lagoon for ca. 20 years, disappeared [Sfriso, 1996; Sfriso and Marcomini, 1996; Sfriso et al., 2003]. In the meantime the clam *Tapes philippinarum* Adams and Reeve rapidly colonised the area free of biomass and an intense clam fishing activity began [Orel et al., 2000]. Those events caused a significant increase of sediment re-suspension/sedimentation rates. In 1998 rates were 5-12 times as high as in 1990 [Sfriso, 2000].

The present study provides information on the recent distribution of phytoplankton in the central area of the Venice lagoon where most of the anthropic activities are concentrated.

2. Materials and methods

Between July and August 2002 a sampling campaign was carried out in 65 sites homogeneously distributed in the central part of the Venice lagoon. Water samples were also collected in three sites of the central area (S. Nicolò, located in the Lido inlet, Celestia placed north of the Venice historical centre, and Tresse selected close to the Porto Marghera industrial area) from July 2001 to June 2002 on a monthly basis.

Water samples of the whole water column were collected by means of a Plexiglas bottle (150 cm high and 4 cm large). Aliquots of 250 ml were preserved in 4% formaldehyde neutralised with hexamethylenetetramine up to the phytoplankton determination and counted by means of a inverted light microscope [Utermöhl, 1958]. Other aliquots (350-1000 ml) were filtered by GF/F Whatman glass fibre filters (0.7 µm), stored at –20°C and analysed to determine chlorophyll *a* (Chl. *a*) concentrations [Lorenzen, 1967].

3. Results and Discussion

In Figs. 1 and 2 Chl. *a* concentrations and cell abundances are plotted, respectively.

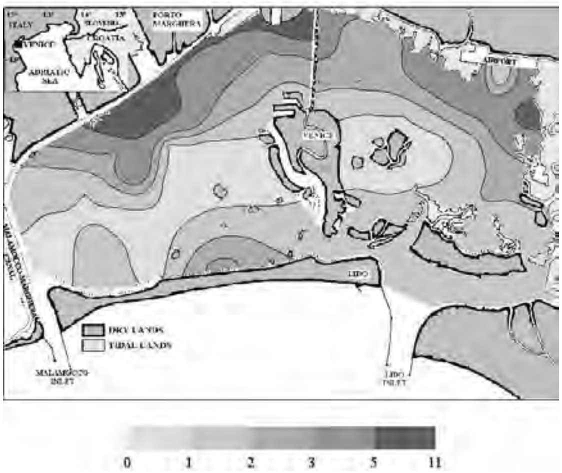

Fig. 1 – Chlorophyll *a* concentration (µg dm^{-3})

The highest cell abundance was recorded along the Malamocco-Marghera canal (near Porto Marghera industrial area) and in the Lido watershed (near Lido island). The mean Chl. *a* concentration (2.2±2.0 µg dm^{-3}) resulted twice as low as during previous surveys in the same area (3.6±5.6 µg dm^{-3} in 1987, 4.0±5.4 µg dm^{-3} in 1993, 3.3±4.5 µg dm^{-3} in 1998; [Sfriso et al., 2003]). The cell abundance confirmed this trend showing an average value (1.7±2.4 x 10^6 cell. dm^{-3}) ca. 4 times lower than in 1998 [Facca et al., 2002b].

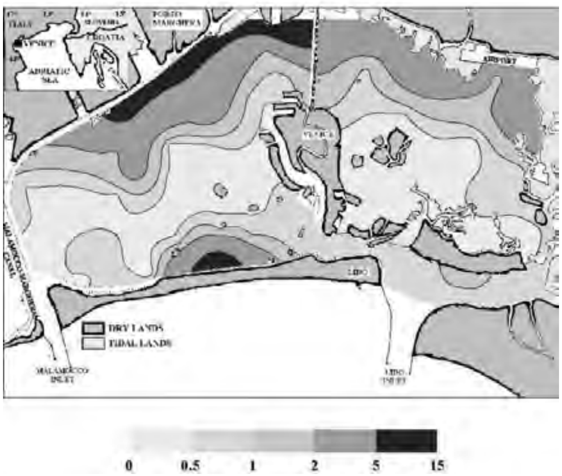

Fig. 2 – Phytoplankton cell abundance (10^6 cells dm^{-3})

By the inspection of Chl. *a* and cell abundance distribution maps we notice that phytoplankton is well related to the trophic state of the study sites, being higher in the areas affected by urban, agricultural and industrial impacts. Only the sites around Venice historical centre (no samples were collected in the canals) displayed Chl. *a* concentrations and cell abundances which are not well related to the anthropic impact since the city lacks a waste treatment plant. But that might also depend on the high water renewal triggered by the proximity of the Lido inlet.

Nanoflagellates (small spherical cell <5 µm) and Cryptophyceae always constituted a significant fraction (up to 80.7% and 53.5%, respectively) of the identified cells. In contrast, Prasinophyceae and Dinophyceae (<10% and 6%, respectively) were negligible. In 45 out of the 65 sampled sites the class of Bacillariophyceae was >30% of the total phytoplankton community and, in 9 stations, even >60%. Each area was characterised by different species. *Nitzschia frustulum* Grunow was the dominant species in the watershed and in many other areas; *Chaetoceros* spp. and *Guinardia flaccida* Peragallo were frequently found near the sea inlets; *Fragilaria* sp. and *Skeletonema costatum* Cleve were recorded close to the mainland and near the industrial area.

The cell abundance, recorded in summer 2001 at S. Nicolò (3.8 x 10^6 cells dm^{-3}), Celestia (44.7 x 10^6 cells dm^{-3}) and Tresse (55.9 x 10^6 cells dm^{-3}), displays data very different (Fig. 3) from the ones recorded during 2002 summer campaign (Fig. 2), in fact they show the same order of magnitude as the one recorded in the late ’80s by Socal et al. [1999]. 2001 was a particular year in that phytoplankton blooms recorded in the whole lagoon and in the sea displayed concentrations which had never been recorded in the ‘90s, in 2002 or in 2003.

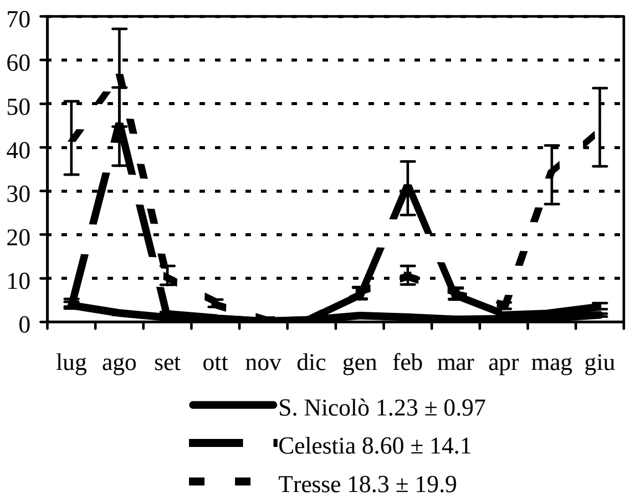

Fig. 3 – Phytoplankton cell abundance seasonal trends (10^6 cells dm^{-3}). Means and standard deviations are reported.

Moreover, on a cell abundance basis, Celestia station was more similar to the industrial area than to the sea inlet site. That highlights the true trophic conditions of the area which is affected by Venice untreated sewage.

Nanoflagellates were always very abundant in all sites. Bacillariophyceae were responsible of the increases observed in early spring and during the summer. *Skeletonema costatum* Cleve bloomed in February while, in summer, *Nitzschia frustulum* Grunow was the dominant species.

Conclusions

Phytoplankton abundance recorded in the whole central lagoon in summer 2002 (mean: 1.7±2.4 x 10^6 cells dm^{-3}, maximum: 14.2 x 10^6 cells dm^{-3}) was significantly different from the results recorded during the previous sampling campaigns, especially 1993 campaign. On the contrary, the values recorded in summer 2001 represented an exception in comparison with the data collected during the last 10 years. In fact, the main bloom reached values close to the results recorded in the ‘80s.

Both phytoplankton maps and seasonal trends are well related to the trophic conditions of the lagoon study area as the highest values were recorded near the industrial zone, Venice historical centre and Lido island.

On the whole the dominant taxa were common to all samples: nanoflagellates represented the background, while Bacillariophyceae were responsible of spring and summer blooms. Dinophyceae were never significantly abundant.

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THE DISTRIBUTION OF PCBs IN WATER AND PHYTOPLANKTON: COMBINING MEASUREMENT AND MODELLING APPROACHES

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Riassunto

L'attività del secondo anno ha riguardato la messa a punto dei modelli di ripartizione di microinquinanti organici sviluppati nel corso del primo anno di attività. E' stato inoltre introdotto il fitoplancton come comparto ambientale a sè stante. E' stata effettuata una campagna di campionamento in Laguna Centrale tesa a corroborare le previsioni del modello, relativamente alle concentrazioni ambientali dei PCB.

Abstract

The second year of activity has focused on the further development of the environmental multimedia models for persistent organic pollutants (POPs) previously applied to the central part of the Lagoon. Phytoplankton has been introduced in the model as an individual environmental compartment. In order to corroborate model predictions, a sampling campaign has been performed in the Central Lagoon by deploying passive samplers in air and water.

1. Introduction

Recent studies [Dachs et al. 1999, 2000; Del Vento e Dachs, 2002] have pointed out the potential importance of phytoplankton in the global cycling of persistent organic pollutants (POPs), in particular concerning the vertical air-water-sediment flux of these chemicals. Although Venice lagoon characteristics are noticeably different of those of the oceans, in particular for depth, concentration of suspended particulate matter and dissolved/colloidal organic carbon, phytoplankton could play an important role in the re-distribution of POPs in the Lagoon ecosystem. Even if a significant proportion of the POPs present in the water column is probably bound to the suspended particulate matter, phytoplankton may exert a significant influence on the dissolved phase concentration of POPs. In addition, the fraction of these chemicals present in phytoplankton can represent a preferential pathway of exposure to the trophic chain, from zooplankton to the higher levels.

2. Modelling activities

The model was applied to the central part of the lagoon (total surface ca. 132 km^2) and comprises 6 compartments, namely: air, water, soil, sediment, suspended particulate matter and phytoplankton (Figure 1).

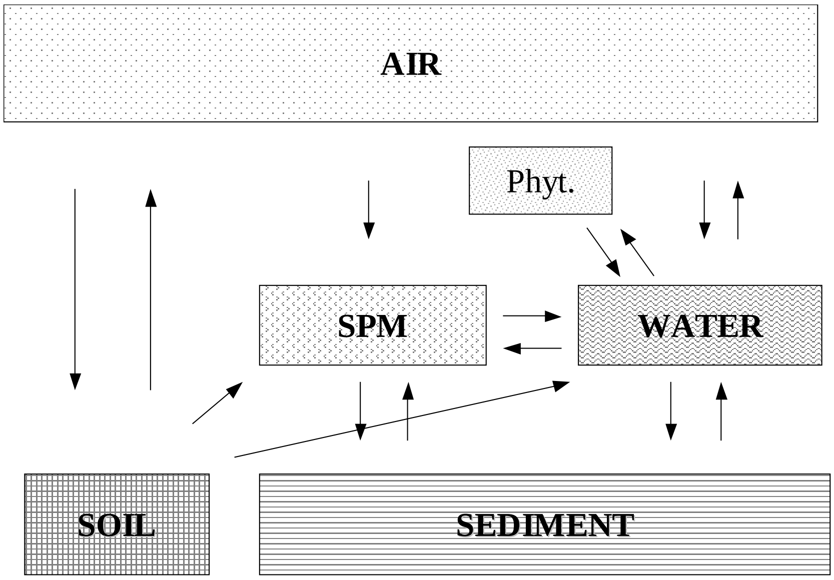

Fig. 1 – Model structure.

The fugacity based dynamic model has been developed using Modelmaker© with the aim of estimating environmental concentrations of a range of PCB congeners in each environmental compartment, in particular examining the concentration in the dissolved phase and the influence of phytoplankton on it. The model is an extension of a model already developed and applied to the same area [Dalla Valle et al. 2002, 2003a,b]. Concentrations have been estimated from the year 2000 to the year 2005, assuming an exponential decrease of emissions (i.e. inputs to the system), according to the equation 1 [Sweetman et al., 2002]:

$$E(t) = E(0) \cdot e^{(-0.4t)} \qquad (1)$$

with $0 < t$ (years) < 5.

Inputs to the lagoon system were estimated from experimental data obtained by recent projects which examined atmospheric deposition and riverine input [Bettiol et al., 2001; Guerzoni et al., 2003; Dalla Valle et al., 2003a, for a short summary of the results]. The estimated input of PCB 118 to the central Lagoon is shown in Figure 2.

Phytoplankton biomass has been estimated from results obtained by monthly measurements performed during the last three years [Facca et al. 2002a,b; Sfriso, personal communication].

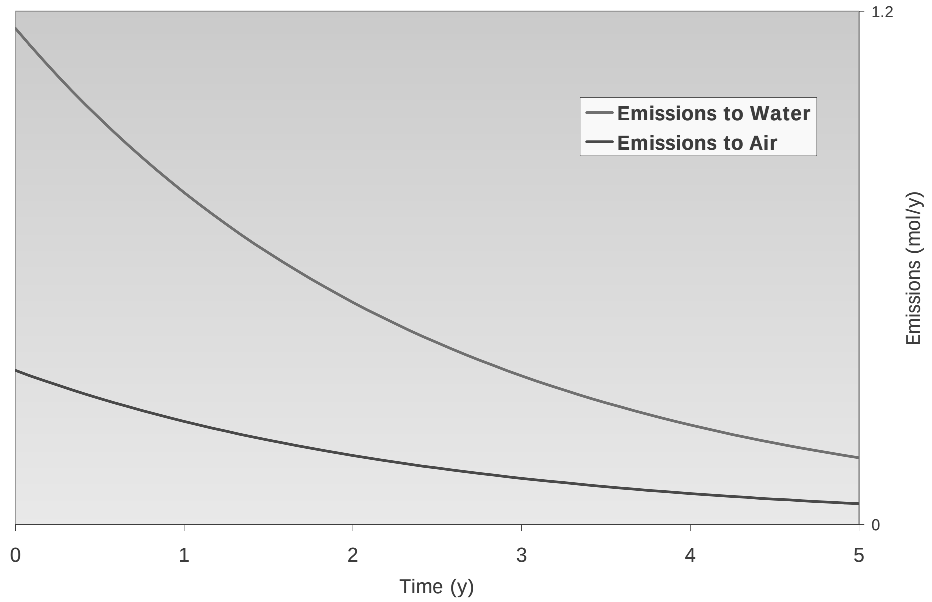

Fig. 2 – Estimation of PCB 118 input to the central Lagoon.

Figure 3 shows the typical average phytoplankton biomass in the central lagoon throughout the year.
The concentration of a chemical in phytoplankton can be expressed using the following equation (2):

$$\frac{dC_P}{dt} = k_u - k_d C_P - k_G C_P \qquad (2)$$

with: C_P = concentration in phytoplankton
k_u = uptake rate;
k_d = depuration rate;
k_g = growth rate;

k_u, k_d and k_g depend on the chemical and on the organism. The equation can be written also with this form (3):

$$C_P(t) = K_{SA}C_w + C_{P,\,eq}\,(1- e^{(-kd+kg)t}) \qquad (3)$$

K_{SA} (m^3kg^{-1}) is the surface sorption coefficient and $C_{P,eq}$ the concentration in phytoplankton at the equilibrium. The coefficients adopted in the equations 2 and 3 are those reported by Del Vento and Dachs (2002, Tab. 1).

Tab. 1 – k_u and k_d values used in the model [Del Vento and Dachs, 2002].

	k_u $m^3 \cdot kg^{-1} \cdot d^{-1}$	k_d d^{-1}
PCB 118	1900	0.94
PCB 105	1800	1.13
PCB 156	2400	1.08
PCB 167	2400	1.08
PCB 180	1300	0.53

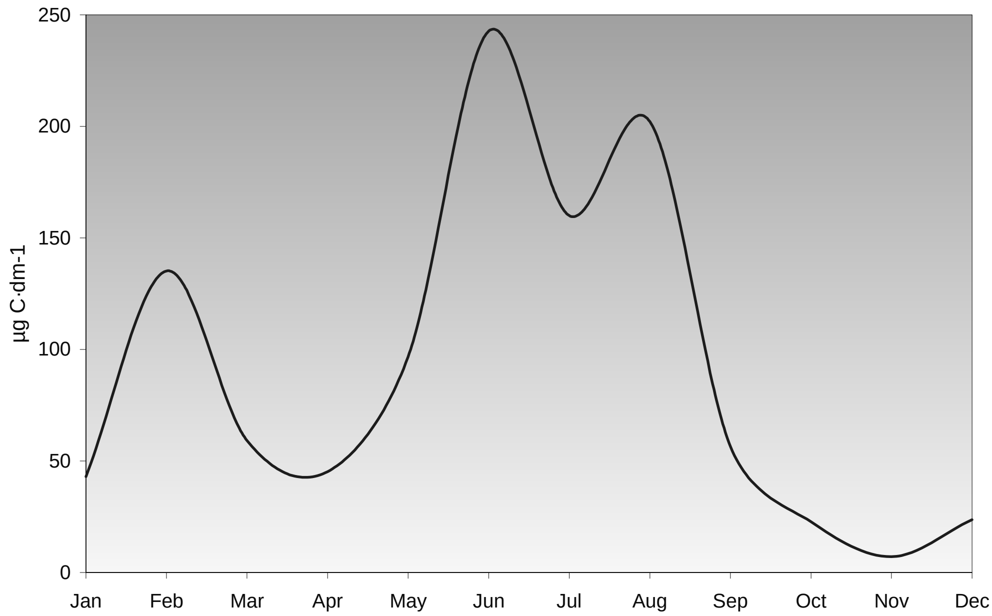

Fig. 3 – Phytoplankton biomass in the central lagoon (µg C·dm^{-3}).

As a result of the seasonal variations of phytoplankton biomass, the concentration of PCBs in water changes noticeably during the year, decreasing when phytoplankton biomass peaks and increasing with its decrease. As an example, PCB 167 concentration in water for the considered period is shown in Fig. 4.

The trend over the 5 years period occurs as the result of the seasonal fluctuations of the phytoplankton biomass and of the reduction of the inputs to the lagoon environment.

Differences observed in the dissolved concentration of the studied PCB congeners depend on the phytoplankton-water transfer rate and on the degradation rate. As a consequence the concentration of PCB 180 seems to be almost constant during the 5 years of the simulation, while that of lighter chlorinated congeners like PCB 118 and 105 decreases more rapidly. PCB 156 and 167 have a higher phytoplankton-water exchange rate, and thus have more pronounced seasonal fluctuation. The same model allows estimation for the same PCB congeners, concentrations in two important species present in the lagoon area like *Tapes philippinarum* and *Mytilus galloprovincialis*. Results are consistent with experimental findings. Estimated concentrations and experimental results are compared in Tab. 2.

Tab. 2 – Comparison between concentrations in Tapes and Mytilus measured and predicted by the model.

	Experimental results	**Model estimates**	
	Tapes philippinarum. ng/kg (mean ± st.dev)	*Tapes* ng/kg (range)	*Mytilus* ng/kg (range)
PCB 105	N/A	56 - 43	26 - 20
PCB 118	477 ± 315	288 - 327	133-160
PCB 167	35 ± 21	56 - 43	26 - 20
PCB 156	41 ± 25	198 - 174	92 - 80
PCB 180	374 ± 277	280 - 370	128 - 171
PCB 170	135 ± 97	313 - 408	144 -189

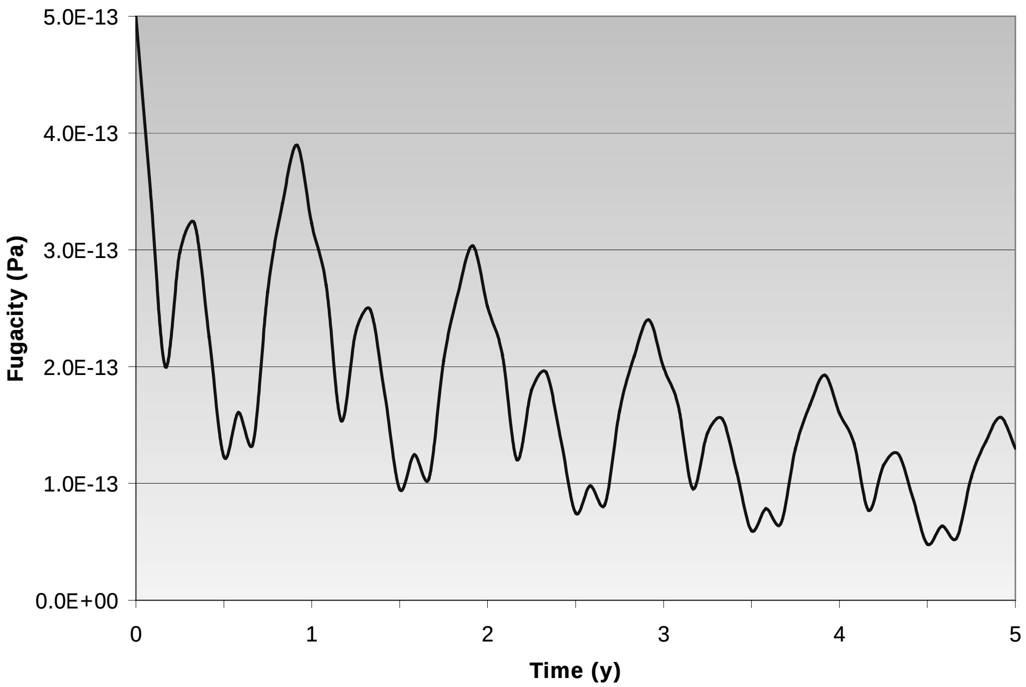

Fig. 4 – Estimation of PCB 167 concentration in the central lagoon expressed in terms of fugacity (Pa).

3. Sampling

The objective of the sampling activity was the estimation of the fluxes of PCBs between air and water and estimating the distance from thermodynamic equilibrium. Other reasons for the sampling campaign were the need for testing the predictions made with the models so far developed and to test new field sampling technologies, forecasting a possible extensive and routinely use. Four sampling stations, already selected by this and other projects (e.g. Orizzonte 2023), have been chosen (Alberoni, Sacca Sessola, San Giuliano and Fusina). Water sampling has been conducted using SPMDs devices (Semi-permeable membrane device), manufactured by the U.S. Geological Survey. They are one of the more widespread passive samplers available for POPs. The SPMD is typically constructed from layflat tubing of low-density polyethylene (LDPE). The thin-walled (<100 µm) LDPE tubing used in SPMDs is normally described as nonporous. However, random thermal motions of the polymer chains form transient cavities with maximum diameters of approximately 10 Å. Because these cavities are extremely small and dynamic, hydrophobic solutes are essentially solubilized by the polymer. The cross-sectional diameters of nearly all environmental contaminants are only slightly smaller than the polymeric cavities. Therefore, only dissolved (i.e., readily bioavailable) organic contaminants diffuse through the membrane and are concentrated over time.

Three SPMDs were deployed at each site for a week in September 2003, protected by a steel cage and kept in place by metal spiders. At San Giuliano three additional samplers were deployed to assess reproducibility. A detailed description of the analysis procedure can be found in Prest et al. [1995a,b].

At the same time, at the same stations, POG passive air samplers were deployed, hanging about 2 m above the water surface, protected by a stainless steel plate. These samplers consist of a glass cylinder coated with EVA (ethyl vinyl acetate). A detailed description of the analytical procedure can be found in Harner et al. [2003], some figures are available online on the Lancaster University website: http://www.es.lancs.ac.uk/ecerg/kcjgroup/pasae_survey.htm.

Because of the theft of some of the POG samplers during the sampling campaign (September 2002), the sampling was repeated as soon as possible. Unfortunately this happened again and as a consequence the number of samples available was not sufficient to provide useful information.

Given the relatively short sampling period, the SPMD uptake is likely to have been constant and linear. Thus PCB concentrations in water could be estimated using the sampling rates reported by Rantalainen et al. [2000]. Results are reported in table 3. The estimated concentrations are consistent to those previously measured at the same sites [for a short summary: Dalla Valle et al. 2003]. The congener profiles are very similar at the four sites, while a gradient of concentration can be observed from Alberoni and moving towards the industrial district. The sum of the PCB congeners analysed is between 90pg/L at Alberoni and 2500pg/L at San Giuliano (ca. 300 pg/L at Sacca Sessola and ca. 700 pg/L at Fusina).

Conclusions

The concentrations of PCBs in the Venice lagoon water seem to be decreasing fairly rapidly, in particular for the less chlorinated congeners. The proposed modelling tool seems to be suitable to predict concentrations in edible molluscs like *Tapes* and *Mytilus*, a significant source of POPs in the diet of the Venetian population.

PCB concentrations measured with passive sampling devices (SPMD) confirm the trend previously observed in sediment and in the water column, decreasing with increasing the distance from the industrial district of Porto Marghera.

Tab. 3 – Estimated water concentrations at the four sampling stations.

	Alberoni pg/L	Sacca S. pg/L	S Giuliano 1 pg/L	S Giuliano 2 pg/L	Fusina pg/L
PCB 18	1	21	80	367	49
PCB 54	0	5	0	7	0
PCB 31	3	23	58	424	46
PCB 28	4	32	100	460	70
PCB 22	4	14	20	203	8
PCB 52	19	52	146	319	140
PCB 49	11	32	98	235	67
PCB 44	14	30	84	220	174
PCB 70	16	28	65	180	55
PCB 118	12	25	70	89	60
PCB 114	0	0	1	1	1
PCB 105	4	19	17	23	8
PCB 167	0	1	2	3	2
PCB 156	1	2	3	4	3
PCB 157	0	0	1	1	1
PCB 180	0	0	0	0	0
PCB 170	1	6	4	6	6
PCB 189	0	0	0	0	0

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DISTRIBUTION OF ARSENIC SPECIES IN ORGANISMS FROM THE LAGOON OF VENICE

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Riassunto

Nell'ambito della linea di ricerca 3.3 del Primo Programma Corila sono stati investigati i potenziali effetti della contaminazione chimica sul metabolismo lagunare. Una particolare attenzione è stata rivolta all'arsenico, che è stato identificato come un inquinante di notevole importanza nella laguna di Venezia. Rispetto alla determinazione delle concentrazioni totali, l'identificazione e la quantificazione delle diverse forme chimiche di questo elemento nei campioni ambientali è di fondamentale importanza da un punto di vista ecotossicologico. Questo studio è perciò stato incentrato sulla speciazione dell'arsenico, sulla quale esistono scarse informazioni per quanto riguarda la laguna di Venezia.

Abstract

In the framework of the line 3.3 of the first Corila Program, the potential effects of chemical contamination on the lagoon metabolism have been investigated. Particular attention has been paid to arsenic, which was identified as a pollutant of high concern in the lagoon of Venice. Compared to the determination of total concentrations, the identification and quantification of the different chemical forms of this element in environmental samples is of fundamental importance from an ecotoxicological point of view. This study therefore focused on arsenic speciation, for which a lack of information in the lagoon of Venice exists.

1. Introduction

The toxic effects and the environmental behaviour of arsenic are tightly linked to the chemical form in which this element appears. The inorganic species, arsenite and arsenate, are more toxic than the simple methylated forms monomethylarsonic acid and dimethylarsinic acid; the more complex compounds like arsenobetaine, arsenocholine and arsenosugars are, on the other hand, considered non-toxic for living organisms.

The determination of the total arsenic content is therefore not suitable for evaluating its impact upon the organisms, whereas the quantification of the different species can provide information about the toxicological risk and about the transformations and the metabolism of arsenic in the environment.

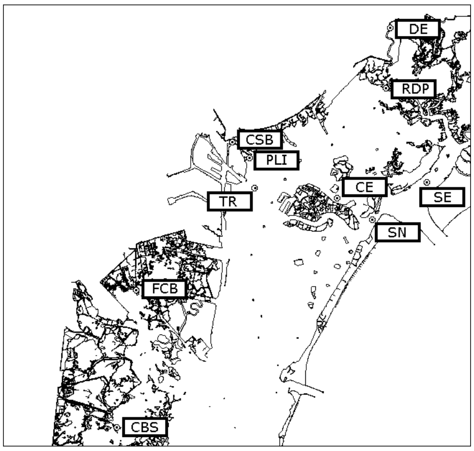
To this purpose, in the first part of the project analytical procedures for the sensitive and efficient speciation of the arsenic species As(III), As(V), monomethylarsonic acid

(MMA), dimethylarsinic acid (DMA), arsenobetaine and arsenocholine were developed. In addition, the phases of collection and treatment of samples, and the methods of extraction of the various arsenic species, were optimized. The analytical approach used for the determination of the arsenic species is the coupling of a separation technique, HPLC, with a very sensitive detector, such as ICP-MS. Arsenic compounds were extracted with a methanol/water mixture, and the extracts were chromatographed in an anion-exchange column.

The speciation procedure was then applied to samples of bivalve molluscs (*Mytilus galloprovincialis*) and of nereid polychaetes (*Hediste diversicolor*) from the Venice lagoon.

2. As speciation in organisms of the lagoon of Venice

The samples of *M. galloprovincialis* were collected in four different sites of the lagoon in the course of four seasonal samplings: October 2001, February, July and October 2002. In addition, samples of *H. diversicolor* were also collected in July 2002 in six other sites (Figure 1).



Mussels:
TR= Tresse
CE= Celestia
SN= S.Nicolò
SE=S.Erasmo

Polychaetes:
FCB=Fine Canale Bondante
DE=Dese
RDP=Ramo dei Passarini
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Fig. 1 – Map of the lagoon of Venice with sampling sites.

The extraction of arsenic species from the samples yielded a very good recovery, in general from 85 to 100% of the total arsenic content. The HPLC-ICP-MS analysis of the extracts showed the presence of various arsenic compounds, the majority of which were identified as organic species, with a predominance of arsenobetaine and a compound supposed to be an arsenosugar. The inorganic species As(III) and As(V) were mostly undetectable and, when quantified, their concentration remained below 8% of total arsenic. The chromatograms displayed the occurrence of other minor species, probably other arsenosugars synthesized by algae or their degradation products (Figure 2).

Though displaying different levels of total arsenic, mussel samples from the various sites of the lagoon showed comparable patterns of arsenic species. The variability among seasonal sampling seemed rather limited, with slight differences in the relative content of arsenosugars.

Arsenic compounds were determined both in the whole body of mussels and in the digestive gland, separated from the other soft tissues, in order to verify if different patterns of arsenic species can be distinguished. As a result, a difference in the relative content of arsenobetaine and arsenosugars was observed in the two kinds of subsamples. These findings are likely to be linked to the metabolic pathways of arsenic in the examined organisms and pose the basis for further investigations using other species along different levels of the trophic chain, in order to better understand the processes involved in the metabolism of arsenic in the lagoon ecosystem.

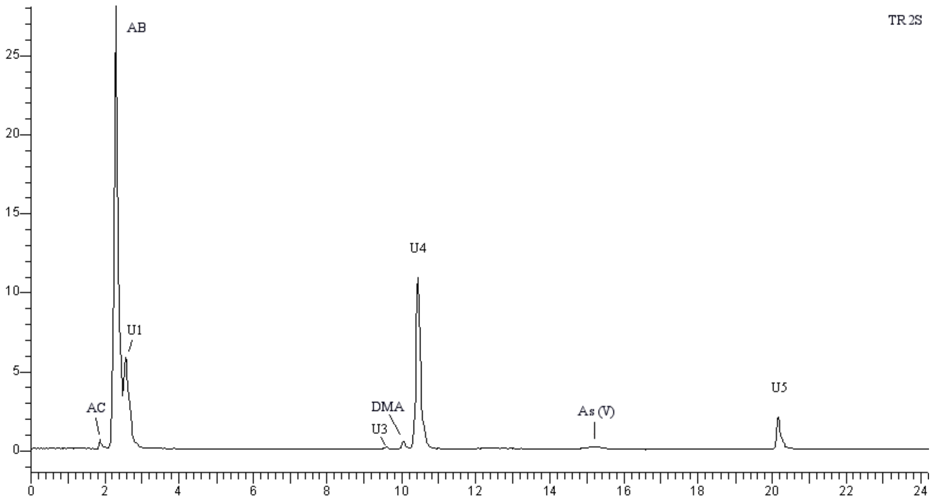

Fig. 2 – Example of a chromatogram obtained by HPLC-ICP-MS analysis of a mussel sample collected at the site of Tresse. AC=arsenocholine, AB=arsenobetaine, DMA=dimethylarsinic acid, As(V)=arsenate, U1-U5=unidentified compounds.

Conclusions

The HPLC-ICP-MS procedure for arsenic speciation developed and optimized in the first part of the project was successfully applied to the study of arsenic species distribution in the organisms of the lagoon of Venice. Both mussel and polychaete samples showed a predominance of organic compounds, whereas the toxic inorganic species As(III) and As(V) were mostly undetectable or present at very low levels. These preliminary results constitute a first step for the understanding of the processes involved in the metabolism of arsenic in the lagoon environment and for the assessment of the risk posed to aquatic organisms and to human health.

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METAL BIOACCUMULATION IN ORGANISMS OF THE VENICE LAGOON

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Riassunto

E' stata studiata la contaminazione da metalli negli organismi e nei sedimenti di diverse aree della laguna di Venezia. I risultati sono stati utilizzati per esaminare le relazioni tra accumulo dei metalli negli organismi e la contaminazione nel sedimento. Mentre la determinazione del contenuto totale di metalli nei sedimenti ha dato scarse indicazioni sulla biodisponibilità dei metalli, l'approccio basato sulla speciazione geochimica sembra rappresentare in questo contesto uno strumento di maggiore utilità.

Abstract

Metal contamination in organisms and in sediments from different areas of the Venice lagoon was investigated. The results were used to examine the relationships between metal accumulation in organisms and sediment pollution. Whereas total metal content determination in sediments gave poor indications on metal bioavailability, the approach based on geochemical speciation seemed to represent a more powerful tool in this context**.**

1. Introduction

This research was aimed at acquiring knowledge on the relationships between the chemical forms of metals and their bioavailability, on metal mobility in the various environmental compartments, on the pathways of introduction in the food chain and on bioaccumulation mechanisms in the Venice lagoon. To this purpose, an investigation on metal contamination in organisms and in sediments from different areas of the lagoon was carried out. The use of organisms as indicators of pollutant bioavailability in sediments is object of a growing concern. A water column species (*Mytilus galloprovincialis*) and a benthic species (*Hediste diversicolor*) were studied.

In the first part of the project, a procedure of geochemical speciation of metals in sediments has been optimized. In addition, analytical methods for total metal content determination in biological samples have been set-up and validated by using certified reference materials. The importance of a correct sample treatment before analysis, in order to acquire significant data on metal bioaccumulation, was also highlighted.

The optimized procedures were then used to characterize metal pollution in different sites of the Venice lagoon, characterized by different levels and typology of metal contamination, and selected on the basis of the distribution and population dynamics of the species.

2. Metal bioaccumulation in organisms and relationships with sediment contamination

The samples of *M. galloprovincialis* were collected in four different sites of the lagoon in the course of four seasonal samplings: October 2001, February, July and October 2002. In addition, samples of *H. diversicolor* were also collected in July 2002 in six other sites (Figure 1). Sediments samples were collected at the same sites in October 2001 and July 2002.

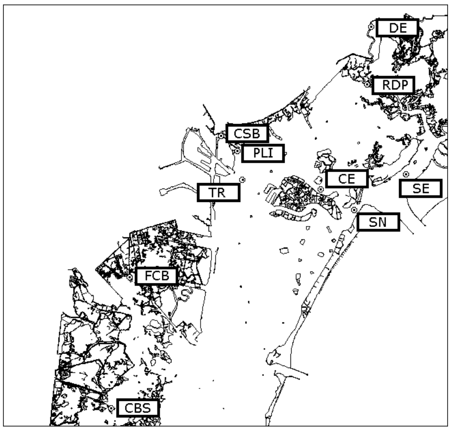

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Fig. 1 – Map of the lagoon of Venice with sampling sites.

The differences between metal concentrations in mussels from the four sites were not very marked. The Celestia site showed higher levels of Cu, Pb and Ni. S. Nicolò and S. Erasmo, chosen as reference sites, had significantly lower levels only for Cd and Zn, whereas they showed the highest concentrations of As.

A comparison between the data for the various sampling campaigns indicates that metal concentrations in tissues show a clear seasonal trend, with lower metal concentrations in summer samples. The observed differences can be ascribed to various factors, among which the reproductive cycles of organisms can play an important role.

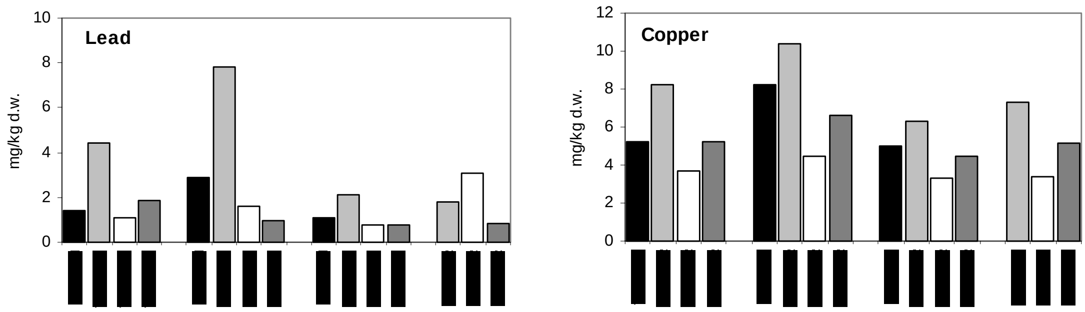

Fig. 2 – Seasonal trend of Lead and Copper in mussel samples.

With respect to mussels, metal levels in polychaetes showed some marked differences among sites, particularly for Pb, Fe, Cd e Cu. In general, the highest concentrations were observed at the sites CSB and Pili, located near the industrial area.

Sediment samples were also subjected to a procedure of sequential selective extractions, in order to determine the partitioning of metals among the various components of sediments, which can be related to their bioavailability.

The results of metal determination were used to examine the relationships between metal accumulation in organisms and sediment pollution. Whereas no significant relationship was found by considering total metal content in sediments, the approach based on the geochemical speciation gave some interesting results. For example, for Cu and Cd a significant correlation was found between the content in mussels and that measured in non-residual geochemical phases.

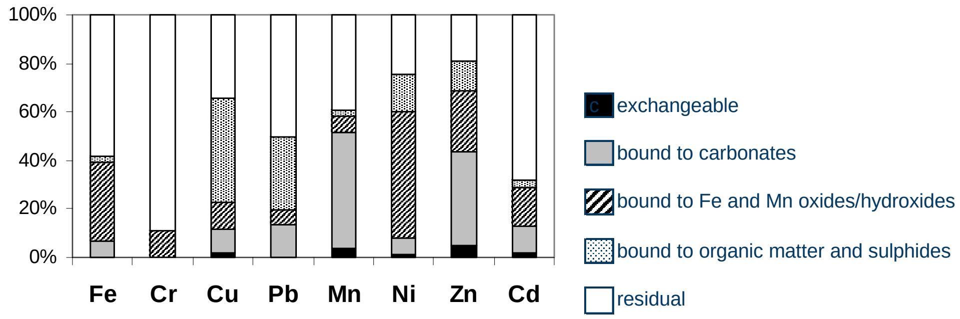

Fig. 3 – Results of geochemical speciation of metals in sediments from the Celestia site (July 2002).

Conclusions

The relationships between metal accumulation in organisms and sediment pollution in the lagoon of Venice have been investigated. The results showed that the relationships between total metal concentrations in the sediments and those in the organisms are rather complex. Sediment composition in the lagoon of Venice is highly variable and thus an evaluation of metal contamination in terms of bioavailability may result extremely difficult. In this context, the relative abundances of the various metal-binding components of sediment may have a strong influence on metal bioavailability and should be taken in to careful consideration.

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RESEARCH LINE 3.4
Chemical contamination

TRANSPORT OF INORGANIC ELEMENTS BY AEROSOL

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Riassunto

A Murano e a Sacca Sessola, due isole nella laguna veneziana centrale, sono stati raccolti campioni di particolato atmosferico per determinare la concentrazione dei metalli in tracce. Si riportano i risultati parziali delle prime tre campagne; nella prima è stato raccolto PM10, nelle successive PM2.5. Si evidenziano differenze di concentrazione tra le due frazioni granulometriche e tra i due punti di campionamento, interpretate in relazione alle diverse condizioni del vento durante i campionamenti.

Abstract

Samples of atmospheric particles were collected in Murano and in Sacca Sessola, two islands in the central Venetian Lagoon, in order to determine the concentrations of trace metals. Partial results of the first three sampling periods are presented here. In the first sampling period PM10 was collected, while in the following ones a PM2.5 collector was used. Different concentrations are shown between the two granulometric fractions and between the two sampling sites, in relation to the seasonal wind conditions.

1. Introduction

The trace metal content was determined in the atmospheric particles with an aerodynamic diameter less than 10 µm (PM10 and PM2.5), in order to understand the contribution of these fractions in the transport of pollutants into the Venice Lagoon. Two sampling sites were chosen: Murano is characterized by the presence of glass-works, and Sacca Sessola, which is influenced by the industrial area of Marghera. Reported here are partial results from the three sampling periods: Sacca Sessola during July 2001, March and October 2002, and in Murano during July 2001, April and December 2002. It was only in the first sampling period that PM10 was collected, in the following ones PM2.5 was because in was found that in the surface microlayer the diameter of most of particles was less than 2.5 µm.

2. Experimental

2.1. Sampling and analytical techniques

During the sampling periods, 34 samples were collected in Murano and 28 in Sacca Sessola. The particulate matter was collected on a mixed cellulose ester filter (47 mm diameter, 0.45μm porosity, Metricel type GN4, GELMAN SCIENCES). A sequential air sampler was used, Skypost PM (TCR TECORA), which operated at a flow rate of 16,67 l/min; each filter was exposed to the airflow for 24 hours. All filters were weighed before and after sampling, after mass equilibration for 24h at a relative humidity of about 50%. The samples were digested using a microwave oven (ETHOS 1600, MILESTONE) using a mixture of 18 MΩ water, HCl, HNO_3, HF and H_3BO_3.

Concentrations of the elements were determined using an Inductively Coupled Plasma Quadrupole Mass Spectrometer (ICP-QMS) using Rh, Sc and Y as internal standards. The accuracy of the analytical procedure was determined using NIST SRM 1648, Urban Particulate Matter, (National Institute of Standards & Technology). The recovery was above 90% for the most of the elements.

2.2. Results and discussion

Indicative results from fractions collected in different time frames are shown in Figure 1. A rigorous comparison between samples is not possible, because the PM10 and PM2.5 collections were carried out at completely different times. Figure 1 shows the concentration of the elements in the PM2.5 (second sampling campaign) fraction expressed as a percentage of the total concentration, which is assumed to be the concentration of the elements in the PM10 fraction (first sampling campaign), i.e. PM10 contains the PM2.5 fraction. From the data obtained it was observed that some of the elements (Sr, Cu, Fe, Ce, Mn) were present in elevated concentrations (> 50% abundance) in the coarse fraction (PM10), whilst other elements (Cd, Se, Pb, Li, Ni and Sb) were “enriched” in the fine fraction (PM2.5). However, Ba and Zn were equally present in both size fractions. The differences in the percent abundances of the elements are due to the different origins of the particles. Coarse particles are usually formed by mechanical action at high temperatures, like in combustion, or at low temperatures, by processes involving crustal erosion. Fine particles arise in the atmosphere due to the condensation of gases and vapour [Chester R., 1990].

Preliminary results of the mean concentrations of the elements are shown in Table 1-a, b, c. The concentrations of the measured solutions were corrected using the “blank fields”, these are filters that were located inside the sampler during sampling but were blanked off to prevent sampling. The final concentrations of the elements are expressed in ng/m3.

During the first sampling periods, 17-20 July 2001 in Sacca Sessola and 26-30 July 2001 in Murano, Mn, Fe, Co, Ni, Cu, Zn, Sb, Ba, Ce, Pb (Tab. 1-a) had higher concentrations in Murano compared to Sacca Sessola. Figure 3 (a wind rose) shows the prevailing wind directions for all three sampling periods. It demonstrates that over the first sampling period two wind directions, North East and South West were prevailing (Fig 3a).

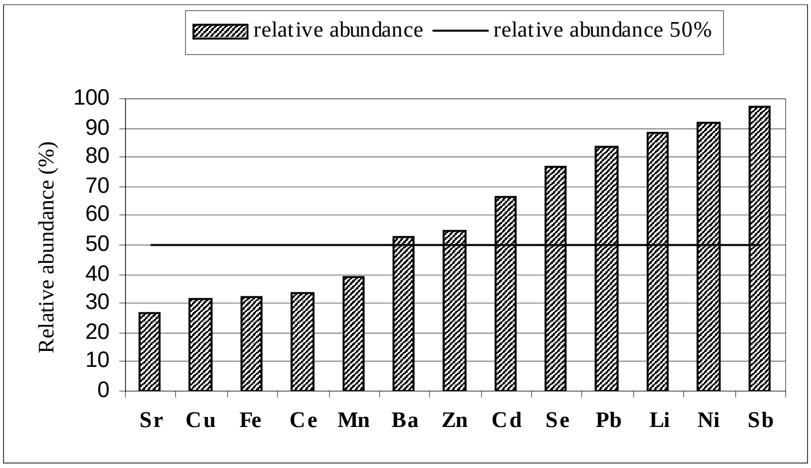

Fig. 1 – Relative percentage abundance of elements (conc PM2.5/ conc PM10) x 100. Above 50% means more abundant in PM2.5.

In March and April 2002, the concentrations of the elements showed considerable daily changes. As an example Figure 2 shows the day-to-day lead distribution. The variability of the concentrations can be explained using the wind roses from spring 2002 (Fig. 3-b) which show no dominant wind direction. This means that understanding the input of particulate matter, depends on the identification of possible local point sources. Table 1-b shows that the mean concentrations of most of the elements are higher in Murano during spring.

In the third sampling period, October 2002 in Sacca Sessola and December 2002 in Murano, concentrations of the elements vary day by day in Murano while their concentrations are more uniform in Sacca Sessola (Fig.2). During sampling the wind was from a NNE direction (Fig. 3-c), from Murano towards Sacca Sessola. This resulted in higher mean elemental concentrations in Sacca Sessola for many of them (Table 1-c)

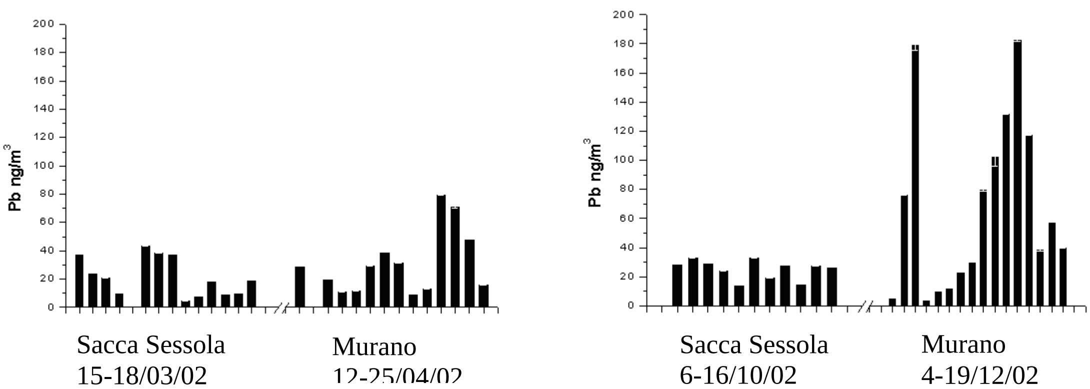

Fig. 2– Daily concentrations of Pb (ng/m3) in Sacca Sessola and in Murano. On the left: second sampling campaign. On the right: third sampling campaign.

except for Pb, Mn, Zn, Sb.

Cadmium and Selenium show an interesting pattern of behaviour; during March and April 2002 their concentrations were highest in Murano and show similar concentration trends. In October and December 2002, the opposite is true, with higher concentrations and the same behaviour at Sacca Sessola. Cadmium and Selenium are two elements used together to colour glass products [Merian E., 1991], and their source maybe the glass-works of Murano. The daily differences in concentrations suggest that their possible emission is from a discontinuous source and that wind plays an important role in their atmospheric distribution.

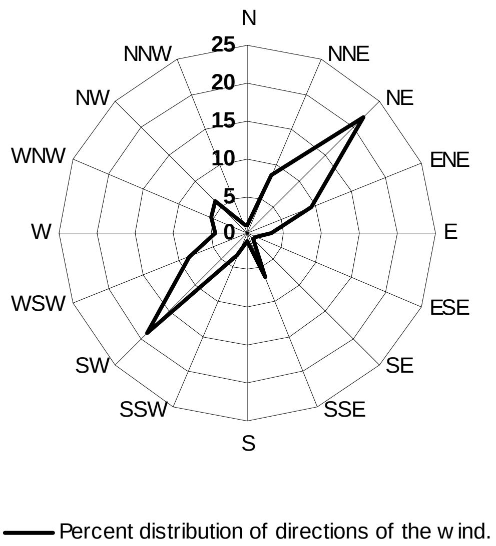

Fig. 3a – Wind rose during 26-30/07/2001. Percent distribution of directions of the wind. (By Ente Zona Industriale di Porto Marghera)

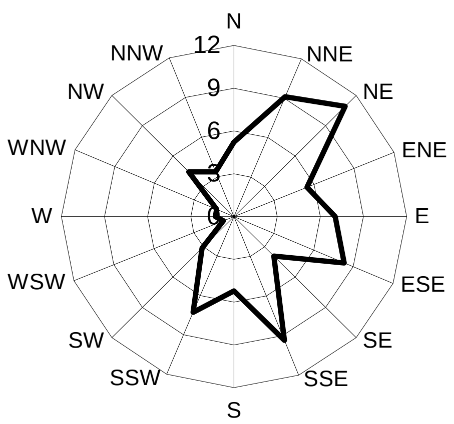

Fig.3b – Wind rose during 15-28/03/2002. Percent distributions of directions of wind.

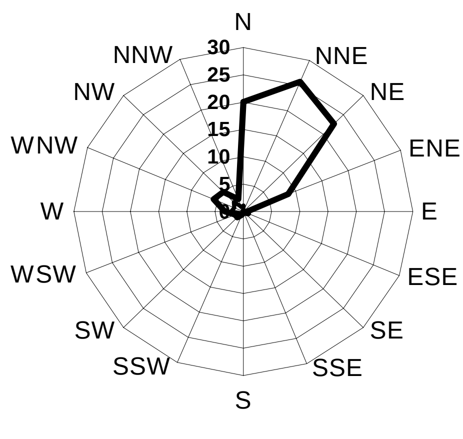

Fig.3c – Wind rose during 4-19/12/2002. Percent distribution of directions of the wind.

Tab. 1a,b,c – Concentrations of the elements during the three sampling periods in Sacca Sessola and Murano. Mean, maximum, and minimum values expressed in ng/m3.

Tab. 1-a (PM10)

	Sacca Sessola 07/2001			**Murano 07/2001**		
	media	**max**	**min**	**media**	**max**	**min**
	ng/m3	ng/m3	ng/m3	ng/m3	ng/m3	ng/m3
Li	0.097	0.16	0.033	0.059	0.12	0.022
Cr	1.41	2.04	0.758	3.56	6.27	0.139
Mn	7.9	12	3.4	14	17	8.2
Fe	184	330	93.7	381	468	294
Co	0.085	0.20	0.039	0.18	0.24	0.11
Ni	2.8	4.0	1.7	4.5	6.2	1.2
Cu	5.9	9.8	2.3	18	23	14
Zn	51	95	19	79	128	30
Ga	0.190	0.307	0.149	0.185	0.308	0.154
Se	2.21	4.98	1.10	3.06	7.75	0.748
Sr	2.07	3.83	0.935	2.46	3.76	1.94
Cd	4.43	13.8	0.664	4.81	16.6	0.594
Sb	6.32	11.3	2.97	17.3	41.9	2.17
Ba	3.90	8.05	1.44	6.5	8.6	5.3
Ce	0.290	0.607	0.176	0.690	1.06	0.436
Pb	24	32	14	42	59	31
Bi	0.580	0.779	0.474	0.446	0.849	0.142

Tab. 1-b (PM2.5)

	Sacca Sessola 03/2002			**Murano 04/2002**		
	media	**max**	**min**	**media**	**max**	**min**
	ng/m3	ng/m3	ng/m3	ng/m3	ng/m3	ng/m3
Li	0,086	0,26	0,019	0,056	0,18	0,024
Cr	0,741	2,21	0,211	<LD	<LD	<LD
Mn	3,3	7,5	1,0	5,0	13	2,0
Fe	51,5	122	15,8	136	223	72
Co	0,15	0,29	0,012	0,16	0,40	0,038
Ni	2,8	8,6	0,1	3,8	19	0,30
Cu	2,5	5,2	0,91	3,60	11,4	0,452
Zn	25	49	6,9	48	163	12
Ga	0,177	0,440	0,140	<LD	<LD	<LD
Se	1,70	5,10	0,207	4,46	13,0	0,253
Sr	0,464	0,762	0,218	0,755	1,66	0,0969
Cd	2,93	9,26	0,146	10,5	38,4	0,0726
Sb	6,16	16,3	0,632	20,3	53,6	0,523
Ba	2,92	5,95	0,834	2,0	4,4	0,79
Ce	0,0928	0,166	0,0363	0,239	0,425	0,0781
Pb	22	44	5,0	32	80	9,7
Bi	0,382	1,09	0,0348	0,657	1,386	0,242

Tab. 1-c (PM2.5)

	Sacca Sessola 10/2002			**Murano 12/2002**		
	media	**max**	**min**	**media**	**max**	**min**
	ng/m3	ng/m3	ng/m3	ng/m3	ng/m3	ng/m3
Li	0.11	0.25	0.036	0.046	0.11	0.0036
Cr	<LD	<LD	<LD	<LD	<LD	<LD
Mn	5.3	7.5	1.8	8.8	43	0.46
Fe	79.0	184	4.04	74.1	337	9.26
Co	<LD	<LD	<LD	<LD	<LD	<LD
Ni	4.0	7.8	1.3	3.0	10	0.26
Cu	5.1	14.8	1.8	4.9	21	0.67
Zn	30	156	3.5	43	166	12
Ga	0.459	1.36	0.0503	0.132	0.264	0.0511
Se	6.90	23.0	2.21	1.79	4.60	0.318
Sr	1.73	8.57	0.650	<LD	<LD	<LD
Cd	13.8	48.5	0.637	3.32	10.4	0.0728
Sb	9.91	27.4	3.04	10.5	49.8	0.221
Ba	8.8	16	0.52	3.5	9.0	0.24
Ce	0.222	0.734	0.0178	0.0961	0.243	0.0119
Pb	25	33	14	68	183	3.9
Bi	1.49	5.32	0.117	0.776	2.57	0.120

Conclusions

It is possible to make several conclusions from the preliminary results, obtained from the daily sampling of particulate matter.

When compared the coarse and fine fractions, the two granulometric fractions PM10 and PM2.5 show different relative percentage abundance of the elements, even though the sampling was not carried out at the same time.

The similar behaviour of the elements on a daily basis suggests possible common origins, that maybe the industrial and urban zone of the mainland, or for the behaviour of Cd and Se, the glass-works of Murano.

Finally, it is worth considering the importance of the wind in the transport of elements, and consequently highlights the necessity of acquiring detailed information on the local micrometeorology for a complete interpretation of data.

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TRACE METALS SPECIATION IN VENICE LAGOON DURING BENTHIC CHAMBERS EXPERIMENTS

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Riassunto

In questo lavoro vengono presentati alcuni risultati relativi alle variazioni dei nutrienti ed alla speciazione di metalli in tracce (Cd, Cu, Fe, Mn, Pb e Zn) in sedimenti e particellato ottenuti negli esperimenti condotti in camere bentiche localizzate rispettivamente presso il Canale delle Tresse (45°26.440'N; 12°16.566'E) e tra Isola Campalto e San Giuliano (45°28.219'N; 12°18.083'E) nel corso di tre campagne, tra l'estate 2001 e l'autunno 2002.

Il campionamento ha seguito due strategie diverse: i sedimenti sono stati prelevati sotto forma di carote di circa 10 cm, successivamente sezionate in quattro porzioni, il particellato e l'acqua sono stati prelevati ad intervalli di circa 3-4 ore per un periodo totale di 45-55 ore.

I sedimenti ed il particellato sono stati sottoposti ad attacchi chimici per la determinazione delle concentrazioni totali di Cd, Cu, Fe, Mn, Pb e Zn, per i sedimenti si sono effettuati anche attacchi selettivi per evidenziare la speciazione degli stessi metalli.

Il comportamento osservato per i nutrienti ha mostrato nette differenze tra le campagne 2001 e quella del 2002.

Relativamente al contenuto totale di metalli, si è notato che le concentrazioni medie nel sedimento e nel particellato sono molto simili.

Nello studio della speciazione nel sedimento i vari metalli hanno evidenziato comportamenti abbastanza tipici, senza differenze significative tra i due siti di campionamento.

Considerazioni più approfondite potranno essere fatte una volta ottenuti i risultati di speciazione del particellato e in seguito al completamento della strategia di campionamento prevista dal progetto.

Abstract

Trace heavy metals (Cd, Cu, Fe, Mn, Pb and Zn) distribution in sediments and in particulate matter together with nutrients variations were examined in benthic chamber experiments carried out in two different sites in Venice Lagoon: Tresse Channel and between Campalto Island and San Giuliano Island. Experiments took place during three surveys carried out from summer 2001 and autumn 2002.

Sediments were sampled as cores of 10 cm in length, then sectioned in four sections. Seawater and particulate matter were sampled every 3-4 hours for a total period of 45-55 hours.

Total trace metals concentrations were determined both in sediments and in particulate matter, while sequential extractions were carried out only for sediments.

The two sampling periods showed very different nutrients trends.

Metals concentration in sediments is very similar to the particulate one. Speciation study highlighted typical behaviour for many analysed elements while no difference between the two locations was observed.

It will be possible to draw more detailed considerations at the end of project sampling strategy and on the basis of particulate speciation analysis, still in progress.

1. Introduction

The sediment-water interface of a marine basin is the site where gradients in chemical, physical and biological properties are the greatest. Fluxes of constituents through this interface, called benthic fluxes, affect element concentrations in both pore waters and overlying bottom waters; thus they are important processes of the whole marine biogeochemical cycles of many elements [Val Klump and Martens, 1981*;* Santschi et al., 1990; Rivera Duarte and Flegal, 1994; Riedel et al., 1997; Zago et al., 2000]. Direct measurements of benthic fluxes can be obtained by using benthic chambers [Ciceri et al., 1992; Giblin et al., 1997].

Benthic chambers are based on a simple principle: a known sea water volume and a known sediment surface are isolated inside the chamber during the experiment period. Water and particulate samples are periodically collected inside the chamber to follow the temporal trend of studied parameters. Differently from the case of large box core sampling, an in situ chamber allows a benthic environment to be enclosed without its removal from the original place, and thus permits estimation of benthic fluxes with minimal perturbations. The employ of a benthic chamber is useful to understand what happens in metal and nutrient cycling when low oxygen concentrations are present in bottom waters, a phenomenon that frequently occurs in coastal and organic rich waters.

In the present study a highly anthropised area of Venice Lagoon, close to Marghera discharge, was selected for the benthic chambers experiment.

The Venice Lagoon is a complex shallow aquatic ecosystem characterised by the presence of different sub-environments with particular hydrodynamics as well as physical, chemical and biological conditions. The lagoon is connected to the Adriatic Sea and exchange waters and sediments following the tidal cycles. This environment is heavily affected by anthropogenic activities and the uncontrolled discharge of pollutants from both diffuse and point sources as rivers, urban wastes, industrial discharges and atmospheric depositions.

The studied regions are Campalto and Tresse. Campalto is located between the town of Venice, the Porto Marghera industrial area, the Murano island and the mainland. Tresse is located close to the industrial site of Marghera. In this work Cd, Cu, Fe, Mn, Pb and Zn distribution is studied in sediment and suspended particulate as well as nutrients fluctuations during the whole experiment time.

2. Materials and methods

Results here presented refer to three different surveys. Experiments were carried out respectively from 9 to 11 July, from 23 to 25 July 2001 and from 28 to 30 October 2002 in two sites: close to Tresse Canal and between Campalto and San Giuliano islands. Analysis were carried out on 27 seawater samples, 28 particulate samples and 12 sediment sample collected in the two different benthic chambers in summer 2001 and on 15 seawater samples and 8 sediment samples collected in Tresse benthic chamber in autumn 2002.

Seawater samples were collected every 3-4 hours for a total period of 45-55 hours inside benthic chambers and stored in polyethilene bottle. Particulate samples were obtained from seawater filtration using polycarbonate filters of pore size of 0.4 μm, previously cleaned with diluted HCl (Merck, Suprapur) and conditioned with seawater.

Sediments were sampled as cores of about 10 cm, then sectioned in four slices and stored in LDPE containers. All the samples were stored at –25°C.

Filter with particulate matter were dried at room temperature under Laminary Flux Hood until constant weight attainment.

Sediments were dried at 40 °C in oven, homogenized using an agate mill and stored at room temperature until analysis.

2.1. Analytical procedure

Nutrients in seawater were determined with colorimetric method using five-channel continuous flow Technicon® Autoanalyzer II, according to the methods described by Hansen and Grasshoff (1983).

In sediment samples both total metal concentration and speciation in three diverse phases are determined, while in the case of particulate matter only total metal concentration was determined.

- The total metal content was determined digesting the samples in PTFE vessels with acqua regia and fluoridric acid in a microwave oven (CEM MDS 2000) with the following program: 5 minutes at 260 W power, 5 minutes at 390 W power and 10 minutes at 520 W. The digested samples were filtered, transferred in polyethylene containers and stored at +4°C until analysis. Blank vessels, containing acid solution but no sample, were processed with the samples and showed no significant contamination. Accuracy of the procedure was checked with Certified Reference Material (CRM) MESS 2 (marine sediment) from National Research Council of Canada. Standard deviation were approximately 5% for all metals, while the accuracy of measurements was generally < 10%, a little higher for Cd and Pb.
- Selective extraction consists in three sequential steps:

Step 1. Exchangeable and acid soluble. Acetic acid 0.11M is added to samples in polyethylene centrifuge tubes, which were shaken overnight (16 h) at room temperature. The extracts were separated from the residues by centrifugation and acidified.

Step 2. Easily reducible phase (Fe-Mn oxides and hydroxides). Hydroxylamine hydrochloride 0.5M, adjusted to pH 2 with nitric acid (65%), was added to the residue and the same procedure of the first extraction was carried out.

Step 3. Bound to organic matter and sulphides. The residue was put in a microwave Teflon vessel and, after the addition of a first aliquot of 8.8 M hydrogen peroxide, left at room temperature for 1 h, then treated at 80°C in a microwave oven using the following program: 10 minutes at 65W power, 10 minutes at 0W power, 20 minutes at 130W power, 10 minutes at 0W power and 20 minutes at 260W power. A further aliquot of hydrogen peroxide was added and the vessels heated in microwave oven for a second cycle of the same program. After cooling, 2M ammonium acetate (pH 2) was added and the procedure was carried out as for steps 1 and 2.

The metal content of the residual phase was obtained by difference between the total content and the sum of the fractions 1, 2 and 3. Sequential extraction reagent blanks showed no detectable contamination. Accuracy of the procedure was tested using Certified Reference Material (CRM) BCR-701 (SM&T). For all analysed metals precision of measurements was around 10%, while accuracy was <8% for step 1 and 2 and a little higher for step 3.

All the reagents employed were of Suprapur grade (Merck Eurolab, Italy).

The determination of Zn, Cu, Fe, Mn, Pb was carried out with an Inductively Coupled Plasma Atomic Emission Simultaneous Spectrometer (ICP/OES) Varian Vista PRO, while Cd was determined by Electrothermal Atomization Atomic Absorption Spectroscopy (ETA/AAS) (Varian Spectra A300 Spectrometer with Zeeman effect background correction and autosampler Varian model 96).

3. Results and discussion

Nutrients behaviour was different in summer and in autumn. As shown in figures 1a and 1b, in both the experiments carried out in July 2001 nitrogen compounds behave in a similar way, well correlated to tidal fluctuations. This fact is probably due to some lifting of the chambers that can favourite the exchange with external waters. Nutrient concentrations are different in the two site: in the Tresse area mean values found for ammonia, nitrate and nitrite are respectively 11.9, 9.4 e 0.8 μM, meanwhile in Campalto site are 2.8, 0.8 e 0.3 μM.

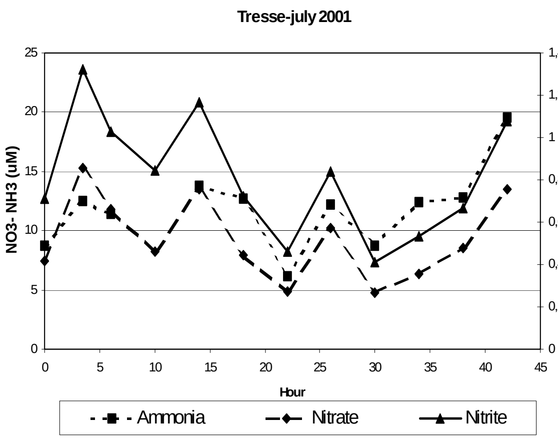

Fig. 1a- Nutrients distribution in Tresse benthic chamber during 2001 experiment.

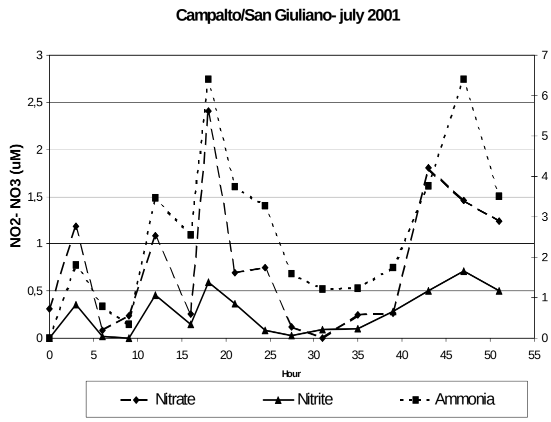

Fig. 1b- Nutrient distribution in Campalto benthic chamber during 2001 experiment.

Results concerning Tresse area in October 2002 highlight a different situation, in fact the various parameters follow peculiar trends which are less correlated to the tidal fluctuations. This could be explained with a better benthic chamber isolation than in July 2001 experiment. In figure 2a, in fact, it could be seen dissolved oxygen decreasing and ammonia increasing in the last hours of experiment, as previously observed in an analogue study [Zago et al., 2000].

Figure 2b shows how in Tresse 2001 experiment particulate matter increases starting from 21th hour, suggesting fluxes between water column and sediments.

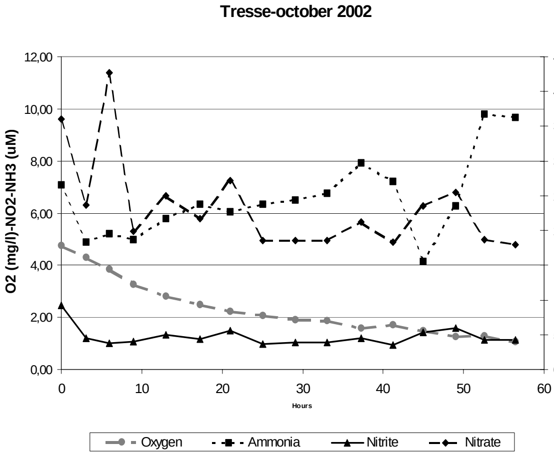

Fig. 2a- Nutrients and dissolved oxygen during Tresse 2002 experiment.

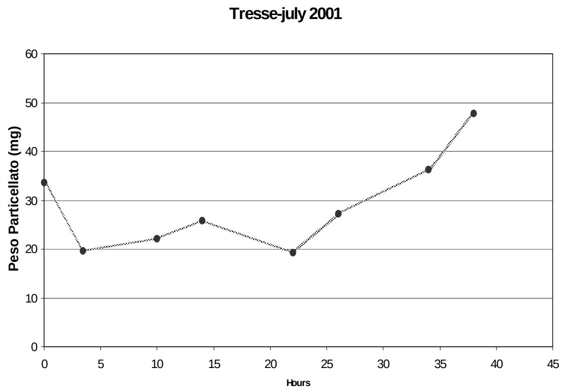

Fig. 2b- Particulate weight (mg) in Tresse 2001 experiment.

Particulate heavy metals content doesn't have any correlation with tidal fluctuation but is very similar to concentrations in sediments, as shown in table 1. This suggests the importance of re- suspended sediment in particulate composition.

Tab. 1- Sediments and particulate mean trace metal concentration found in Tresse 2001 (St. 1) and in Campalto 2001 (St. 3) experiments.

	Zn	Pb	Fe	Mn	Cu	Cd
	g/g	g/g	g/g	g/g	g/g	g/g
St. 1 Sediment	235	35,9	15137	292	29,3	1,35
St. 1 Particulate	537	77,0	27889	561	69,4	2,31
St. 3 Sediment	269	47,0	20224	368	34,7	1,36
St. 3 Particulate	316	48,4	21437	475	34,6	0,81

As regards particulate matter, the highest metal concentrations were found in Tresse area, closest to the industrial area. Zn, Pb and Cd mean values are, in both stations, higher than typical background concentrations reported for coastal sediments [Solomons and Forstner, 1984], suggesting significant anthropogenic inputs for these metals. The high contents of Zn, Pb and Cd in sediments confirm the importance of the Porto Marghera industrial area as a source of pollution, as well as the atmospheric input. In fact, fallout contribution of Pb and Zn accounts for 35% and 10% of the inventories, respectively [Frignani et al., 1997].

Heavy metal mean values in sediments are quite similar in the two areas and don't show any significant temporal trend as concern Tresse site. However, some differences could be distinguished in the cores. For example, in cores sampled in 2002 it can be seen that all analysed metals have the lowest concentrations in surface core slices. In figure 3a, 3b and 3c are reported histograms representing Pb, Zn and Cd total concentrations. This metals behaviour confirms the decreasing of pollutants inputs in the last years in the studied area, as reported by other authors [Bellucci et al., 2002].

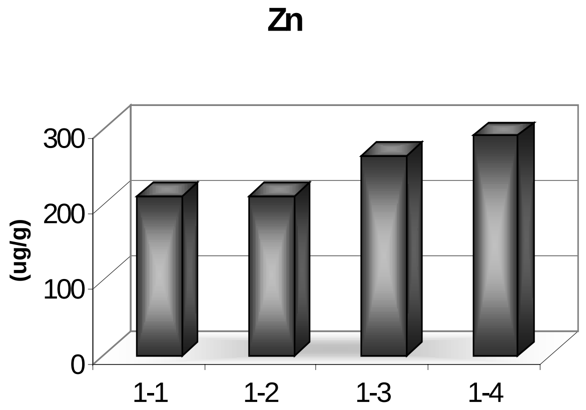

Fig. 3a - Zn total concentration in Tresse 2002 experiment.

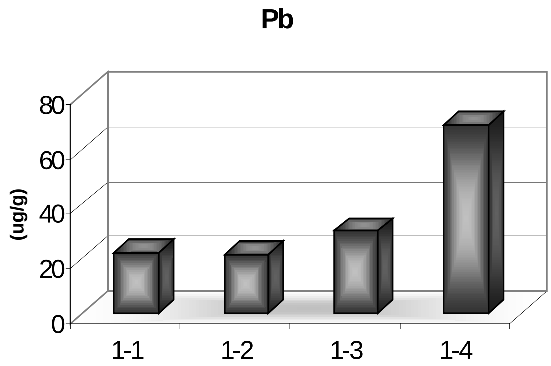

Fig. 3b- Pb total concentration in Tresse 2002 experiment.

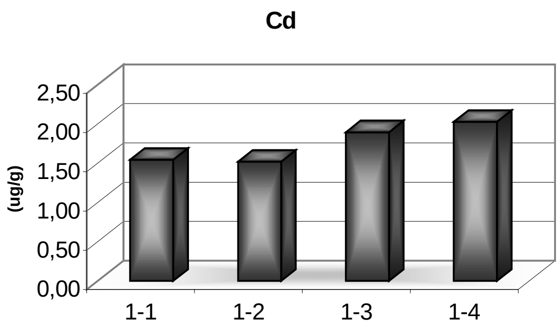

Fig. 3c- Cd total concentration in Tresse 2002 experiment.

Speciation studies show that there isn't any significant difference between the two sites and during the time in the same location. As an example, in figure 4 Mn, Cd, Fe, Cu, Zn and Pb distributions, found for Tresse 2002 experiment, are reported.

It can be seen that Mn has a characteristic behaviour; in fact it is present for 20% of total concentration in the labile phase and for 60% in the residue one. Also Cd and Zn are associated with the labile fraction for 20%, but for these metals their concentration in the residue fraction is significantly smaller. This kind of distribution is due to the good affinity of Mn and Cd to carbonates, in particular calcium carbonates [Span and Gaillard, 1986], which are abundant in lagoon environment [Bellucci et al., 2002]. Moreover the good percentage of Cd, Mn and Zn in labile phase and Cd and Zn concentrations (0.81μM and 104 μM respectively) suggest that inputs for these metals are quite recent.

More than 90% of total Fe is in the residue phase so it has probably a natural origin and it can hardly be mobilized.

Cu is associated for about 40% to oxidable fraction and for another 40% to the residue. This confirm its high affinity to organic matter, already reported by other authors [Griscom et al., 2000]. Copper could easily form complexes with organic matter due to the high stability constant of organic-Cu compounds. [Xiangdong et al., 2001].

Pb too has a good affinity to oxidable phase (more than 30%), as shown in figure 5c, but the reason is different. Pb, in fact, is easily bound to sulphides.

For these last two metals concentrations measured in the first fraction are very low, limiting their potential dangerousness as pollutants.

First results obtained in the study of particulate speciation highlighted some differences as regards sediments, at least for some metal. In particular, the percentage of Fe, Pb and Cu associated to the residual fraction is lower than in sediments. However, detailed considerations will be done only after a good data elaboration, at the end of project sampling strategy.

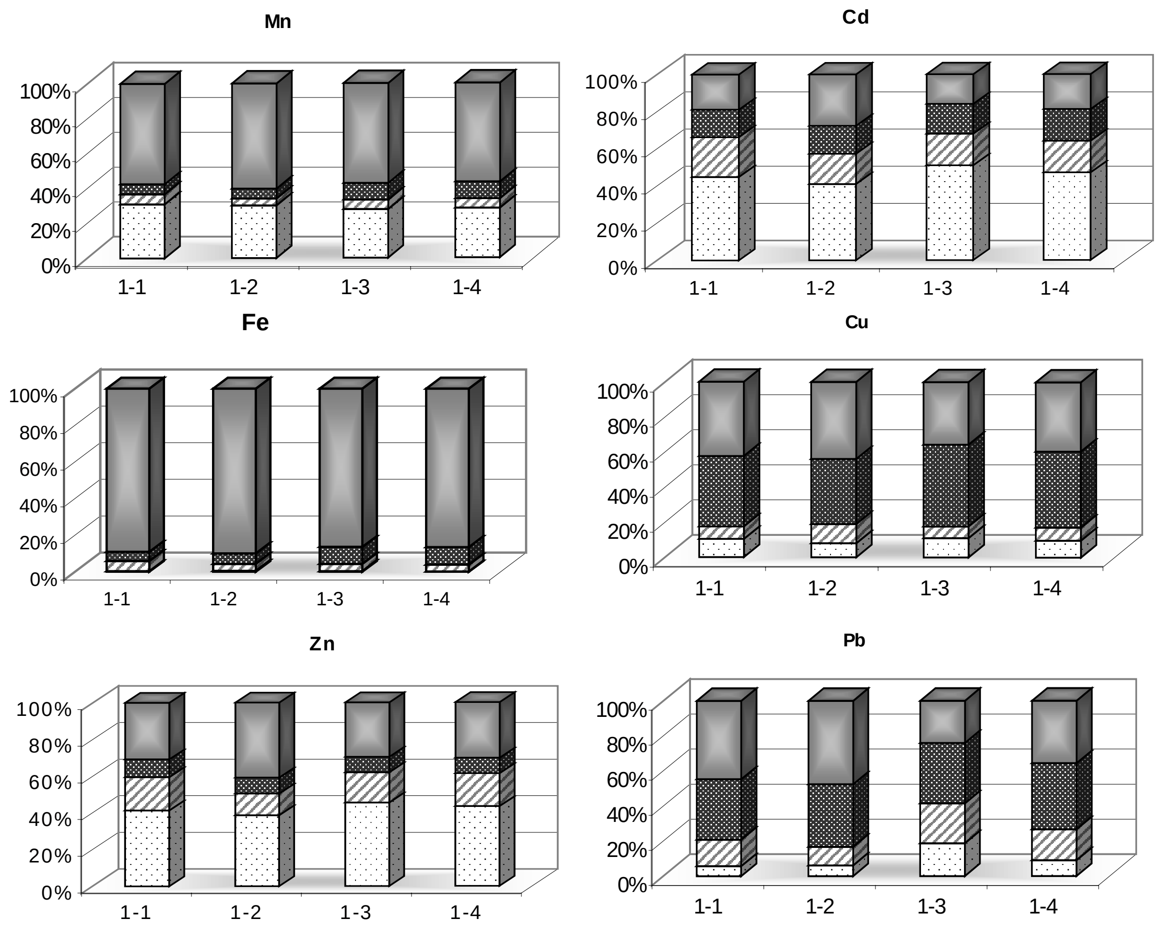

Fig. 4 - Mn, Cd, Fe, Cu, Zn and Pb speciation in sediments in Tresse 2002 experiment.

Conclusions

Nutrients trend observed in 2002 appears the more significant. In fact, the experiments performed in 2001 were greatly affected by tidal excursions. This fact is probably due to a better benthic chamber isolation from external waters, realized in the 2002 experiment.

As regards total metal concentrations, mean values are very similar for particulate matter and sediments suggesting an important re-suspension contribution in particulate composition. Speciation studies showed typical behaviour for considered metals, but for Cd and Zn the labile fraction concentration is quite high, suggesting a recent input and possible toxic effects. No significant difference for the two experiment site and for the different sampling time was observed. This could point out that pollutant accumulation at studied location maintains the same relative importance in time, as already reported in other works [Frignani et al., 1997].

Particulate speciation is in progress. As these data will be available, it will be possible to study metal fluxes between sediments, particulate and seawater and how they vary under anoxic conditions.

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TRACE ELEMENTS AND ORGANIC POLLUTANTS (PCBs AND PAHs) IN THE AEROSOL OF THE VENICE LAGOON

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Riassunto

Lo scopo di questo lavoro è valutare il ruolo dell'aerosol nella contaminazione della laguna di Venezia. I campionamenti di aerosol per la determinazione di elementi in tracce e di inquinanti organici (policlorobifenili e idrocarburi policiclici aromatici) sono stati effettuati in tre siti localizzati nei pressi della laguna, caratterizzati da sorgenti di diverse (sorgente urbano-industriale, sorgente marina e sorgente di 'long range', cioè non influenzata da apporti locali).

I risultati preliminari ottenuti hanno evidenziato una diversa distribuzione granulometrica degli elementi in traccia, a seconda della loro origine: quelli di origine crostale si sono rivelati più abbondanti nella frazione più grossolana, mentre quelli di origine antropica nella frazione più fine. Per la maggior parte degli elementi la concentrazione totale risulta più elevata nella stazione caratterizzata da impatto urbano-industriale.

Le concentrazioni di policlorobifenili e idrocarburi policiclici aromatici hanno mostrato un andamento stagionale, diverso tra loro: la concentrazione dei primi è risultata maggiore durante le stazioni estive, mentre quella dei secondi era maggiore durante i mesi invernali.

Abstract

The aim of this study is to evaluate the role of the aerosol in the contamination of the Venice lagoon by trace elements and organic pollutants (polychlorinated biphenyls and polycyclic aromatic hydrocarbons). Samplings have been performed at three sites near the lagoon, chosen by their different source emissions (urban and industrial source, marine source and 'no local' source).

The preliminary results have shown that the size distribution of trace elements is different according to their origin: crustal elements are most abundant in coarse particles whilst anthropic elements prevail in the finest fraction. Generally, trace elements present higher concentrations in samples collected at the industrial and urban site than in the other ones.

Polychlorobiphenyls (PCBS) and polycyclic aromatic hydrocarbons (PAHs) have shown a temporal trend related to the temperature changes: highest PCBs concentrations

have been found during summer months whilst PAHs concentrations increased in cold season.

1. Introduction

The atmosphere is a major pathway where anthropogenic organic compounds and trace elements of a persistent nature are cycling in the environment, so air masses could be an important source of contamination. It has been found that the air concentrations of semivolatile organic compounds have a strong relationship with the ambient temperature and they show different environmental behaviours due to their different sources and physical-chemical properties.

Polychlorinated biphenyls (PCBs) are persistent, bio-accumulative, carcinogenic and mutagenic compounds found widely spread in sediments, waters and biota of the Venice lagoon [Green et al., 1999; Moret *et al.*, 2001; Scarponi et al., 1998]. Their emission peaked in the late 1960s and then decreased to present levels because their use has been restricted or prohibited [Backe et al., 2000].

Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous and hazardous pollutants released into the atmosphere from anthropogenic and natural sources. They are formed primarily during incomplete combustion of coal, oil, petrol and wood; natural sources such as volcanoes and fires are to be neglected in comparison to anthropogenic sources (residential heating, traffic, coke production, etc) at least in Europe. These organic contaminants have recently gained attention as possible endocrine disrupting chemicals [Colborn et al, 1993].

Trace elements chemically toxic to humans, such as Hg, Pb, Cd, are emitted into the atmosphere from anthropogenic sources by combustion and industrial processes. They contribute to the worsening of the air quality and to increase the problems related to human health [Morales et al, 1996; Guieu et al, 1997; Chow et al, 2001].

The aim of this study is to evaluate the role of the aerosol in the contamination of the Venice Lagoon by trace elements and organic pollutants and their temporal variation.

2. Methods

2.1. Samples collection

Aerosol sampling was carried out at three sites of the Venice lagoon, as described in our previous work [Gambaro et al, 2002], each one subjected to a different kind of anthropic impact. Briefly, station 1 is located close to the industrial zone of Porto Marghera where aerosol derived from the urban and industrial sources was collected. The station 2 is located in the Lido inlet, onto the light house in front of the sea, to collect aerosol derived from marine sources (Adriatic Sea). The Station 3 is located in the Uganei Hills, about 70 km from Venice where aerosol influenced by no direct sources was collected.

We performed 13 campaigns from March to December 2002, each one lasted 10-15 days. Sampling was done by High-Volume air samplers, which have been periodically calibrated. They were equipped with an anemometer so they worked only when wind blew from a fixed direction [Gambaro et al, 2003].

Samples of trace elements were collected on cellulose filters accurately cleaned with acidified water before their use. Samplings were performed by a six-stage cascade impactor mounted on a high volume pumps equipped with a PM10 size-selective inlets [Chan et al, 2000].

Aerosol samplers used to collect organic compounds were equipped with a quartz filter (QFF) followed by an adsorbent material, a polyurethane foam plug (PUF).This kind of sampler allows us the simultaneously collection of ‘particle bounded’ and ‘vapour phase’ compounds and their separate analysis.

2.2. Analytical method

Cellulose filters were weighed before and after sampling, to evaluate the amount of particulate matter collected; then they have mineralized in acid mixture using a microwave digestion system. Elemental analysis was carried out by ICP-SFMS. Accuracy and repeatability of the used analytical method were determined by means of certified material (urban particulate matter SRM 1648 supplied by NIST).

Analytical method applied to determine organic pollutants has been described elsewhere [Gambaro et al, 2002]. Briefly, before sampling the supports were pre-extracted, then wrapped in aluminum foils and kept in a drier until use. After sampling, PUFs and QFFs were Soxhlet extracted separately for 24 hours using a dichloromethane:*n*-pentane mixture (1:2 v/v). Dehydrated extracts were cleaned up by florisil-alumina adsorption chromatography eluting with *n*-hexane. The elutes were reduced to 100 µl under a gentle nitrogen stream and analyzed by HRGC-LRMS. Quantification was performed by the isotope dilution method, adding to samples a known amount of ^{13}C labeled phenanthrene and ^{13}C labeled PCBs mixture before extraction. Quality control of this analytical procedure was carried out by blank control, by evaluating the limit of detection, the recoveries, the accuracy and the repeatability.

3. Results and discussion

3.1. Trace elements

The results of the SRM 1648 analysis are in good agreement with the certified values. Recoveries were obtained in the range of 81% (V) and 97 % (Ba) (tab. 1). Relative standard deviation were calculated using the replicate digested samples and it was found between 1% (Zn) and 15% (U).

Tab. 1 - Accuracy and recovery of SRM 1648.

Element	*Certified mean value*	*Obtained mean value*	*Standard Deviation*	*% Standard Deviation*	*Mean % recovery*
Pb (mg/g)	*6,55*	*6,31*	*0,08*	*1,0*	*96*
Al (mg/g)	*34,2*	*28,1*	*0,85*	*3,0*	*82*
Fe (mg/g)	*39,1*	*36*	*1,1*	*3,1*	*91*
Zn (mg/g)	*4,76*	*4,4*	*0,15*	*3,4*	*92*
Cd (µg/g)	*75*	*68*	*1,6*	*2,4*	*91*
Cu (µg/g)	*605*	*507*	*12*	*2,5*	*84*
Mn (µg/g)	*786*	*704*	*23*	*3,3*	*90*
Ni (µg/g)	*82*	*68*	*1,6*	*2,4*	*83*
V (µg/g)	*127*	*103*	*3,8*	*3,7*	*81*
Ba (µg/g)	*737*	*712*	*10*	*1,4*	*97*
Rb (µg/g)	*52*	*42*	*0,71*	*1,7*	*91*

The preliminary results show that the size distribution of particulate matter is bimodal (fig. 1) and quite similar at three sampling stations: the finest particles (0 – 0.49 µm) are the most abundant, followed by particles with aerodynamic diameter between 3 and 7.2 µm.

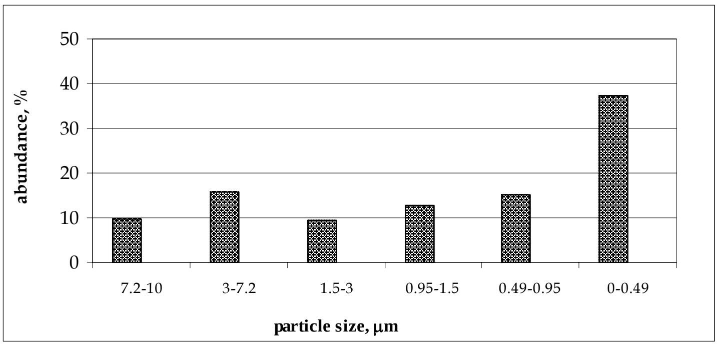

Fig. 1 - Size distribution of the collected particles.

In the case of the major trace elements it can be established that the total concentration (aerodynamic diameter < 10 µm) is higher at Station 1 than at other ones (fig. 2). Trace elements derived from crustal sources, such as Fe, Al, Mn, Li, show the highest concentrations in particles with aerodynamic diameter greater than 3 µm whilst elements related to the anthropic sources (for example V, Pb, Cd) are most abundant in smaller particles than 1.5 µm (figs. 3 and 4).

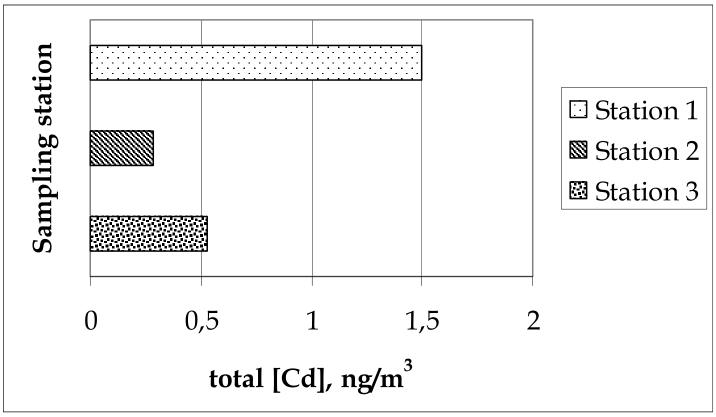

Fig. 4 - Cd total concentration at the three sampling sites.

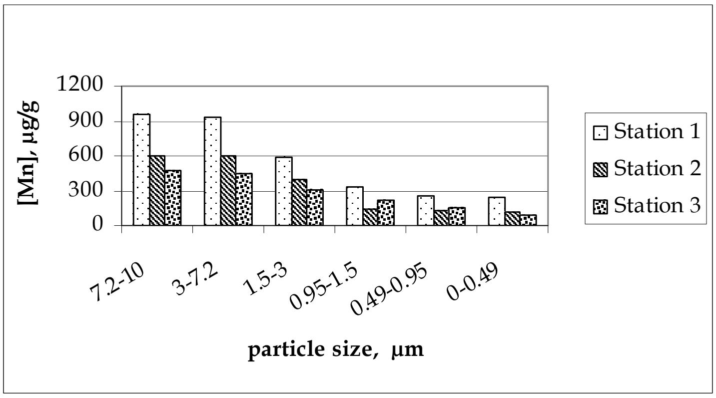

Fig. 5 - Mn size distribution at the three sampling sites.

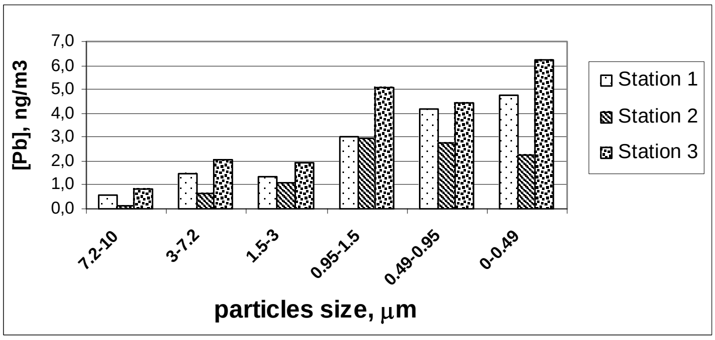

Fig. 6 - Pb size distribution at the three sampling sites.

3.2. Organic pollutants

For determining the accuracy of the 'dissolved' phase PCBs and PAHs spiked PUF plugs with known amounts of PAHs and PCBs mixture were tested. The average total PCBs and total PAHs were found between 7% and 10% of the real values, respectively. The accuracy of the 'particulate' PCBs and PAHs determination was carried out using five aliquots of NIST Standard Urban Dust Reference Material (SRM-1649a) deposited on QFFs. Most of the considered compounds were within the standard error intervals of the certified values.

The recoveries of PCBs and PAHs ware estimated analysing PUFs and QFFs spiked with a standard mixture containing the full range of these compounds. Results show that no correction for laboratory bias is necessary [Gambaro et al., submitted].

The repeatability of the method was obtained by consecutive measurements of spiked PUFs with known amounts of PCBs and PAHs and from repeated analysis of NIST Standard Urban Dust Reference Material (SRM-1649a). The relative standard deviations were 5% and 6% for the total of PCBs and 18%, 10% for the sum of PAHs in PUF and QFF, respectively [Gambaro et al., submitted].

The laboratory detection limit (LDL) and the limit of detection (LOD) were quantified as the mean concentration in the pre-sampling blanks and in the field blanks respectively plus three time their standard deviation. Pre-sampling blanks are PUFs and QFFs pre-extracted before sampling as described above; field blanks were obtained placing the supports in the sampler for 10-15 days without air flowing. Both kind of blanks were analyzed as samples as previously described. The field blanks and LOD were higher than pre-sampling blanks and LDL, probably due to transport and passive sampling. Generally the contamination derived from the sampling procedure and the analytical method is negligible for the 'dissolved' PCBs and PAHs, whereas for 'particle-bounded' determination high volume of air has to be sampled [Gambaro et al., submitted].

Pollutants concentrations varied largely between the three different stations and over the sampling period. As previously reported [Gambaro et al, 2002] the PCBs and PAHs concentrations were higher in the 'dissolved phase' than in the 'particulate' one at all sites. Station 1 showed the highest 'dissolved' PCBs concentration (fig. 5) and surprisingly station 34 the highest 'dissolved 'PAHs one (fig. 6). It is important to mention that PCBs mean concentration at Station 2 is about a quarter of the value at Station 1. A quite similar ratio has been observed in the PAHs mean concentrations.

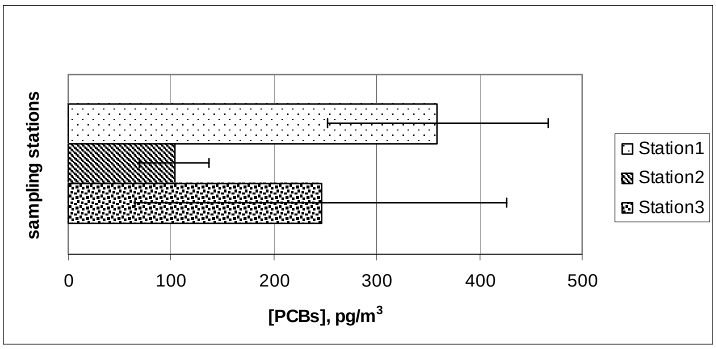

Fig. 7 - Mean 'dissolved phase' PCBs concentrations

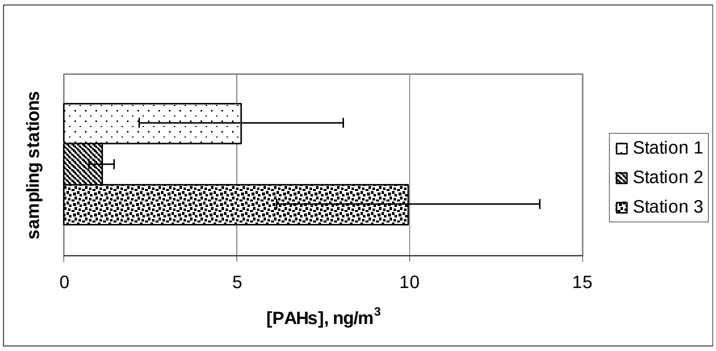

Fig. 6 - Mean 'dissolved phase' PAHs concentrations

The concentrations of 'dissolved' PCB homologs are different at the three stations: the penta-CB homolog is the most abundant at station 1 and station 2 whilst at station 3 the concentration of the tri-CB homolog is also elevated (figs. 7a, 7b and 7c). At all three sites the predominating 'vapour phase' PAH is phenanthrene, followed by fluoranthene; at station 3 also fluorene is relevant.

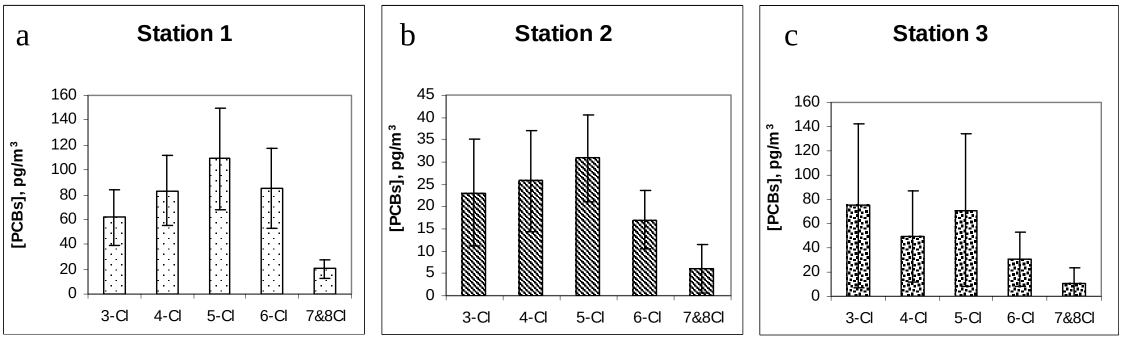

Fig. 7 - 'Dissolved-phase' PCBs homologs distribution at the three sampling sites.

Generally, it can be stated that broad variations in the concentrations of these organic pollutants were observed in correspondence to seasonal temperature changes but PCBs and PAHs show an opposite temporal trend. In fact at all three stations PCBs concentrations are higher when the temperature is increasing (figs. 8a, 8b and 8c)), whilst PAHs concentrations decrease in the warmer months (figs.9a and 9b) except at station 3 (fig. 9c).

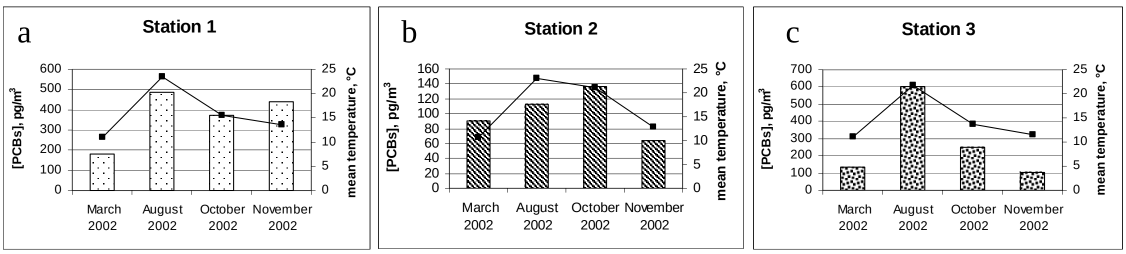

Fig. 8 - Temporal trend PCBs concentrations at station 1 (a), station 2 (b) and station 3 (c)

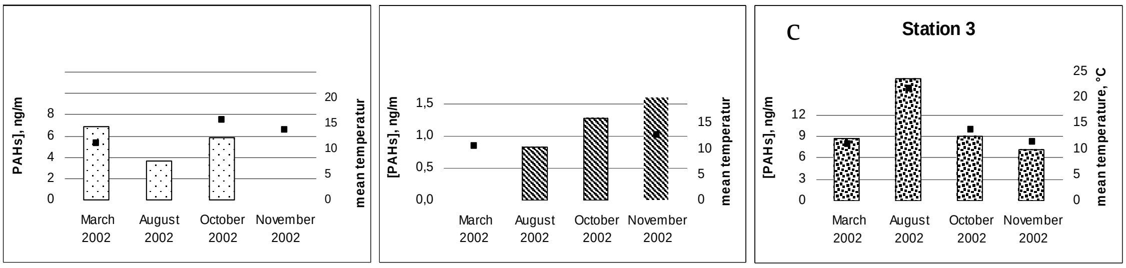

Fig. 9 - Temporal trend in PAHs concentrations at station 1 (a), station 2 (b) and station 3 (c)

This different behaviour with the temperature may be explained by considering the different sources of these compounds. We suppose that higher temperature help the volatilization from the surfaces (soil, atmospheric particles, water, vegetation, buildings) where they have been collected increasing PCBs concentrations during warm seasons [Halsall et al, 1995, Sofouglu et al, 2001]**.** PAHs are mainly set out from residential heating systems, so their emissions are higher in cold months than in the rest of the year [Park et al, 2002]. The opposite PAHs concentration trend at station 3 is not clear: it may be due to the emission related to the activities of the nature park close to the sampling site, where the attendance during the summer is very large.

Conclusions

The long-drawn-out sampling activity allows us to evaluate the temporal trend of organic pollutants and to identity an important factor namely the temperature that could influence their concentrations in the aerosol.

The study has confirmed the importance of industrial zone emissions but it has been also highlighted that marine source contributions are not negligible.

Acknowledgement

This work was supported by the CORILA under the Project ‘Role of aerosol and secondary pollution to the chemical contamination of the lagoon of Venice’ and by the National Research Council of Italy (CNR). The authors thank the staff of ARPAV – Meteorological Centre of Teolo and of EZI – Industrial Zone Agency of Porto Marghera and V. Zampieri for their sampling support.

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LAST DEVELOPMENTS ABOUT WATER SURFACE FILM FOR THE ESTEEEM OF POLLUTANT FLUXES IN VENICE LAGOON

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Riassunto

In questa fase del programma di ricerca si è voluto mettere in evidenza la relazione che esiste tra i vari inquinanti presenti all'interfaccia aria-acqua (film di superficie), e le altre matrici coinvolte (acqua ed atmosfera). Il sistema-laguna esaminato mostra dei comportamenti per gli inquinanti ed elementi considerati diversi. Gli inquinanti organici considerati (PCB e IPA) sono fortemente arricchiti nella fase particellata del microlayer (porzione del film di superficie campionato). Nel caso degli elementi in tracce, e in particolare per il Pb (origine antropica), si nota un arricchimento nella fase disciolta. Altre valutazioni riguardanti i flussi e il destino per gli PCB, IPA ed elementi in tracce sono in corso di avanzamento.

Abstract

In this phase of the search program it is intentional to put in evidence the relation that exists between several pollutants presents at the air-water interface (surface film), and the other been involved matrices (water and atmosphere). The examined lagoon-system show different behaviours for pollutants and elements considered. Organic pollutants her considered (PCBs & PAHs) are strongly enriched in the particulate phase of microlayer (sampled portion of surface film). In the case of traces elements in the dissolved phase, they show also low enrichment factor, but for the Pb (anthropic origin) a high enrichment is evident (single value and mean values). Other flux and fate assessments for PCBs, PAHs, and trace elements are still in progress.

1. Introduction

Surface film, which is present in the air-water interface of any water body, could be considered as gradient region between atmosphere and water. In surface film (microlayer assumed as the portion of sampled film) there are chemicals, which have different origin (man-made and natural). First results got during the first year activity pointed out that chemical species are enriched in the surface film [Schnitzer and Kahn., 1972] and their were closely connected with the particulate phase [Mackay, 1980]

Specifically speaking, the organic and inorganic compound are associated to the particulate matter. On the other hand, the dissolved phase shown no evident values of Enrichment Factor (EF). Studies on organic and inorganic are still in progress.

In this paper the results of sampling campaigns performed from 2001 to 2003 are reported. The areas considered where Sacca Sessola and Murano (central lagoon basin zone), and microlayer samplings where contemporaneously performed during the aerosol sampling period. Some considerations about contribution from sediment and atmosphere are also reported.

2. Experimental

Microlayer and subsurface water (-30 cm from the surface) where contemporaneously collected by the Multi-Use Microlayer Sampler (MUMS) [Stortini et al., 2001]. Samples where filtered and treated according the chemicals to detect. For organics, the filtered water (pore size 0.75 μm) was extracted according a liquid-liquid procedure extraction as reported elsewhere [Hermans et al., 1992]. The particulate matter was extracted using a Soxhlet extractor [Letellier M., 1999].

Inorganics where detected by ICP-MS in filtered samples (pore size 0.45 μm). More details are reported elsewhere [Stortini et al., 2001].

Enrichment factors were calculated according the following formula:

$$EF = [X]\ microlayer\ /\ [X]\ subsurface$$

were X correspond to the monitored chemical or element.

3. Result and discussion

The data samplings and the EF for microlayer and subsurface for Sacca Sessola and Murano, are reported in tables 1a and 1b.

<u>Organic compounds</u>

Values of EF for PCBs in the dissolved phase are no higher than 2 (mean value = 1.3), while in the particulate phase EF are higher (mean value 7.5 with a single case with EF = 35). Values of EF for PAHs for dissolved phase is 1-2 (mean value = 1.6), while in the particulate phase values go from 3 to 10 (mean value = 13.4 with a single case with EF = 21). These values are comparable with those obtained in Leghorn quay [Cincinelli et al., 2001]. Making a comparison of the EF values for the two surveyed areas, values look similar for the dissolved phase, while for the particulate phase; EF values are higher in Sacca Sessola area. This could be justified by a greater traffic of boats.

Tab. 1a - Place and data sampling of microlayer and subsurface, for the dissolved (d), and the particulate (p) phases. The enrichment factor (EF) for PCB and PAHs are also reported.

Place and data sampling (mm/dd/yyyy)	*Matrix*	*EF PCB*	*EF IPA*
Sacca Sessola 07/18/2001	microlayer (d)/subsurface (d)	1.5	1.2
	microlayer (p)/subsurface (p)	2.0	6.5
Sacca Sessola 03/21/2002	microlayer (p)/subsurface (p)	10.1	12.5
Sacca Sessola 10/15/2002	microlayer (d)/subsurface (d)	1.5	2.2
	microlayer (p)/subsurface (p)	6.3	20.7
Sacca Sessola 03/26/2003	microlayer (d)/subsurface (d)	0.7	1.4
	microlayer (p)/subsurface (p)	4.2	5.5
Sacca Sessola 06/05/2003	microlayer (d)/subsurface (d)	1.1	1.9
	microlayer (p)/subsurface (p)	3.8	11.6
Murano 07/27/2001	microlayer (d)/subsurface (d)	1.1	1.2
	microlayer (p)/subsurface (p)	2.2	3.2
Murano 04/18/2002	microlayer (d)/subsurface (d)	1.5	2.0
	microlayer (p)/subsurface (p).	3.6	6.9
Murano 12/16/2002	microlayer (d)/subsurface (d)	1.3	2.7
	microlayer (p)/subsurface (p)	7.6	4.1
Murano 03/12/2003	microlayer (d)/subsurface (d)	2.0	1.6
	microlayer (p)/subsurface (p)	34.8	4.0
Murano 06/19/2003	microlayer (d)/subsurface (d)	0.8	0.9
	microlayer (p)/subsurface (p)	0.7	0.7

d = dissolved; p = particulate

Tab. 1b - Enrichment factor (EF) for trace elements in the dissolved phase.

EF	*As*	*Pb*	*Sb*	*Al*	*Cr*
Sacca Sessola 07/18/2001	1.08	164.45	0.97	5.67	1.40
Sacca Sessola 10/15/2002	0.58	73.02	0.59	1.56	0.61
Sacca Sessola 6/05/2003	1.01	1.32	1.04	0.99	0.95
Murano 07/27/2001	1.10	1.21	1.03		0.76
Murano 04/18/2002	0.98	1.32	0.87	10.72	1.11
Murano 12/16/2002	1.38	201.28	1.89	2.27	0.78
Murano 03/12/2003	2.54	4.63	2.38	3.39	1.59
Mean Value	**1.24**	**63.89**	**1.25**	**4.10**	**1.03**

In the sampling of June 19th 2003, EF are smaller than 1. This fact is due to a no good meteorological conditions for sampling, with a homogeneous distribution of particles in the water column.

In this case is clear that organics are well enriched in the particulate phase with respect to the dissolved one. This is in a good agreement with the low depth of the Venice lagoon basin, which is subordinate to tide oscillations. The particulate matter in Venice lagoon can be introduced or by atmospheric fall-out, or by resuspension of material. Surfactants in every case can trap particles in the air-water interface, so particulate matter carry out the function of vector, as well as, of aggregator of pollutants. Making a comparison between EF values for PCBs and PAHs, for dissolved and particulate matter, PAHs are more enriched than PCBs, and this can testify the high polarity of PAHs with respect o PCBs. A contribution from atmosphere is also possible.

In figure 1 is shown the percentage contribution of the PCBs homologous families for their total concentration in the particulate matter, and in the dissolved phase, for microlayer and subsurface samples, regarding Murano area. The values are reported in Table 2.

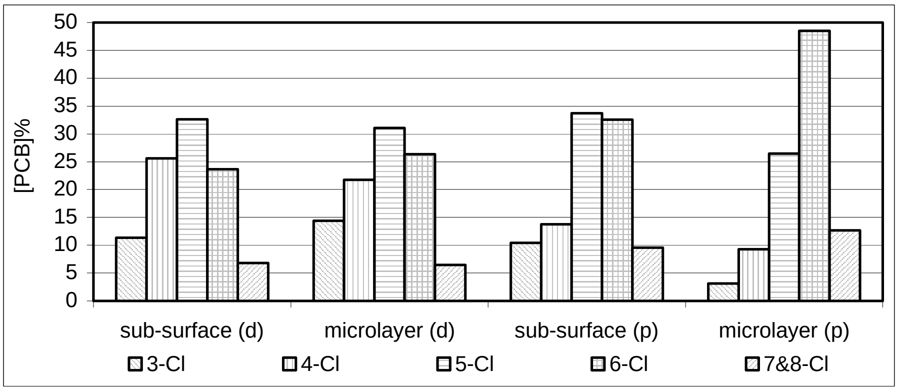

Fig. 1 - Percentage total amount for PCBs homologous families in the dissolved (d) and particulate (p) phases of microlayer and subsurface water from Murano area.

Tab. 2 - Percentage values for the PCBs homologous families in the dissolved (d) and in the particulate (p) phases of microlayer and subsurface water from Murano area.

% PCBs homologous family	subsurface (d)	microlayer (d)	subsurface (p)	Microlayer (p)
3-Cl	11	14	10	3
4-Cl	26	23	14	9
5-Cl	33	31	34	27
6-Cl	24	26	32	48
7&8-Cl	6	6	10	13

The water pattern is principally represented by the 5-Cl, but also by the 4-Cl and the 6-Cl families (even if smaller percentage). The most chlorinated families are present for values around 30%. Also particulate matter pattern is well represented by the 5-Cl family, and 6-Cl and 7&8-Cl are increased with respect to the dissolved phase and they are present for values around 42%. These values are representative both for water and for particles, and they are directly connected with the division coefficient particulate/water, which is higher for the most chlorinate families.

The microlayer pattern in the dissolved phase looks similar with respect to the subsurface, with a light increase both for 3-Cl, and for 6-Cl. It probably could be due to the atmosphere exchange (3-Cl), and the increase of colloidal material in the microlayer (6-Cl).). The most chlorinated families are present for values around 32%. On the other hand, particulate matter in microlayer has smaller quantities in 3-Cl, 4-Cl and 5-Cl, while 6-Cl and 7&8-Cl are well present, with a contribution of 61%.

Taking into account PCBs in superficial sediments (from 0 to 1 cm), it is possible to have an idea about the contribution of resuspended particles on microlayer sample. In figure 3 is reported the percentage value of PCBs homologous families (average value on 18 samples) for superficial sediments in Campalto area (near to Murano).

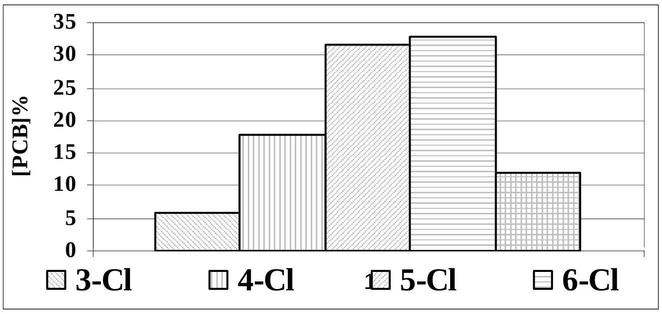

Fig. 2 - Percentage values for PCBs homologous families for superficial sediment (from 0 to 1 cm) in Campalto Area.

Values in Table 3 show in the Campalto area the most chlorinated families are present for values around 45% and let to hypothesize that surfactants has an important trapping role for particles in microlayer, so in to lengthen resuspended particles from the sediment, in surface water.

Tab. 3 - Percentage values of PCBs homologous families in sediments of Campalto and Tresse areas.

% PCBs homologous family	Campalto	Tresse
3-Cl	6	6
4-Cl	18	17
5-Cl	31	28
6-Cl	33	34
7&8-Cl	12	15

In figure 4 is shown the percentage of PCBs homologous families for microlayer (d), microlayer (p), subsurface (d), and subsurface (p) of Sacca Sessola.

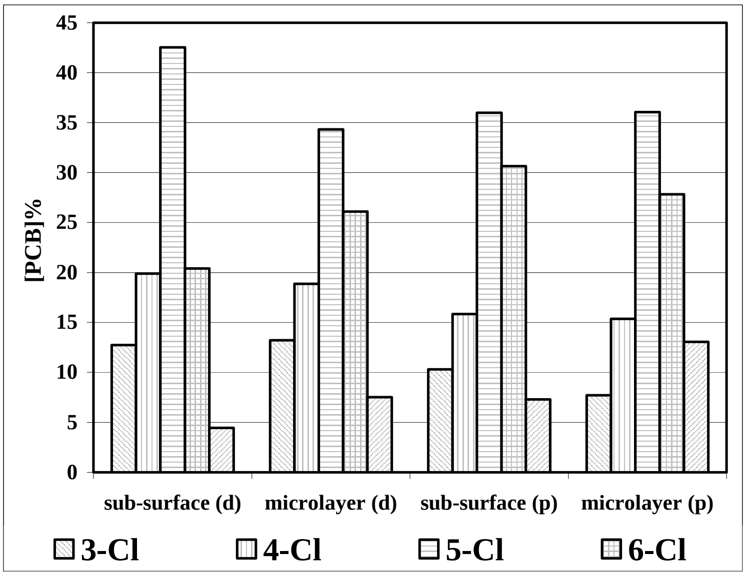

Fig. 3 - Percentage total amount for PCBs homologous families in the dissolved (d) and particulate (p) phases for Sacca Sessola area.

The pattern of water seems strongly influenced by the 5-Cl family (as in Murano), but in this case the amount is more than 40%. The less chlorinated families are present for values around 33%, and this value is low if compared with the aerosol's value. For particulate matter, the situation looks similar as the water, but 6-Cl and 7&8-Cl families are more important. Less chlorinated families are weak represented, and the picture looks similar than Murano area. The most chlorinated families are present for values around 38%. Values are reported in Table 4.

Tab. 4 - Percentage values from of PCBs homologous families (from the total concentration) for the dissolved (d) and particulate (p) phases in the Sacca Sessola area.

% PCBs homologous family	subsurface (d)	microlayer (d)	subsurface (p)	microlayer (p)
3-Cl	13	13	10	8
4-Cl	20	19	16	15
5-Cl	43	34	36	36
6-Cl	20	26	31	28
7&8-Cl	4	8	7	13

Considering the microlayer pattern, the most representative family is the 5-Cl. As in Murano area, also 6-Cl and 7&8-Cl are consistent families. The 3-Cl family is almost absent, in fact in Sacca Sessola the influence of low chlorinated families can be neglected. The hypothesis that aerosol in this area is not so influent could be considered.

The pattern of microlayer are prevalent constituted by the 5-Cl family, while in Murano the 6-Cl family is prevalent. The percentage for the most chlorinated families (6, 7&8-Cl) in microlayer (dissolved and particulate phases) is 34-41%. In figure 5 is shown the percentage contribution of the PCBs homologous families (average value on 18 samples), for superficial sediments (0-1 cm), in Tresse area. The two predominant families are: 5-Cl and 6-Cl, and the most chlorinate families have a percentage value of almost 50%. These values shown that microlayer is strongly influenced by sediment.

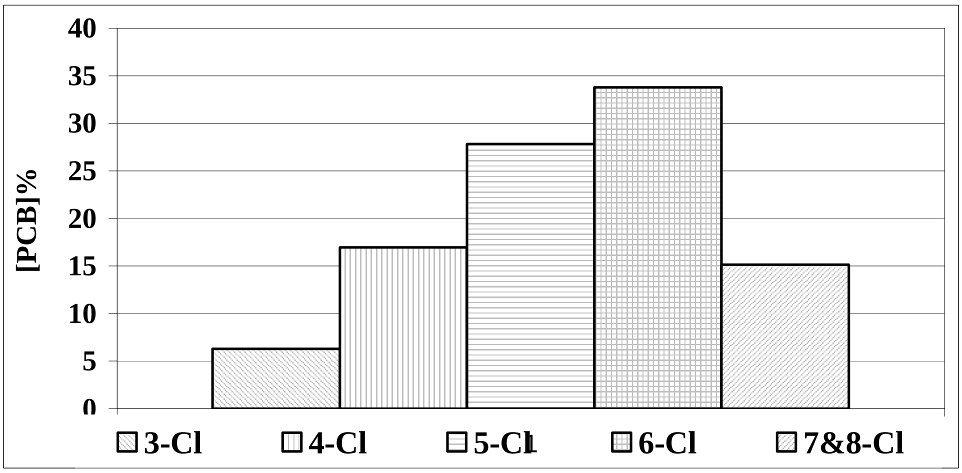

Fig. 5 - Percentage values for PCBs homologous families for superficial sediment (from 0 to 1 cm) in Tresse area.

Considering the pattern of atmospheric aerosol in this area, it is possible to extrapolate that atmosphere is no so influent in this area, both for water and for particulate matter [Gambaro et al, 2001]. The aerosol reference area for Sacca Sessola was Moranzani-Faro area [Gambaro et al., in this book]. This comparison lets to have an idea about the influence of the atmosphere from northeast and southeast quadrants with respect to the surface composition of waters in Sacca Sessola.

In figures 6 and 7 are reported the percentage contribution of the total concentration for the homologous families of PCBs in atmospheric aerosol for the Tessera-Faro e Moranzani-Faro areas respectively. The values are reported in table 5. In both figures, the prevalent homologous families are: 5-Cl and 3-Cl, the families 4-Cl, 6-Cl and 7&8-Cl are also present but their contribution is smaller than the 5-Cl and 3-Cl. Less chlorinated families are predominant in atmospheric aerosol, and this can probably due by their high volatility. The high-chlorinated families (6, 7&8-Cl) are present in a 20% average percentage.

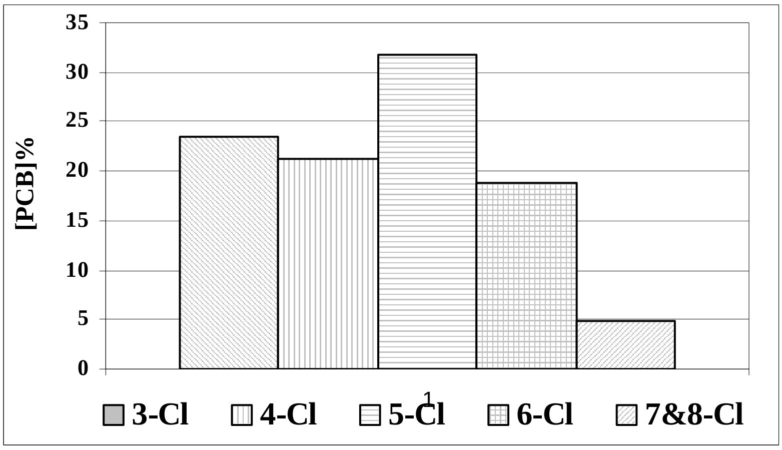

Fig. 6 - Percentage values of total concentration for PCBs homologous families in atmospheric aerosol in the Tessera-Faro area.

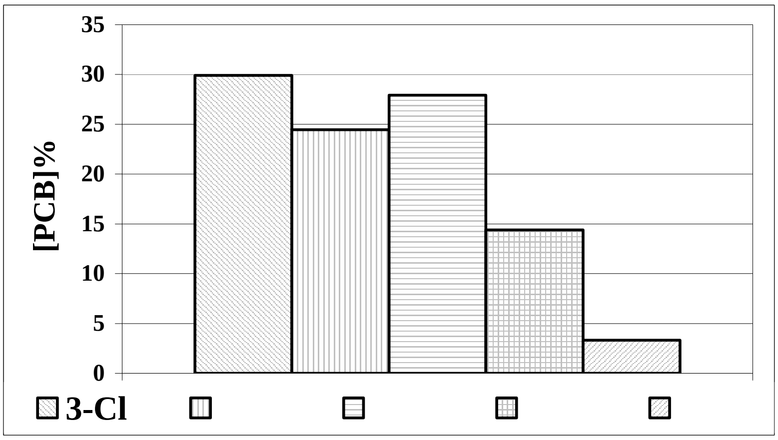

Fig. 7 - Percentage values of total concentration for PCBs homologous families in atmospheric aerosol in the Moranzani-Faro area.

Tab. 5 - Percentage values of PCBs homologous families (from the total concentration) in atmospheric aerosol.

% PCBs homologous family	*Tessera-Faro*	Moranzani-Faro
3-Cl	30	23
4-Cl	25	21
5-Cl	28	32
6-Cl	14	19
7&8-Cl	3	5

Making a comparison between the atmospheric aerosol patterns in the two considered areas, Tessera-Faro area is richer in 3-Cl, 4-Cl and 5-Cl with respect to the Moranzani-Faro area.

Instead, for Murano area the comparison of PCBs have been performed with percentage average values got from the Tessera-Faro areas (north-east and south-east quadrants). In aerosol, both for Tessera-Faro area, and for Moranzani-Faro area, the less chlorinated families are prevalent because of their higher volatility with respect to more chlorinated one. More details are reported by [Gambaro et al. in this book].

Trace elements

Concentrations of Al, As, Cr, Pb and Sb are investigated in microlayer (ML) and subsurface water (SSW) samples from the two considered areas (Sacca Sessola and Murano) to evaluate the different sources of these elements, which can be a potential risk for human health.

Elements like As, Pb and Sb are environmentally significant because of their toxicity. The primary source of these elements in an urban environment (except industrial source) is the motor vehicle, including exhaust emission, fluid leakage, tire and body wear [Sutherlan and Tolosa, 2000].

Lead concentration shows a considerable high value, as expected, in ML in comparison with value for SSW; this is in agreement with the characteristics of this element, which is known as important urban pollutant.

Antimony usually receives much less attention then Pb despite its toxicity and carcinogenic properties [van Velzen at al, 1998]. A close association of traffic volumes with Sb content on road-deposited sediment is documented [Dietl et al, 1996] in particular major source of Sb derive from asbestos-free brake linings. We have found higher values in ML samples then in SSW confirming the possible urban source of this element. For few samples we have found quite the same value for ML and SSW. This fact may be caused from the different time of sample acquisition: to collect microlayer sample requires much more time then to collect subsurface water. This different time can lead to a greater mixing of different kind of water for ML with respect to SSW.

To consider As concentration in ML and SSW it is to take in account that 60% of the anthropogenic emission of As can be related to only two sources: coal combustion and Cu-smelting. Other important sources of As are the use of herbicides, glass production and waste incineration [Matschullat, 2000]. By comparison of ML and SSW data we can highlight and enrichment in ML sample especially in Murano (the “glass island”) samples.

We have also analysed two other elements: Al and Cr.

For Al the high level of metal content in ML with respect to SSW may be related to atmospheric input of crustal particles, while for Cr, that shows a higher value in SSW then in ML, we can relate its concentration with lagoon sediment composition; the possible source of Cr in lagoon water is the re-suspension from bottom sediment.

Comparison between microlayer and subsurface water for trace element concentrations are reported in figure 8.

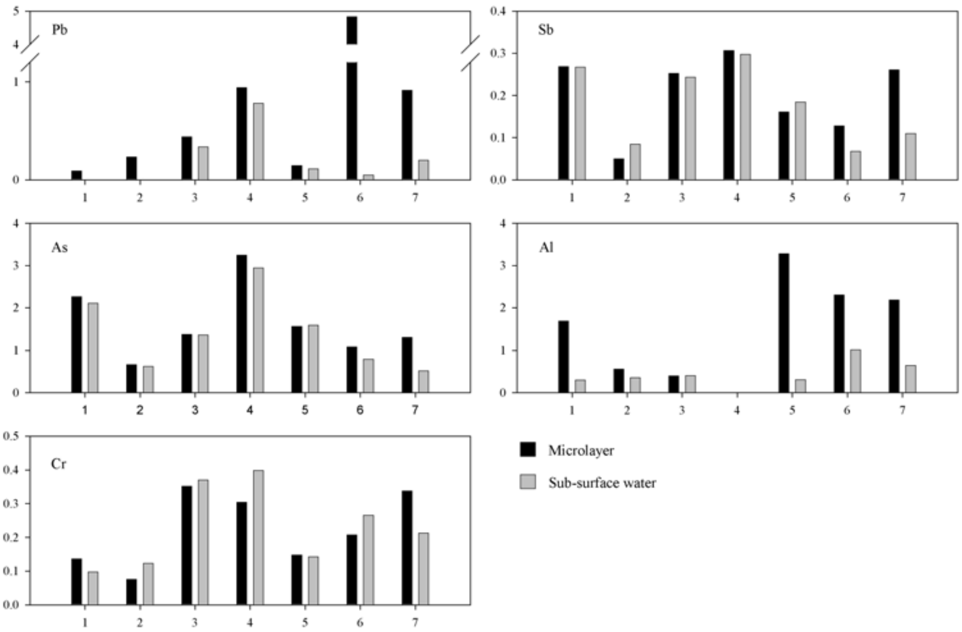

Fig. 8 - Comparison between microlayer and subsurface water. Trace element concentrations are in ppb.

4. Concluding remarks

On the base of considerations made for microlayer and subsurface data, as well as, their connection with sediment and atmospheric aerosol data, is possible to remark the following affirmations:

1) Microlayer is strongly influenced by sediments, in particular by particle ≤ of 2.5 μm [Stortini et al., 2001]. It is probably to hypothesize that surfactants play an important role in the lengthening of the period of permanence of fine particles;
2) The contribution of atmospheric aerosol for organic compounds is no so influent in microlayer as sediment particle resuspended are. In fact the less chlorinated families are no representative, making a comparison between atmospheric aerosol data and microlayer data.
   On the other hand, for trace elements aerosol contribution may be more influent then sediment particle resuspended one, depending from considered element.
3) The pattern of particulate matter in microlayer, as well as, in subsurface looks similar with respect to pattern of superficial sediments, both for Sacca Sessola, and for Murano;
4) Particles can be a useful surface for pollutants adsorbing, because of their vector and aggregator roles in Venice Lagoon basin water column.

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BENTHIC FLUXES EVALUATION OF PCBS AND PAHS BY MEANS OF EXPERIMENTS WITH BENTICH CHAMBERS

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Riassunto

L'utilizzo di sistemi non perturbabili per lo studio dei flussi di microinquinanti, rappresenta uno dei mezzi più utili al fine di meglio comprendere le dinamiche e i processi, che guidano il loro passaggio attraverso le varie fasi. Il proseguimento degli studi della mobilità dei microinquinanti con l'uso di camere bentiche (sistema non perturbabile) ha messo in evidenza come eventi di ipoossigenazione e/o variazione di pH, possano portare a un flusso di particellato e microinquinanti verso il sedimento. Allo stesso modo ha messo in evidenza che la risospensione di materiale particellato sia un evento che regola, in qualche modo, la rimessa in circolo di microinquinanti ad esso associato. Sulla base delle diversità che caratterizzano ciascuno dei siti esaminati, si evince che sotto regime di ipossigenazione , la fase colloidale del corpo acquoso mostra un comportamento diverso con il passare del tempo, sia nella sua precipitazione verso i sedimenti, sia nella sua risospensione verso la colonna d'acqua. Valutazioni per i Poli Cloro Bifenili (PCB) e per gli Idrocarburi Policiclici Aromatici (IPA), sono riportati per l'illustrazione delle dinamiche di cui sopra. Altri parametri oggetto di osservazione sono anche riportati.

Abstract

The utilization of not perturbing systems for the study of the micropolluttants flows, represents one of the more useful tools for better comprise the dynamics and the processes, that govern their passage through the phases. The progress for the studies of micropollutants mobility using bentich chambers (not perturbing systems) has evidenced that hypo-oxygenation event and/or variation of pH, can carry particulate matter flow and micropollutants towards the sediment. In the same way, bentich chambers experiments have put in evidence that the resuspensione of particulate matter is an event that regulate the remittance in circle of micropollutants associated to it. On the base of the diversities that characterize everyone of the examined areas, hypo-oxygenation has different influence for colloidal material, both for it precipitation, and for it resuspension in the water body. Evaluations with Polychlorinated Biphenyls (PCBs), and for Polycyclic Aromatic Hydrocarbons (PAHs) pointed out the concepts here expressed. Other parameters are reported.

1. Introduction

In water-sediment interface take place a continuous exchange of organic compounds, nutrients, and metals. The sink's role of sediments with respect to lipophilic pollutants is well reported by literature [Hong H., 1995; Frignani M., 2001]. However, natural dynamic events as resuspension, bioturbation, hypo-oxygenation, can affect remobilisation and transport of all this compound associated to sediments, with effects on the whole ecosystem [Dannenberg D. et al., 1997]. In addition, the role of particulate matter (PM) in water column is not negligible for organic pollutants flux in water-sediment direction.

Concentration gradients between the pore water and the water column can promote fluxes of organics across the water-sediment interface. Changes of pH can induce the coagulation of dissolved organic material or his aggregation with the pre-existing particles, leading to sedimentation. These processes or changes are common in a transitional environment such as the Venice Lagoon is. The use of an *in situ* monitoring tool, based on a non-perturbing system, appears one of the most appropriated methods for better understanding fluxes across water-sediment interface. This approach let not only to make an evaluation about fluxes, but also to overcome the low concentrations to which such organics have in waters [Al-Rasheed R. e Cardin D.J., 2003].

The aim of the study here reported is to evaluate the exchange of organic pollutants at water-sediment interface in some areas of Venice Lagoon. Benthic chambers has been used for fluxes evaluation, both for Polychlorinated Biphenyls (PCBs), and for Polycyclic Aromatic Hydrocarbons (PAHs). In this stage of the research, we report new results about benthic chambers, and new behavioural hypotheses. A first highlight about this monitoring project has been reported in the proceedings of the first CORILA meeting 2002 results [Moret et al., 2001].

2. *Experimental*

Two benthic chambers experiments were carried out in two different areas of the Venice Lagoon (Tresse and Campalto), as reported elsewhere (Chapman et al., this volume). The two experiments were carried out in two different periods of the year: in autumn 2002 (Tresse), and in spring 2003 (Campalto). The experiment consisted of the isolation of a portion of water and its respectively underlying sediment, from the surrounding environment, using 6 benthic chambers. This isolation produced a decreasing trend in dissolved oxygen (DO), showing that an hypo-oxygenic state has been reached after about 15 hours. Water sampling has been performed at the beginning of the experiment, and at different time interval up to 57-60 hours. Sediment cores were collected at the beginning of the experiments and after 33-36 and 57-60 hours after the evacuation of the chambers in the area covered by the chambers.

For each chamber 11 L of water were collected, and immediately filtered in the laboratory, using a quartz filter (0,7 μm). The dissolved and particulate phases were extracted respectively by a continuous liquid-liquid extraction, and by an ultrasonic bath and were analysed by GC-MS, as reported elsewhere [Hermans, 1992; Grimalt, 1984]. Persistent organic pollutants were extracted and purified using a Sohxlet extractor as reported elsewhere [Letellier, 1999] and determined by the procedure used for the dissolved phase.

3. *Results and discussion*

During the experiments of Tresse and Campalto has been measured the following parameters: tidal level, salinity, dissolved oxygen (DO), redox potential, temperature, and pH. The values are reported in table 1. A decrease of pH and DO was observed as a consequence of the decomposition of decomposition of organic matter due to aerobic micro-organism. Tidal variation level is not connected with the trends of parameters and organics in the benthic chamber. This fact exclude any exchange between the internal part of the chamber and the external one.

Tab. 1 - Values of tidal level, salinity, dissolved oxygen (concentration and percentage), redox potential, temperature, and pH for Tresse and Campalto experiments.

Tresse (start 10:00-May 28th 2002 _ end 22:00-May 30th 2002)							
t (hour)	Tidal level (cm)	Salinity (psu)	O_2 ($mg.l^{-1}$)	O_2 %	Eh (mV)	Temperature (°C)	pH
0	160	29.15	4.77	60.0	257	18.1	8.02
9	106	29.32	3.28	42.0	197	18.2	7.90
21	152	29.45	2.24	27.1	141	16.3	7.79
33	118	29.45	1.87	22.5	128	18.2	7.71
45	146	29.37	1.50	18.7	127	16.7	7.65
57	120	29.57	1.07	12.8	146	17.8	7.60
Campalto (start 10:00-May 6th 2003 _ end 22:00-May 8th 2003)							
t (hour)	Tidal level (cm)	Salinity (psu)	O_2 ($mg.l^{-1}$)	O_2 %	Eh (mV)	Temperature (°C)	pH
0	75	28.22	7.3	85.6	112	22.4	7.81
9	98	28.26	3.7	52.0	100	23.9	7.50
20	83	28.23	2.3	29.8	188	21.9	7.33
32	113	28.70	2.9	40.6	117	24.6	7.32
36	110	28.87	2.9	39.2	157	23.6	7.32
48	70	28.93	2.8	34.5	117	23.2	7.28
60	115	28.75	3.1	43.1	232	24.2	7.37

3.1. Tresse experiment (autumn 2002)

<u>PCBs</u>

Values of total concentration of PCBs ($pg.l^{-1}$) in the dissolved phase, as well as, DOC values ($mol.l^{-1}$) versus time, give a progressive decreasing trend during the whole time of the experiment. In literature is evidenced the affinity between PCBs in the dissolved phase and DOC [Evans 1998, Jin-Hsiang 1995]. From this result, it is possible to hypothesize a transfer of PCBs from the dissolved phase to the particulate phase, or to the sediment. In figure 1 is reported the plot of PCBs and DOC versus time.

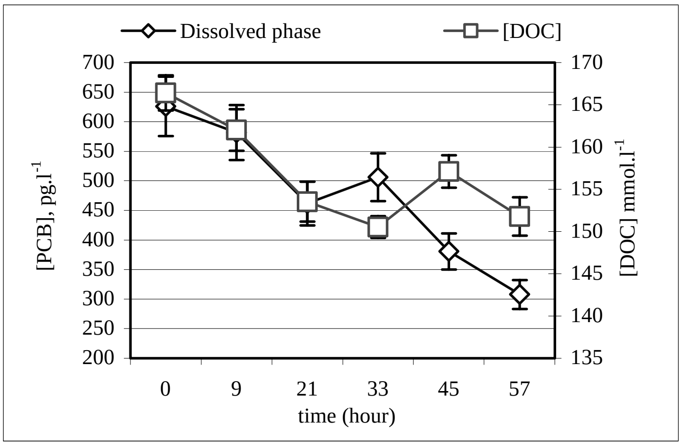


Fig. 1 - PCBs total concentration (pg.l^{-1}) in the dissolved phase and DOC (mol.l^{-1}) in the Tresse experiment.

PCBs in particulate phase, expressed in pg.l^{-1}, shows a variable trend at the beginning of the experiment and followed by a gradual decreasing up to the end of the experiment (figure 2). An increment for the PCBs in pg.l^{-1} was observed around the 21st hour. The particulate matter (PM) and particulate organic matter (POC) show an evident increase at the beginning of the experiment reaching the maximum after 9-21 hours (figure 3). This fact could be explained by the following hypotheses: a) the resuspension of particles due to a physical phenomenon or bioturabtion; b) the formation of fresh particles due to the aggregation of colloids present in the closed area.

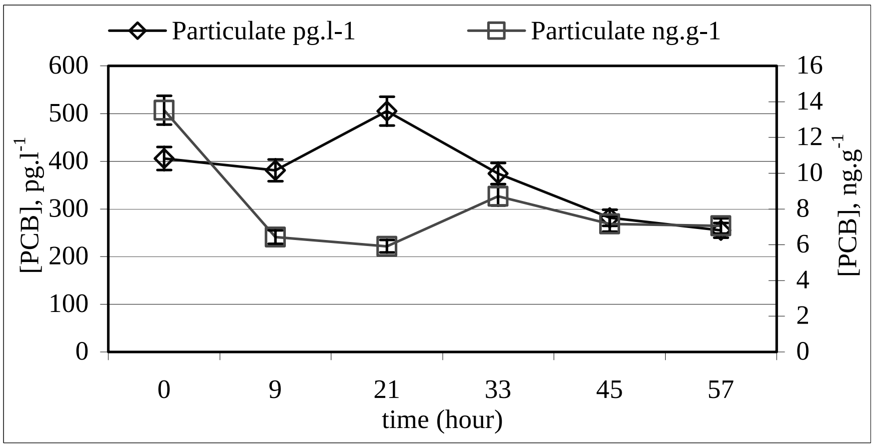


Fig. 2 - PCBs concentration expressed in pg.l^{-1} and PCBs ng.l^{-1} in the Tresse experiment.

An hypothetical increase of particulate PCBs deriving from resuspension of sediment must be excluded, because that must produce an increase of total PCBs content, while the results of total concentration of PCBs (particulate + dissolved) did not show any increase (figure 4). The PCBs concentration in particulate matter, expressed as $ng.g^{-1}$, corresponding the increase of PM and POC shows a decrease, pointing out a change of particulate composition during the experiment. Therefore, we aspect that increase of PM take place for a coagulation of humic substances (represents ≥50 % of DOC), as a consequence of pH changing [Al-Rasheed e Cradin, 2003].

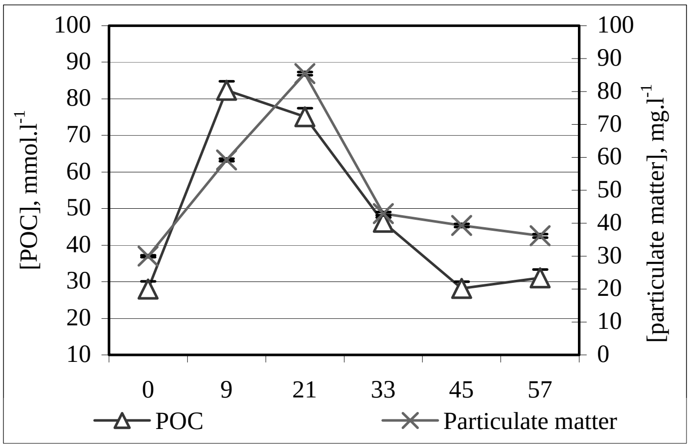


Fig. 3 - Concentration POC and particulate matter in water in the Tresse experiment.

PCBs concentrations in dissolved phase and in particulate one have the same order of magnitude, the criteria to define dissolved and particulate phase is based on a filtration operation, which is performed with a 0.7 μm quartz fibre membrane. The dissolved phase are also composed of particles and colloids smaller than 0.7 μm, which had adsorbed or bounded PCBs on them. Organic carbon concentration supports this hypothesis. In figure 4 it is reported total PCBs concentration (particulate + dissolved phases).

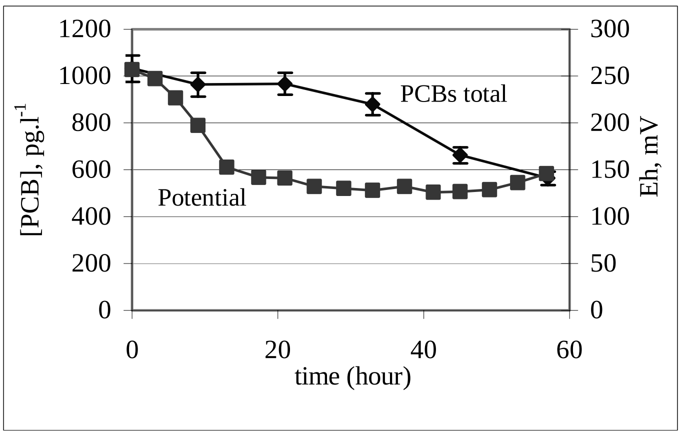


Fig. 4 - Total PCBs concentration in water (particulate + dissolved phases) in the Tresse experiment.

In the dissolved phase, the less chlorinated families are the dominant PCBs homologous. The 5-Cl and 6-Cl are the PCBs dominant families in the particulate phase and sediment. The PCBs concentration in superficial sediments, inner and external of the benthic chambers, was homogeneous (figure 5). In consequence of this, we can assert that changes inside benthic chamber can not derive from differences in the surface sediment composition.

The concentration and pattern of PCBs in sediments are similar to the values of particulate matter. This support the hypothesis that the resuspension of sediments is an influent element for the composition of particulate matter in the lagoon water. Fluxes trend for total PCBs (dissolved + particulate) gives a negative flux.

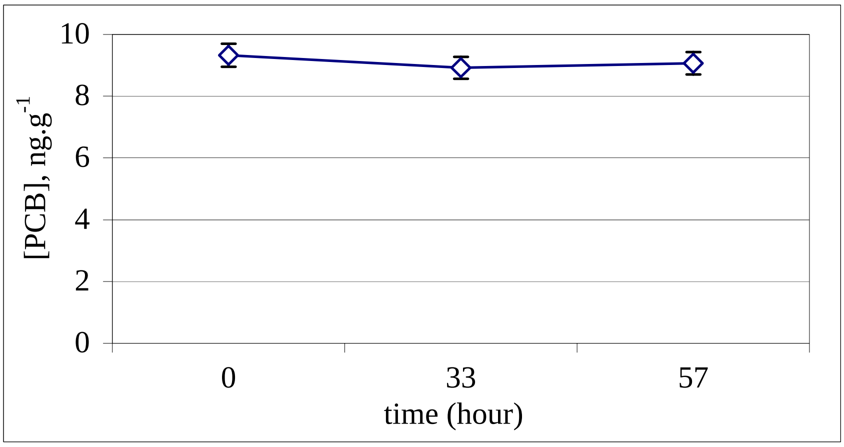


Fig. 5 - Concentration of PCBs in sediments during the benthic chambers experiment in the Tresse area.

PAHs

The PAHs concentration in dissolved phase decrease following the DOC concentration (figure 6). In figures 7A e 7B are reported the particulate PAHs concentrations, in $ng.l^{-1}$ and in $ng.g^{-1}$ respectively.

The PAHs, analogously to PCBs, show a consistent initial increase reaching the maximum around the 21st hour and strongly correlated to the particulate matter in water. By comparison the initial and final concentration, both the dissolved and the particulate PAHs have a decreasing trend. The average PAHs fluxes are negative, and the dissolved phase fluxes approach zero at the end of the experiment.

Concentration of IPA in superficial sediments collected at t_0 to $t_{final\ hour}$ present a difference that can be associated at a non-homogeneous distribution (figure 8). Comparable difference of concentrations were observed in nine cores collected before settling the chambers. In fact, for samples got during the 33rd and 57th hours it is possible to observe an increase and a decrease respectively of PAHs concentration. Our hypothesis is also corroborate by the fact that, if changes of sediment composition were due to processes becoming inside the chambers, we aspect variation of concentration in water much more elevated than 20%.

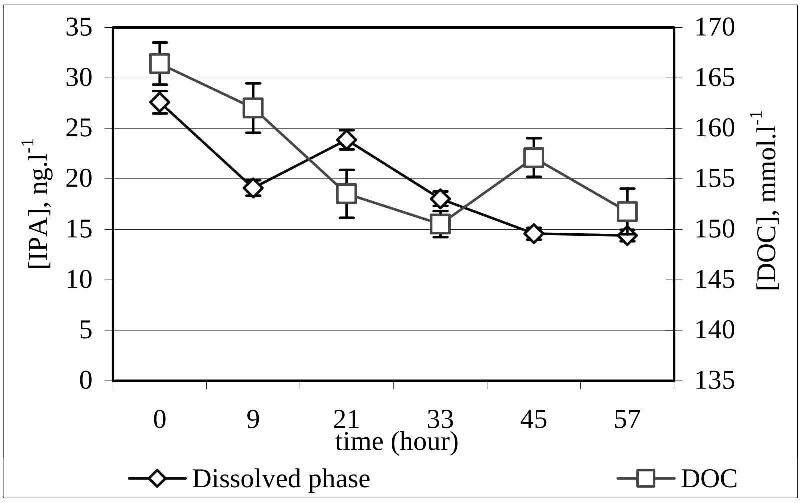
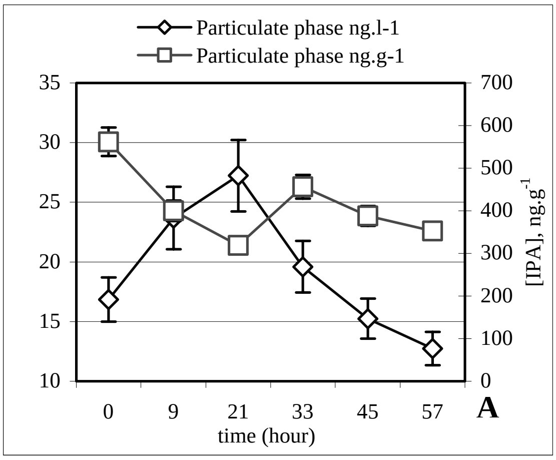


Fig. 6 - Dissolved PAHs concentration and DOC in the Tresse area experiment.



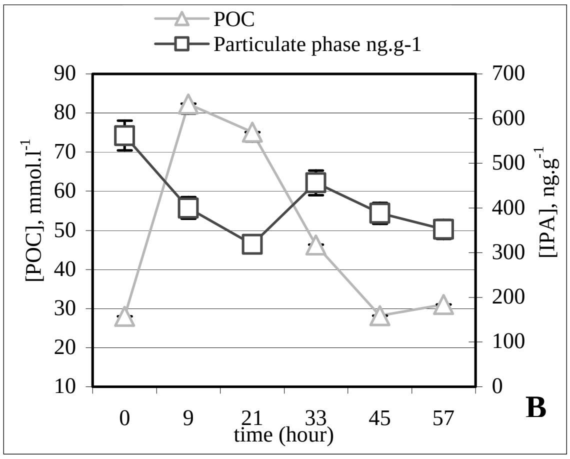


Fig. 7 - Trend of PAHs concentration, in the Tresse area, in the particulate matter in $ng.l^{-1}$, and in $ng.g^{-1}$ (A), and concentration of POC in $mmol.l^{-1}$ and particulate matter PAHs in $ng.g^{-1}$ (B).

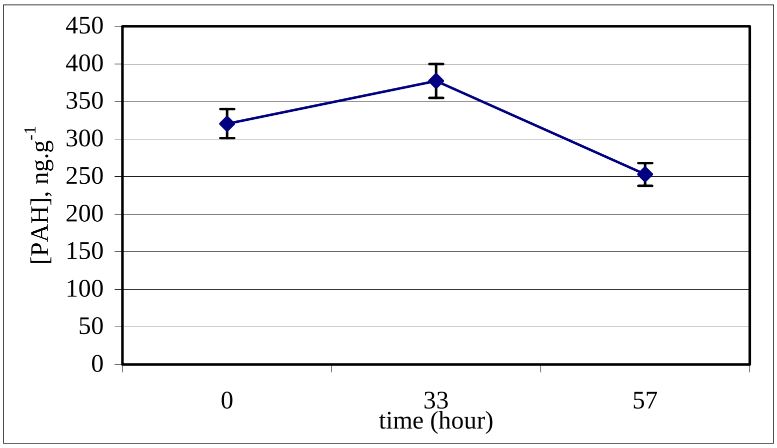


Fig. 8 - PAHs concentration trend in superficial sediment the Tresse area.

3.2. Campalto experiment (spring 2003)

PCBs

Data of PCBs concentration in dissolved and particulate phases are reported in figure 9. Both the phases show a final concentration decreased of about 40-50% respect the initial values. After 48 hours it is possible to observe a light increment in the dissolved phase, while, particulate PCB increments were observed at the 24th and 48th hour. The first 12 hours were characterized by a decrease of concentration for both the phases while the particulate composition (ng g^{-1}) did not changes (figure 10). Therefore, the PCBs decrease, for both the phases, derived from a flux from water to sediment coupled with an adsorption process of dissolved components on particles.

Between the 12th to the 24th hour the concentration of PCBs in the dissolved phase decreased of 25%, while the concentration in particulate phase increased of 12%, the concentration of PCBs in the particulate decreased from about 6 to less than 4 pg g^{-1}. In this period, the pH value reaches the minimum of 7.3. Therefore, we can make the same hypothesis made to explain the results obtained in the Tresse experiment, a pH decreasing favors the coagulation of macromolecules and biopolymers [Miano and Senesi, 1992; Campanella et al., 1993]. Coagulation process lets an increase in the particulate matter amount and a contemporary PCBs adsorption; but, if the adsorption is not efficient, that change the mean particulate composition, decreasing the PCBs concentration in the particulate. By the mass balance, between the 12th to the 24th hour, we estimated a decreasing of 11. ng in the dissolved phase, and an increase of 5.8 ng in the particulate phase, corresponding to a flux of – 255 fg..cm^{-2} h^{-1}, and 132 fg.cm^{-2} h^{-1} respectively. Therefore, as emphasized also from the trend in the total PCBs concentration (figure 11), it is possible to hypothesize that, contemporary to the transfer from the dissolved phase to the particulate, there is a gross PCBs flux from the dissolved phase to the sediment.

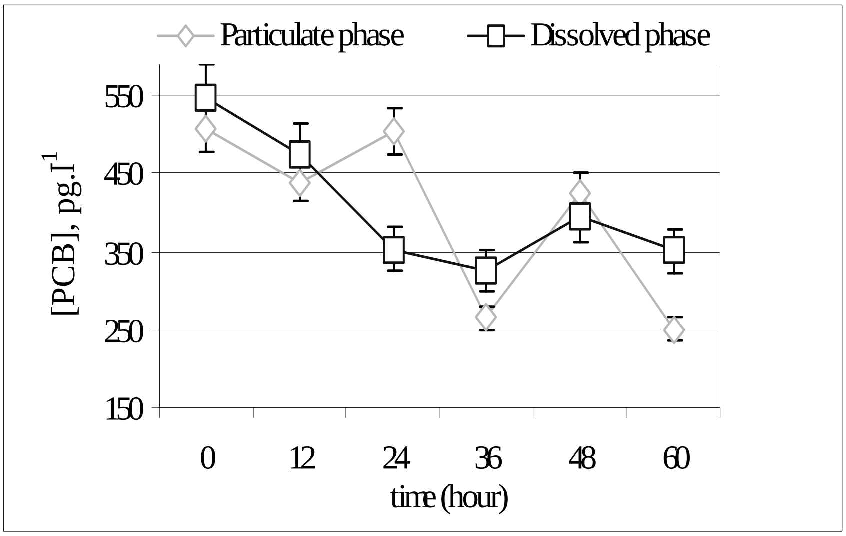


Fig. 9 - Trend of PCBs in dissolved and particulate phases in the Campalto benthic experiment.

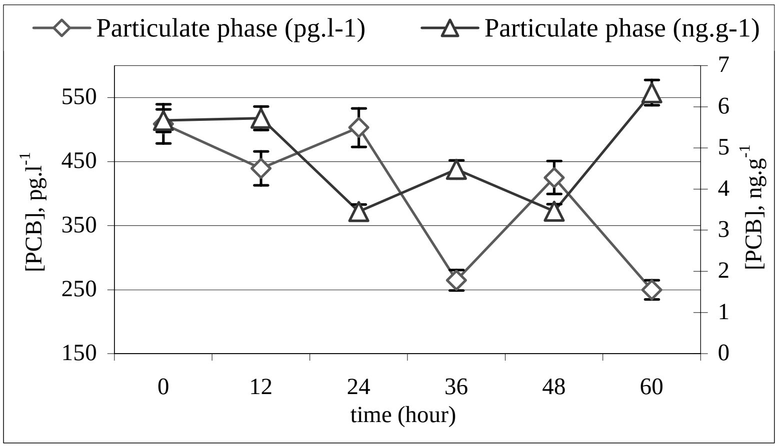


Fig. 10 - PCBs concentration in the particulate phase in pg.l^{-1} and ng.g^{-1} during the Campalto experiment.

At the 60th hour, the PCBs concentration in the particulate matter (ng.g^{-1}) increase. This fact can be due to a sedimentation of coarse particles, let to the fine one, that presenting high surface are able for more efficient adsorption of PCBs (surface/volume rate).

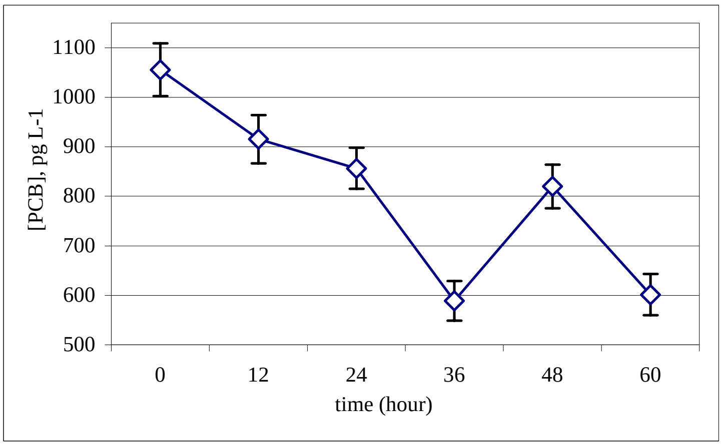


Fig. 11 - Total PCBs concentration (dissolved + particle) in the Campalto experiment.

During the benthic experiment changes in the PCBs pattern were observed, both for dissolved phase and the particulate. Difference of pattern were observed by comparison of particulate and sediment. In consequence of this, it is possible to assume that many processes –and not only sediment resuspension- have an influence on the particulate composition.

Tab. 2 - PCBs concentration in sediments of Venice Lagoon (Moret et al., 1999).

Homologous	Marghera		Dese		Venezia		S.Sessola		Chioggia	
N. Cl	*ng g^{-1}*	*%*	*ng g^{-1}*	*%*	*ng g^{-1}*	*%*	*ng g^{-1}*	*%*	*ng g^{-1}*	*%*
3	3,33	16	4,11	27	4,61	5	2,31	21	3,81	38
4	2,38	12	2,27	15	11,1	12	1,44	13	1,33	13
5	4,94	24	4,76	31	41,2	43	3,64	32	1,69	17
6	6,13	30	3,22	21	29,1	30	2,82	25	2,2	22
7	2,54	12	0,82	5	7,39	8	0,79	7	0,79	8
8	1,08	5	0,17	1	2,05	2	0,22	2	0,21	2

By comparison the PCBs composition of both experiments, a difference of pattern is observed. In particular, the percentage of less chlorinated PCBs in the Campalto area was higher than in the Tresse area. Because less halogen compounds are more mobile than the chlorine compounds, we can hypothesize that Campalto area is farer from the source than Tresse (the industrial area). Data from Moret et al. (1999) shown that PCBs composition change in relation to the distance from the industrial area. In table 2 are reported values along a transect from Marghera to Chioggia, it was possible to distinguish a prevalence of 6-Cl homologous family in Marghera, while in Chioggia the 3-Cl homologous family was the more important.

PAHs

In figures 12A and 12B are shown PAHs trend on the dissolved and the particulate phases as a function of time.

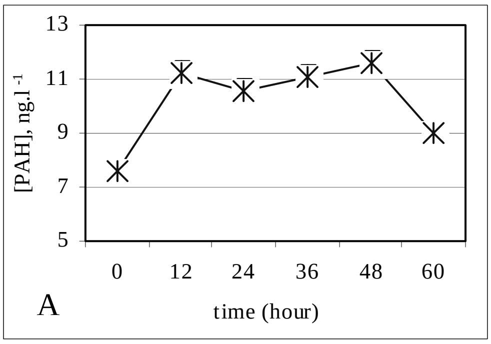


Fig. 12 A - Dissolved PAHs e vs. time, phase respectively

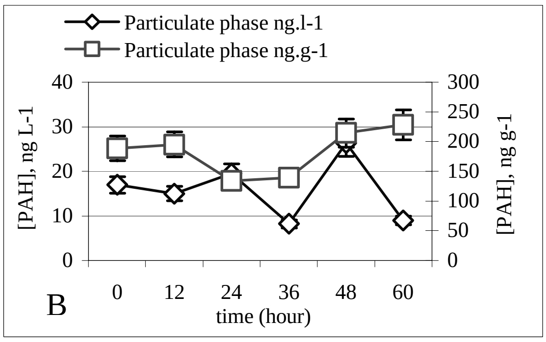


Fig. 12 B - Particulate (B) PAHs e vs. time, phase respectively

During the first 12 hours there is an increase of PAHs concentration in the dissolved phase, then a constant trend, and finally a decreasing in the last 12 hours. Just in the first 12 hours, PAHs concentration in the dissolved phase increase, while in the particulate phase is almost constant. In this case, a release from sediment, or from pore-water could be considered. Resuspension is not considered in this case, because of a sediment mass very compact and no evidence are noticeable from particulate matter concentration.. In consequence of these considerations, a PAHs increase at the beginning of the experiment could be explained by a pumping effect on pore waters during the benthic chambers settling [Turetta et al., 2003]. At the 24th hour it is possible to hypothesize a concentration decreasing of PAHs in the particulate phase ($ng.g^{-1}$) as the result of the coagulation of colloidal macromolecular organic matter, but colloids didn't have any nucleation role for dissolved PAHs. In fact, the decreasing of PAHs in the dissolved phase can be consider within the experimental error range. At the 36th hour a decreasing of the particulate matter doesn't correspond to a variation of composition in the particulate phase ($ng.g^{-1}$), as well as, in the dissolved one. We can affirm that the only carrier for PAHs is the sedimentation process.

At the 48th hour, there is an increase of particulate matter in water, probably due to a resuspension of particulate matter deposited in the chamber's walls during the first part of the experiment. This hypothesis can explain the comparable particulate composition with respect to the beginning of the experiment. In this way, it is possible to have not only a particle composition change, but also an increase of concentration of the particulate PAHs. Not difference in the dissolved phase were detected, and the remobilization of particles didn't influence phase changes.

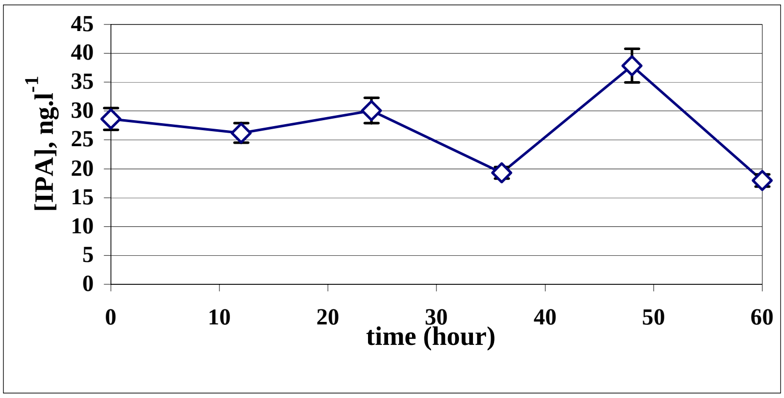


Fig. 13 - Trend of total PAHs concentration vs. elapsed time.

At the end of the experiment, the particulate composition ($ng.g^{-1}$) was constant notwithstanding a decreasing of particulate material, while PAHs concentration in the dissolved phase was decreasing. In figure 13 is reported the total PAHs concentration, as a result of the sum of concentration of dissolved and particulate phases. The average flux during the entire experiment was –22 $pg.cm^{-2}\ h^{-1}$. During the first hours of the experiment the concentration trend seems to be constant, later, the concentration was affected by the particulate matter in water. From the beginning up to the end of the experiment, the concentration decreased of 30% Also in the Campalto area the PAH concentration in surface sediments was not homogeneous, the mean concentration was 440 ng g^{-1}, about 30% higher than in Tresse area.

4 Concluding remarks

The results emphasize that the ratio of PCBs concentration in dissolved phase (particles < 0.7 μm, colloids and free organics) and in particulate form was 1, both in the Tresse and Campalto areas. Concentration in the particulate phase had the same order of magnitude of superficial sediments. In particular, comparable values were obtained for both the components in the Tresse area, while the particulate phase assumed a concentration almost double with respect to superficial sediments for the Campalto area. The likeness of the pattern for the homologous families let to assume that the particulate matter in lagoon water is originated principally from sediment resuspension. Moreover the superficial sediment give a homogeneous distribution for PCBs in both sites (Campalto looks a little more variable). The intense traffic of boats and peach of benthic organisms in the Tresse site, produce a mainly sediment mixing and maintaining in suspension. That give, in absence of an high energy hydrodinamic character, an homogeneity in the sediment distribution, as also confirmed by the particulate and superficial sediment composition.

In the Campalto area, the sediment has an higher PCBs concentration than Tresse. This can be justify by a reduced resuspension that doesn't influence the exchange of this organics between particulate matter and the dissolved phase, as well as, a higher concentration of organic carbon with respect to the Tresse area.

Literature data of total PCBs in water relative to the central Venice Lagoon area, got from 1992 to 1994, reported concentrations of 5-6 ng.l^{-1} [Fanelli et al., 2000]. Concentration determined during previous 2001 experiments were ranging between 2.0 and 2.8 ng.l^{-1}. Similar concentrations were detected in samples collected between 2000 and 2001 in the "*Canale della Giudecca*" (Moret, personal communication). Results relative to the 2002 and 2003 experiments show concentrations of about 1 ng.g^{-1}. These data pointed out a decreasing trend on the PCBs input in the last 10 years. Must be noted, since the ends of 80ties the plants for industrial sewage treatment was beginning to function.

If the above reported hypothesis is true, must be emphasized that an increased resuspension activity can produce the preferential mobilization of the less chlorinated PCBs homologous, due to the lower affinity of the less halogenated species for the particulate matter, as confirmed by the 2002 experiment. Therefore, from the industrial area to the Venice lagoon boundary areas, we aspect a decrease in the relative importance of the most chlorinate homologous in the pattern of PCBs in the sediments, as reported by Moret et al. (1999). In our case, Tresse has the higher percentage of chlorinate families respect to Campalto.

The decrease of oxygen and pH can induce to a negative flux of organic pollutants from the dissolved phase by sedimentation (colloidal phase), due to a coagulation of humic substances. On the other hand, transfer of organic pollutants from sediment to water are due principally by the sediment resuspension effect (physical effect).

The PAHs show a weak transfer from water phase to sediment By a mechanism similar that can control the PCBs flux. The PAHs distribution in the sediment is less homogeneous that PCBs, in particular in the Campalto area.

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SEDIMENTS AS A SOURCE OF METALS AND COMPLEXING LIGANDS, A STUDY IN THE VENICE LAGOON, ITALY

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Riassunto

In due siti, scelti per la elevata concentrazione di metalli nei sedimenti, sono stati condotti esperimenti per la stima dei flussi bentici di Cd, Cu, Mn e Zn. Il contenuto di metalli disciolti, la loro speciazione e il contenuto di tioli (leganti specifici del rame) sono stati determinati in campioni di acqua prelevati da camere del volume di 90 L.

La concentrazione di tutti i metalli mostrava un aumento iniziale a causa della risospenzione dei sedimenti durante la posa delle camere che era seguito da un flusso negativo. Questo era particolarmente evidente per il rame durante l'esperimento eseguito nell'ottobre 2002 nell'area di Tresse. La concentrazione media del cadmio disciolto era simile in entrambi i siti (0.59 e 0.62 nmoli/L rispettivamente per Campalto e per Tresse), ma, alla fine degli esperimenti la concentrazione determinata a Campalto raggiungeva un valore di 9 nmoli/L mentre a Tresse raggiungeva un valore di 1.2 nmoli/L. Nonostante questa differenza, per entrambi gli esperimenti era evidente, alla fine, un flusso positivo. Il contenuto di Zn e Mn era notevolmente differente nei due siti (la concentrazione media a Tresse era tripla rispetto a quella rilevata a Campalto). La concentrazione di rame mostrava un iniziale amento seguito da un successivo flusso negativo, la concentrazione diventava quindi costante fino alla fine dell'esperimento, la concentrazione media di rame disciolto, dopo 20 ore dall'inizio, era 20 nmoli/L in entrambi i siti. La concentrazione di tioli durante l'esperimento mostrava una generale tendenza a crescere.

Nonostante le differenze di concentrazione rilevate tra i due siti, i flussi bentici di Cd, Zn, Mn e Cu disciolti mostrano che i metalli presenti nei sedimenti risultano sufficientemente mobili da poter considerare il sedimento una sorgente potenziale di elementi in traccia, specialmente se vengono indotte perturbazione.

Abstract

Experiments were carried out to estimate the benthic fluxes of Cd, Cu, Mn, and Zn. at two sites chosen for their known high sediment concentrations (Canale delle Tresse and Campalto). The dissolved metal concentration and speciation were determined in water samples collected from 90L chambers placed on the sediments. Thiol concentration was also determined as a specific copper-complexing ligand.

The dissolved concentration for all the metals showed an initial increase deriving from the sediment resuspension during the chamber settling, that was followed from a negative flux. This trend was particularly evident for copper during the experiment carried out in October 2002 in the Tresse area. The mean dissolved Cd concentration was similar for both the sites (0.59 and 0.62 nmol/L for Campalto and Tresse respectively), but at the end of the experiment the concentration at Campalto reached a value of 9 nM while in the Tresse area was 1.2 nM. Both sites had a positive Cd flux at the end of the experiment. Large differences in dissolved Zn and Mn were evident between the two sites (the mean value in the Tresse area was three times higher than at Campalto). The Cu concentration showed an initial increase followed by a negative flux, the concentration gradually becoming practically constant near the end of the experiment; after about 20 hours the mean dissolved Cu concentration was 20 nmol/L at both sites. The thiol concentration showed a generally increase during the experiment.

Despite the concentration differences at the two study sites, the benthic flux of dissolved Cd, Zn, Mn and Cu show that the metals in the sediment may be considered sufficient mobile to be considered as a potential source of metals to the water column, especially when initiated by sediment perturbation.

1. Introduction

It has been shown from previous studies that sediments of some areas in the central basin of the Lagoon of Venice have significant problems with pollution in particular from historical deposits [Frignani et al., 1997; Donazzolo et al., 1984]. In an ever-changing environment like the Lagoon the remobilisation of contaminants from sediments can be responsible for secondary contamination. This is important in relation with the planned realization of a mobile barrier which is expected for the next decade. For example, the lagoon undergoes intense microalgal and phytoplankton production which has been associated with mobilisation of Cu, causing the Cu to become effectively remineralised and kept out of the sediments [Martin et al., 1994]. It is still unclear to what extent this mobilisation occurs in the Venice Lagoon and it is necessary to further the understanding of mobility of the contaminants from the sediments as this would be an important factor in their biogeochemical cycle.

The main factors affecting the flux from the sediments (the benthic flux) of the contaminants are as follows. The vertical diffusion of pore water is due to pressure gradients, chemical diffusion caused by enrichment in the sediment, bioturbation [Mugnai et al., 2001], and anthropogenic activities. Speciation is also vital in understanding the bioavailability of the released contaminants to the marine system. The speciation determines how much of a metal is complexed by organics and its oxidation state [Bruland et al., 1991 ; Bruland, 1992 ; Boye and van den Berg, 2000]. Coastal areas are typically shallow, organic rich waters that can exhibit variable oxic/anoxic conditions. The changes in the oxic state can affect the biogeochemical cycle and coupled with the other factors, can enhance either the positive or negative flux [Simpson et al., 1998; Zago et al., 2000]. The Lagoon of Venice is a transitional environment where these variable conditions are common resulting in the need to carry out detailed metal benthic flux measurements and take these further with modelling.

The aim of this research is to quantify, using benthic chambers, the benthic flux and speciation of contaminants under natural and variable conditions. This work will present preliminary data for two sites chosen for their high metal concentrations and will concentrate on the flux and speciation of dissolved Pb, Cd, Cu, Mn, and Zn. Data of particulate metals are reported in another chapter of this volume (Magi et al., 2003). Thiols will be measured as a specific copper-complexing ligand which are known to exist in sediments [Luther et al., 1986] and are an important constituent of phytochelatin produced by metal stress of phytoplankton [Ahner et al., 1995]. Variations in fundamental parameters like nutrients, oxygen, salinity and pH will be used as tracers of the processes at the sediment surface in the benthic chambers.

2. Experimental

Experiments were carried out using six benthic chambers in July 2001 and October 2002. The chambers were placed in two contaminated sites, Canale delle Tresse (site 1) near the industrial site of Porto Maghera and the second in the Campalto area (site 2) near the causeway (see Fig. 1). Water samples were collected over approximately 50-60 hours every 3-4 hours from 90L chambers. Samples for determination of total dissolved metals and thiols were collected from a single chamber to reduce the variability deriving from inhomogeneous sediment composition in the area. Samples used for metal speciation were taken in sequence through the six chambers, which were sampled only once each because collection of large water samples tends to cause excessive changes to the sediment surface/water volume ratio in each chamber. The samples were taken by means of a peristaltic pump and filtered by cartridge filter (0.20 μm), samples used for speciation and for particulate analysis were filtered by a membrane (0.45 μm).

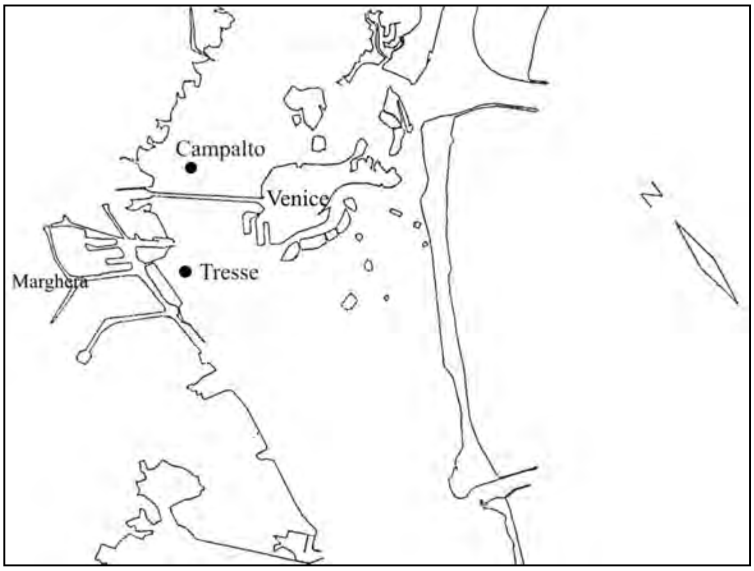

Fig. 1 - Sites where the benthic chamber experiments were carried out.

Comparative methods were used for the dissolved metal analysis. Samples for dissolved metals by voltammetry were acidified using redistilled HCl to 0.01M while samples for speciation were frozen for analysis later. For total dissolved metals samples are UV digested for 45 min. Pb and Cd were determined using anodic stripping voltammetry (ASV), using 300 min deposition at -1.3V (*Fischer and van den Berg, 1999)*. Copper was determined by cathodic stripping voltammetry

(CSV) using SA as ligand (Campos and van den Berg, 1994). Aliquots were also taken for analysis of thiols and frozen. They were analysed using CSV as set out by Le Gall [Le Gall and van den Berg, 1993].

Total dissolved metal concentrations were determined by Inductively Coupled Plasma-Sector Field Mass Spectrometry (Element, Finnigan-MAT); Cd and Pb were determined in low-resolution mode (m/Δm=300) using a micro-concentric nebulizer and a desolvation system (Aridus, Cetac) to reduce oxide interferences, Cu and Mn were determined in medium resolution mode (m/Δm=3000) by direct introduction using a microconcentric nebulizer and a Teflon spay chamber [Turetta et al. 2003]. Pre-treatment of the water samples was restricted to dilution (1:10) to minimise matrix effects, acidification to 10% with ultrapure grade HNO_3 (UPA, Romil) and addition of Y and Sc as internal standards. Quantification was carried out by a calibration curve obtained by multiple-standard addition to one aliquot of coastal certified reference material (CASS-4).

The complexing capacity of seawater for Cd and Zn was determined by two different electroanalytical techniques, both involving the titration of natural organic ligands present in the sample with the metal under study: Zn was determined by CSV [van den Berg, 1986] and Cd by ASV [Scarponi et al., 1996]. Calculations were then carried out using the total metal concentrations determined by ICP.

The data from above was then used to display the benthic flux as the change in concentration of the components between samples as a function of time and area and is shown in the following equation:

$$F_i = \frac{V_i \Delta C_i}{S \Delta T_i}$$

Where i = 1 to 15
Fi = benthic flux in time interval (pmol cm^{-2} h^{-1})
Vi=chamber volume (cm^3)
ΔCi = concentration gradient denoted as $C_i - C_{i-1}$ (pmol cm^{-3})
S=sediment surface covered by the chamber (3600 cm^2)
ΔTi = Time interval denoted by $t_i - t_{i-1}$ (hours)

Positive fluxes result when concentrations increase with time. In this event material release from the sediment and/or from particulate matter to the water phase is inferred. Conversely, negative fluxes result when concentrations in water decrease with time.

3. Results and Discussion

The benthic fluxes of the total dissolved metals (Cd, Zn, Mn, Cu), Zn and Cd speciation and thiols, is shown here for the two benthic chamber experiments; the data is discussed along with fundamental parameters such as O_2 saturation (%) and redox potential values (mV).

During the summer 2001 experiment in Campalto, suboxic conditions were not reached in the benthic chamber, although changes in potential and O_2 saturation % were observed. Suboxic conditions were reached after about 12 hours during the fall 2002 experiment in Canale delle Tresse. The dissolved Cd concentration at the two sites studied was similar, but at the end of the experiment the concentration reached was higher at Campalto (9 nM). The dissolved Zn concentration was higher at site 2 (average conc. 167 nM) than at site 1 (average conc. 56 nM). As observed for Zn, the dissolved Mn concentration was higher at site 2 (average. conc. 360 nM) than at site 1 (average conc. 120 nM). The dissolved Cu concentration was similar at both the sites studied (average conc. 20 nM). During the experiment carried out in the Campalto Area in July 2001, as a consequence of aeration the chamber due to high tide excursion, the fluxes showed a high variability for all the elements.

The benthic flux of total dissolved Cu at Campalto fig.2 and in Canale delle Tresse is shown in fig. 3. The concentration shows an initial increase (positive flux), deriving from the sediment resuspension during the chamber settling, followed from a negative flux; after about 20 hours the flux become practically nil until the end of the experiment, this trend was evident during the experiment carried out in October 2002. During the experiment carried out in Campalto 2001, the trends was rather variable and the average benthic flux of this element was slightly positive (18 pmol cm^{-2} h^{-1}). The benthic flux of dissolved Mn was also rather variable, as shown in fig. 4 for Campalto and fig 5 for Canale delle Tresse. However, the average benthic flux was more positive at both sites respect to copper and it was more pronounced at Campalto (397 pmol cm^{-2} h^{-1}) than Tresse. In fig. 6 and 7 are reported the benthic flux of dissolved Cd at the two sites. The variability was more pronounced at Campalto, since at the end of the experiment the benthic flux was positive. However the average flux was positive at both sites but very low if compared to other elements. The average benthic flux of dissolved Zn (fig. 8 and 9) was positive and similar at Campalto and Canale delle Tresse (30 pmol cm^{-2} h^{-1} in site 1 and 55 pmol cm^{-2} h^{-1} in site 2).

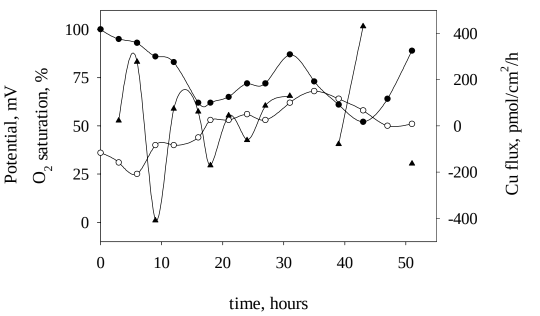

Fig. 2 - Cu flux (▼), potential (○) and oxygen saturation (●). Campalto 2001.

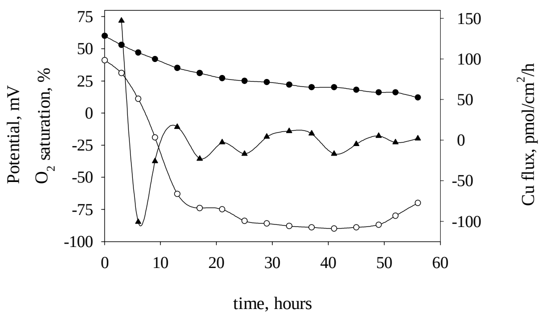

Fig. 3 - Cu flux (▼), potential (○) and oxygen saturation (●). Tresse 2002.

The concentration of Cd and Zn complexing ligands in Campalto is shown in fig.10 and 11 where it can be compared to the redox potential and the degree of O_2 saturation. On average the complexed Cd fraction was 88% of the total. The benthic flux of Cd-ligand was changeable throughout the experiment, but the average flux was positive and comparable to that of the dissolved Cd concentration. Furthermore, the flux appeared to be related to the changes in O_2 saturation. Compared to that of Cd ligand, the benthic fluxes of labile and bound Cd were rather constant throughout the experiment and they averaged out as nil. On average more than 90% of Zn was complexed by organic ligands. The benthic fluxes of Zn ligand and of bound Zn were extremely changeable, while the flux of labile Zn was constant and nil all through the experiment. However, the flux for Zn ligand was slightly positive, similar to that for the Cd ligand. The slightly positive benthic flux observed for both the Cd ligand and the Zn ligand may be related to the release of organic matter (which may contain partially decomposed cells, faecal pellets, etc) from the sediment towards the water column.

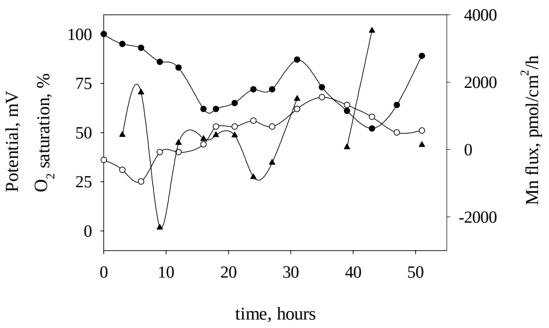

Fig. 4 - Mn flux (▼), potential (○) and oxygen saturation (●). Campalto 2001.

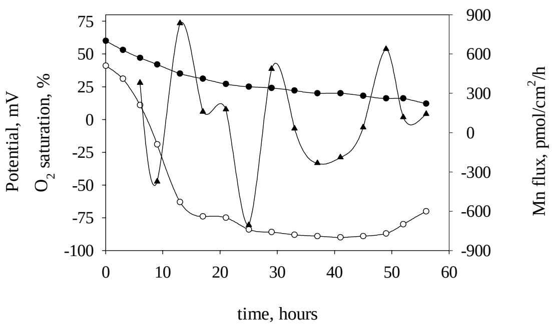

Fig. 5 - Mn flux (▼), potential (○) and oxygen saturation (●). Tresse 2002.

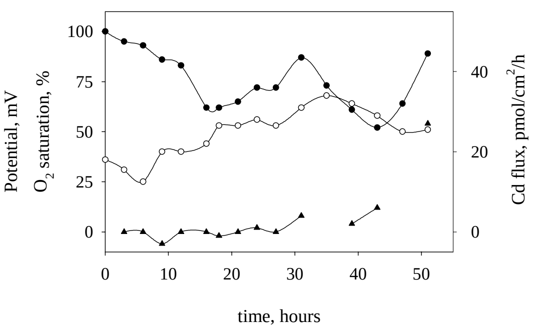

Fig. 6 - Cd flux (▼), potential (○) and oxygen saturation (●). Campalto 2001.

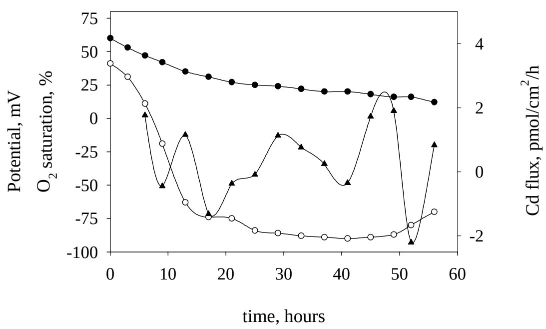

Fig. 7 - Cd flux (▼), potential (○) and oxygen saturation (●). Tresse 2002.

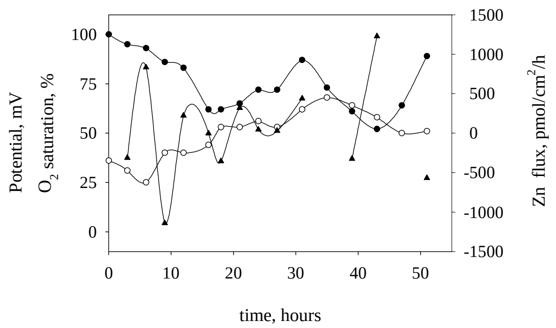

Fig. 8 - Zn flux (▼), potential (○) and oxygen saturation (●). Campalto 2001.

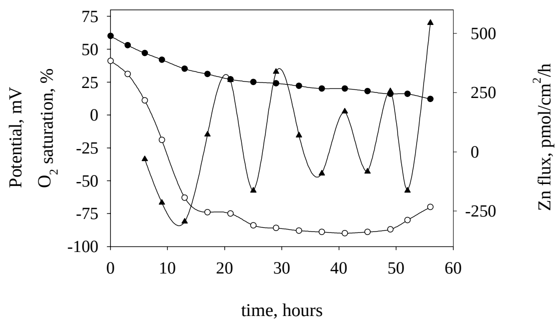

Fig. 9 - Zn flux (▼), potential (○) and oxygen saturation (●). Tresse 2002.

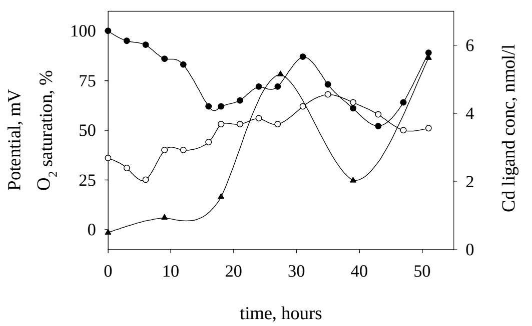

Fig. 10 - Concentration of Cd complexing ligands (▲), potential(○) and oxygen saturation(●). Campalto 2001.

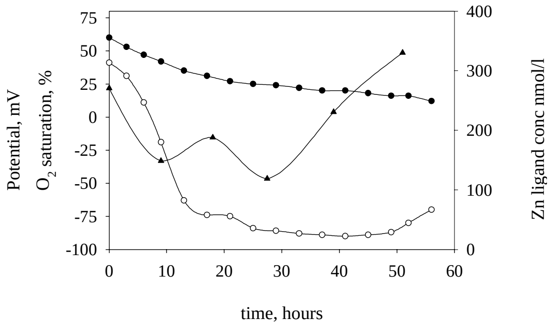

Fig. 11 - Concentration of Zn complexing ligands (▲), potential(○) and oxygen saturation(●). Campalto 2001.

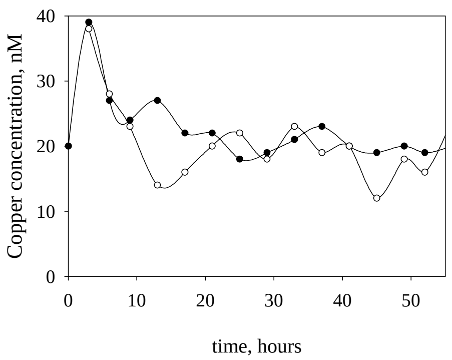

Fig. 12 - Cu concentrations by ICP (○) and CSV (●) Tresse area 2002.

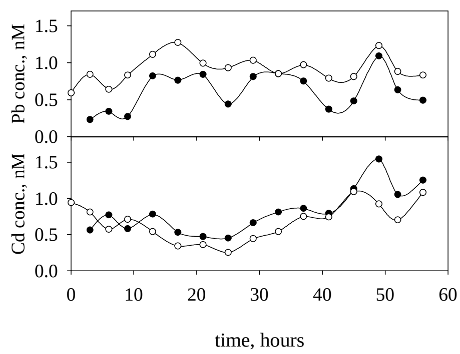

Fig. 13 - Cd and Pb concentrations by ICP (●) and CSV (○) Tresse area 2002.

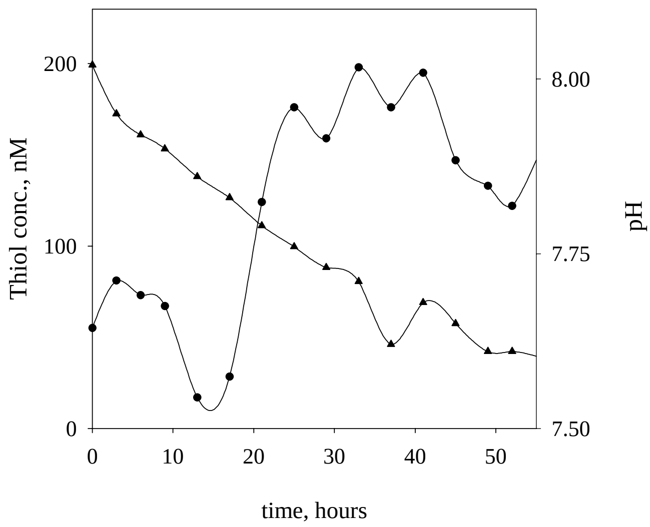

Fig. 14 - Thiol concentration (●) and pH (▲), Tresse 2002.

Figures 12 and 13 show the differences between the dissolved metal concentrations obtained from ICP and voltammetry for Cd, Cu and Pb from the Canale delle Tresse 2002. Figure 12 for Cu shows close correlation for the two different methods with the exception of the first few samples and two other outlying samples at t = 25 and 45 hours. On the other hand Figure 13 shows concentration profiles for Cd and Pb which at first sight do not appear to agree; this will be further investigated. The Cd determined by ICP was mostly higher than ASV and the inverse was true for Pb which had the greatest differences. However, the general shape of each curve was similar confirming that the same thing was being measured by the two methods.

Tab. 1. Effect of adding Cu, Pb, and Cd, on the reactive thiol species from Canale delle Tresse 2002.

	Added metal (nM)	Peak height Before (nA)	Peak height After (nA)	% Reduction
Cu	125	28.3	1.6	75
Pb	100	20.9	11	48
Cd	100	22.1	18	20

Figure 14 shows the thiol concentration determined during the 2002 campaign by calibration against glutathione. Although there appeared to be an initial decrease, the data showed a general pattern of increases. The samples which showed the initial decrease showed a different analytical pattern than the other samples, suggesting that there may have been difficulties with these due to contamination or other unexplained sample problems. After this initial decrease, starting about 10 to 20 hours from the beginning of the experiment, the pH was reduced from about 8 to about 7.8, which can produce a flocculation of colloidal matter. Only further speciation analysis of these two samples may shed some light on them. Overall the flux is positive although some thiol did return to the sediments towards the end. Table 1 shows an experiment conducted using seawater collected from the chamber and frozen. The natural thiol (calibrated against glutathione) content was titrated against the three metals Cu, Pb and Cd. The results show a varying affinity of the metals with the thiol in the order Cu>Pb>Cd with almost four times as much Cu complexed compared to Cd. This would be significant when considering the mobility of a metal.

4. Conclusions

The results obtained in two contaminated areas show that trace elements can remobilised from sediment to the water from resuspension or sub-oxygenation of water. The results obtained during the experiment carried out in Campalto 2001 may have had problems deriving from admixture of surrounded water causing re-aeration. This was highlighted by the absence of anoxia and some fluctuating metal concentrations. Some preliminary conclusions can be drawn from the data. Despite the differences in concentrations observed in the two sites studied, the benthic flux of total dissolved Cd, Zn, Mn and Cu seem not to be particularly affected by the seasonality and by biological processes (growth, uptake and diagenesis). At the beginning of the experiment, the benthic flux of the trace elements studied was often positive, possibly due to the remobilisation caused by the setting of the benthic chambers. Therefore, the sediments may be considered an important source of trace elements for the water column, especially when they are disturbed. Furthermore, by studying the organic speciation of these trace elements we may better clarify whether the sediments are a source of bound metal and ligands, since benthic fluxes may be relevant for the biogeochemical cycle of the trace elements studied in the lagoon.

The calculation of fluxes on basis of point-to-point variations contributes to an apparent high variability of the results. This calculation might work for data with a very low experimental error but is unsuitable for trace components subject to a relatively high uncertainty. We are in process of modelling the data using to obtain more accurate overall fluxes.

Further and in-depth studies of these two sites are necessary to better comprehend all the processes (physical, chemical, biological, etc) involved and how they are related to each other. Other work includes a microbenthic flux chamber which can sample over a shorter period and *in-situ*. This enables the user to identify quickly areas of different contamination and measure some key component fluxes.

Acknowledgments

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RESEARCH LINE 3.5
Quantity and quality of exchanges between lagoon and sea

VORTICITY PATTERNS OFFSHORE OF THE VENETIAN LAGOON FROM HF RADAR OBSERVATIONS

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Riassunto

Una rete di sistemi Radar HF è stata utilizzata per produrre le mappe della corrente marina superficiale al largo della bocca di porto di Malamocco, per un periodo di un anno, dal Novembre 2001 all' Ottobre 2002. L'analisi dei campi di flusso, sottratta la componente mareale, rivela la presenza di strutture vorticali su piccola scala (10 km), sia a nord che a sud della bocca. Inoltre, diverse mappe delle medie mensili della velocità della corrente indicano la presenza di persistenti meandri. Una tecnica più oggettiva, basata sulla vorticità, è stata sviluppata per la ricerca di vortici nelle vicinanze della bocca, separandoli dalla presenza dei meandri su più larga scala. La vorticità, sulla scala di 5 – 10 km, è stata verificata su base oraria, utilizzando le correnti filtrate con un filtro passa basso, e quindi studiata statisticamente su base annua. L'istogramma della vorticità e la sua variabilità temporale sono significativamente diverse in funzione della posizione relativamente alla bocca di Malamocco. Su entrambi i lati, nord e sud della bocca, i valori di vorticità sono deboli ma negativi, indicando la presenza di un meandro a grande scala la cui cresta si trova allineata con il canale. Inoltre, la variabilità più ampia si nota a nord, dove si osservano eventi con valori positivi significativi ($\sim 5 \times 10^{-5}$ s^{-1}), indicando una rotazione in senso anti-orario. A sud, invece, non si rivelano eventi analoghi. In base ad un criterio stabilito sul valore e sul senso di rotazione, sono state costruite le mappe della circolazione tipica associata agli episodi caratterizzati dalla presenza di vortici relativamente forti. L'indagine sulla possibile influenza dei parametri forzanti esterni ha stabilitio che un forte vento tende a distruggere questi moti rotatori, e crea un campo di corrente piuttosto omogeneo ed uniforme. Sono state studiate le eventuali influenze del livello del mare e della intensià della corrente al largo.

Abstract

A network of high frequency (HF) radar systems was used to produce maps of surface velocity offshore of the Malamocco inlet during the 12-month period from November 2001 through October 2002. Inspection of the sub-tidal residual flow fields revealed frequent occurrences of small-scale (~10 km) eddy structures both north and

south of the inlet. In addition, several monthly averaged velocity maps indicate the presence of a persistent meander in the mean current patterns. A more objective technique, based on vorticity, was developed to search the data set for the presence of eddies near the inlet and to separate those features from the larger-scale meander pattern. The vorticity at scales of 5-10 km was computed each hour using the low-pass-filtered data set and year-long vorticity statistics were investigated at selected locations surrounding the inlet.

The vorticity histograms and temporal variability changed significantly as a function of location relative to the Malamocco inlet. Both north and south of the inlet, the mean vorticity was weakly negative reflecting the larger-scale meander pattern whose crest is aligned, approximately, with the inlet. However, the range of vorticity north of the inlet was much greater than it was south of the inlet. A minor peak (or shoulder) in the year-long histogram of vorticity north of the inlet highlighted frequent occurrences of strong ($\sim 5 \times 10^{-5}$ s^{-1}) positive vorticity events in that area. A similar statistical behaviour was not seen south of the inlet. This observation was used to define a conditional sampling criteria that lead to a map of the typical flow field associated with strong eddy events.

The vorticity time series were also used to investigate the relationship of eddy events to external forcing parameters. Strong winds, for instance, acted to destroy vorticity in the surface current field since they lead to a strong but horizontally uniform response in the surface currents. The roles of sea level variability and offshore current velocity were also investigated.

1. Introduction

The two antenna system of the HF radars (SeaSonde, by COS, LTD) installed on Lido and Pellestrina islands enabled monitoring of the surface currents in the zone depicted in Fig. 1. A regular grid with about 750 m of resolution, and the surface of about 145 km^2 is denoted with bold dots, while the colour scale reflects the data return during the one-year period of measurements, from November 1, 2001 through October 2002. Due to various reasons (noisy environment, for instance) there are gaps within the hourly time series over the study zone. The best covered area is in the central zone offshore the Malamocco inlet, where more than 90% of data were collected. The black bold dots denoted the grid nodes which were not considered at all. The thin dots represent the potential area to be covered in combination with the third antenna from the CNR Oceanographic Platform. The third site did not operate continuously during the study period due to the lack of a reliable power supply. Therefore data from that site was not used in the time series analysis.

All details about the installation, configuration and determination of the surface current vectors have been reported in [Kovačević et al., 2002].

The long term mean currents (Fig. 2), as well as the mean monthly current maps [Kovačević et al., 2003b] have revealed the presence of a meandering feature. Moreover, the presence of small scale eddies, north and south to the Malamocco inlet was observed on several occasions. Consequently the vorticity maps and the times series of vorticity at selected locations near the inlets were examined in more details.

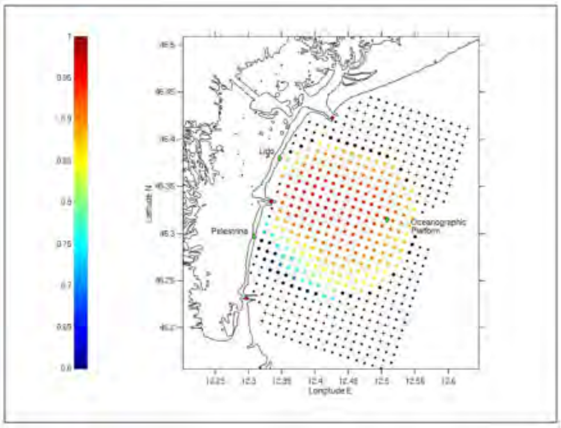


Fig. 1 - Regular spatial grid for the hourly HF radar data set. Coloured scale indicates the rate of the data return for the one year period from November 1, 2001 through October 31, 2002.

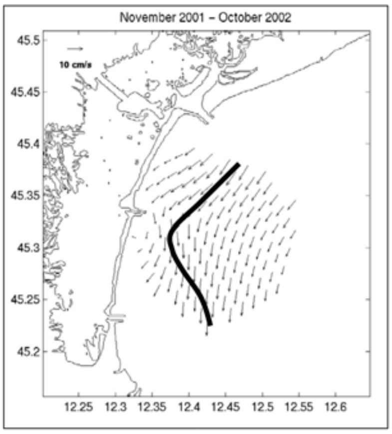


Fig. 2 - Annual mean surface velocity from the Lido and Pellestrina CODAR - SeaSonde HF radar systems.

2. Data Preparation

Times series of hourly currents were formed over the study area. The tidal signal was filtered out using harmonic properties of the most important tidal constituents [Kovačević et al., 2003a, Kovačević et al., 2003b]. Such residual time series were interpolated for gaps not greater than 6 hours, and subsequently filtered for other high frequency oscillations (of the inertial period) applying a digital symmetrical filter with 25 weights.

The time series of such residual and filtered currents over the study area were used for determining the 2-dimensional best fit for u (eastward) and v (northward) current velocity over a 5 km spatial scale. Such a fit was then used for calculating vorticity ($\partial v/\partial x - \partial u/\partial y$) in each node of the new regular grid at a time step of one hour.

3. Vorticity Analysis

From the time series of vorticity values at established grid points, the mean annual vorticity for the period November 1, 2001 – October 31, 2002 was calculated (Fig. 3). Positive values indicate anti-clockwise motion, while the negative ones represent clockwise rotation. The central zone of slightly positive vorticity is enclosed between the two zones of negative vorticity to the north and to the south of Malamocco inlet. Such a pattern corresponds to a meandering feature derived from the annual mean current field (Fig. 2).

Several examples of vorticity maps and the associated surface current field are reported in Fig 4. In some cases elevated vorticity values are associated with small scale eddies. One or two of them are seen from the HF data in the study zone. In rare cases the eddies are detached from the coast (Fig. 4f), and they mostly appear close to the northern and southern side of the Malamocco inlet, as an along-shore current became relaxed. From HF radar data sometimes only one-core eddy is observed (Fig. 4a), and sometimes it is associated with the eddies to the south. When the two-core vortex structures occur they may be rotating in the same sense (both clock-wise, like in Fig. 4h) or in an opposite sense (Fig. 4b, 4k, 4l).

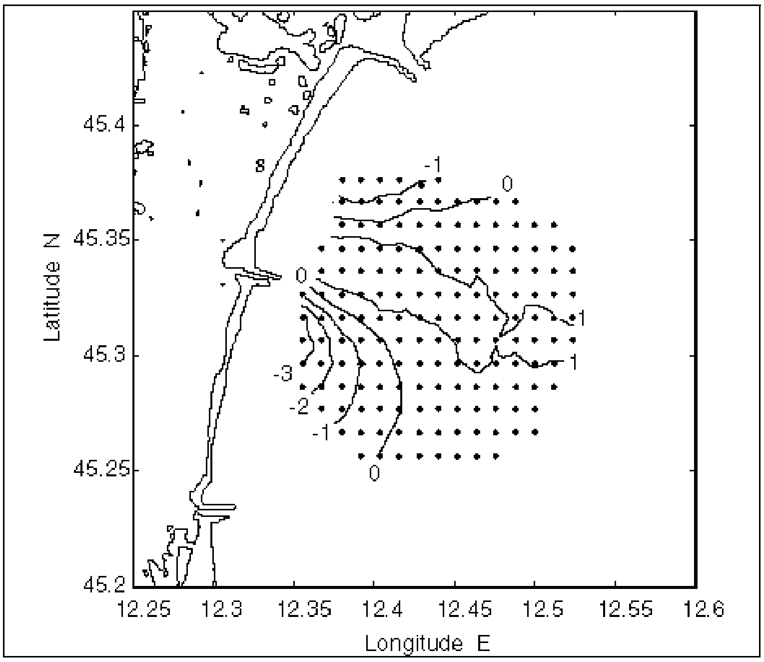


Fig. 3 - Annual mean vorticity calculated as an average from the hourly vorticity values (unit scale 1e-5 s-1) in the locations indicated by heavy dots, for the period November 2001 through October 2002.

In a few situations the presence of the eddies is accompanied with the southward flow further off shore (Fig. 4h, 4l), and, less frequently, with the northward flow (Fig. 4c, 4g). The southward flow is a signature of the prevalent general circulation pattern in the Northern Adriatic, while the northward one is associated with the reversal, probably related to a mesoscale variability. The speeds associated with the eddies are about 5cm/s, and duration are of the order of a day.

In particular, one of the events with vorticity values higher than 5×10^{-5} s^{-1} observed north and south of the Malamocco inlet, occurred at the beginning of October (Fig. 4f, 4g). The vorticity field evolved from a multi-core eddy field into a two counter-rotating eddies. The event is associated with a current reversal to the south of the study zone, possibly due to mesoscale variability within the study area.

There are two examples showing relatively strong, coherent southward flow and no eddies present near the inlet (Fig. 4e, 4i).

The histograms representing the vorticity distribution over a one year period at three selected locations surrounding the Malamocco inlet (Fig. 5) are depicted in Fig. 6.

Two of the locations are from the zone of prevalent negative vorticity (gp24 and gp09) and one is from the zone of prevalent positive vorticity (gp22; see Fig. 2). At locationgp24 (Fig. 6a) negative vorticity (clock-wise sense of rotation) prevails over the zero values, but the secondary peak indicates occurrences of relatively strong positive vorticity events. At location gp22 (Fig. 6b) the vorticity is prevalently zero, but then events of positive vorticity (anti-clockwise rotation) prevail. At location gp09 (Fig. 6c) south of Malamocco inlet, negative vorticity is dominant.

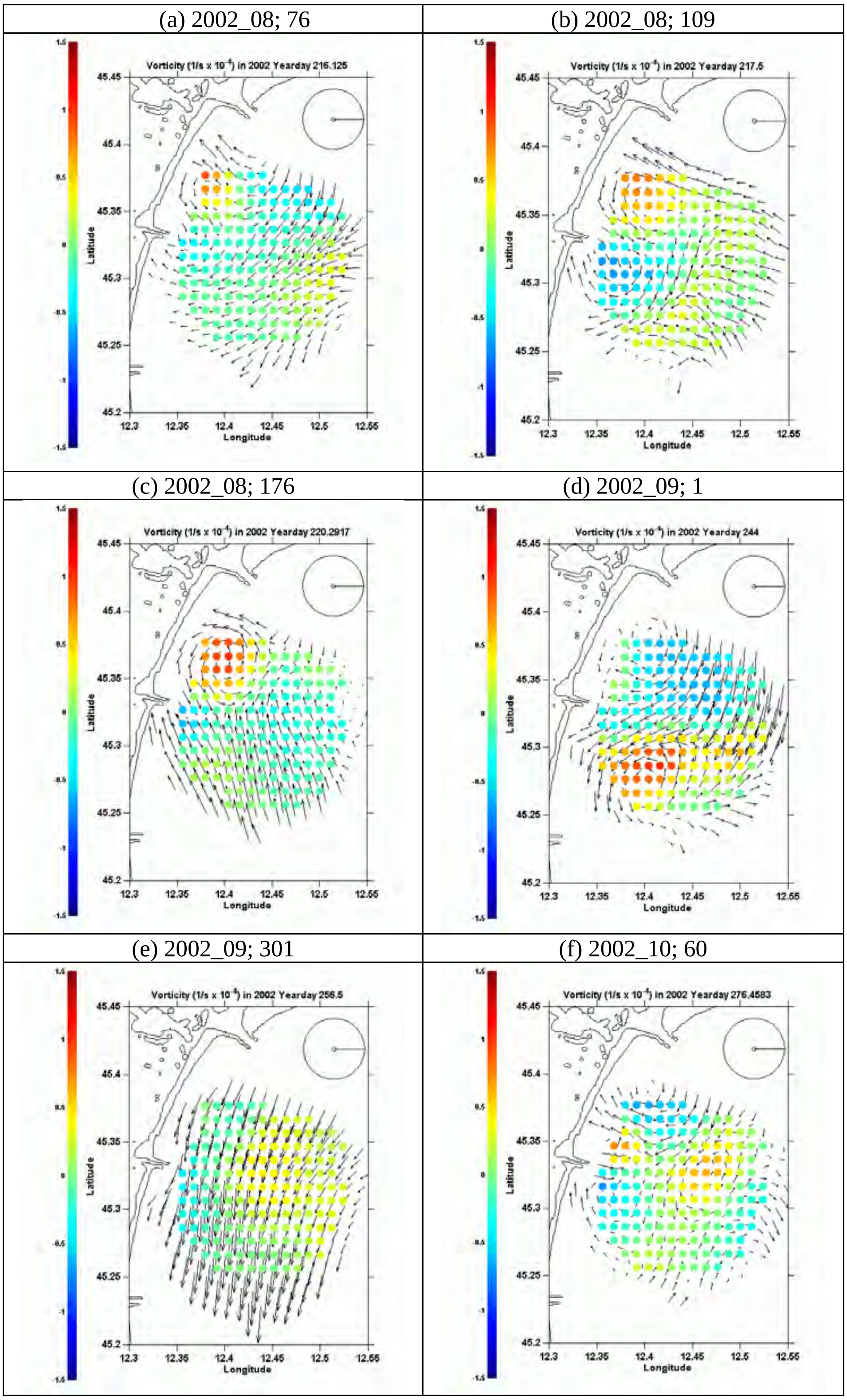
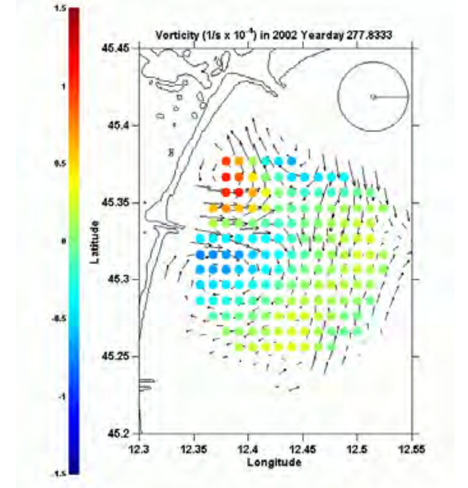
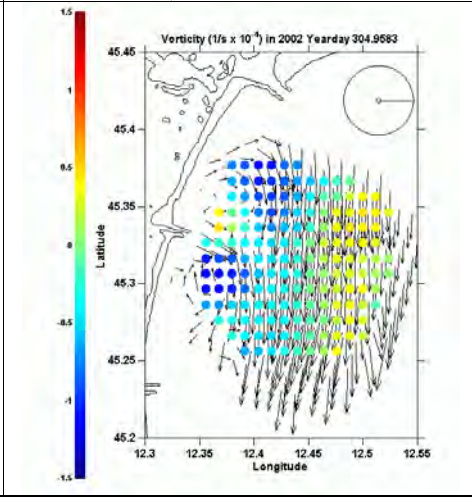


Fig. 4 - Some patterns of the de-tided, low-pass-filtered velocity vectors and vorticity estimated over 5-10 km horizontal scales (reference circle). The time is indicated as the year_ month and a sequential hour of the month

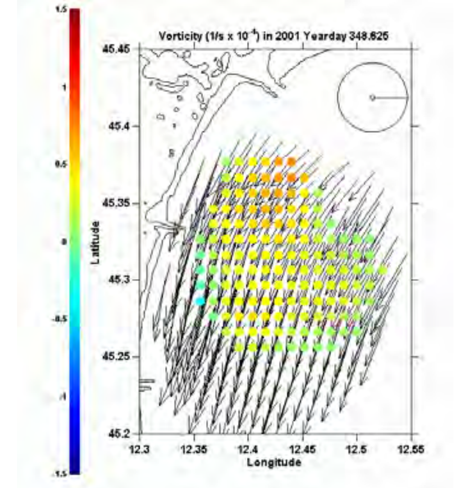
(g) 2002_10; 93



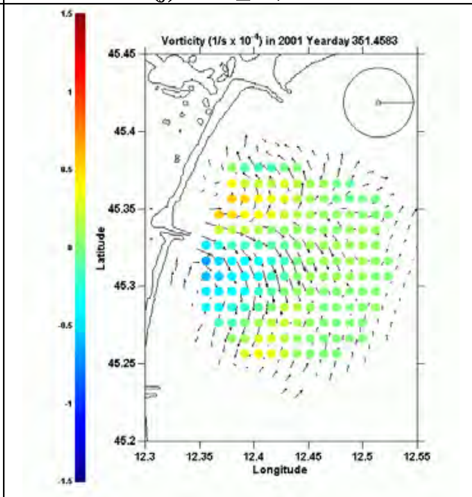
(h) 2002_10; 744



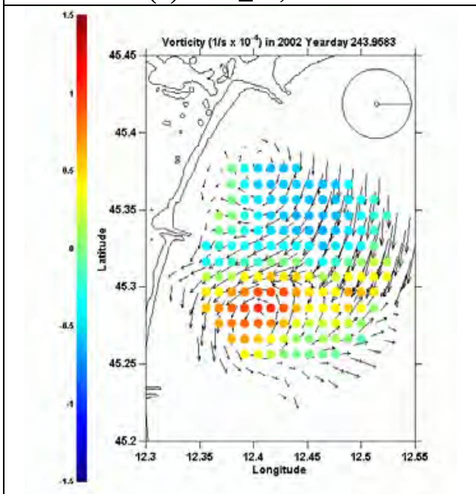
(i) 2001_12; 328



(j) 2001_12; 396



(k) 2002_08; 744



(l) 2002_01; 676

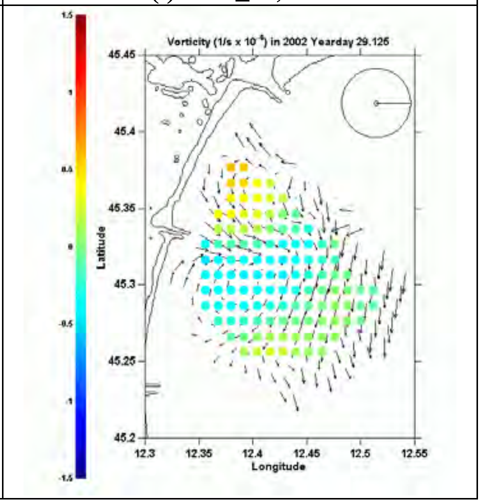


Fig. 4 - cont.

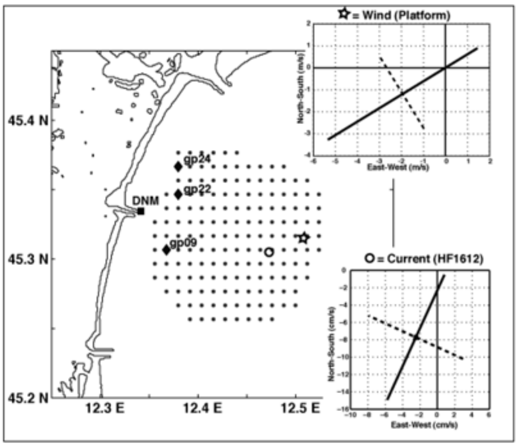


Fig. 5 - Vorticity analysis grid with locations selected for statistical analyses (gpxx) along with location of tidal height station (DNM), representative offshore current (HF1612) and research platform. The annual mean speeds, together with major (solid) and minor (dashed) principal axis components of the current and wind, are also shown.

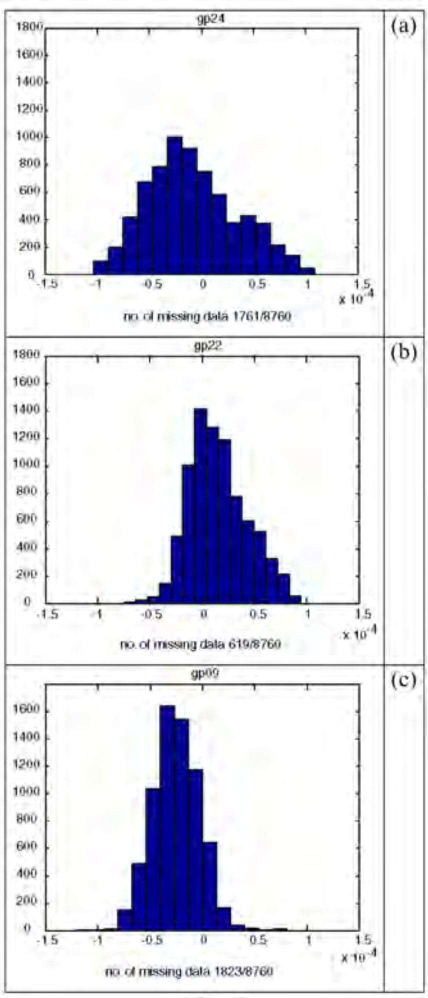


Fig. 6 - Histograms of the vorticity distribution for a period November 1, 2001 through October 31, 2002 at three selected locations near the Malamocco inlet.

Some mechanisms possibly responsible for the generation of vorticity were taken into consideration for the same time interval as vorticity data (Fig. 5), such as the tidal regime near the inlet. This was determined from the hourly sea level data available from the Northern dyke of the Malamocco inlet (DNM), and smoothed by a moving average with a window length of 51 hours). The wind data time series from the CNR Oceanographic Platform was decomposed into two orthogonal principal components, which resolve very well the two principal wind directions, namely that of the bora (blowing from the ENE direction) and of the sirocco (blowing from the SE direction). The hourly mean wind data were treated with the same kind of digital filter as currents with the scope to eliminate high frequency variability.

The current time series near the platform at location HF1612 (Fig. 5) was taken as representative of the current regime off shore. The current data were decomposed into major and minor principal components, which highly correspond to the along-shore and across-shore current orientation.

In Fig. 7 the time series of vorticity at two locations, gp24 and gp09, together with all other investigated data are presented: shaded areas denote absolute vorticity values higher than $5 \times 10^{-5}\ s^{-1}$. It has been observed on several occasions that values higher than this threshold correspond to the presence of eddies while values lower than this indicate usually only a meandering of the along-shore current in the vicinity of the inlet.

Both by visual inspection of the time series, and by scatter plotting of the vorticity as a function of other external parameters, it seems that there is no straight-forward cause-effect relationship that would indicate the forcing for the eddies to occur. No relationship with the tidal regime may indicate that there is no influence of the 'tidal pumping' from the lagoon on the formation of these vortex structures. The only reasonable relationship, in a very wide sense of the meaning, is the fact that during low wind conditions, the vorticity tends to develop more than during strong wind conditions.

This is most evident from the scatter plot between the vorticity and the major principal wind component (representing the bora wind) in Fig. 8. This is coherent with the current structure observed in some occasions during the strong bora episodes, when the surface current field in front of the lagoon is relatively homogeneous, and parallel to the shore, while during calm the current filed near shore is weaker and small eddies of about 5 km in diameter develop and persist off-shore the lagoon islands.

During some of the episodes of high vorticity presence near the inlet, such as the event that occurred at the beginning of October 2002 (see Fig. 4g, 4h), while the winds were low, strong positive vorticity to the north is coupled with a strong negative vorticity to the south of the inlet. At the same time, the current reversal off shore is observed. However the matching of the latter is not always the case. There is a hypothesis that the prevalent along shore, southward flow as a branch of the general circulation of the Northern Adriatic sea, encounters morphological "obstacles" in the vicinity of the inlet, caused by the dykes, which extend to few km off shore. Therefore the flow is in some way constrained to meander around them.

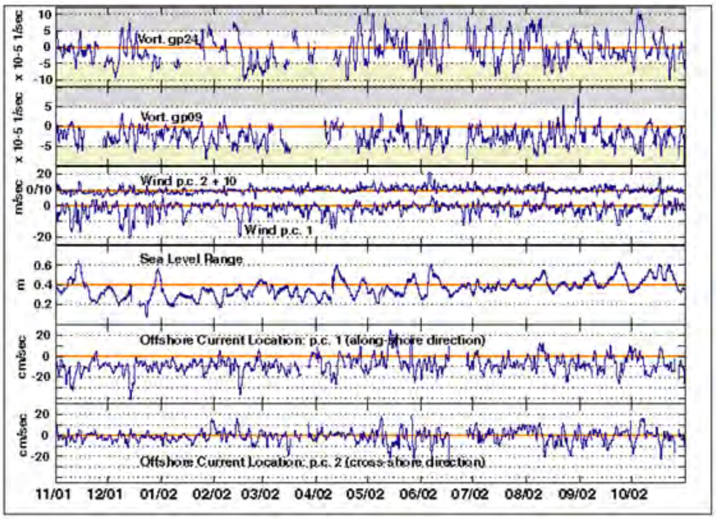


Fig. 7 - Time series of the hourly values of the vorticity at the two selected locations (24 and 9), the tidal sea level regime, the principal wind components and principal off-shore current components for the period November 1, 2001 through October 31, 2002.

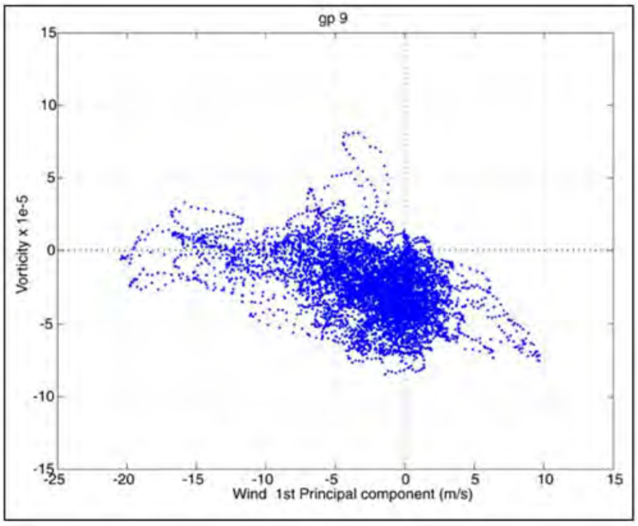


Fig. 8 - Scatter plot of the vorticity at the location 9 as a function of the major principal wind component.

4. Conditional Average Currents

The mean flow structures over the study area have been determined according to three different conditions, namely, for very large negative vorticity values, for very large positive vorticity values, and for very low vorticity values. The thresholds have been determined such that large vorticity corresponds to the values with magnitudes greater than $5 \times 10^{-5}\ s^{-1}$. These are emphasized in Fig. 7 as gray and yellow bands, for positive and negative sense of rotation, respectively. Each criterion has been considered separately or simultaneously for the two locations, gp09 and gp24, as stated in Table 1.

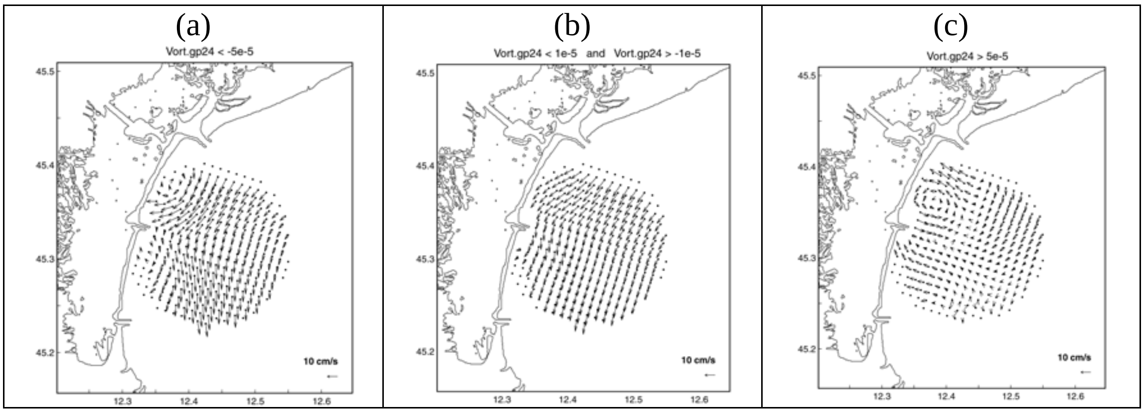


Fig. 9 - Maps of the mean flow structure corresponding to the cases 1, 2, and 3 from Table 1.

The mean flow patterns considering only gp24 to the north of the inlet, are illustrated in Fig. 9. Very large negative vorticity at gp24 seems to be associated with a prominent meandering of the residual southward flow (Fig. 9a), with current intensities within the meander larger than offshore. On the contrary, large positive vorticity at gp24 seem to be associated with a weak and non uniform southward flow (Fig. 9c). Small vorticity values at gp24 reveal relatively uniform and homogenous southward flow, with not much meandering. The patterns considering only gp09 to the south of the inlet (Fig. 10) show that large negative vorticity at this location is associated with a residual southward flow detached from the coast, and relatively weak. Low vorticity seems to be associated with the presence of non uniform southward flow (Fig. 10b), while large positive vorticity is probably associated with a mesoscale feature further offshore, lasting about a day (23 cases). This shows that large positive vorticity is not very common to the south of the inlet, as it is to the north of it. In Fig. 11, the criteria for very large negative vorticity applied simultaneously at both locations reveal a meandering flow intensified in the south-eastward portion of the study area (Fig. 11a), while a dipole-like structure, with large positive vorticity to the north, and large negative vorticity to the south seems to be associated with a blocking of the southward flow in the southernmost portion of the study area, which perhaps may be induced by temporary reversals. However, in this preliminary analysis of these phenomena we are not able to give the final answers yet.

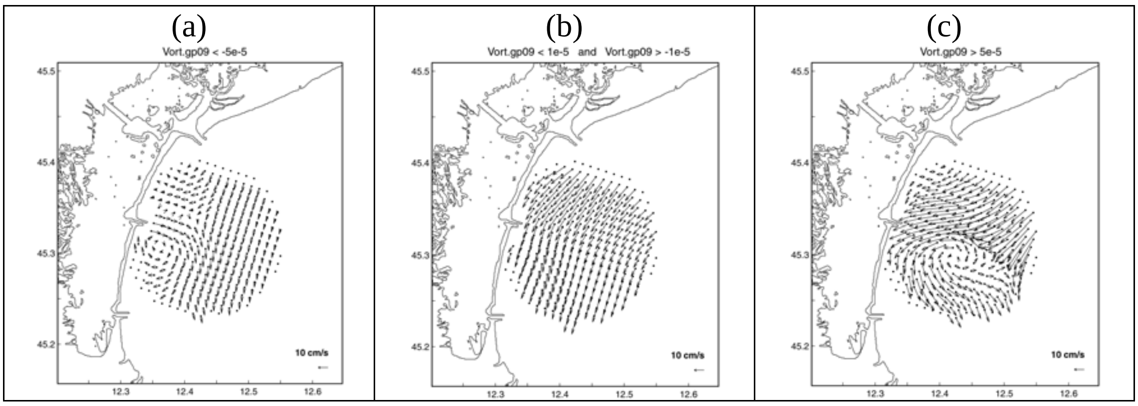


Fig. 10 - Maps of the mean flow structure corresponding to the cases 4, 5, and 6 from Table 1.

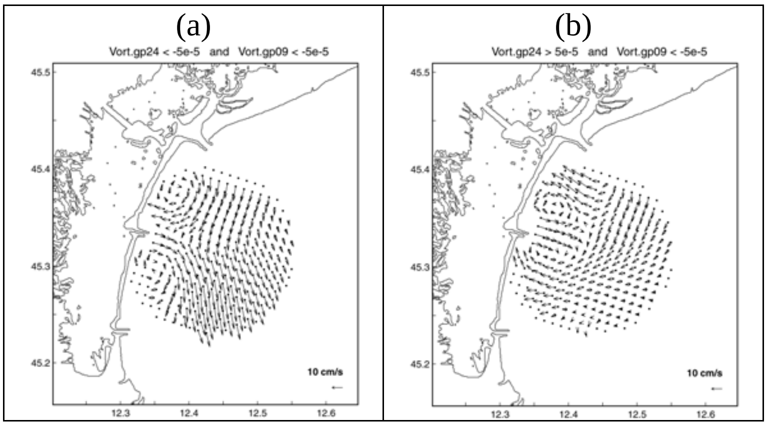


Fig.11 - Maps of the mean flow structure corresponding to the cases 7, 8 from Table 1.

Table 1. - The number of cases for each of the following eight criteria defined with respect to the vort. (vorticity): 1) vort. at gp24 < -5e-5; 2) –1e-5 < vort. at gp24 < 1e-5; 3) vort. at gp24 > 5e-5; 4) vort. at gp09 < -5e-5; 5) –1e-5 < vort. at gp09 < 1e-5; 6) vort. at gp09 > 5e-5;7) vort. at both gp24 and gp09 < -5e-5; 8) vort. at gp24 > 5e-5 and gp09 < -5e-5. The criterion vort. at gp24 < -5e-5 and vort. at gp09 > 5e-5 does not yield any solutions. Vorticity units: s-1. For the locations of the grid points gp09 and gp24, see Fig. 5.

Criterion	1	2	3	4	5	6	7	8
No. of cases	1223	1114	828	855	1404	23	126	188

6. Conclusions

The present work is focused on describing the small scale structures in the current filed, as observed from the HF radar data. Near the Malamocco inlet their presence is quite frequent, in particular during calm wind conditions. During strong bora or sirocco winds, the current field tends to be spatially coherent and parallel to the shore over the investigated region. The phenomenology of these structures is described, confirming that the shore morphology (as inlet dykes) influences the along shore flow causing it to deviate and meander, as already stated by Gatto [Gatto, 1984]. In some dynamically favoured conditions the small scale eddies then develop. The available spatial coverage made it possible to observe them only in the vicinity of the Malamocco inlet, but there are hints of their presence in the vicinity of the other two inlets: Lido and Chioggia. We suppose that they may influence the along-shore sediment transport from north to the south and possibly have some influence also on the sediment transport between the lagoon and the adjacent sea. We argue that they may take part, together with the wave motion and a non-tidal coastal circulation, in a complex dynamical mechanism that plays a significant role in the processes of erosion and sand deposition, which are observed along the littoral of the lagoon and qualitatively synthesized by Gatto [Gatto, 1984]. He derived qualitative characteristics of the near shore circulation on a basis of geological observations of the littoral band of the Venetian lagoon. He showed the scheme in which the most important property of this circulation consists of the southward residual current, which is deviated offshore due to the inlet dykes causing a complex pattern within which vortices of small scale, not quantitatively determined, develop. Having for the first time the possibility to measure a surface circulation on the portion of the sea surrounding the lagoon, these structures may be quantified in terms of velocity and duration, as preliminary illustrated here. The argument, however, needs more in depth analysis.

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NON – TIDAL RESPONSE IN INLET FLUXES OF THE VENICE LAGOON.

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Riassunto

Le correnti alle bocche di porto ed i livelli nella Laguna di Venezia risentono dell'azione combinata di forzanti astronomiche e meteorologiche. Le registrazioni di corrente esaminate, ottenute da correntometri acustici alle bocche di porto, si riferiscono al periodo Febbraio – Dicembre 2002. Le registrazioni di livello, relative all'anno 2002, si riferiscono invece ad una serie di stazioni interne ed esterne alla Laguna.

L'analisi spettrale di correnti e livelli residui (non astronomici), ha messo in evidenza l'importanza delle sesse adriatiche generate, a scala di bacino, dall'azione combinata di vento e pressione atmosferica. Le risposte indotte da tali oscillazioni coinvolgono le tre bocche di porto e l'intera Laguna di Venezia con ritardi trascurabili. Inoltre, le sesse rappresentano le oscillazioni "più lunghe" alla bocca di Malamocco. Al contrario, la variabilità di lungo periodo svolge un ruolo molto importante nelle due bocche di porto di Chioggia e Lido. Le correnti di lungo periodo sono quasi in opposizione di fase, e quindi un ingresso (uscita) di acqua dal Lido è sostanzialmente bilanciato da un'uscita (ingresso) attraverso Chioggia.

Sono stati analizzati due eventi tipici, uno di scirocco (Novembre 2002) ed uno di bora (Dicembre 2002), che evidenziano la complessa dinamica nelle correnti e nei livelli, come pure il ruolo giocato dalle bocche di porto della Laguna in relazione ai diversi regimi.

Abstract

Currents and sea surface levels inside the lagoon are driven by astronomical (tidal) and meteorological forcing. Current data are obtained by three bottom–mounted $ADCP_s$, one for each inlet, for the period February 2002 – December 2002. Sea level data 2002 from several tide gauge stations inside and outside the lagoon are analysed.

Spectral analysis of non tidal currents and levels reveals the role played by Adriatic seiches, which are triggered on Adriatic basin scale by atmospheric disturbances. Seiche motions force the currents at the same time, and represent the longest period of non tidal forcing at the Malamocco inlet. On the contrary, long period variability appears very important in the Lido and Chioggia non-tidal currents. The phases of long-period

currents are almost in opposition that's to say, an inflow at Lido (or Chioggia) is balanced by an outflow at Chioggia (or Lido).

The analysis of events helps in studying the response to transient events. Two typical scenarios of sirocco (on November 2002) and bora (on December 2002) wind are considered, revealing the complex dynamics both in the residual currents and levels, and the different role played by the three inlets under meteorological forcing.

1. Introduction

The currents and the sea level in the Venice Lagoon are driven mainly by two different forcing functions. The first one is represented by tidal (astronomical) forcing, which is strictly periodic and deterministic, so that it can be predicted with small errors. The second kind of forcing functions are non – periodic functions, such as wind and atmospheric pressure. Particular care must be paid to the last two forcing functions, because they can contribute appreciably to lagoon circulation and water exchange with the open sea. Because of the lack of field measurements of marine currents, the response of the lagoon has been studied up to now mainly with the aid of numerical models.

This work presents results of data analysis aimed at studying the non-tidal variability of sea level and currents which are mainly generated by atmospheric forcing. The present research follows two main approaches; one is based on spectral analysis of wind, currents and sea level time-series which gives average properties of measured data. The second approach is based on the analysis of relationship between currents and sea-level in extreme events which are characterised by the occurrence of sea-level maximums ("acqua alta") in the lagoon.

2. Data

2.1. Wind and atmospheric pressure data

Five minute records of wind speed and direction for year 2002 at the oceanographic tower are analysed. Wind vectors, relative to geographical North, are represented according to oceanographic convention. Both wind speed and direction are subjected to linear interpolation, in order to fill gaps and missing data, and then hourly values are obtained according to NDBC (NDBC – NOAA) "true" vector averaging procedures. According to this procedure, wind speed and direction represent respectively magnitude and orientation of the wind vector. This vector is decomposed into u and v components, which are averaged separately. The resulting average speed and direction are then calculated. Wind is expressed as wind stress, according to formulation *Large & Pond* (1981), from hourly values of eastward (u) and northward (v) components of wind:

$$\tau_{<x,y>} = \rho\, c_d < u, v > |\mathrm{u}| \tag{1}$$

ρ is air density, c_d the drag coefficient, $|u|$ wind speed. $\tau_{x,y}$ represent eastward and northward components of wind stress in dyn/cm^2.

Hourly values of atmospheric pressure for year 2002 are obtained from a meteorological station located at CNR IBM. Pressure data are expressed in hPa.

2.2. Sea-level data

Time series of sea surface elevation for year 2002 from several tide gauge stations inside and outside the lagoon are analysed. Tide gauges inside the lagoon belong to a network managed by CPSM (*Centro Previsione e Segnalazione Maree*), and to a tide gauge network managed by Magistrato alle Acque.

The inner stations are located in the southern lagoon (Chioggia Vigo) in Chioggia, in the northern basin (Le Saline), and in the city of Venice respectively (Fig. 1).

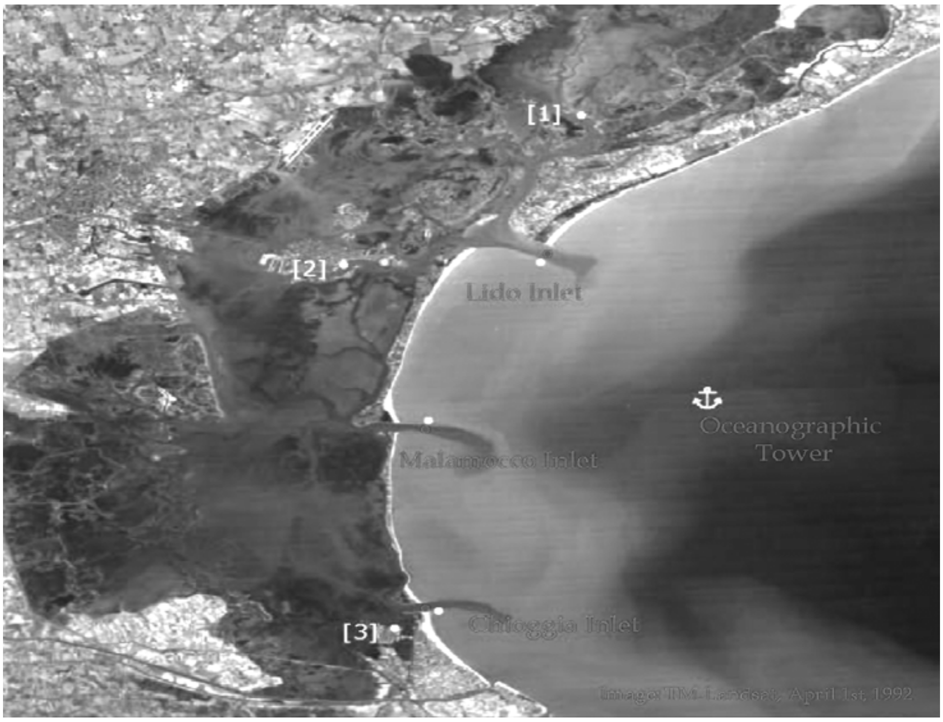

Fig. 1 – Location of the tide gauges inside the Lagoon, ADCP moorings at the inlets, meteorological station at CNR ISMAR (ex IBM), and of the Oceanographic Tower.

The northern and the southern stations are examined in order to evaluate the response of the lagoon to typical wind conditions of bora and sirocco. The last station, located at P.ta Salute, is mainly used as a reference for extreme events, i.e. for flooding episodes in Venice.

The outer stations are located at the oceanographic tower and at the piers of the lagoon inlets of Chioggia, Malamocco and Lido. Sea level time series at the oceanographic tower is used to evaluate the response of Adriatic Sea with respect to Venice Lagoon to wind and pressure forcing.

Raw data consist in five minute records of sea level, and are first subjected to linear interpolation in order to fill gaps and missing values. Least squares harmonic analyses of hourly averaged values are then carried out, so to extract the astronomical tide from the record. Residual sea level time series are obtained by subtracting the astronomical tide from sea surface elevation recordings, since it is supposed that astronomical and non astronomical tides are simply superimposed [Tomasin, 1999].

2.3. Current data

Current data for the period February 2002 to December 2002 are obtained by three bottom mounted acoustic Doppler current profiler (ADCP), one at each inlet. The acoustic current meters are placed in a suitable place [Gacic et al., 2002], and provide speed and direction of sea water along water column with a vertical resolution (*bin size*) of one meter and a time step of ten minutes. Time series of horizontal components of water speed are subjected to quality control procedures, in order to check sampled data. Hourly averages are obtained from horizontal velocity components and then projected along maximum variance axis. Time series of water speed at each depth are finally subjected to least squares harmonic analyses, in order to extract the tidal currents. Again, non-tidal time series are obtained by subtracting astronomical currents from the measured ones.

In order to estimate water fluxes between the Lagoon and the Adriatic Sea through the three inlets [Gacic et al., 2002], a depth – averaged current is calculated. Depth averaged tidal and non-tidal currents are obtained, as for the sea-level, applying least square harmonic analysis.

3. Methods

In this work the non-tidal response of the water flow between the Lagoon of Venice and open sea will be addressed primarily by studying in details strong atmospheric forcing events which largely coincide with the “acqua alta” episodes. A criterion for the definition of “events”, is based on the search for the times when the sea level exceeded the one meter over mean sea level, as recorded at P.ta Salute tide gauge for the year 2002. Such a reference height is significant because it is responsible of the flooding of 10% of Venice town area. Hourly values of sea surface elevation are first divided into five centimetre classes, starting from the height of eighty centimetres up to values that exceed one metre. Once these times are obtained, time series of wind and pressure up to a week before the events are analysed.

On the other hand, statistical methods (harmonic and spectral analysis) are useful in understanding the so called “ensemble” (average) properties of the signal, while the analysis of events helps in studying the response to transient events which might not be so evident in average statistical properties of time-series.

3.1. Least square harmonic analysis

Theoretical basis for least square harmonic analysis (LSHA) is described in many works [Dronkers, 1964; Jenkins and Watts, 1969; Bloomfield, 1976]. Given a number of fixed frequencies which are supposed to be contained in a signal, LSHA fits the signal to a sum of sinusoidal terms, looking for a particular set of harmonic constants (amplitude and phase). The method minimizes the square of the distance of the reconstructed signal with respect to experimental data.

Sea level and horizontal current time series at each depth are analysed with the aid of a code named *t_tide*, written in MATLAB language [Pawlowicz et al., 2002] on the basis of a FORTRAN code [Foreman, 1976]. A different approach is used for harmonic analysis of scalar time series (such as sea surface elevation) and vector time series (such as horizontal currents), as described in Foreman, (1976 & 1977). In the latter case, tidal ellipse parameters are obtained.

Tidal constituents are included in the analysis according to the Rayleigh criterion; for a comparison with other criteria, see [Jay & Flinchem, 1999]. Long time series will include in the analysis a large number of tidal constituents, so that the astronomical signal will be extracted with great accuracy. The choice of tidal constituents used to extract tidal currents from the experimental time-series is a *Signal – to – Noise Ratio* (*SNR*) major or equal to two; this means that only those tidal constituents with SNR >= 2 will be included in the “synthetic” signal. In Venice Lagoon, this choice will include the main diurnal and semidiurnal frequency, together with many minor tidal harmonics. The contribution of tidal oscillations to the overall variability is expressed as a percentage of tidal variance with respect to the total one.

3.2. Spectral analysis

Spectral analysis describes a time-series (signal, random process or system) in terms of the variance distribution over a frequency range. Estimation of power spectra of time-series of finite length can be obtained in many different ways, both parametric and non parametric [Jenkins and Watts, 1969; Wei, 1990]. In this work, power spectra of non-tidal current time series and forcing functions (wind stress and atmospheric pressure), as well as cross – spectra and phase spectra, are obtained according to a non parametric method proposed by Welch, 1967; Harris, 1978; Attivissimo et al., 1995; Trethewey, 1999; Jokinen et al., 2000. A set of MATLAB functions have been written on purpose. Each time series is divided into 512 hourly value segments; a 50% overlap with the previous segment is introduced. Each sub sample is detrended in order to remove the constant term (the zero frequency term), and then a cosine bell window is applied. For each weighted segment the discrete Fourier transform (DFT) *via fft* is found, and a modified periodogram is estimated by multiplying the DFT by its complex conjugate. The *power spectral density* is finally evaluated averaging each single modified periodogram estimate. Whenever two or more time series are involved, a *cross spectral density* can be obtained in a similar way; the cross periodogram is evaluated for each sub sample by multiplying the DFT of each segment of the first time series by the complex conjugate of the DFT of segment of the second time series. The cross spectrum is finally obtained by averaging each single estimate. Since the cross spectrum is not, in general, a real quantity, the module must be considered.

The phase spectrum is useful to evaluate the relative phase of two or more processes as a function of frequency, i.e. to evaluate the lag of the response of a system to a forcing function at each frequency. Once the cross spectrum is calculated, the phase spectrum is easily obtained as the arctangent of the ratio of the real to the imaginary part of the cross spectrum (details can be found in [Jenkins and Watts, 1969; Wei, 1990].

Seiches are always present in non-tidal Adriatic sea surface elevation time-series, and in non-tidal currents as well, their amplitude depending only on meteorological forcing that excites them. Because of such an ubiquitous presence and in order to analyse sub-inertial variability, a low pass filtering is necessary to remove fluctuations on time scales shorter than a day. A linear low pass filter is applied to non-tidal currents and sea-surface elevation time-series. The filter used is the *pl33* filter (a cosine bell filter) [Rosenfeld, 1983, WHOI Technical report 85-35, p. 21]. Filter half amplitude period is 33 hours, so that only periods greater than 33 hours are present in low passed data.

4. Some results of spectral analysis of non-tidal currents, levels and forcing functions

Power spectra (Figs. 2 and 3) of non-tidal currents at the Lagoon inlets (Chioggia, Malamocco and Lido) show many common properties, revealing however at the same time some interesting features at Malamocco inlet which are not evidenced at other two inlets.

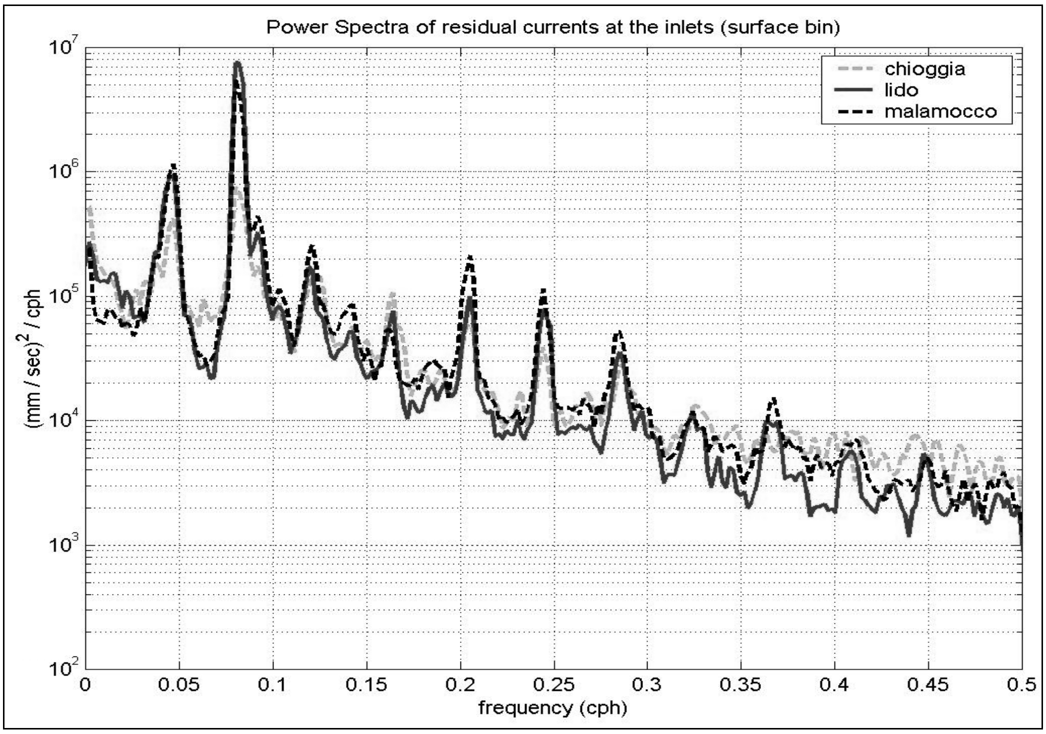

Fig. 2 – Power spectrum of residual (non tidal) currents at the three inlets of Chioggia, Malamocco and Lido for the surface bin.

All the spectra show broad peaks centred on the Adriatic seiches frequency bands, respectively at $11^{h}40^{min}$ for binodal seiche, and at $22^{h}14^{min}$ for the fundamental longitudinal uninodal seiche. Peaks at these frequencies also exist in residual sea level, as shown by power spectra of residual level at oceanographic tower, as well as at all tide gauges analysed. The periods well agree with the values obtained by *Kasumovic* which can be found in [Caloi, 1973]. Lido and Malamocco show stronger diurnal seiches than the semi-diurnal ones, while in Chioggia the two have variance of the same order of magnitude.

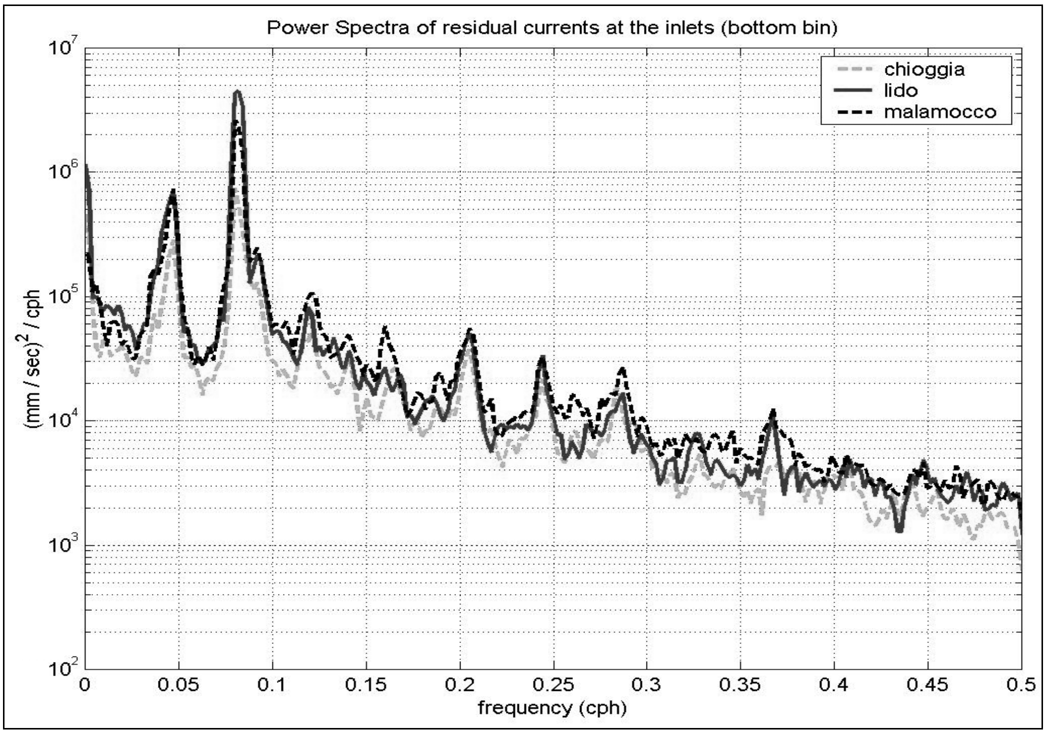

Fig. 3 – Power spectrum of residual (non tidal) currents at the three inlets of Chioggia, Malamocco and Lido for the bottom bin.

If we compare the non-tidal currents at seiche frequencies between different inlets and along the water column, we notice how the seiche peaks are, in general, greater at Lido than at Malamocco and Chioggia; also, a peak decrease with depth can be seen. Phase spectra do not seem to reveal any significant phase variations along the water column, and the same seems to hold between similar depths at the three inlets. These results thus show that seiche induced currents are in-phase over the whole water column at each inlet and have negligible phase differences between inlets. (Fig. 4)

According to [Polli, 1962], the third peak centred at 8^h period might correspond to a binodal seiche of a hypothetical Adriatic basin with a closed border at Otranto Strait.

Many works [Caloi, 1938, 1973; Mosetti, 1971] focused mainly on non-tidal levels in the Adriatic Sea, have shown that seiches, as well as long period fluctuations, can be triggered by atmospheric perturbances that induce temporary water displacement. When the forcing ceases, the equilibrium surface is reached through a series of modes of oscillations. Seiches can then be thought as a sort of an indication of the meteorological forcing both in non-tidal sea level and in non-tidal currents.

Low-frequency bands (i.e. the long period flow variations) in Malamocco show significant differences with respect to Chioggia and Lido. In Malamocco, in fact, the two prominent seiche peaks contain the major portion of non-tidal variance, while only a minor portion of non-tidal energy is associated with long term oscillations. Seiches can thus be considered the most important non-tidal fluctuations in Malamocco. On the contrary, long period variability appears very important in Lido and Chioggia non-tidal currents, as shown by power spectra, and great portion of the variance is present in this frequency band.

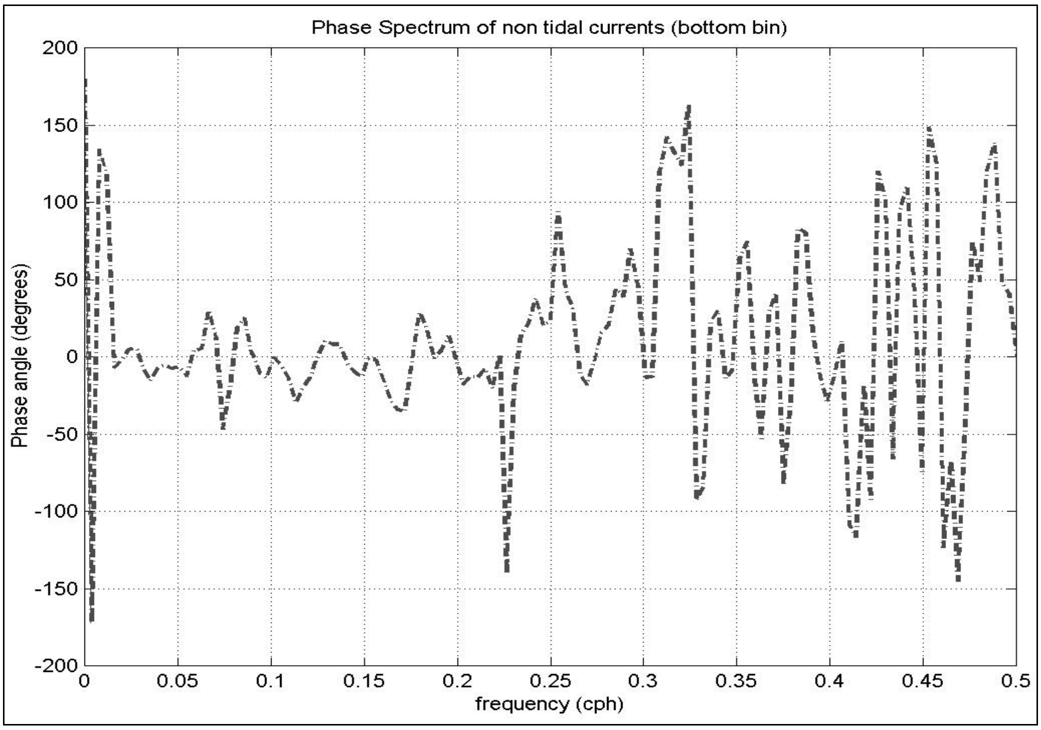

Fig. 4 – Phase spectrum of residual (non tidal) currents between Chioggia and Lido for the bottom bin.

Power spectrum of Chioggia non-tidal currents, in particular, reveals that low frequency peaks are even stronger than diurnal and semidiurnal seiche peaks. Phase spectra of residual currents in Chioggia and Lido at low frequencies reveal that long-period currents are almost out-of-phase, the maximum phase difference of long term non-tidal currents between the two inlets being equal to 150° - 160°, that's to say an inflow at Lido (or Chioggia) is balanced by an outflow at Chioggia (or Lido). If we show that these low-frequency flow variations are associated with the wind then the scheme of the internal circulation pattern generated by bora with the inflow in Lido and outflow in Chioggia proposed by Zecchetto (1997) would be confirmed.

Power spectra of wind stress components show high variance content at very low frequencies close to zero. In addition, in particular the north – south component τ_y, show an important peak centred on diurnal frequencies which is however almost two orders of magnitude lower than the zero-frequency variance and it is probably associated to thermally driven sea breeze.

5. Atmospheric effects on non-tidal low-frequency sea level and currents: The events

The results of the search for events in year 2002 at P.ta Salute tide gauge are briefly summarized below (Tab. 1).

Tab. 1 - Percentage of hourly events exceeding the reference level of one meter at P.ta Salute tide gauge for year 2002.

Sea level statistics at P.ta Salute tide gauge for year 2002		Percentage of hourly events
Level >= .80	: 301 of 8760 obs	3.44%
Level [.80,.85)	: 93 of 8760 obs	1.06%
Level [.85,.90)	: 70 of 8760 obs	0.80%
Level [.90,.95)	: 47 of 8760 obs	0.54%
Level [.95, 1)	: 34 of 8760 obs	0.39%
Level >= 1 m	: 57 of 8760 obs	0.65%

The last line refers to the times during year 2002 when the criterion chosen for flooding events is satisfied. Only 57 hourly values are higher than the reference level of one meter, so that the overall percentage of events is less than 1%. However, the occurrence of almost all flooding events, more than 93% of the all of them, took place in autumn or winter months of the year 2002 (September to December 2002). Moreover, more than 60% of the events took place in the last fifteen days of November 2002. In November, the strongest flooding of the year 2002 also occurred, which reached the level of 144 centimetres. A check of the hourly values of wind speed and direction at the oceanographic tower, located eight miles off the coastline, reveals that sirocco wind occurred with 72% of flooding events in the year 2002. Bora wind was blowing when 20% of flooding events occurred. Sirocco and bora winds are mainly responsible for water rising in the Lagoon of Venice as already evidenced by e.g. [Pirazzoli, 1999], and are the two typical seasonal winds in the area. Bora is a katabatic wind which blows from ENE, piles up water along the Italian coastline, and since in the lagoon it blows parallel to its longitudinal axis from north to south, generates locally sea level differences between its northern and southern extreme on the order of tens of centimetres [Rusconi, 1994; Zecchetto, 1997]. Sirocco wind, in general is weaker than bora wind, blows from SE along the Adriatic main axis with a fetch larger than bora, being responsible for storm surges on Adriatic basin scale. These surges reach, in general, the maximum value in the northernmost part of the Adriatic. It does not seem, however, that sirocco generates locally important piling up of water in the lagoon as it is the case of bora.

In order to evaluate the response of the lagoon to wind and pressure forcing, two episodes corresponding to two wind scenarios (sirocco and bora winds) are analysed. The first event occurred in November 2002, when the strongest 2002 flooding event happened. The second one is a bora wind event, which happened in the first two weeks of December. This event is very similar to the one described in [Rusconi, 1994] and also similar to the one found in [Zecchetto, 1997].

5.1. The "acqua alta" event in November 2002

The flooding event of the 16th November 2002 reflects a possible scenario of the genesis and evolution of the inlet flow associated to acqua alta under the influence of sirocco. Ever since November 12 there was a continuous wind building up. A strong sirocco wind started 14 November with a first peak of speed of about 10 m/sec occurring in the second half of 14 November. After short period of weakening at the second half of 15 November there was an interval of more than a day of the sirocco wind reaching even 15 m/sec. As a response to such a wind forcing there was a continuous inflow at Lido and an outflow at Chioggia probably due to wind set-up over the open Northern Adriatic area. Sirocco locally has a strong component perpendicular to lagoon islands generating also set-up along the lagoon shore. Differences in sea-level at Malamocco and oceanographic tower reached about 15 cm magnitude and the maximum cross-shore sea-level slope occurred slightly after the wind maximum (Fig.5).

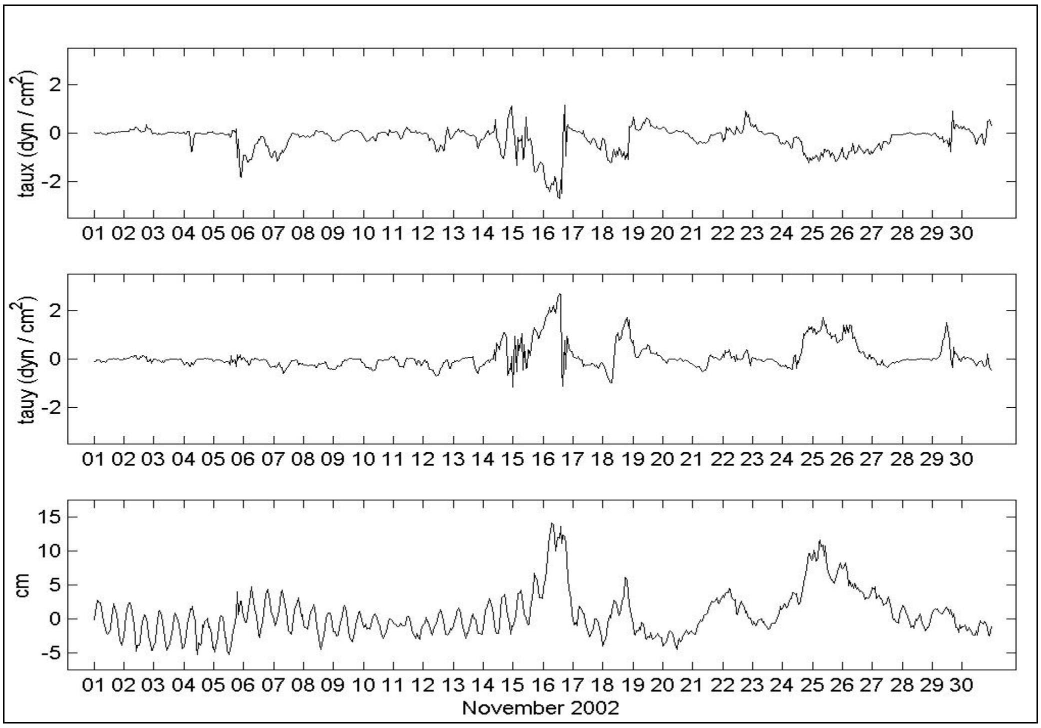

Fig. 5 – Time series of wind stress components (dyn / cm^2), and non tidal sea level difference (cm) between the Oceanographic Tower and Malamocco inlet tide gauge for November 2002.

It is interesting to note that time-series of the cross-shore sea-level differences show rather strong semi-diurnal oscillations which suggest that semi-diurnal seiche behaves as a progressive Kelvin wave around the Adriatic coast. Only after a cessation of the wind, strong outflow emptying the lagoon through all three inlets took place.

Wind forcing is in general responsible for sea level slope both inside and outside the lagoon. In this case, no significant sea level difference is found inside the lagoon. On the contrary, significant wind set – up is found between the inlets and the oceanographic tower.

The analyses of low passed residual currents along the water column at each inlet show similar features, i.e. the whole water column is forced in the same way by meteorological forcing, and no differences exist between the surface and the bottom layer. At the same time, a time shift seems to exist between the maximum inflow at the three inlets. Malamocco inflow leads both Lido (3 hours) and Chioggia (7 hours), and leads also the maximum level at P.ta Salute (12 hours). Such a delay for Malamocco inflow with respect to P.ta Salute maximum level is also described in a paper by [Accerboni & Mosetti, 1971] where electromagnetic current meter recordings are analyzed.

Outflow occurs almost at the same time at Lido and Malamocco, a delay of one hour existing between the maximum at Malamocco and the maximum outflow at Lido. Finally, a four hour delay exists between Chioggia with respect to Malamocco maximum outflow (Fig. 6).

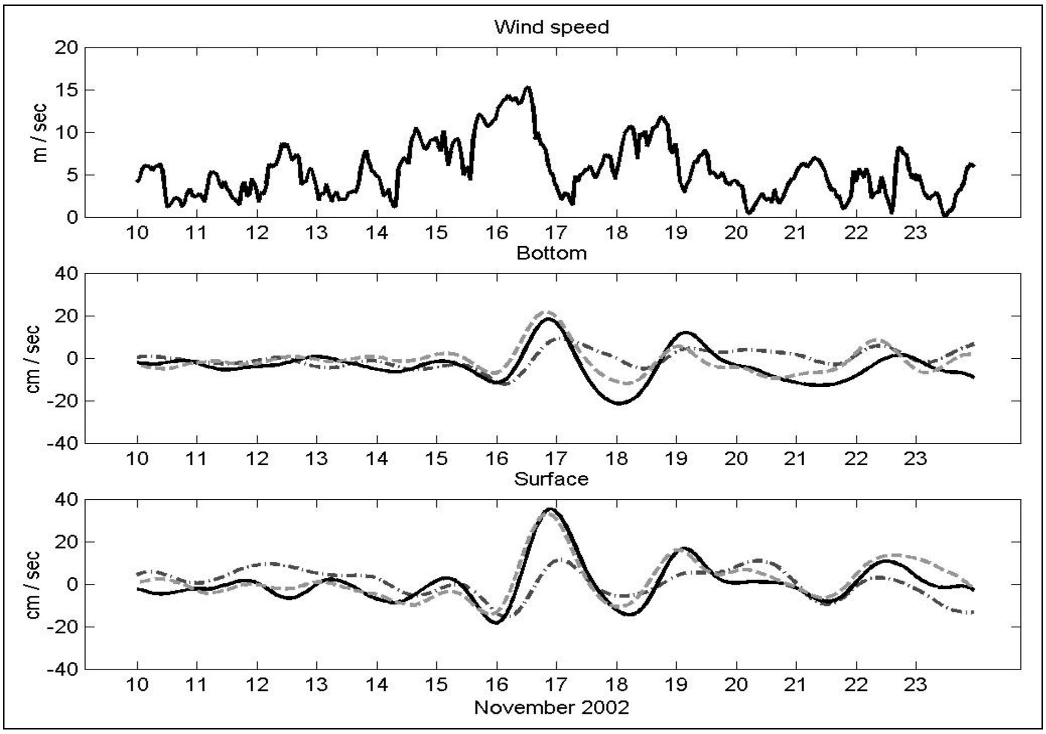

Fig. 6 – Time series of wind speed and low – passed non tidal currents for the bottom bin and the surface bin at Chioggia inlet (dash – dotted line), Malamocco inlet (dashed line) and Lido inlet (solid line) for November 2002 flooding event.

5.2. The bora wind event in December 2002

December 2002 bora seems to confirm the circulation pattern suggested in [Umgiesser, 2000] and in [Zecchetto, 1997] for bora wind regime.

A strong easterly wind blew since November, 30th, up to December, 13th, with a mean speed of 11 m / s (standard deviation 4.5 m / s) and mean direction of 230°, clockwise with respect to geographical North (standard deviation 23°). Wind direction can be assumed to be constant around 240° (standard deviation 5°) since December, 3rd, up to December, 10th, with a mean speed of 15 m / s (standard deviation 2 m / s).

In this situation is clearly present local (internal) wind set-up since in parallel of the general building up of the wind, there is continuous increase in a nort-south sea-level slope (Fig. 7). Thus, sea-level differences between northern and southern part of the lagoon (Le Saline and Chioggia Vigo tide-gauge stations) reached about 20 cm.

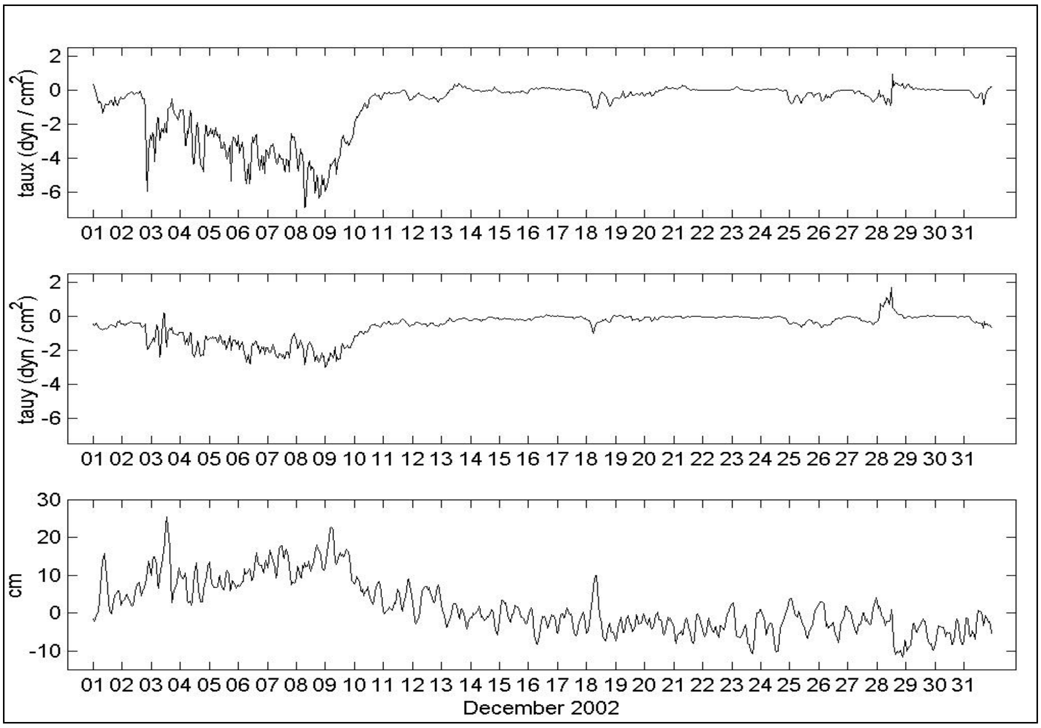

Fig. 7 – Time series of wind stress (dyn / cm^2) at the Oceanographic Tower and time series of non – tidal sea level differences (cm) between Le Saline tide gauge (Northern Lagoon) and Chioggia Vigo tide gauge (Southern Lagoon) for December 2002 bora wind event.

Low passed residual currents at the three inlets reveal significant differences with respect to the sirocco episode (Fig. 8). Bora wind forced a marked water inflow along the whole water column at Lido, while at Malamocco an inflow on the bottom seems to be balanced by an outflow in the upper layer, so that it does not contribute in a significant way to non-tidal low-frequency water exchange between the lagoon and the open sea. On the contrary, Chioggia reveals some unexpected features. The first wind impulse forces only the upper layer, while the bottom layer maintains the "memory" of a circulation pattern internal to the lagoon. A few days after bora wind was blowing, the whole water was characterized by the outflow. A comparison of the low passed surface layer residual currents at the three inlet shows that the first wind impulse forces a water inflow at each inlet, but only Chioggia and Lido seem to contribute in a significant way to water exchanges. Moreover, a delay exists between Chioggia and Lido, the first lagging the second one by about twelve hours.

This flow pattern with the inflow in Lido and outflow in Chioggia can be explained in terms of the sea-level differences between the lagoon and the open sea due to the internal lagoon wind set-up. In the northern part of the lagoon the bora wind generates sea-level lower than at the open sea resulting in an inflow in the Lido inlet. On the other hand, in the southern part of the lagoon internal sea-level is higher than at the open sea generating an outflow through the Chioggia inlet.

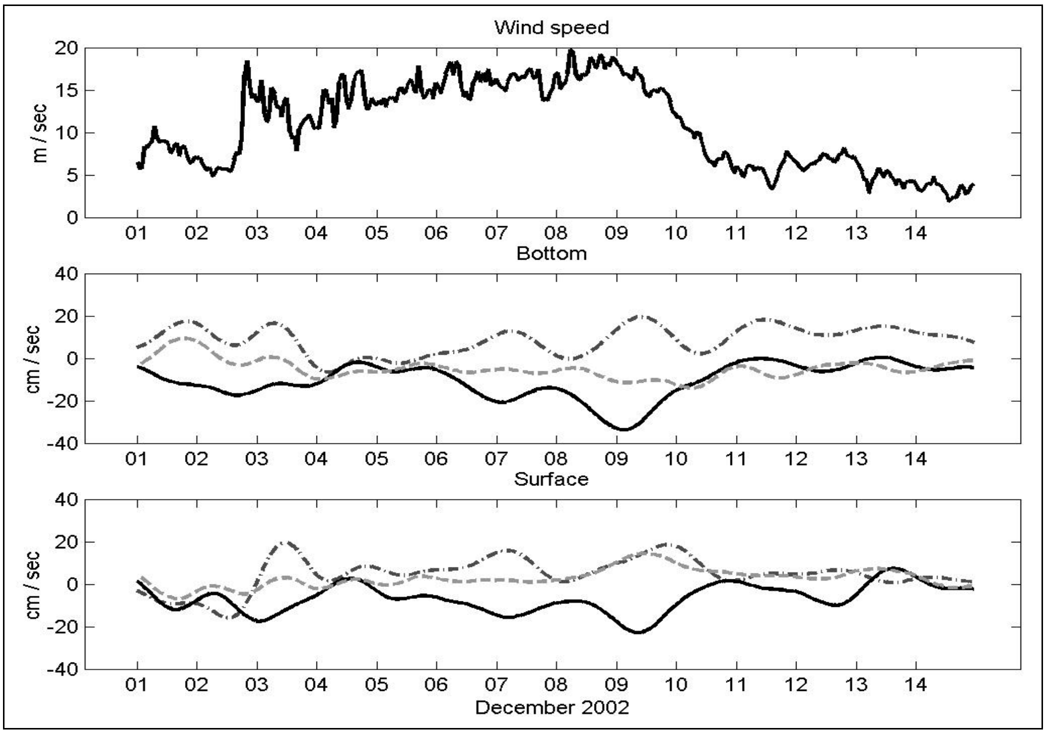

Fig. 8 – Time series of wind speed and low – passed non tidal currents for the bottom bin and the surface bin at Chioggia inlet (dash – dotted line), Malamocco inlet (dashed line) and Lido inlet (solid line) for December 2002 bora wind event.

6. Conclusions

Time series of non-tidal sea level, both inside and outside the lagoon, together with non-tidal currents at the inlet are examined, in order to evaluate response of the Lagoon to atmospheric forcing.

Spectral analysis of the non-tidal flow has shown common features for the three inlet (the ubiquitous presence of seiche motions), but at the same time revealed a different behavior of Malamocco with respect to both Lido and Chioggia at low frequencies. No significant low-frequency motions are present in Malamocco so the response to atmospheric forcing there appears mainly at Adriatic seiche frequencies. Lido and Chioggia, in addition to strong seiche induced motions show appreciable long-term circulation pattern. Also, cross-spectral analysis suggests that low-frequency flow in Lido is out-of-phase with respect to those in Chioggia. Flow variations at Adriatic seiche frequencies (diurnal and semi-diurnal ones) are in-phase at all three inlets.

In order to describe in details wind-induced circulation patterns in the lagoon inlets, one prominent sirocco and one bora event were chosen.

The sirocco event shows that the inflow occurs in all three inlets with only a slight phase lag. The same happens with the outflow taking place almost simultaneously in all three inlets. Sirocco wind locally has a strong component perpendicular to lagoon’s islands generating cross-shore sea-level gradient outside the lagoon which then generates an almost simultaneous inflow and, after its cessation, the outflow.

In the bora wind scenario, an internal circulation pattern (as proposed by numerical modeling) seems to be confirmed. Water inflow occurs mainly through Lido inlet, and is balanced by an outflow from Chioggia. Malamocco does not contribute to water exchanges with the Adriatic Sea. This pattern can be explained by the internal sea-level slope between the northern and southern part of the lagoon generated by bora, which locally blows parallel to the lagoon longitudinal axis. The internal sea-level set-up is responsible for the sea level difference between the lagoon and open sea of opposite signs in northern and southern parts (Lido and Chioggia) which then generates inflow in the northern and the outflow in the southern part.

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MESOZOOPLANKTON AT THE THREE INLETS OF THE LAGOON OF VENICE: LONG- AND SHORT-TERM SURVEYS 2001–2002

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Riassunto

Scopo di questa ricerca, eseguita alle tre bocche di porto (nord, o di Lido; centrale, o di Malamocco; sud o di Chioggia) della laguna di Venezia in entrambe le fasi tidali, era confrontare tra loro le comunità zooplanctoniche da un punto di vista sia quantitativo che qualitativo. Le serie annuali evidenziano alcune differenze tra comunità di alta e bassa marea, con abbondanze mediamente superiori durante la fase uscente; tale fenomeno appare principalmente dovuto al copepode *Acartia tonsa* Dana, di recente ingressione in laguna. In marea entrante le comunità appaiono sostanzialmente le stesse alla bocca di porto del Lido e di Malamocco, mentre quella di Chioggia presenta caratteristiche alquanto differenti. In marea uscente, causa la diversa idrodinamica dei tre bacini, alla bocca di Lido prevale *Acartia clausi* Giesbrecht, un copepode ben adattato ad ambienti estuarini costieri, a Malamocco *A. tonsa,* mentre nessun taxon prevale nettamente nella comunità di Chioggia. Il confronto tra le comunità zooplanctoniche raccolte contemporaneamente alle tre bocche durante una campagna estiva ad alta frequenza temporale confermano come le abbondanze siano superiori in alta marea a Chioggia, mentre l'opposto si verifica alle altre due. Data la stagione calda, nei campioni prevalgono i taxa termofili: i cladoceri (soprattutto *Penilia avirostris* Dana) in marea entrante, e *A. tonsa* in uscente, soprattutto a Malamocco.

Abstract

This study, carried out at the three port inlets (northern or Lido, central or Malamocco, southern or Chioggia) of the Lagoon of Venice at both flow and ebb tide, deals with quantitative and qualitative comparisons among the zooplankton communities. The annual survey results showed some differences between flood and ebb tidal phases. On average, loads were higher during ebb; this phenomenon was mainly due the copepod *Acartia tonsa* Dana, a new incoming species more abundant in the inner areas of the Lagoon. During flood tides, incoming communities were substantially the same both in the northern and central inlets, whereas at Chioggia some differences were highlighted in the zooplankton composition. During ebb tide, at Lido *Acartia clausi* Giesbrecht, a copepod well adapted to harbour waters, showed its highest values and *A. tonsa* at Malamocco. At Chioggia, none of the most abundant species of copepods prevailed. The comparison among zooplankton communities collected during a short term summer cruise confirmed this trend: at the southern inlet (Chioggia) the abundances were higher at flood than at ebb tide, whereas opposite patterns were

observed at the other inlets. Due to the summer season, cladocerans (mainly *Penilia avirostris* Dana) dominated in flood tide samplings; at ebb tides *A. tonsa* abundances were higher, especially in the central basin.

1. Introduction

The Lagoon of Venice communicates with the sea through three inlets called Lido, Malamocco and Chioggia, leading respectively into the northern, central and southern basins (see Fig. 1 in Bianchi *et al*., this vol.). The Lagoon, like all brackish ecosystems, is greatly influenced by space-time variations in hydrochemical parameters and tidal dynamics (UNESCO, 1981), so that plankton communities are heavily exposed to physical stresses.

Previous studies carried out on zooplankton in the Lagoon have highlighted a phenomenon called "vivification" from the Adriatic waters (D'Ancona *et al*., 1951; Ranzoli, 1954): unlike what normally takes place in estuarine ecosystems (Colombo *et al*., 1984), no autochthonous species reached high abundance values, so that the marine zooplankton flowing into the Lagoon proved more abundant than that outflowing.

Although in the last thirty years the composition of the lagoon zooplankton has greatly changed (Comaschi *et al*., 2000), only since the 1990^{s} an inversion of the just mentioned trend has been observed (Comaschi and Cavalloni, 1995). This was mainly due to the presence of *A. tonsa*, only recently entered in the Mediterranean Sea (Gaudy and Vinas, 1985), and never found in the Lagoon before 1990 (Carazzi and Grandori, 1912; Ranzoli, 1954; Comaschi *et al*., 2000). At the present time, the zooplankton community in the inner northern basin, composed almost entirely of individuals belonging to the species *A. tonsa* (Comaschi and Cavalloni, 1995; Bianchi *et al*., 2002), has proved more abundant than that living in areas affected by seawaters (Bianchi *et al*., 2003).

However, even if several researches on zooplankton were performed in the three basins of the Lagoon (northern basin: Comaschi and Martino, 1981, Socal *et al*. 1987; central basin: Comaschi, 1976, Comaschi and Dalla Palma, 1988; southern basin: Canevari, 1994; Minio, 1995; Reale, 1998), until now an effort to compare the features of zooplankton communities of coastal and lagoon waters had never been attempted simultaneously at all three mouths; so the present research allowed us to fill this gap and to highlight any difference among inflowing and outflowing communities.

2. Materials and methods

Zooplankton was collected simultaneously at the three inlets following two sampling strategies at different time-scale, thus allowing both to assess differences in exchange rates and to follow seasonal trends: 1) monthly, from July 2001 to June 2002, both at flood and ebb syzygial tides; 2) during an intensive seasonal cruise carried out on August 2002, following eight syzygial tidal cycles (48h), at 3 hours intervals.

The zooplankton samples were collected from bottom to surface by means of a Clarke-Bumpus horizontal sampler (equipped with a net of 200 µm mesh size), and fixed with 4% of buffered formalin. Statistically significant subsamples were obtained by means of a Folsom splitter (Mc Ewen *et al*., 1954). Only copepods and cladocerans, the most abundant taxa, were determined to species level.

For the long term series, mean temporal values from the original data of zooplankton abundances and some environmental parameter values (i.e., temperature, salinity, saturation percentage of dissolved oxygen, chlorophyll-a, phaeopigments, particulate organic carbon (POC), and total suspended matter (TSM), both organic and inorganic) (Bianchi *et al*. this vol.), were used to produce data matrices and perform multivariate analyses using P.R.I.M.E.R. software. After standardizing data on matrices of the Bray-Curtis similarity index, hierarchical agglomerative clustering was carried out with the group-average link (Clarke and Warwick, 1994). MDS ordination (non-metric multi-dimensional scaling) was applied to the same similarity matrices, and the stress value was calculated measuring the goodness-of-fit of bidimensional plot ordination (Clarke and Warwick, 1994). STAX2000 software produced a condensation of the original matrix into fusion groups, for variables and objects separately. A principal components analysis (PCA) was then carried out on the same data, using the biplot technique: this allows simultaneous ordination of objects and variables in the same space, thus highlighting trends and associations (Lagonegro and Feoli, 1986).

3. Results

During the long term surveys, zooplankton abundances ranged from a maximum of 14.575 ind m^{-3} on August to a minimum of 85 ind m^{-3} on January, both at Malamocco-flood (Fig. 1). Copepods prevailed; among them, mainly *A. clausi*, well adapted to lagoon areas influenced by inflowing waters, *A. tonsa,* living in the most confined zones (Bianchi *et* al., 2003), and *Paracalanus parvus* Claus, a species of coastal water. Other well-represented taxa were cladocerans, and larval stages of decapods, respectively during flood and ebb tides. Cladocerans showed the lowest abundance values at Chioggia, where the highest concentration of *P. parvus* was also observed (Fig. 2).
Contrarily to what had been previously reported (Ranzoli, 1954; Comaschi, 1976), zooplankton abundances proved higher during the ebb tides both at Lido and Malamocco, whereas at Chioggia the highest concentration was observed at the flood tide, mainly due to high amounts of *P. parvus* (Fig. 2).

During flood tides, *A. clausi* in percentage prevailed in the northern basin (35%), and *P. parvus* (37%) in the southern one. At any port mouth, higher abundances of *A. tonsa* and lower of cladocerans were observed during ebb tides. During the same tidal phase the highest per cent values recorded were *A. clausi* (34%) and larvae of decapods (19%) at Lido, *A. tonsa* (47%) at Malamocco; at Chioggia the three most abundant species of copepods showed similar percentages (Fig. 3).

The biplot technique, carried out on the condensated matrix, holding associations of variables and cluster of objects (Fig. 4), linked Lido-flood with Malamocco-flood with association 1 of variables, grouping organisms well adapted to marine habitats, and some environmental parameters (i.e. temperature, salinity and dissolved oxygen). The series of Lido-ebb was characterised by group 2 of variables, composed of euryecious species, typical of coastal waters; among these, decapod larval stages were the most abundant. In the PCA ordination space, Malamocco-ebb and Chioggia-ebb were very closed, but characterised by two different associations of variables: Chioggia-ebb by the

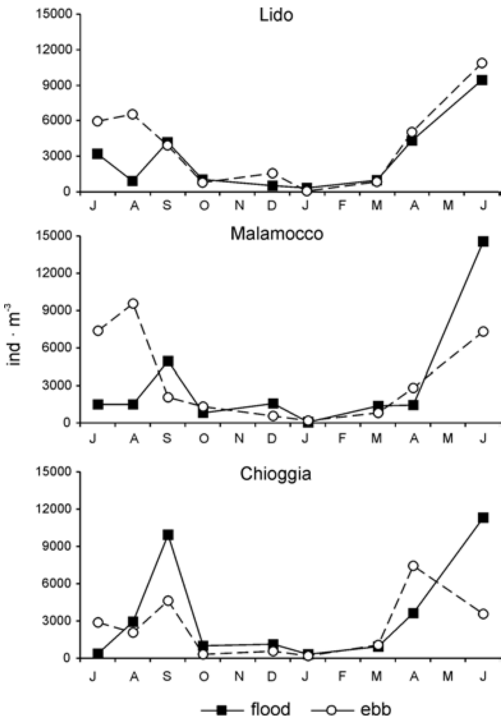

Fig. 1 - Abundances of total zooplankton (ind m^{-3}) at the three port mouths at flood and ebb tides. July 2001 – June 2002.

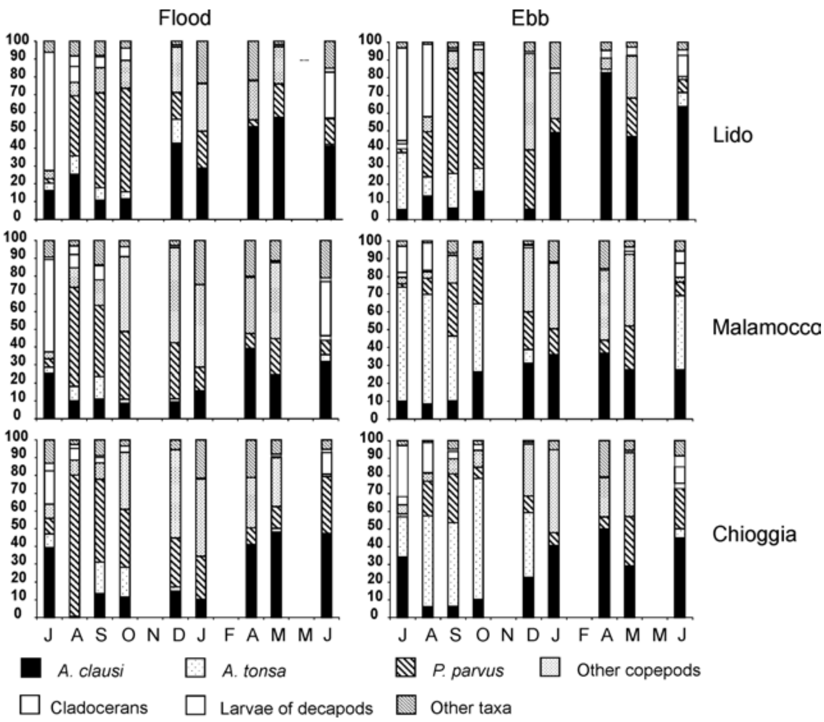

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Fig. 2 – Monthly percentages of main zooplankton taxa at the three port mouths at flood and ebb. July 2001 – June 2002

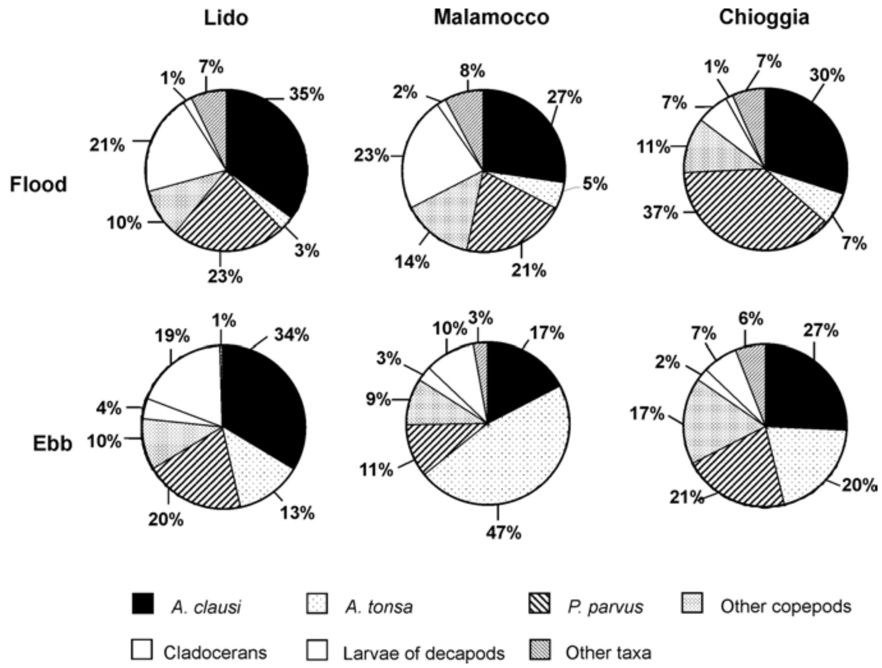

Fig. 3 – Mean percentages of main zooplankton taxa at the three port mouths at flood and ebb. July 2001 – June 2002.

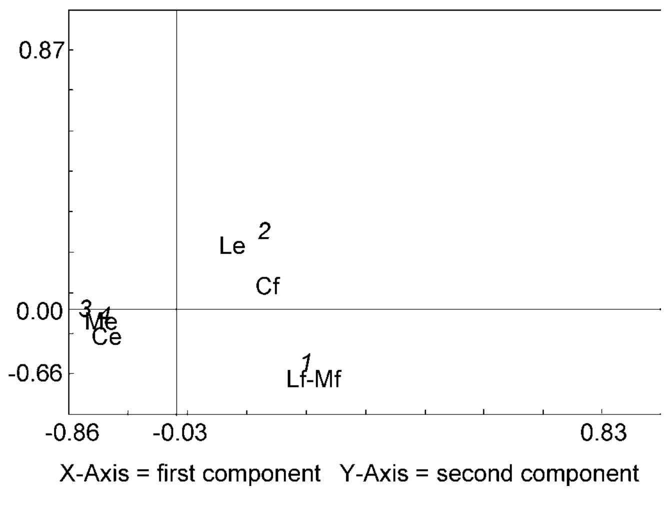

Fig. 4 – Principal components analysis (PCA) by means of the biplot technique. Lf: Lido-flood; Le: Lido-ebb; Mf: Malamocco-flood; Me: Malamocco-ebb; Cf: Chioggia-flood; Ce: Chioggia-ebb.. *1*, *2*, *3*, *4*: associations of variables; *1*: *C. typicus*, *O. nana*, Cladocera, Chaetognatha, *N. scintillans*, larval stages of Echinodermata, Bivalvia and Gastropoda, temperature, salinity, dissolved oxygen; *2*: *A. clausi*, *P. parvus*, *C. ponticus*, *E. acutifrons*, *Clausocalanus* sp. pl., *Oncaea* sp. pl., decapod larval stages, organic suspended matter; *3*: *O. similis*, *P. elongatus*, *T. longicornis*, Harpacticoida, clorophyll-a, POC, TSM; *4*: *A. tonsa*, inorganic suspended matter.

association 3, grouping epibenthic Copepoda Harpacticoida coming from inner areas (probably due to turbulence in shallow waters), some species from marine coastal waters well adapted to lagoon habitat, and environmental parameters (i.e. clorophyll-a, POC and TSM); Malamocco-ebb was characterised by the association 4, grouping only *A. tonsa* and inorganic suspended matter. No association characterised Chioggia-flood, although the biplot technique placed it near the group Lido-Malamocco at flood (Fig. 4).

Also during the short-term survey performed in August 2002, total zooplankton abundances were higher during ebb phase at Lido and Malamocco inlets, whereas the opposite occurred at Chioggia mouth. The lowest values were recorded at Lido (3210 ind m^{-3}), the highest one at Chioggia (5114 ind. m^{-3}) (Fig. 5). The most abundant taxa were the same as in the monthly samplings (Fig. 6). During flood tides, due to the summer season, at all inlets cladocerans (mostly *Penilia avirostris* Dana) dominated, especially at Chioggia (83%), while during ebb tides *A. tonsa (* mainly at Malamocco, 33%), and larval stages of decapods (mainly at Lido, 15%), showed the highest percentages.

Regression calculated between tidal heights and total mesozooplankton abundances resulted statistically significant only at Malamocco (negative correlation) and Chioggia port mouths (positive correlation) (Tab. 1). Regressions between tidal heights and the abundances of *A. tonsa*, *A. clausi* and *P. parvus*, were always significant for *A. tonsa* (negative correlation, due to its inner origins), significant only at Chioggia inlet for *P. parvus* (positive correlation, showing its neritic derivation), never for *A. clausi* (Tab. 1).

Tab. 1 – Correlation coefficients and significance of regression between tidal heights (independent variable) and abundances of total zooplankton, *Acartia clausi*, *Acartia tonsa* and *Paracalanus parvus* (dependent variables). * = 0.01< P ≤0.05; ** = 0.001< P ≤0.01; n.s. = not significant.

	Lido		Malamocco		Chioggia	
Total zooplankton	-0.234	n.s.	-0.677	*	0.654	*
A. clausi	0.553	n.s.	-0.651	n.s.	0.044	n.s.
A. tonsa	-0.778	**	-0.814	**	-0.838	**
P. parvus	0.587	n.s	0 .340	n.s.	0.711	*

4. Discussion

In the Lagoon of Venice, zooplankton communities vary according to several factors, such as seasonal succession of species, tidal phases and geomorphological differences (i.e. in shape, size, and depth) among the three basins. The annual cycle of zooplankton, studied during several previous surveys (Comaschi, 1976; Comaschi and Martino, 1981; Comaschi and Dalla Palma, 1988; Canevari, 1994; Bianchi *et al*., 2003), is well known.

Thus, the main aim of this study was to highlight the variations between the tidal phases and the differences among the port-mouths.

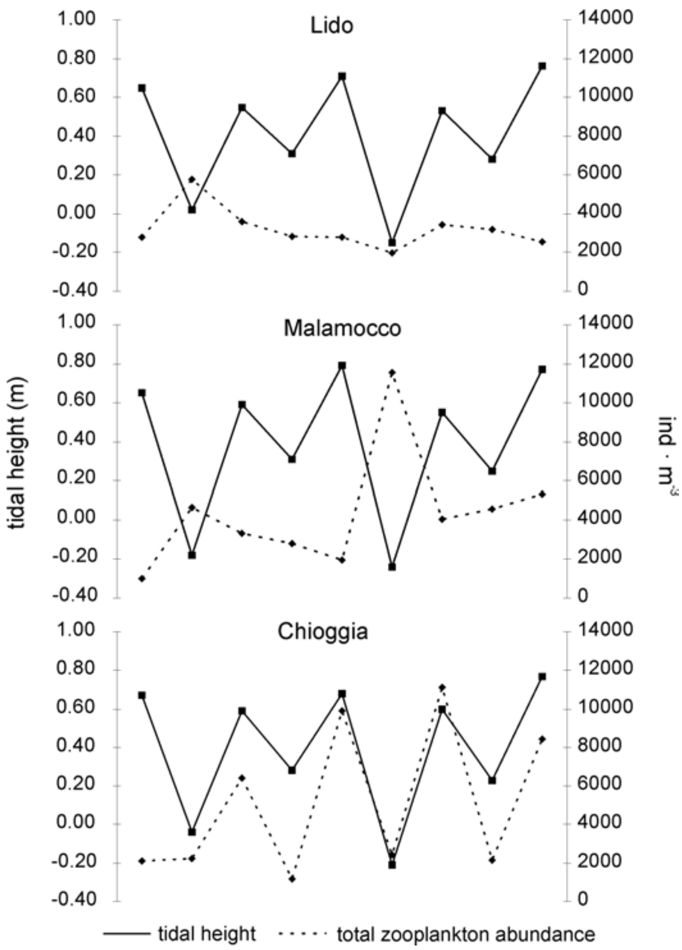

Fig. 5 – Abundances of total zooplankton (ind m^{-3}) and tidal height at the three port-mouths during short-term surveys in August 2002.

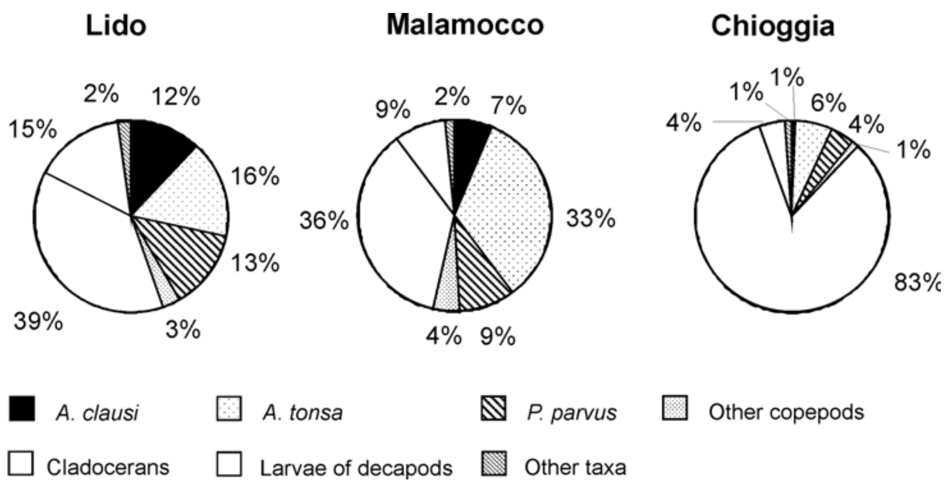

Fig. 6 – Mean percentages of main zooplankton taxa at the three port-mouths during short-term surveys in August 2002.

Literature on plankton in the lagoon of Venice reports the phenomenon of “vivification” (D’Ancona *et al*., 1951; Ranzoli, 1954), linked to low abundances of species living in the inner lagoon waters. The recent ingression of *A. tonsa*, with a strong affinity for high trophic habitats (Paffenhofer and Stearn, 1988), may have reversed this trend.

In fact, this paper points out that, at the present time, zooplankton abundances are on average higher at ebb than at flood tide (Fig. 1), whereas the “vivification” phenomenon persists at Chioggia inlet (Fig. 5).

During flood tide, at Lido and Malamocco zooplankton community compositions were substantially the same, whereas at Chioggia showed different features, more resembling those of Lido-ebb. During ebb tide, at Lido the community was more similar to the inflowing ones; conversely, the Malamocco community seemed to be more influenced by the inner waters, exhibiting the highest abundances of *A. tonsa*. At Chioggia, where the highest *P. parvus* and cladoceran abundances were recorded, the community composition was quite different.

These differences are mainly due to the different hydrodinamic of the three basins: at the Lido mouth, during ebb tides, zooplankton comes mostly from an area placed near the port mouth (Treporti channel); in the central basin the outflowing syzygial current drains the waters from the “*barene*” in front of the islands of S. Pietro in Volta and Pellestrina (see Fig. 1 in Bianchi *et al*., this vol.). The different features of the southern basin, both at flood and ebb tide, are probably due to the slower current-speed (Cucco, 2000): water coming from the inner zones of the lagoon takes longer to exit, thus the zooplankton community at this mouth became more diluted. At Chioggia, zooplankton abundances at ebb tide were, on average, the lowest among the three port-mouths, so that there the “vivification” process still there persists.

5. Conclusions

In conclusion, this study highlights that during flood tide at Lido and Malamocco the zooplankton communities were almost the same, quite different at Chioggia. During ebb tide, stronger differences were observed; the community at Lido, dominated by coastal species, little resembles to those of the inner areas; differences between the Malamocco and Chioggia communities also became evident, mostly ascribable to the abundances of *A. tonsa*, low at Chioggia, the highest at Malamocco, which reflected the great difference in water residence times between the two basins, higher in the southern than in the central one.

Acknowledgements

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PHYTOPLANKTON AND PRIMARY PRODUCTION AT THE INLETS OF THE LAGOON OF VENICE

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Riassunto

Nell'ambito del programma di ricerca sulla laguna di Venezia finanziato dal CORILA, linea 3.5, WBS2 "Quantità e qualità degli scambi tra Laguna e Mare", sono stati analizzati gli scambi di fitoplancton tra la laguna di Venezia ed il mare Adriatico, con campionamenti sinottici alle bocche di porto di Lido, Malamocco e Chioggia, da luglio 2001 a giugno 2002.

Il fitoplancton non ha mostrato differenze significative, nè quali- nè quantitative, tra le bocche. Le abbondanze massime sono state osservate nel periodo estivo, quelle minime in inverno. Nanoflagellati e diatomee hanno caratterizzato i campioni dell'intero periodo di analisi con i maggiori contributi medi all'abbondanza totale (rispettivamente 58% e 38% del totale), mentre percentuali molto basse, mediamente pari al 4%, erano a carico di dinoflagellate e coccolitoforidee. Per la maggior parte dell'anno il carico fitoplanctonico di marea entrante è risultato più elevato rispetto a quello di marea uscente. Le abbondanze erano maggiori nelle acque di marea uscente in coincidenza di fioriture, osservate in laguna nell'agosto-ottobre 2001 e nel febbraio 2002.

Le curve luce/fotosintesi sono state analizzate alla bocca di porto del Lido in maggio ed agosto 2002. I valori di produzione potenziale sono variati tra 1,3 e 2,2 $mgC/m^3/h$ in maggio 2002 e tra 5,8 e 6,8 $mgC/m^3/h$ in agosto 2002. I parametri delle curve luce/fotosintesi in marea entrante ed uscente hanno evidenziato l'importanza della variazione della concentrazione dei nutrienti piuttosto che della composizione e dell'abbondanza della comunità.

Abstract

Exchanges of phytoplankton between the Venice lagoon and the Adriatic Sea have been studied from July 2001 to June 2002 with synoptic surveys performed at Lido, Malamocco and Chioggia inlets. The phytoplankton at the three inlets showed a very similar seasonal pattern. The highest phytoplankton abundance was observed in summer, the lowest in winter. Nanoflagellates and diatoms (mean values 58% and 38% of total abundance, respectively) dominated, dinoflagellates and coccolithophorids accounting for the remaining 4%. Also the abundance and the alternations of species at flood and ebb tide at the three inlets were influenced by the seasonal phytoplankton cycle. For most of the year the phytoplankton abundance was higher at flood tide than at ebb tide and neritic species prevailed; only in the periods August-October and in

February abundances were higher at ebb tide due to species blooming in the lagoon waters.

The photosynthesis/light (P/I) curves were analysed for the phytoplankton communities of the Lido inlet, in May and August 2002. The potential production ranged between 1,3 and 2,2 and between 5,8 and 6,8 mg C m^{-3} h^{-1}, respectively in May and August. The comparison of the P/I curves parameters for the pytoplankton at flood and ebb tide indicated a major effect of nutrient concentrations rather than of community abundance and taxonomic composition.

1.Introduction

The Lagoon of Venice (Fig. 1) is separated from the Adriatic Sea by sandbars (Cavallino, Lido and Pellestrina) which are interrupted by three inlets: Lido, Malamocco and Chioggia (e. g. Zille 1955). The water renewal, essential for the organisms of the lagoon, is maintained by the tidal cycle through the inlets (Ravera, 2000). Tides can be expected to be the major factor controlling the distributions of properties in lagoons (Cervantes Duarte, et al., 2001; Kirugara, 2001; Ounissi et al., 2002). The Lagoon of Venice is strongly influenced by space-time variations in hydrochemical parameters and tidal dynamics (Bianchi et al., 2000). Plankton communities are exposed to physical stresses caused by flood and ebb tides, i.e. continuous changes in salinity and turbulence, as well as seasonal variations in temperature.

The seasonal phytoplankton variations have been described in the southern (Tolomio and Bullo, 2001), central (Socal et al., 1999; Facca et al., 2002) and northern basins (Voltolina, 1973; Bianchi et al., 1999). The phytoplankton of the Lagoon of Venice is characterized by neritic species, adapted to survive to large salinity ranges, and tychopelagic species (often diatoms), i.e. benthic or epiphytic species, re-suspended by means of high hydrodynamics (Socal et al., 1985; Tolomio and Bullo, 2001). Neritic species are often introduced by saline waters of the flood tide whilst, in ebb tide, we can find oligoaline species which grow in the inner areas of the lagoon (Socal et al., 1987). Thus, the species composition is represented by a complex and mixed assemblage of taxa.

Within this framework, and in order to complete information about the phytoplankton community in areas of exchange between Adriatic Sea and Lagoon of Venice, synoptic samplings at the three inlets in the same tidal phase were carried out, for the first time, in the present work. The main objectives were:

- to identify spatial differences among the three mouths
- to highlight differences of phytoplankton community between flood and ebb tides
- to typify a seasonal pattern of phytoplankton abundance and taxonomic composition
- to evaluate physiological differences, in relation to the photosynthetic activity, between flood and ebb tides.

2. Material and methods

Synoptic samplings were performed at Lido, Malamocco and Chioggia inlets (Fig. 1), from July 2001 to June 2002, in order to gather information about the taxonomic composition and abundance of the phytoplankton community.

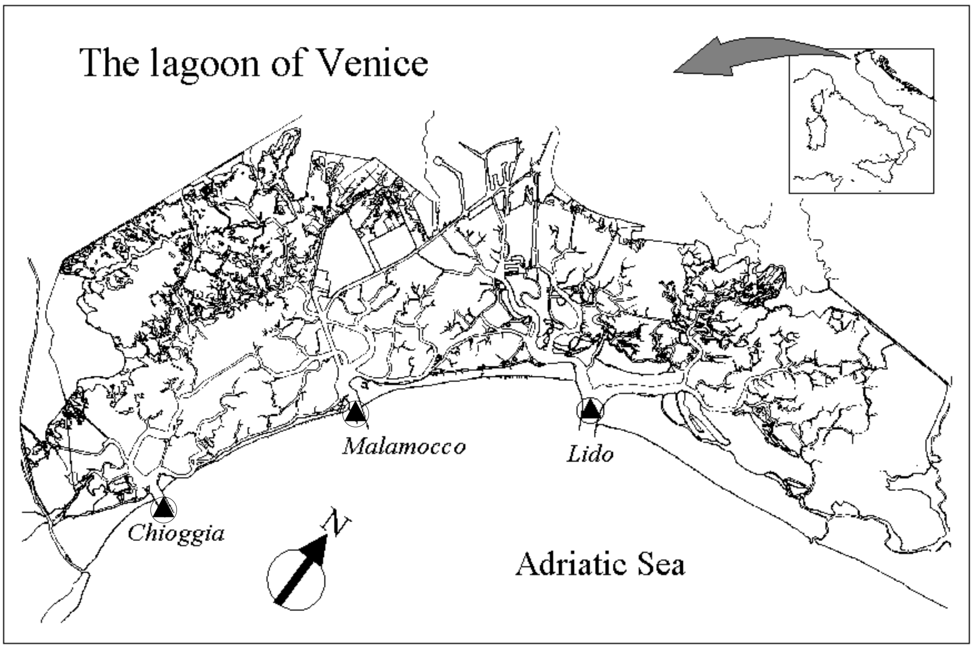

Fig. 1 – The sampling stations.

Phytoplankton samples, together with all hydrochemical and biological parameters, were taken by a Niskin bottle monthly at both flood and ebb syzygial tides at a depth of 5 m. This intermediate level was chosen due to different reasons: i) it is the level that best-fits physical data (current speed and discharge) integrated over the whole water column; ii) a preliminary survey carried out at different depths inside the inlet did not show statistically significant difference among the levels; iii) the apparent discrepancy between low transparency detected (mean Secchi disk = 2 m) and the sampling depth (5 m) should be overcome considering the study area (inlet) as a sort of "channel" through which plankton is passively transported, occupying in this way all the depths of the water column.

Hydrological profiles on the water column were carried out by a multiparametric probe. Discrete samples for dissolved nutrients (ammonia, nitrite, nitrate, orthosilicate, orthophosphate), total suspended matter (TSM), particulate organic carbon (POC), total particulate nitrogen (TPN) and chlorophyll *a* were filtered onto Whatman GF/F fiberglass filters (nominal porosity 0.7µm). Nutrient analyses were performed with a Systea-Alliance autoanalyzer (Hansen and Koroleff, 1999; Strickland and Parsons, 1972). Dissolved inorganic nitrogen (DIN) is reported as a sum of ammonia, nitrite and nitrate. TSM was determined gravimetrically after Stickland and Parsons (1972); the organic fraction was estimated after incineration at 480°C. Particle size distribution was assessed by a Coulter Counter Multisizer III, following Sheldon et al., (1972). POC and TPN were determined according to Hedges and Stern (1984). Chlorophyll *a* was determined by spectrophotometric method (Holm-Hansen et al., 1965). Tidal height data were kindly provided by the Centro Previsioni e Segnalazioni Maree of the Venice Municipality. Irradiance data were obtained from the meteorological archive of ISMAR, Venice section.

Phytoplankton samples were collected in 250-cm^3 glass dark bottles, and fixed with 10-cm^3 of 20% hexamethylenetetramine-buffered formaldehyde (Throndsen, 1978) and stored. Counts were made according to Utermöhl's (1958) method. The taxa examined (according to Tomas, 1997) fall into the following main groups: diatoms, dinoflagellates (naked and armoured cells), coccolithophorids and other flagellates. This last group here is referred to as nanoflagellates and includes the sum of cells belonging to different classes (cryptophyceans, crhysophyceans, prasinophyceans, chlorophyceans and prymnesiophyceans -except coccolithophorids-), whose sizes are between 4 and 20 µm and often remain undetermined. Other flagellates < 4 µm and picophytoplankton have not been considered. Cell volume was estimated from cell measurements (Edler, 1979), and phytoplankton carbon (PPC) was calculated using conversion factors (Strathmann, 1967; Smetacek, 1975).

Statistical analyses (one-way ANOVA) were performed using Statistica by Statsoft, after log-transformation of biological data (Cassie, 1962). Original data of phytoplankton abundances were used to produce data matrices and perform multivariate analyses, using the P.R.I.M.E.R. software (Clarke and Warwick, 1994). This software, at the beginning used for benthos community studies (Field et al., 1982; Gray et al., 1988), has been applied successfully to describe the phytoplankton distribution in ecosystem characterized by marked salinity gradient (Budford et al., 1995; Froneman et al., 1997; Acri et al., 2000). After standardizing and transforming data in double-square root, on matrices of Bray-Curtis similarity index, hierarchical agglomerative clustering was carried out with the group-average link. MDS ordination (non-metric multi-dimensional scaling) was applied to the same similarity matrices and the stress value, measuring the goodness-of-fit of the bidimensional plot ordination, was calculated (Clarke and Warwick, 1994). Species diversity was calculated according to Shannon and Weaver (1949).

The photosynthesis/light (P/I) curves were analysed for the phytoplankton communities of the Lido inlet, in May and August 2002, at flood and ebb tide. During each survey, eleven 50 ml phytoplankton samples, gathered at 5 m depth, were inoculated with 370 KBq of ^{14}C, according to the classic method by Steeman Nielsen (1952); they were then incubated at artificial light (OSRAM HQI–T 250 W/D) in an incubation chamber, maintained at the *in situ* temperature. In this incubator, based on the model of the radial photosynthetron proposed by Babin et al., (1994), the phytoplankton community is subjected to a decreasing gradient of light, measured by a Biospherical 4 π sensor QSL-1012. After one hour incubation the samples were passed through cellulose nitrate filters and placed in scintillation vials after removal of ^{14}C by addition of 0.2 ml of HCl 6 N. A scintillation cocktail (Filter Count, Perkin Elmer) was added to the filters, before being counted on a Beckman scintillation counter (LS-6000). The parameters of the P/I curves have been calculated following the classic models proposed by Platt et al. (1980):

$P_b = P_{bmax}\tanh(\alpha I/P_{bmax})$ (not considering photinhibition)
$P_b = P_{bs}(1-\exp(-\alpha I/P_{bs}))\exp(-\beta I/P_{bs})$ (considering photoinhibition)
where:
I = photosynthetically active radiation measured in each sample (μE m^{-2} s^{-1})
P_b = hourly specific production (mg C mg chl a^{-1} h^{-1})
P_{bs} and P_{bmax} = hourly specific production at saturating irradiances (mg C mg chl a^{-1} h^{-1})
α = photosynthetic efficiency (mg C (mg chl *a*) $^{-1}$ (μE m^{-2} $s^{-1})^{-1}$)
β = photoinhibition index (mg C (mg chl *a*) $^{-1}$ (μE m^{-2} $s^{-1})^{-1}$)
$P_{bmax}/\alpha = I_k$, photosaturating irradiance (μE m^{-2} s^{-1})

3. Results

3.1 Environmental variables and structure of phytoplankton communities

Mean and range values of the main environmental variables are reported in table 1.

Tab. 1 - Range of variations, average and standard deviation of some hydrobiological variables. Seasonal changes are significant for whole parameters (results from One-way ANOVA).

	min	**max**	**avg**	**st. dev.**
Trasparency (m)	0.3	4.5	1.8	0.9
Temperatura C	2.2	28.7	14.3	6.9
Salinity	29.7	37.3	34.2	1.7
pH	8.1	8.4	8.2	0.1
O_2 (%)	64.8	127.0	103.2	8.3
N-NH_3 (μM)	0.4	10.7	3.5	2.0
N-NO_2 (μM)	0.0	1.7	0.5	0.3
N-NO_3 (μM)	0.0	30.2	11.8	6.9
DIN (μM)	1.4	41.9	15.7	8.4
SiO_4 (μM)	1.4	69.6	11.5	7.8
P-PO_4 (μM)	0.0	0.4	0.1	0.0
N/P	10.7	1636.8	339.7	303.7
POC (μg/dm^3)	63	2909	455	393
PTN (μg/dm^3)	11.4	522.0	73.1	70.6
TSM (mg/dm^3)	2.4	135.6	24.7	22.9
CHL *a* (μg/dm^3)	0.7	36.7	4.3	5.3
PPC (μg/dm^3)	1.4	371.6	48.6	57.2
PPC Diatoms (μg/dm^3)	1.0	370.7	33.3	54.0
PPC Dinoflagellates (μg/dm^3)	0.0	71.1	9.2	13.3
PPC Nanoflagellates (μg/dm^3)	0.1	10.9	1.7	1.7
PPC Coccolitophorids (μg/dm^3)	0.0	15.5	1.5	3.0
Total Phytoplankton (cell/dm^3 *10^3)	89	9071	2185	1665
Diatoms (cell/dm^3 *10^3)	27	4723	826	864
Dinoflagellates (cell/dm^3 *10^3)	0	252	46	55
Nanoflagellates (cell/dm^3 *10^3)	58	7106	1267	1151
Coccolitophorids (cell/dm^3 *10^3)	0	360	41	72

Three potential sources of variability of phytoplankton communities, expected to be the most important in the lagoon, were analysed:

i. Spatial differences among the three mouths
ii. Differences between flood and ebb tides
iii. Seasonal succession

i. *Spatial differences among the three mouths* - The quantitative differences of phytoplankton among the three inlets were not significant (ANOVA, F-test= 1.03; n.s.; Fig. 2), although at the Chioggia inlet higher abundances were recorded than at Malamocco and Lido (mean values respectively 2932, 1978 and 1999 10^3cells/dm^3), as well as lower diversity values.
Also the PPC values did not change significantly among the three inlets (Lido, Malamocco and Chioggia 53, 77 and 61 µg/dm^3, respectively; ANOVA, F-test= 0.18; n.s.).

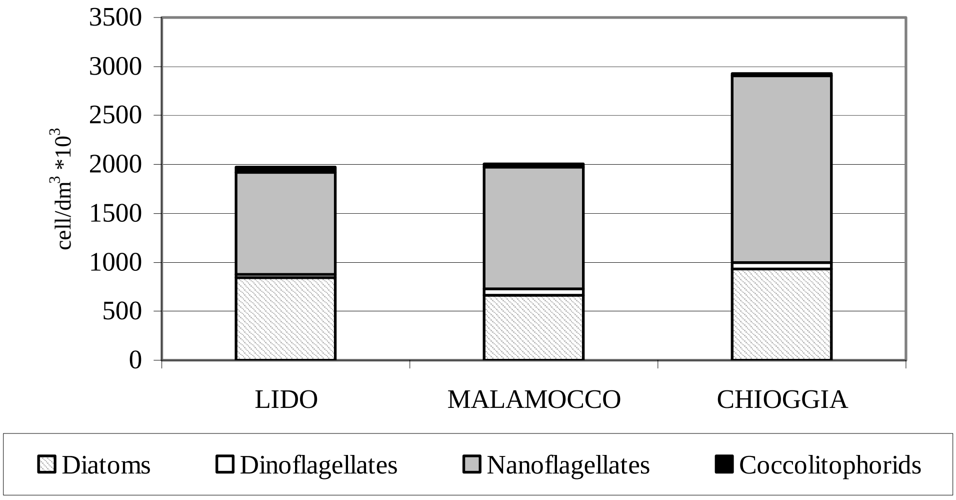

Fig.2 - Mean phytoplankton abundance at the three inlets.

ii. *Differences between flood and ebb tides* - Considering the whole data set, phytoplankton abundance and chlorophyll *a* concentrations were not different at ebb or flood tide (ANOVA F-test= 1.37; n.s. and F-test= 1.66; n.s., respectively). The diversity of phytoplankton expressed in Shannon index was not tide dependent (ANOVA F-test = 0.9, n.s.). As regards PPC, significant differences were detected between tidal phases, with higher values at flood tide (63 µg/dm^3) respect to ebb tide (33 µg/dm^3; ANOVA F-test = 5.9, $p<0.05$) due to higher biomasses of dinoflagellates and coccolithophorids.

Significant differences between flood and ebb tide were detected in some hydrologic parameters: flood tide waters were more transparent (higher Secchi Disk values and lower concentrations of TSM) and characterised by fewer nutrients and POC with respect to those of ebb tide waters (Tab. 2).

These features did not influence the phytoplankton community structure, which showed significant differences between flood and ebb tide only at some periods of the year (Tab. 3):
- the January-July period (except February) was characterized, at flood tide, by higher

Tab. 2 - Mean values of the hydrobiologic parameters characterizing flood and ebb tide (results from One-way ANOVA; significant values: * p <0.05; ** p <0.01).

	FLOOD	EBB	
TRANSPARENCY (m)	2	1.5	**
SALINITY	35.6	33.9	**
DIN (µg/dm^3)	13.9	20.8	**
SIO4 (µg/dm^3)	10.6	14.3	**
TSM (mg/dm^3)	23.7	36.2	*
POC (µg/dm^3)	416.6	614.5	*
PPC (µg/dm^3)	62.4	34.2	*
Ticopelag. Diatoms (cell/dm^3 *10^3)	2.7	7.4	**

abundances. Neritic species (*Emiliania huxley*, *Pseudo-nitzschia delicatissima* complex, *Hemiauls hauckii*, *Cerataulina pelagica*, *Chaetoceros decipiens*, *Asterionellopsis glacialis*) prevailed;

- in the period August-October high abundances of nanoflagellates and *Nitzschia frustulum* were recorded at ebb tide, whereas elevated abundances of *Skeletonema costatum* were present in February at Lido. Both these species have previously been described as blooming in the lagoon waters.

Among diatoms, only tychopelagic species showed significant differences over the year between tidal phases (mean contribution of 7% and 17% respect to total diatom at flood and ebb tide respectively); they showed significant higher abundances and biomasses at ebb tide (ANOVA F-test = 31.8, p<0.01 and F-test= 29.4, p<0.01 respectively; Fig. 3 and Tab 3).

iii. *Seasonal succession of species* - During the annual cycle, abundances ranged from 89 10^3 (December, flood tide, Lido) to 9 10^6 cells/dm^3 (October, ebb tide, Chioggia). The highest abundances were observed at the tree inlets in late summer-early

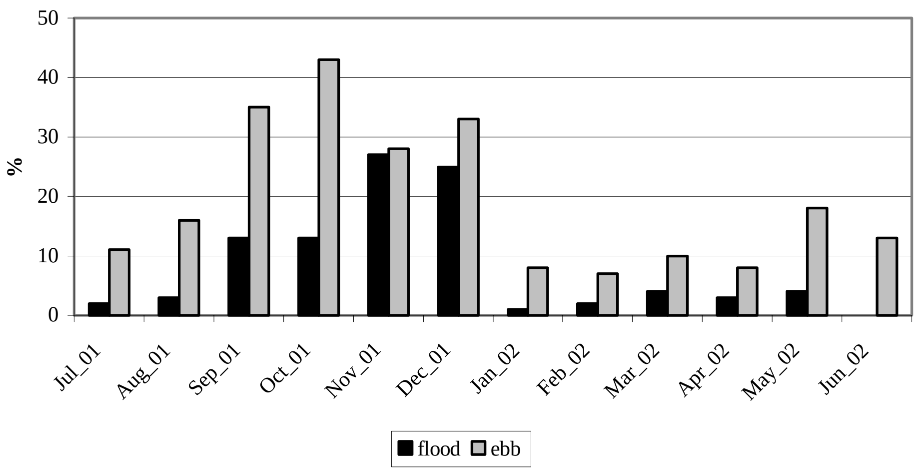

Fig. 3 - Average contribution (%) of tycopelagic species abundance.

Tab. 3 - Relative contribution of the most important phytoplankton species at flood and ebb tide.

		FLOOD	EBB
January-July (except February)	*Chaetoceros decipiens*	76	24
	Cerataulina pelagica	92	8
	Hemiaulus hauckii	79	21
	Asterionellopsis glacialis	89	11
	Pseudo-nitzschia delicatissima	69	31
	Emiliania huxleyi	75	25
February	*Skeletonema costatum*	31	69
always	*Cocconeis scutellum*	19	81
	Navicula cryptocephala	20	80
	Navicula spp.	22	78
	Nitzschia frustulum	11	89

autumn (August, September and October) and in January (bloom of *Asterionellopsis glacialis* at flood tide), the lowest in late autumn (November and December). Changes in abundance over the year were significant (ANOVA F-test =13.6, $p<0.01$; Tab. 4).
Nanoflagellates and diatoms dominated (mean contribution to total abundance: 58% and 38%, respectively), dinoflagellates and coccolithophorids accounted for the remaining 4% of total abundance (Fig. 4).

The mean Shannon diversity index ranged from 0.78 bit (October 2001, ebb tide, Lido) to 3.15 bit (January 2002, ebb tide, Malamocco). It revealed significant changes over the year (ANOVA F-test = 10.9, $p<0.01$) with higher values in November-May (high species number, low abundances) and lower values in August-October (high abundances, low species numbers; Fig. 4).

A phytoplankton seasonal succession common to the three inlets could be outlined (Fig. 5):

a) late winter: colonies of diatoms (*Skeletonema costatum*, *Asterionellopsis glacialis*, *Chaetoceros* spp) with a high growth rate (Mozetic et al. 1998), together with the small coccolithophorid *Emiliania huxleyi*;

b) spring: colonies of diatoms (*Pseudo-nitzschia delicatissima* complex, *Cyclotella* spp) and nanoflagellates;

c) summer: diatoms (*Nitzschia frustulum*, *Thalassiosira* spp, *Cerataulina pelagica*), dinoflagellates (*Gymnodinium* spp) and nanoflagellates;

d) autumn: tychopelagic diatoms (*Navicula* spp., *Navicula cryptocephala*, *Amphora* spp.).

PPC ranged from 1 $\mu g/dm^3$ to 372 $\mu g/dm^3$. The highest biomass was observed in August and in January-February, the lowest in November-December. Changes in biomass over the year (Tab. 4) were significant (ANOVA F-test = 7.7, $p<0.01$).

Biomass of diatoms and dinoflagellates (mean contribution: 69% and 19%, respectively) dominated, whilst nanoflagellates and coccolithophorids, both composed by small cells, accounted for the remaining 11%. Diatoms showed high biomass in winter due to contribution of *Asterionellopsis glacialis* (26% of total biomass), *Chaetoceros decipiens* (22%) and *Skeletonema costatum* (5%) whilst dinoflagellates-

Tab. 4 - Mean abundance, biomass, dominant species and contribution in abundance and biomass in different seasons.

	Abundances cells/dm^3 * 10^3	**PPC µg/dm^3**	**Dominant species**	**abundances mean contribution (%)**	**PPC mean contribution (%)**
WINTER	1987	70	*Asterionellopsis glacialis*	6	26
			Chaetoceros decipiens	13	22
			Emiliania huxleyi	4	1
			Skeletonema costatum	13	5
			nanoflagellates	36	2
SPRING	1983	30	*Chaetoceros decipiens*	3	11
			Cyclotella spp	7	4
			Gymnodinium spp.	2	18
			Prorocentrum micans	0.2	9
			Pseudo-nitzschia delicatissima complex	1	2
			nanoflagellates	49	6
SUMMER	3719	54	*Cerataulina pelagica*	1	14
			Gymnodinium spp.	1	10
			Nitzschia frustulum	13	2
			Prorocentrum minimum	0.4	4
			Protoperidinium spp	0.1	4
			Thalassiosira spp	6	10
			nanoflagellates	49	6
AUTUMN	479	18	tychopelagic diatoms	20	34
			Und. coccolitophorids	0.1	5
			nanoflagellates	46	8

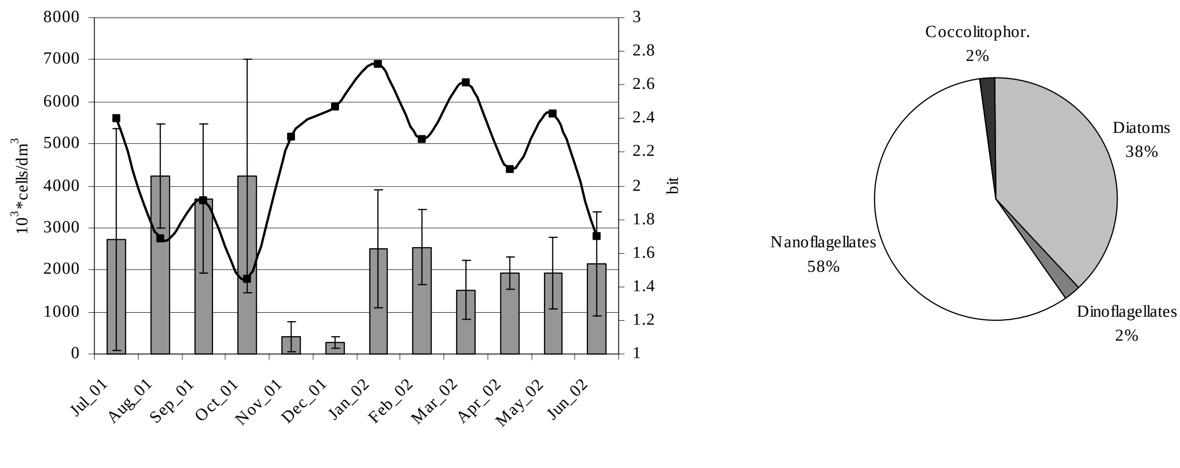

Fig. 4 - Mean phytoplankton abundance (bars) with standard deviations and Shannon diversity (solid line) (left); average contribution (%) of main phytoplankton groups to the total abundance (right).

reached higher values in spring mainly with *Gymnodinium* spp (18% of total biomass) and *Prorocentrum micans* (9%). In summer the diatoms *Cerataulina pelagica* (14%), *Thalassiosira* spp (10%) and the dinoflagellates (18% with *Gymnodinium* spp, *Protoperidinium* spp and *Prorocentrum minimum*) dominated. In autumn tychopelagic diatoms (mainly *Navicula* spp., *Nitzschia* spp. and *Amphora* spp.) prevailed (34%), followed by dinoflagellates (14%), nanoflagellates (8%) and undetermined coccolitophorids (5%).

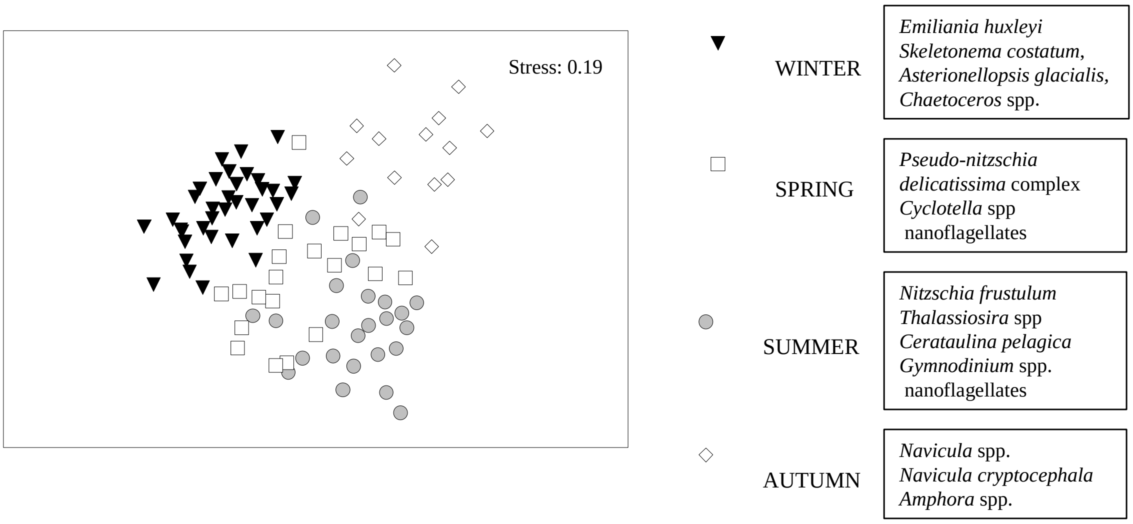

Fig. 5 - MDS plot from a matrix of the abundances of 132 taxa and the most important phytoplankton species in the different seasons.

3.2 Photosynthesis light curves

A synthesis of the phytoplankton production experiments is reported in table 5.

The highest photosynthetic rates (PP_{max}), specific production (P_{bmax}) and photosynthetic efficiencies (α) were observed in August.

In May 2002 PP_{max}, P_{bmax} and α showed the highest values at ebb tide, when the highest nutrient concentrations were observed too; on the contrary the PAR conditions and the phytoplankton community abundance and taxonomic composition remained very similar at flood and ebb tide.

In August 2002 PP_{max}, P_{bmax} and α were very similar at flood and ebb tide and so did PAR and nutrient concentrations, while the phytoplankton community differed markedly as it regards both its abundance and composition.

Tab. 5 - Primary production experiments: phytoplankton abundance (Ab_p), biomass (C_p), chlorophyll *a* and composition, parameters of the P/I curves (PP_{max}, P_{bmax}, α), irradiance (PAR) and nutrient concentration.

	May		**August**	
	flood	**ebb**	**flood**	**ebb**
Ab_p (cells dm^{-3})	2128	2106	1167	2461
C_p (µg dm^{-3})	42	42	39	70
Chl *a* (µg dm^{-3})	3.5	2.4	4.6	4.9
Diatoms (% Ab_p)	22	27	51	23
Dinoflagellates (% Ab_p)	5	5	8	10
Nanoflagellates (% Ab_p)	68	67	41	66
Coccolithophorids (% Ab_p)	3	0	0	2
PP_{max} (mg C m^{-3} h^{-1})	1.2	2.2	6.8	5.8
P_{bmax} (mg C mg chl *a* $^{-1}$ h^{-1})	0.4	0.9	1.5	1.1
α (mg C mg chl *a*$^{-1}$ h^{-1} (µE m^{-2} s^{-1})$^{-1}$)	0.0003	0.004	0.0058	0.0062
PAR (µE m^{-2} s^{-1})	434	722	1965	1900
DIN (µM)	12	31	8	7
SiO_4 (µM)	6	15	15	15

4. Discussion

Significant positive correlation between total phytoplankton, irradiance and temperature was detected, as well as with some biological parameters like chlorophyll *a*, POC and TPN (Table 6).

An inverse seasonal pattern was observed for phytoplankton and nutrients (DIN and $P\text{-}PO_4$). Nutrients were characterised by summer minima, because of the strong uptake by phytoplankton, and winter maxima, due to the lower activity of this biological component and the land runoff.

No correlation was highlighted between phytoplankton and salinity, and between phytoplankton and transparency, due to the high contribution of inorganic debris to seston (mean values of 76%). Very low transparency values were observed during our samplings, showing that light generally does not penetrate below the first few meters of water, mainly due to particulate matter re-suspended by high tidal hydrodynamics, and relative great amount of tychopelagic species in ebb tide waters. Looking at the general trend of phytoplankton, the main forcing factors for phytoplankton distribution at the three inlets of the Venice lagoon are the seasonal variation in irradiance ($r = 0.26$ $p< 0.05$), and, consequently, in temperature ($r = 0.37$ $p< 0.01$). As expected in an estuarine system, DIN and $Si\text{-}SiO_4$ appeared to be in excess, rarely limiting phytoplankton growth (Marcomini et al., 1995). Conversely, the concentration of phosphates was low for all the study period. For this reason, very high N/P ratio values, far above the Redfield ratio, were observed (Tab. 1). The low ortophosphate concentrations and the high

Tab. 6 - Bravais Pearson's correlation coefficients between phytoplankton and main environmental parameters (significant values: * $p < 0.05$; ** $p < 0.01$).

	PHYTOPLANKTON (cells/dm^3)	
TRANSPARENCY (m)	0.18	
TEMPERATURE (C)	0.37	**
IRRADIANCE (W/m^2)	0.26	*
SALINITY	-0.08	
DIN (µg/dm^3)	-0.24	*
SI_SIO4 (µg/dm^3)	0.09	
P_PO4 (µg/dm^3)	-0.54	**
POC (µg/dm^3)	0.21	*
TPN (µg/dm^3)	0.29	**
CHL *a* (µg/dm^3)	0.47	**
TSM (mg/dm^3)	-0.1	

phytoplankton biomass could indicate fast phosphorus regeneration (Degobbis et al., 1986). Moreover, in shallow near shore waters, dissolved phosphate is known to be in equilibrium with that in sediments trough absorption–desorption processes (Pomeroy et al., 1965; Delmas and Treguer, 1983). Sediments represent a nutrient supply for the water column, mainly in cases of nutrients depletion by autotrophic organisms, in the lagoon of Venice too (Degobbis et al., 1986; Socal et al., 1999).

The typical seasonal succession of species composition, known for the Venice lagoon (Bianchi et al., in press (a); Socal, 1981; Socal et al., 1985; Tolomio et al., 1999), was common to all the three inlets at ebb and flood tide (Fig. 5).

The differences between the phytoplankton abundance and taxonomic composition, observed at flood and ebb tide, confirm the considerations coming from other works (i. e. Socal, 1981, Barillari et al., 1984, Socal et al., 1985): most lagoon species are common to the coastal ones and are introduced at flood tide; only from time to time species blooming in the lagoon are "exported" to the sea.

It has been pointed-out by long-term studies (Bernardi Aubry et al., in press) that the phytoplankton composition of most of the coastal belt of the North-Western Adriatic Sea do not show high spatial variability: the complex hydrodynamism and hydrologic features of the area (Franco and Michelato, 1992) have their main influence on the spatial distribution of phytoplankton abundances, rather than of species composition. The low spatial variability of the coastal area is also reflected in the species composition of the phytoplankton that is transported inside the lagoon by the tide. The mean phytoplankton abundances of two coastal stations located in front of the Lido and Chioggia inlets (Bernardi Aubry et al., in press) evidenced values comparable with that of the present study, while the phytoplankton abundances of inner areas of the lagoon of Venice could attain values higher up to two times (Tab. 7**).** In these areas, where nutrients are generally in excess (Bianchi et al., in press (a), Bernardi Aubry et al., in press, Acri et al., in press), the low water speed and the high stability of the water column (Umgiesser, 2000) could play an important role in the enhancement of the phytoplankton blooms.

Tab. 7 - Comparison between mean phytoplankton abundance of the lagoon of Venice and of two coastal stations in front of the Lido and Chioggia inlets (N = number of data considered).

	flood tide	**ebb tide**	**inner areas**	**coastal belt**
	This study N= 42	**This study** N= 38	**Acri et al. in press** N=330	**Bernardi Aubry et al. in press** N=510
Phytoplankton (cell/dm^3 * 10^3)	2321	2034	5930	2659
Diatoms (cell/dm^3 * 10^3)	807	847	3774	1738
Nanoflagellates (cell/dm^3 * 10^3)	1394	1126	1920	833
Dinoflagellates (cell/dm^3 * 10^3)	56	36	64	69
Coccolitophorids (cell/dm^3 * 10^3)	61	20	3.9	19

Phytoplankton composition of the inner areas show frequently a marked spatial heterogeneity (Bianchi et al., in press (b)), that was not observed at the inlets. In outflowing stream the movement of the water masses, related to the tide (Socal et al., 1987), could contribute to reduce the qualitative differences among the three inlets, if compared with the inner areas.

Information on the phytoplankton photosynthetic activity date back to the late fifties (Vatova, 1960). Since then, phytoplankton production data were gathered sporadically in the framework of various research programs, with different aims, as well as spatial and temporal extent (Battaglia et al., 1983; Creo et al., 1995; Sorokin et al., 1996; Bianchi et al., 2000; Sorokin et al., 2002). These previous works have indicated that the phytoplankton production in the Venice Lagoon attains the highest values from spring to summer, following the seasonal variations of the phytoplankton biomass. The photosynthetic activity appears to be enhanced by increased nutrient concentrations and hampered by an elevated hydrodinamism and by industrial pollution: the lowest production values were in fact usually found in the channels, in the industrial and in the low nutrient area. The production efficiency are reported to be quite low, frequently below or around 1 mg C mg chl a^{-1} h^{-1}, in particular in the channels.

In the present study the production measurements were carried out in two periods (spring and summer) when the photosynthetic activity is expected to be the highest of the year. The PP and P_b values were in the lowest range of variations of the spring-summer data in the lagoon. In accordance with observations by other Authors (Battaglia et al., 1983; Sorokin et al., 1996, 2002) they indicate a depression of the photosynthetic activity, very likely linked to the elevated hydrodinamism of the sampling area.

The comparison between the photosynthetic activity of the phytoplankton community at flood and ebb tide seems to emphasize, from one side, the role of nutrient concentrations, rather than that of phytoplankton abundance and composition or of the photosynthetic activity daily cycle. This finding, that need to be verified by further experiments, stresses the importance of nutrient concentrations not only on a large temporal and/or spatial scale (well known for the lagoon) but also on the short time scale, related to the tide cycle. On the other side, it indicates that information on the physiological aspects can be complementary to those concerning phytoplankton abundance and composition, allowing to differentiate community that appear quali-quantitatively similar (May) and vice versa (August).

5. Conclusions

The present research evidenced, first of all, the lack of significant differences in the phytoplankton communities at the three inlets. Despite the importance of the short time scale variability, described in the lagoon of Venice (Bianchi et al 2000) and in other coastal lagoon (Nuccio et al., 2003), phytoplankton abundance and community succession was mainly driven by the seasonal cycle. The phytoplankton composition through the seasons changed according to a pattern that had already been described by other authors (Marchesoni, 1954; Voltolina, 1973; Moschin & Moro, 1996; Socal et al., 1999; Tolomio et al., 1999) in the Lagoon of Venice. Generally the species detected in this study are euriecious, mostly of sea origin, while the continental species are scarce. Most of them are commonly found in the other italian brackish waters (Tolomio 1978).

For most of the year the phytoplankton charge was higher at flood tide, with dominance of neritic species, commonly found in the NW Adriatic coastal waters. The phytoplankton abundance was higher at ebb tide only during blooms, enhanced by favorable environmental conditions in the inner areas.

The analysis of the P/I curves of the phytoplankton gave an indication of a depression of the photosynthetic activity, a usual characteristic of the community in the channels of the lagoon. The comparison between the P/I curve parameters at flood and ebb tide emphasizes the importance of the physiological aspects in differentiating the phytoplankton community during the tidal cycle. This preliminary observations gave a different and complementary insight into the role of the lagoon in the export/import of phytoplankton, considering not only the quali-quantitative aspects, but also the physiological state and the potential for production.

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SEASONAL FLUXES OF NUTRIENTS AND SUSPENDED MATTER BETWEEN THE VENICE LAGOON AND THE ADRIATIC SEA THROUGH THE LIDO INLET (YEARS 2001 – 2002)

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Riassunto

Nell'ambito del programma di ricerca sulla laguna di Venezia finanziato dal CORILA, linea 3.5 "Quantità e qualità degli scambi tra Laguna e Mare", si espongono i risultati preliminari relativi ai flussi stagionali dei nutrienti e del materiale sospeso tra laguna e mare attraverso la bocca di porto di Lido. I risultati indicano: i) velocità di corrente massime di 1.5 m s^{-1}, con portate a volte superiori a 12000 m^3 s^{-1}; ii) una stretta relazione tra flussi di nutrienti e processi biologici, rappresentati principalmente, nel periodo di campionamento, da bloom fitoplanctonici nelle aree lagunari; iii) un'esportazione di materiale sospeso dalla laguna verso il mare in tutte le situazioni stagionali, mostrando la dominanza dei fenomeni di erosione sulla sedimentazione; iv) un contributo della frazione inorganica sempre superiore all'80% del totale.

Abstract

In this paper, preliminary calculations of fluxes and budgets related to dissolved nutrients and particulate matter, derived from four intensive seasonal field experiments at the Lido inlet, are reported and discussed. Results highlighted: i) very high values of current speed (> 1.5 m s^{-1}) and water exchange rates (> 12000 m^3 s^{-1}); ii) variable nutrient fluxes, mainly due to their chemical nature and to the occurrence of phytoplankton bloom inside the lagoon; iii) a generalised export of particulate matter from the lagoon, pointing out the dominance of erosion processes; iv) a contribution of the inorganic fraction always >80% of the total.

1. Introduction

The increasing occurrence of extreme flooding events in the lagoon of Venice (known as "acqua alta"), with the consequent degradation of the buildings and paralysis of the human activities, is actually one of the most important problems at local scale. The solution of the construction of mobile gates at the three inlets, recently approved by the Italian Government to defend the city against the "acqua alta", is an argument of lively debate, because it did not encounter many enthusiastic supporters. In this frame, several considerations have been done on variations of fluxes between the lagoon and the sea, caused by the construction and utilisation of these barriers, that could alter the equilibrium of this fragile lagoon ecosystem. Therefore, all these observations have not a counterpart in the scientific literature, because the very few contributions about fluxes and budgets are represented by technical papers (ISDGM/CNR 1978a, 1978b, 1979; OGS, unpublished data; Consorzio Venezia Nuova, 2002).

The recent project launched by the Consortium for the promotion and co-ordination of the scientific activities on the Venice lagoon (CORILA 2000-2004 Research Program) gave us the opportunity to perform a detailed study on fluxes of dissolved and particulate matter and plankton organisms between lagoon and sea (line 3.5 “Quantity and quality of exchanges between lagoon and sea”, WP2 “ Biogeochemical parameters”). Some preliminary results on variability of hydrology, seston and plankton have already been reported in a previous work (Bianchi et al., 2002).

Being the experimental phase of WP2 still running at Malamocco and Chioggia, in this paper some preliminary considerations about seasonal fluxes and budgets of nutrients and particulate matter through the Lido inlet are reported and discussed. The considered period is November 2001 – August 2002.

2. Materials and methods

To investigate the wide variability of this coastal ecosystem in the short-time, hydrological measurements and samplings have been carried out every 3 hours in a spring tide, for a total of 48 hours (17 samples). The station was in the centre of the inlet, in correspondence with a bottom-mounted Acoustic Doppler Current Profiler (ADCP) (Gacic et al., 2002; Fig. 1).

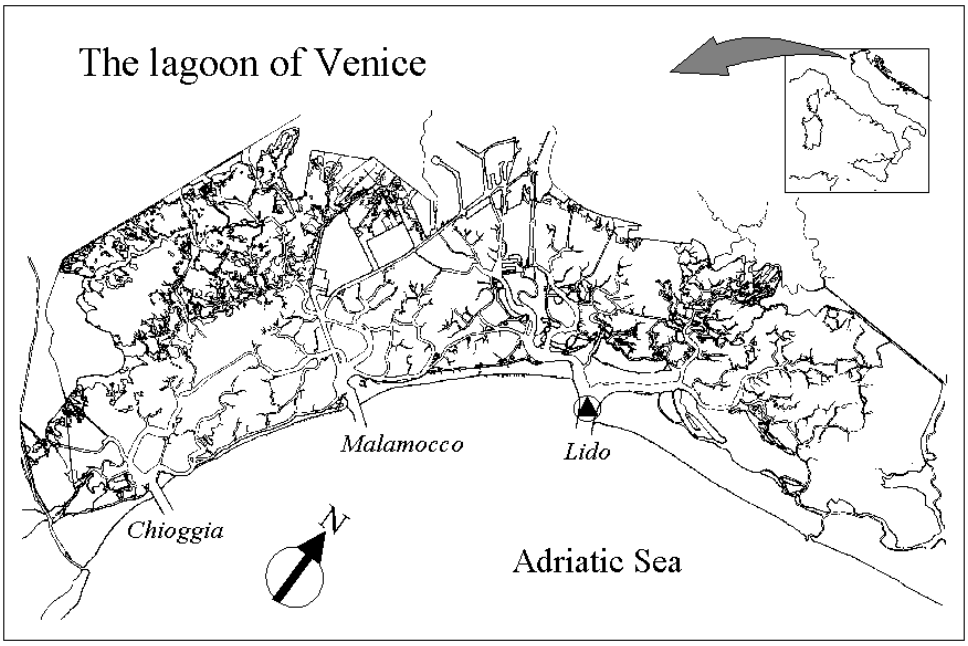

Fig. 1 - The sampling station.

Hydrological profiles on the water column were carried out by a multiparametric probe; discrete samplings by a Niskin bottle at 5 m depth.

Samples for dissolved nutrients (ammonia, nitrite, nitrate, orthosilicate, orthophosphate) and total suspended matter (TSM), were filtered onto Whatman GF/F fiberglass filters (nominal porosity 0.7µm). Nutrient analyses were performed with a Systea-Alliance autoanalyzer (Hansen and Koroleff, 1999; Strickland and Parsons, 1972). Dissolved inorganic nitrogen (DIN) is reported as a sum of ammonia, nitrite and nitrate. TSM was determined gravimetrically after Stickland and Parsons (1972); the organic fraction was estimated after incineration at 480°C. Particle size distribution was assessed by a Coulter Counter Multisizer III, following Sheldon et al. (1972).

Tidal height data were kindly provided by the Centro Previsioni e Segnalazioni Maree of the Venice Municipality, while current data were furnished by Istituto Nazionale di Oceanografia e di Geofisica Sperimentale of Trieste - OGS.

According to different seasons, four periods were considered: autumn (STG01, November 2001), winter (STG02, February 2002), spring (STG03, May 2002), summer (STG04, August 2002).

Instantaneous fluxes were calculated relating the concentration of each parameter to the correspondent discharge, computed from a cross-section of about 8272.73 m^2, an average value obtained from several ADCP tracks across the Lido inlet (Arena, OGS, pers. comm.). Seasonal budgets were obtained by a simple time-integration of the instantaneous fluxes over the considered tidal cycles, 8 in winter and spring, 6 in summer, when a sampling was skipped due to bad weather. In November, an exceptional flooding event (>115 cm), due to strong E-N-E winds (>20 m s^{-1}), forced us to miss some samplings; due to this random lack, with the integration method it was impossible to compute autumnal budgets. Finally, only 2 tidal cycles were considered in calculations of TSM summer budget, because some filters were damaged.

3. Results and discussion

3.1. Particle size distribution

Figs. 2 and 3 show the particles size distributions at Lido in November 2001 and in May 2002; in these figures, the respective volumes of each dimensional class are reported in the 48 hours of observations.

In November, during the flooding event (Fig. 2), diluted coastal waters from the Northern rivers (mainly Sile and Piave) were conveyed long-shore by E-N-E winds and entered into the lagoon through the Lido inlet (see Bianchi et al., 2002). These waters were rich in sediment, as demonstrated by the shape of particles after 24h. In this picture is well evidenced:

- a significant contribution of small particles (range 2 – 10 µm) to the total;
- a trend in accordance with tide.

In the other seasons, a shift in the size spectra was observed, as well as a contribution of slight larger particles (5 – 20 µm). In May, few particles belonging to the high classes of the dimensional range (40 – 60 µm) contributed to the total (Fig. 3).

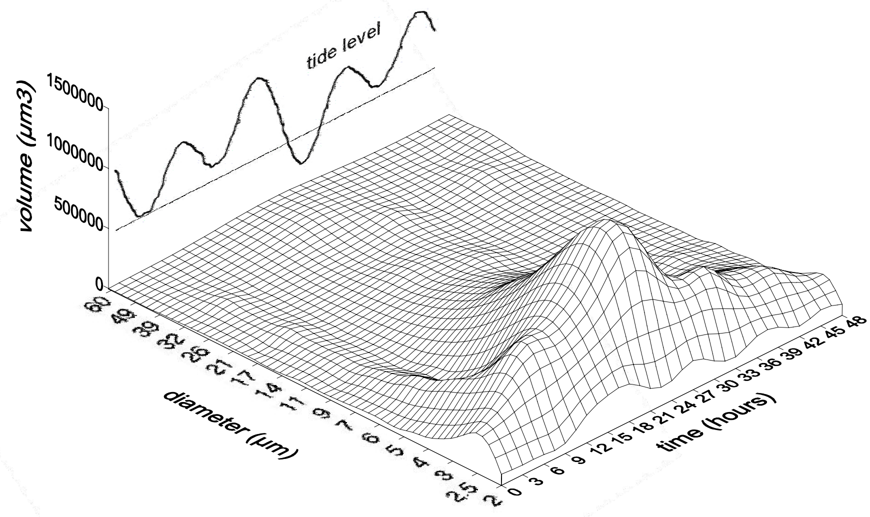

Fig. 2 - Particle size distribution in autumn (November 2001).

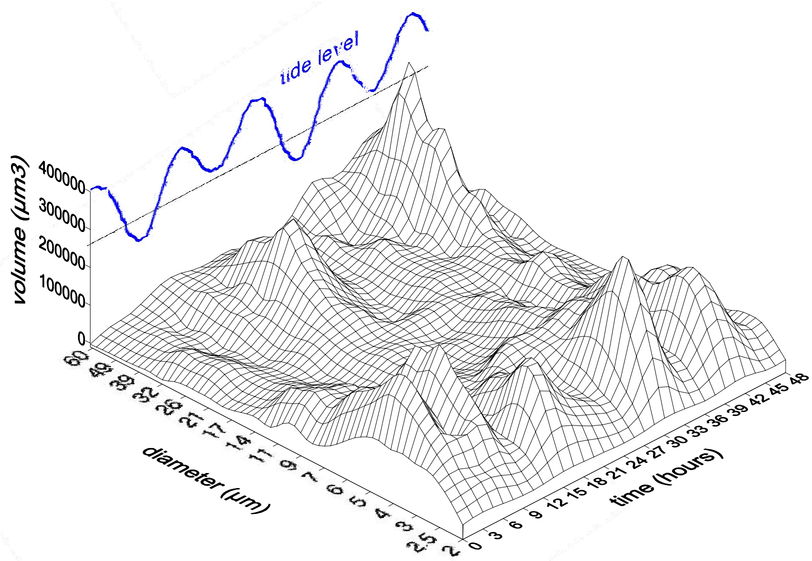

Fig. 3 - Particle size distribution in spring (May 2002).

3.2.Current speed and discharges

Current speeds were very high, with maxima > 1.5 m s^{-1}, corresponding to water exchange rate > 12000 m^3 s^{-1} (Figs. 4 – 7). These values are of the same order of magnitude of the Po river flow, that has an average daily discharge of about 1500 m^3 s^{-1}, with rare maxima up to 11000 m^3 s^{-1}. The “acqua alta” event, in November 2001, did not generate current speed and flow rate significantly higher than other seasons.

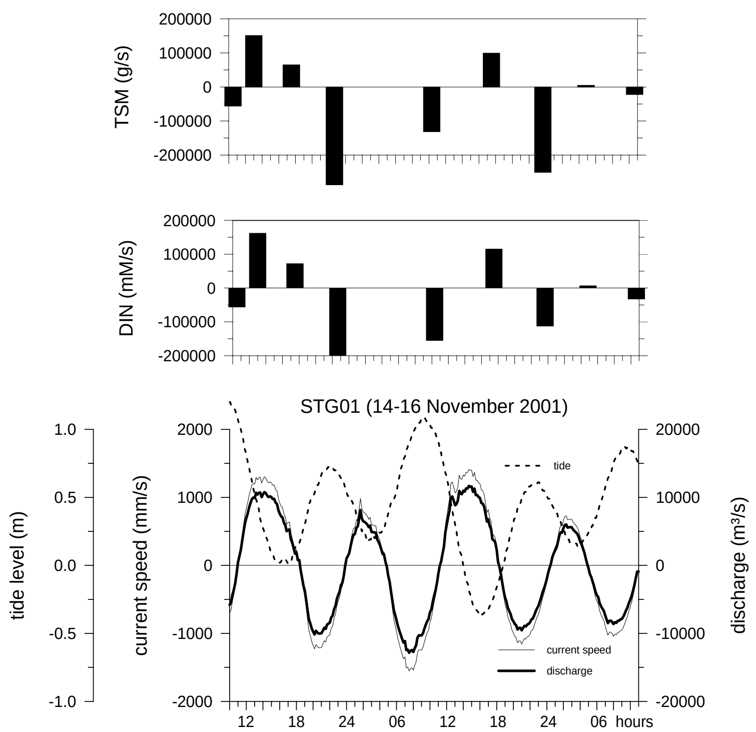

Fig. 4 – Autumn campaign STG01 (14–16 November, 2001). Bottom: tide level, current speed and discharge. Top: instantaneous fluxes of DIN and TSM.
+ = outcoming flux (from the lagoon towards the sea);
– = incoming flux (from the sea into the lagoon).

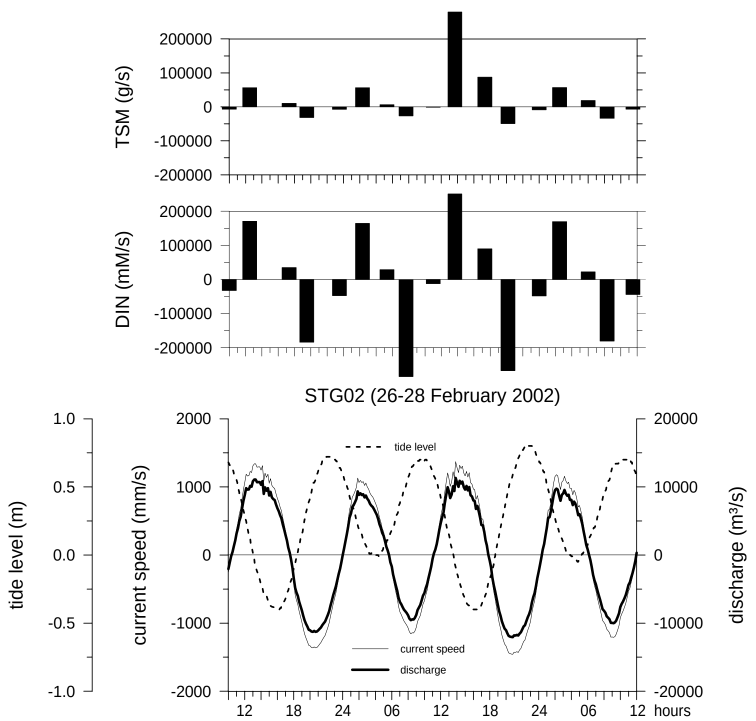

Fig. 5 - Winter campaign STG02 (26–28 February, 2002). See fig. 4 caption.

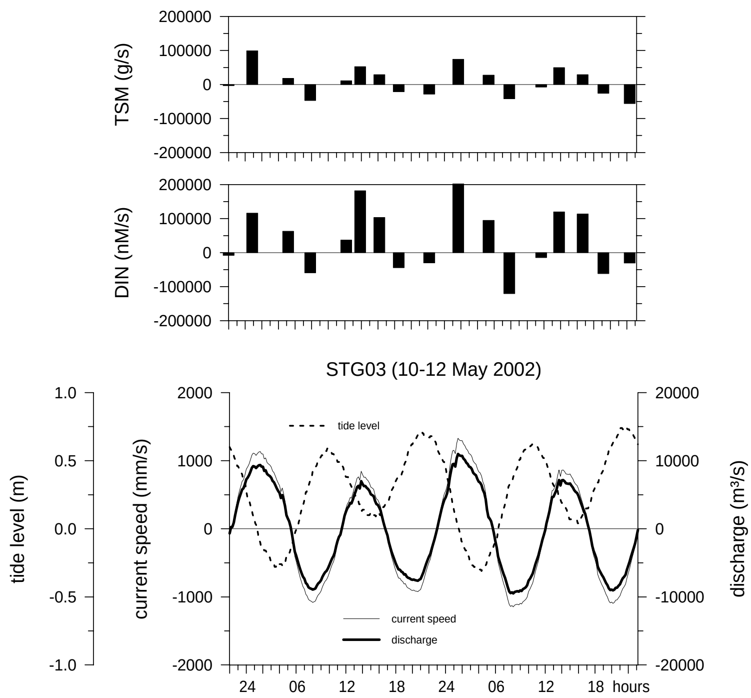

Fig. 6 - Spring campaign STG03 (10–12 May, 2002). See fig. 4 caption.

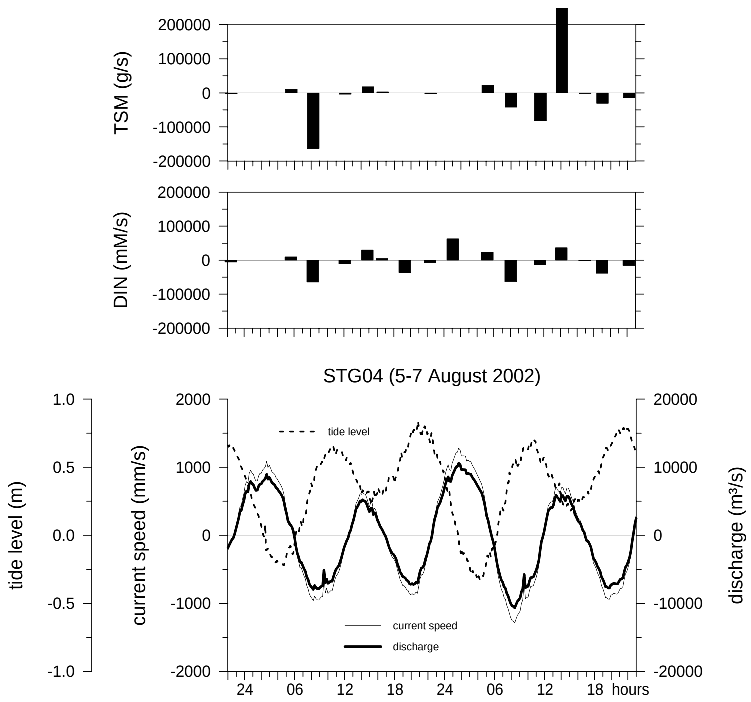

Fig. 7 - Summer campaign STG04 (5–7 August, 2002). See fig. 4 caption.

3.3. Nutrients and TSM fluxes

Nutrient fluxes between lagoon and sea were very variable, according to: i) seasons; ii) tide level; iii) biological processes, very pronounced in late winter and summer 2002, when phytoplankton blooms were observed in the inner lagoon: diatoms in February (mainly *Skeletonema costatum*), small nanoflagellates in August (Bernardi-Aubry and Acri, submitted).

In February, the availability of dissolved nutrients, typical of late winter, was highlighted by fluxes higher than the other seasons (respective DIN, orthosilicate and orthophosphate maxima > 250, 120, 1 M s^{-1}), while the lowest values were measured in summer. During the "acqua alta" of November, the resuspension of sediment caused TSM fluxes > 280 kg s^{-1} towards the lagoon. Occasional high fluxes were recorded in February, due to a local event, and in August, because of a storm (Figs. 4 – 7).

3.4. Nutrients and TSM budgets

As regards dissolved nutrients budgets, different behaviours were shown, mainly due to their chemical nature and to the presence of the biological component (table 1).

Tab. 1 - Dissolved nutrients and TSM budgets through the Lido inlet
(+ = export from the lagoon into the sea, – = import from the sea into the lagoon).

	units	Winter (February 2001)	Spring (May 2002)	Summer (August 2002)
Tidal cycles	*n*	8	8	6 *
Samplings	*n*	17	17	13
DIN	*t* d^{-1}	- 6.4	+ 32.8	- 1.3
Orthosilicate	*t* d^{-1}	- 6.9	+ 27.0	+ 9.4
Orthophosphate	*kg* d^{-1}	+ 47.5	- 20.9	- 54.0
TSM	*t* d^{-1}	+ 2376	+ 762	+ 1766 **
Inorganic fraction	*%*	84	81	87
Organic fraction	*%*	16	19	13

* 2 tidal cycles not considered in budgets computation;
** TSM summer integration performed on 2 tidal cycles.

In February, when the uptake by diatoms bloom was high, DIN and silicate were imported into the lagoon (6.4 and 6.9 t d^{-1}, respectively). In spring, no particular event occurred, so an export of DIN and silicate from the lagoon took place, as usually in a coastal ecosystem. In summer, the nanoflagellates bloom caused a new deficiency of DIN in the lagoon, so 1.3 t d^{-1} of this nutrient were imported from the sea; on the contrary, silicate was exported, because not assimilated by these organisms (9.4 t d^{-1}).

These results agree with those of other Authors published in the '90s (Sfriso et al., 1994), but only partially, because in the last ten years the trophic conditions of the lagoon of Venice changed deeply, mainly because of the reduction of macroalgal biomass, with consequent effects on availability and fluxes of dissolved nutrients.

Phosphate budgets, always very low, showed a disagreement with the other nutrients, highlighting an export in February (47.5 kg d^{-1}) and an import in spring (21 kg d^{-1}) and summer (54 kg d^{-1}), probably due to its particular chemistry and high reactivity.

The lagoon exported always particulate matter through the Lido inlet, highlighting the dominance of erosion processes on sedimentation: as a matter of fact, TSM export increased progressively from 762 t d^{-1} in spring to 1766 t d^{-1} in summer, with a winter maximum of 2376 t d^{-1}. The contribution of the inorganic fraction ranged from 81% and 85% of the total.

These budgets, extrapolated to an annual cycle, are of the same order of magnitude with those reported in the technical study for the evaluation of the environmental impact of the mobile gates (Consorzio Venezia Nuova, 2002).

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RESEARCH LINE 3.6
Biodiversity in the Venice Lagoon

IDENTIFICATION OF ACTIVELY TRANSCRIBED GENES IN REFERENCE ORGANISMS OF THE VENICE LAGOON: *ZOSTERISESSOR OPHIOCEPHALUS*

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Riassunto

Questo lavoro è stato sviluppato nell'ambito della Linea di Ricerca 3.6 (Partner associato P.M. Bisol).

La scarsa disponibilità di informazioni genetiche su organismi di riferimento dell'ambiente lagunare veneziano rende più difficile delucidare le relazioni funzionali all'interno dell'ecosistema e, in particolare, le risposte biologiche conseguenti a variazioni ambientali. L'evidente carenza di dati di sequenza è stata affrontata in *Mytilus galloprovincialis* (Lmk, 1819) e *Zosterisessor ophiocephalus* (Pallas, 1811) con un approccio metodologico già applicato con successo nell'identificazione di geni umani e nello studio dei loro profili di espressione. In ogni cellula e in un certo momento i geni che vengono attivamente trascritti in RNA messaggero, destinati ad essere tradotti in proteine, forniscono infatti un'istantanea, un profilo trascrizionale, che può rendere comprensibili modulazioni funzionali e risposte biologiche indotte.

Qui vengono riportati specificamente i risultati complessivamente ottenuti in *Z. ophiocephalus.* A partire da tessuti rappresentativi di gò, è stata purificata la popolazione eterogenea degli RNA messaggeri e definita una collezione rappresentativa (libreria di cDNA 3'specifica) il cui sequenziamento sistematico ha fornito i dati di sequenza (1612 3'EST) per procedere nell'analisi informatica e nell'attribuzione di una identità putativa ai trascritti genici (967 sequenze consenso 3' terminali). Queste sequenze rappresentano il primo contributo all'identificazione di geni espressi nel gò e rappresentano una preziosa risorsa per ulteriori studi su questo organismo.

Abstract

This work has been undertaken in the frame of the Research Line 3.6 (Associated Partner P.M. Bisol).

The paucity of genetic information on reference organisms of the Venice lagoon makes the understanding of functional relationships within the ecosystem, in particular the biological responses to environmental changes, more difficult. The evident lack of sequence data has been approached in *Mytilus galloprovincialis* (Lmk, 1819) and *Zosterisessor ophiocephalus* (Pallas, 1811) with experimental protocols successfully applied to the identification of human genes and gene expression profiling. In fact, the genes actively transcribed in a given cell and in a certain moment essentially give us a

snapshot, a transcriptional profile, from which we may infer functional tuning and induced biological responses.

The overall results obtained on *Z. ophiocephalus* are specifically described in this report. Multiple tissues of the grass goby have been used to isolate the heterogeneous population of messenger RNAs and, subsequently, to define a 3'end-specific cDNA library. Systematic sequencing yielded 1612 3'ESTs which electronic processing allowed the recognition of 967 independent gene transcripts (putative identity was searched for the related consensus sequences). These sequences represent the first input to the identification of transcribed genes in the grass goby and a valuable resource for further research on such organism.

1. Introduction

In the frame of the Research line 3.6 (Biodiversity in the Venice lagoon) methods and data for identifying actively transcribed genes in *Mytilus galloprovincialis* (Lmk, 1819) and *Zosterisessor ophiocephalus* (Pallas, 1811) have been developed. Both mussels and grass gobies have been previously used as reference species for detecting early biological effects caused by genotoxic agents in different sites of the Venice lagoon [Venier et al., 1996; Dolcetti and Venier, 2002; Venier et al., 2003; Venier and Zampieron, 2004; MAV, 2003-2006].

This report specifically refers to results obtained in *Zosterisessor ophiocephalus*. In addition to the above mentioned studies, the importance of the grass goby is emphasized by its significant presence in the fish community of the Venice lagoon and its use as a model for understanding fish reproductive strategies [Gandolfi et al., 1991; Torricelli et al., 1997; Scaggiante et al., 1999; Pastres et al., 2002; Pilastro et al., 2002; Malavasi et al., 2003]. Additionally, the grass goby have been selected as bioindicator organism in other past and recent studies [Livingstone et al., 1995; Livingstone and Nasci, 2002; Franco et al., 2002; Corsi et al., 2003].

Unlike other fish species (e.g. *T. rubripes, B. rerio, O. mykkis, I. punctatus*) genetic knowledge concerning grass gobies is far to be comprehensive. Interestingly, substantial progress in understanding genetic biodiversity of the native populations derives from the current work in the frame of the Research line 3.6 [Bisol, 2002; Zane et al., 2003; Gallini et al., 2004]. As well, this report describes the identification of species-specific gene sequences starting from almost complete absence of data [see Fig. 1 in Venier et al., 2002]. Taking into account the genome size of the grass goby (a diploid complement consisting in 46 chromosomes and ~2 pg of DNA, as referred by Angelo Libertini in Research line 3.6) the availability of 5 goby sequences (3 and 2 nucleotide and protein sequences, respectively, recorded at the National Centre for Biotecnology Information, Bethesda, at February 2004) is clearly irrelevant.

2. Experimental approach and results

Selected subsets of genes transcribed in any moment in specific cells and tissues provide messenger molecules for protein translation, thus allowing essential functions and specific responses induced by endogenous and exogenous factors. Owing to previous experience developed on human skeletal muscle we could propose a molecular approach for the systematic identification of transcribed genes in *Zosterisessor ophiocephalus* [Aviv and Leder, 1972; Chomczynski and Sacchi, 1987; Diatchenko et al., 1999; Gubler and Hoffman, 1983; Ko, 1990; Lanfranchi et al., 1996; Soares and Bonaldo, 1998; Toppo et al., 2003].

In fact, current bio-molecular techniques and specific software have been used for 1) synthesis of a “back-copy” of single transient RNA transcripts (mRNA) into double stranded DNA (cDNA or DNA complementary), 2) unidirectional cloning in suitable plasmid vector, 3) definition of a cDNA library in bacterial host cells (collection of bacterial clones containing specific cDNAs), 4) amplification of cDNAs with universal primers, 5) systematic DNA sequencing and identification of the transcribed genes.

Subsequently, number and amount of the expressed genes resulting from software analysis of the sequence data can define the so-called “transcriptional profiles”, i.e. the molecular signature of the cellular response for a given tissue, life stage and environmental situation [Campanaro et al., 2002]. Moreover, specific identified sequences can be used for full-length identification and functional characterization of relevant genes [Salamon et al., 2003].

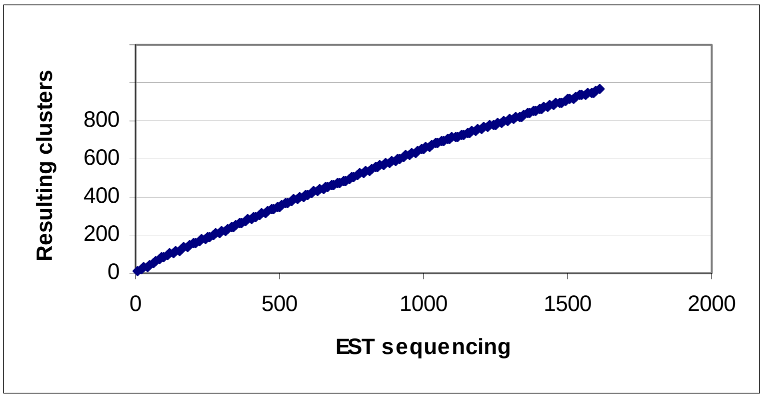

Fig. 1 –The 3’end-specific library from grass goby is highly productive: increased amounts of sequenced ESTs yield linear cluster increase (still high the chance to detect new gene transcripts).

Messanger RNA was purifed from multiple tissues of grass goby (gills, liver, spleen, digestive tube, muscle, brain, eye) and used to prepare the 3’end-specific cDNA library. Single pass sequencing of the goby cDNAs yielded 1612 reliable 3’EST (Expressed Sequence Tags, i.e. sequence fragments univocally identifying individual transcripts present in variable amounts in the original sample) and 967 clusters (the related consensus sequences being representative of individual transcripts) (Fig. 1).

The analysis of EST abundance revealed a majority of singletons (84.4% clusters grouping one EST only) whereas the remaining clusters grouped from 2 to 115 ESTs (Fig. 2).

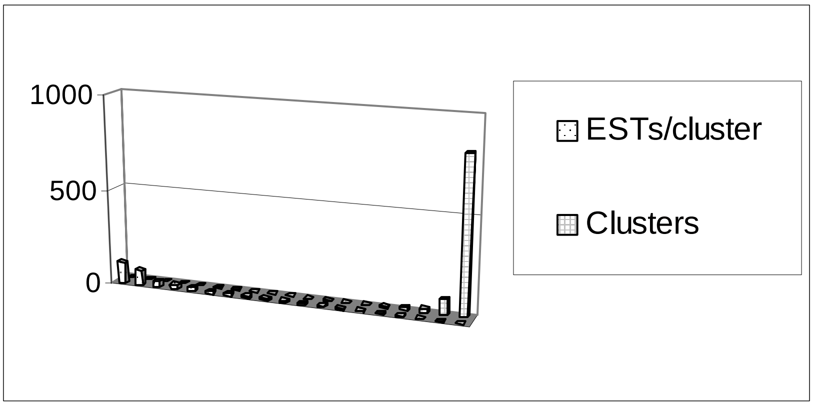

Fig. 2 – Frequency distribution of clusters and related number of clustered ESTs: one only cluster is composed by 115 ESTs whereas 816 clusters are singletons.

BLAST similarity searches in the non-redundant public sequence databases allowed putative identification of 574 consensus sequences (59,3%) whereas a substantial fraction of them (40.6%) is still unknown. The latter possibly represent typical genes of the grass goby and deserve further investigation.

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BLASTN 2.2.5 [Nov-16-2002]
Reference:
Altschul, Stephen F., Thomas L. Madden, Alejandro A. Schäffer,
Jinghui Zhang, Zheng Zhang, Webb Miller, and David J. Lipman (1997),
"Gapped BLAST and PSI-BLAST: a new generation of protein database search
programs",  Nucleic Acids Res. 25:3389-3402.
Query= ZOPD00327
         (987 letters)
Database: All GenBank+EMBL+DDBJ+PDB sequences (but no EST, STS,
GSS, or phase 0, 1 or 2 HTGS sequences)
           1,735,617 sequences; 8,484,804,551 total letters
                                                                 Score    E
Sequences producing significant alignments:                     (bits) Value

gb|AF391340.1|Gillichthys mirabilis cytochrome c oxidase s        412   e-112
gb|AF391356.1|  Mugilogobius sp. CET-2001 cytochrome c oxida…   400   e-108
gb|AF391350.1|  Stiphodon elegans cytochrome c oxidase subun…   385   e-103
gb|AF391388.1|  Bathygobius cocosensis cytochrome c oxidase …   375   e-101
gb|AF391378.1|  Amblygobius phalaena isolate 2 cytochrome c …   369   6e-099
gb|AF391360.1|  Gobiodon histrio cytochrome c oxidase subuni…   367   2e-098
dbj|AP004408.1|  Diplacanthopoma brachysoma mitochondrial DN…   367   2e-098
emb|AJ421455.1|TRU421455  Takifugu rubripes complete mitocho…   365   9e-098
gb|AF391380.1|  Ptereleotris microlepis cytochrome c oxidase…   363   4e-097
gb|AF391357.1|  Ptereleotris monoptera cytochrome c oxidase …   363   4e-097

>gb|AF391340.1| Gillichthys mirabilis cytochrome c oxidase subunit I gene,  artila
           cds; mitochondrial gene for mitochondrial product
          Length = 1551
```

Fig. 3 – Putative identification of the gene for the cytochrome C oxidase, subunit I.

Fig 3 provides an example of one goby gene putatively identified following early BLAST search in the nucleotide database: the goby sequence ZOPD00327 (Query size: 987 letters) submitted to the similarity search was found highly similar (E value e^{-112}) to the existing entry AF391340 (Subject size: 1551 letters) representing a mitochondrial gene of the Gobiidae fish *Gillichthyis mirabilis*.

Among the most abundant putatively identified genes, Apoprotein A-1 (see O42175 and AF266178 records in GeneBank, respectively representing the gene expressed in *Gillichthys seta* and *Sparus aurata*) is intriguing since it appears differentially expressed in liver compared to the digestive tube and involved in the tolerance to hypoxic conditions [Gracey et al., 2001].

Specifically, the study performed at the Hopkins Marine Station (Stanford University, CA) on the Gobiidae fish *G. mirabilis* and *G. seta* emphasises the great potential of the gene profiling approach (i.e. preparation and validation of DNA microarrays) for understanding species-specific biological responses to hypoxia (5-10% pO_2 in the above study). Such critical condition is commonly encountered by species living in transition environments and possibly mimics certain pathological situations unfortunately frequent in humans.

Other genes putatively identified are exemplified by ficolin B, C-type lectin 2, cadherin 1, different proteases, genes involved in cellular synthesis such as elongation factor 1-alpha and a number of ribosomal proteins. Also genes involved in cell adhesion and motility (e.g. fast skeletal muscle troponin T, fast myosin heavy chain) and genes possibly involved in response to stress conditions (e.g. heat shock protein hsp90 beta, complement factor H-related protein, Saxitoxin and tetrodotoxin binding protein 2 precursor, immunoglobulin M, ect.) have been found.

Conclusions

Advanced knowledge on genes and DNA-related functions is essential for understanding regular and abnormal development, life performance and reproductive success of the living organisms. In addition, genetic differences detected among individuals, populations and species are the basis of the biological richness of a given ecosystem. The work developed on the grass goby, in parallel to the more advanced study still in progress on *Mytilus galloprovincialis*, highlights the multiplicity of actively expressed genes in the selected tissues of *Zosterisessor ophiocephalus* and supports additional EST analysis as well as *in silico* extension and full length identification of those genes possibly modulated in critical conditions (apolipoprotein A1, ficolin B, heat shock proteins, etc.).

Both in goby and mussels, extension of the EST database and gene identification represent essential steps for the systematic detection of genes recruited in normal development and functioning as well as genes which expression is modulated by exposure to toxic agents and critical environmental conditions.

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SEASONAL DISTRIBUTION OF FISH FAUNA IN THE VENICE LAGOON SHALLOW WATERS: PRELIMINARY RESULTS

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Riassunto

La fauna ittica costituisce un'importante componente della biodiversità caratterizzante le lagune costiere e le zone estuarine. Lo scopo della presente indagine è l'analisi della struttura e della dinamica della comunità ittica dei bassi fondali della laguna di Venezia. I risultati, riportati qui in via preliminare, sono il frutto di una campagna di campionamento condotta da Aprile a Novembre 2002 in 68 diverse stazioni, ripartite fra i tre bacini lagunari e stratificate per tipologia di habitat. Per il campionamento è stata utilizzata una sciabica a maglia fitta, trainata a mano su aree di superficie nota e costante, in modo così da stimare le densità locali di fauna ittica. Tra i risultati, emerge una chiara dinamica di colonizzazione dei bassi fondali, suggerita dall'andamento stagionale delle abbondanze totali, che presenta un netto picco in estate. Inoltre, anche le variazioni delle abbondanze tra le diverse tipologie di habitat appaiono dipendenti dalla stagione: in primavera e in estate sono i "ghebi" che concentrano il più alto numero di individui, mentre in autunno tale differenza scompare e le densità tendono ad essere più elevate in stazioni in prossimità delle bocche di porto, caratterizzate da habitat a substrato sabbioso. Analogamente, la composizione della comunità in termini di gruppi funzionali ("guild" ecologiche) varia nel tempo, con le specie migratrici (in particolare i migratori giovanili) più abbondanti nelle stagioni di transizione rispetto all'estate. Questo dato suggerisce anche il ruolo di "nursery" delle aree campionate. I dati di abbondanza sono poi stati utilizzati per l'elaborazione di mappe GIS, al fine di fornire degli strumenti che permettano una rapida visualizzazione di informazioni essenziali per la conservazione e la gestione delle risorse ittiologiche in laguna di Venezia. E' stata posta particolare attenzione alla distribuzione delle abbondanze dei giovanili (% di giovanili sul totale degli individui) e alle specie di interesse conservazionistico (Direttiva Habitat 92/43/EEC). Queste mappe sottolineano l'importanza del bacino Nord e degli apporti di acqua dolce nell'attirare alte densità di giovanili, e il ruolo di certe tipologie di habitat, quali i "ghebi" e le praterie di fanerogame, nel supportare le popolazioni delle specie di interesse conservazionistico.

Abstract

The fish assemblage is an important component of the biodiversity of estuaries and coastal lagoon. The aim of the present work is to analyse the structure and dynamic of the fish assemblages of the Venice lagoon shallow waters. The goal was reached by means of a standardized, semi-quantitative sampling (using a beach seine), which allowed the estimation of the fish local density in 68 stations, equally distributed in the three main basins of the lagoon and stratified by habitat type. The sampling was carried out from April to November 2002, allowing to obtain a seasonal based data set. Results showed a strong seasonal effect in the variation of the total fish abundance, with a major peak in the Summer, suggesting a colonisation pattern of the shallow waters by fish species. Variation of fish abundance among habitats appeared also to be season-dependent: mean number of individuals were higher in salt marsh creeks than in the other habitats only during the Spring and Summer, whereas differences disappeared by the Autumn when density tended to be higher on sandy bottoms near the sea-inlets. The relative abundance of the ecological guilds changed also over time, being migrant species more abundant in the Spring and Autumn, than in the Summer, suggesting a role as nursery of the sampled areas. Fish abundance data were also used to develop GIS maps, which are here proposed as useful tools for management and conservation of the ichthyological resources of the Venice lagoon. The visual inspection of some of these maps highlights the importance of the Northern basin and the freshwater inlets in attracting large number of juveniles of many fish species, as well as the role of salt marsh creeks and sea-grass meadows in supporting the endangered species included in the Habitat and Species Directive (92/43/EEC).

1. Introduction

Estuaries and coastal lagoons are dynamic and unpredictable systems, consisting of a wide diversity of shallow water habitats, which support high fish production [Elliott, 2002].

The Venice Lagoon is mostly composed of shallow water areas, which are strongly influenced by tidal flows (of up to 1 m in height), coming from three inlets which connect it to the sea. This system is subjected to strong temporal and spatial changes with regard to its morphological and physico-chemical parameters [Sacchi, 1985], which determine high levels of spatial heterogeneity, consisting of several types of habitats suitable for fish species, such as seagrass meadows, macroalgal beds, sand bare areas, intertidal flats, sandy and muddy subtidal beds, and tidal marshes.

Therefore, the fish assemblage is an important component of the biodiversity characterizing this system, although an adequate analysis of it has never been carried out.

The present work is part of a wider project, aiming to assess structure and dynamic of the ichthyological community of the Venice lagoon shallow waters. A preliminary report on the composition of the ichthyological community, based on fyke nets data, that is on passive gears used by local fishermen, was given at the end of the first year of CORILA project [see Mainardi et al., 2002].

In the present work, further information on the spatial structure and seasonal changes of the shallow water fish assemblages of the Venice lagoon is given. The goal was reached by means of a semi-quantitative, standardized sampling, carried out with an active gear. This method allowed an estimation of the local fish density in a grid of stations, equally distributed among the three main basins of the lagoon, stratified by habitat types, and sampled on a seasonal basis. Further, some methodological tools for the use of these data in terms of conservation and management of biological resources and endangered species are proposed.

2. Materials and Methods

2.1. Sampling

The sampling was carried out on a seasonal basis, during the Spring (Sp: April-May), Summer (Su: July-August), and Autumn (Au: October-November) of the year 2002, in 68 stations distributed in the lagoon, using a 10 mt long beach seine (mesh size 2 mm). Each trawl covered an area of about 120 m^2 and was repeated 3 times in each station. Five main types of habitat were identified based on the bottom characteristics: vegetated habitats, which were divided into continuous seagrass meadows (area covered by seagrass > 95%; V1; n=15) and sparse vegetated habitats adjacent to seagrass beds (with seagrass covering less than 30% of the area; V2; n=16); unvegetated habitats with sandy bottoms (US; n=8); unvegetated habitats with soft bottoms, further divided into mudflats (UM; n=17) and salt marsh creeks (UC; n=12). In general the V1, V2 and US stations were located near the sea inlets or near canals connecting the lagoon to the sea, whereas the UM and UC were found in the more internal areas of the lagoon (Fig. 1).

2.2. Data analysis

The specimens were identified at the species level and were classified as either juveniles or adults on the basis of the knowledge of the size at maturity typical of each species.

The fish abundance in each sampling station was estimated as the number of individuals per one-trawl sampling area, averaged on the three repeated (within stations) trawls. The temporal changes in the mean fish abundance within each station across seasons, as well as its spatial variation among habitats within each season, were tested by means of Kruskall-Wallis test, given that assumptions of normal distribution of data and homogeneity of variances were not met.

Further, an analysis of the fish assemblages composition based on functional guilds was carried out, following Mathieson et al. [2000] and Mainardi et al. [2002]: the use of these guilds provides a description of the fish assemblages from a functional point of view, i.e. based on the ecological requirements of the different estuarine fish species. Species were therefore allocated to a number of functional groups, which, according to the above cited authors, were: estuarine residents (ER), marine adventitious visitors (MA), diadromus (catadromous/anadromous) migrants (D), marine seasonal migrants (MSM), marine juvenile migrants ('nursery species') (MJ) or freshwater adventitious visitors (FA). The composition of the fish assemblage in terms of % of abundance of individuals belonging to the different functional groups was then analysed.

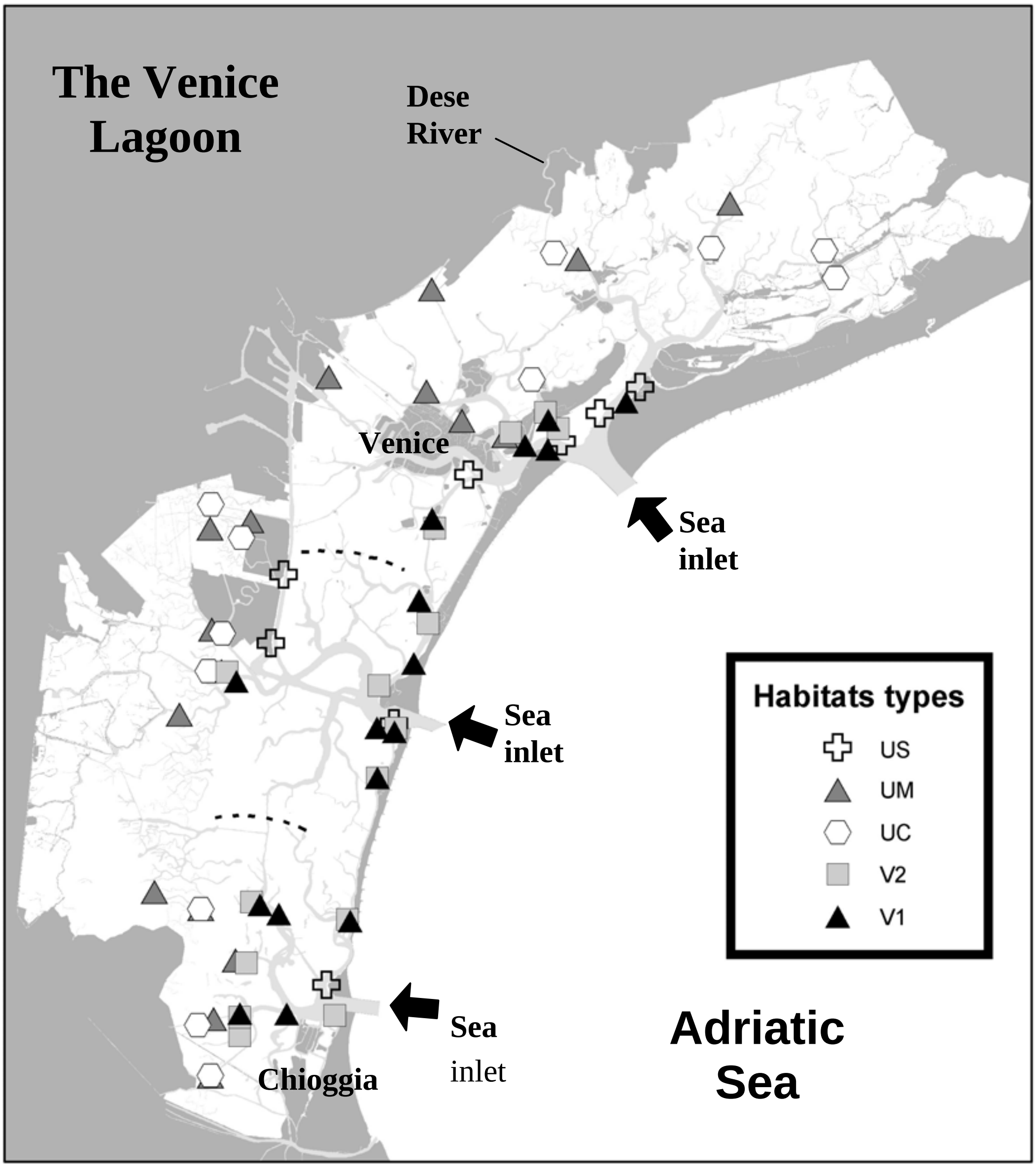

Fig. 1 – Map of the sampling stations, divided by type of habitat, within the Venice lagoon.

2.3. GIS maps

The presence/absence data of the four endangered species included in the Habitat and Species Directive (92/43/EEC), *Knipowitschia panizzae*, *Pomatoschistus canestrinii*, *Aphanius fasciatus*, and *Syngnathus abaster*, and those on the incidence of juveniles (n° juveniles/total number of fish, %) during the Spring were georeferenced by means of a GIS software. Moreover, the data on the incidence of juveniles were spatially interpolated using the IDW (inverse distance weighted) method. In this way maps of the distribution of these components of the fish assemblage in the lagoon were developed.

3. Results

3.1. Composition of ichthyological community

The fish assemblage consisted of 52 species, belonging to 24 families (Tab. 1). The total number of sampled individuals was 39964. About 38% of the total number of species were marine adventitious (MA), 31% were estuarine residents (ER), 15% marine juveniles migrants (MJ), 14% marine seasonal migrants (MSM), and less than 2% (1 species) was freshwater adventitious (FA) (Tab. 1). The most abundant species were the marbled goby *Pomatoschistus marmoratus* (estuarine resident) and the sand smelt *Atherina boyeri* (estuarine resident), which represented about the 33% and 17% of the total catch, respectively.

Tab. 1 – List of the species sampled in the Venice lagoon with the seine net. Species are also divided by family and functional group (FG) (see text for details).

species name	**family**	**FG**
Atherina boyeri	Atherinidae	ER
Belone belone	Belonidae	MSM
Salaria pavo	Blennidae	ER
Parablennius sanguinolentus	Blennidae	MA
Parablennius tentacularis	Blennidae	MA
Callionymus risso	Callionymidae	MA
Sardina pilchardus	Clupeidae	MSM
Sprattus sprattus	Clupeidae	MSM
Carassius auratus	Cyprinidae	FA
Aphanius fasciatus	Cyprinodontidae	ER
Engraulis encrasicolus	Engraulidae	MSM
Merlangius merlangus	Gadidae	MA
Gobius cobitis	Gobiidae	MA
Zosterisessor ophiocephalus	Gobiidae	ER
Gobius niger	Gobiidae	ER
Knipowitschia panizzae	Gobiidae	ER
Pomatoschistus canestrinii	Gobiidae	ER
Pomatoschistus minutus	Gobiidae	MJ
Pomatoschistus marmoratus	Gobiidae	ER
Symphodus sp.1	Labridae	MA
Symphodus sp.2	Labridae	MA
Symphodus roissali	Labridae	MA
Dicentrarchus labrax	Moronidae	ER
Chelon labrosus	Mugilidae	ER

Tab. 1 – Continue.

species name	**family**	**FG**
Liza aurata	Mugilidae	MSM
Liza ramada	Mugilidae	MJ
Liza saliens	Mugilidae	MJ
Mugil cephalus	Mugilidae	ER
Mullus surmuletus	Mullidae	MJ
Platichthys flesus	Pleuronectidae	ER
Gambusia affinis	Poeciliidae	ER
Sciaena umbra	Scianidae	MA
Scophthalmus rhombus	Scophthalmidae	MA
Solea vulgaris	Soleidae	MJ
Solea impar	Soleidae	MJ
Arnoglossus laterna	Bothidae	MA
Boops boops	Sparidae	MA
Diplodus puntazzo	Sparidae	MA
Diplodus annularis	Sparidae	MA
Diplodus sargus	Sparidae	MA
Lithognathus mormyrus	Sparidae	MSM
Sparus aurata	Sparidae	MJ
Hippocampus guttulatus	Syngnathydae	MA
Hippocampus hippocampus	Syngnathydae	MA
Nerophis ophidion	Syngnathydae	ER
Syngnathus abaster	Syngnathydae	ER
Syngnathus acus	Syngnathydae	MA
Syngnathus taenionotus	Syngnathydae	MSM
Syngnathus tenuirostris	Syngnathydae	MA
Syngnathus typhle	Syngnathydae	ER
Echiichthys vipera	Trachinidae	MA
Trigla lucerna	Triglidae	MJ

3.2. Seasonal and spatial changes in the ichthyological community

Mean fish abundances, as number of individuals/120 m^2, changed markedly across seasons (Kruskal Wallis test: $H_{2,204}$=215, p<0.01), as shown in Fig. 2a, being the density at least threefold higher in the Summer than in the other two seasons.
The mean density changed also across habitats but this change seemed to be season-dependent: in the Spring and Summer, there was a tendency to higher densities in UC than in the other habitats, but the differences were statistically significant only within Spring (Spring: $H_{4,68}$=14.05, p<0.01; Summer: $H_{4,68}$=8.90, p>0.05) (Fig. 2b). By contrast, in the Autumn there was a tendency to higher densities in US, although the difference across habitats was not statistically significant (Autumn: $H_{4,68}$=5.12, p>0.05) (Fig. 2d).

The analysis of the fish assemblage composition, in terms of percent abundance of functional guilds, revealed that ER is the most abundant functional group through all the year (Fig. 3). By contrast, MJ were relatively abundant only during the Spring and Autumn, whereas during the Summer the community was mostly constituted by ER.

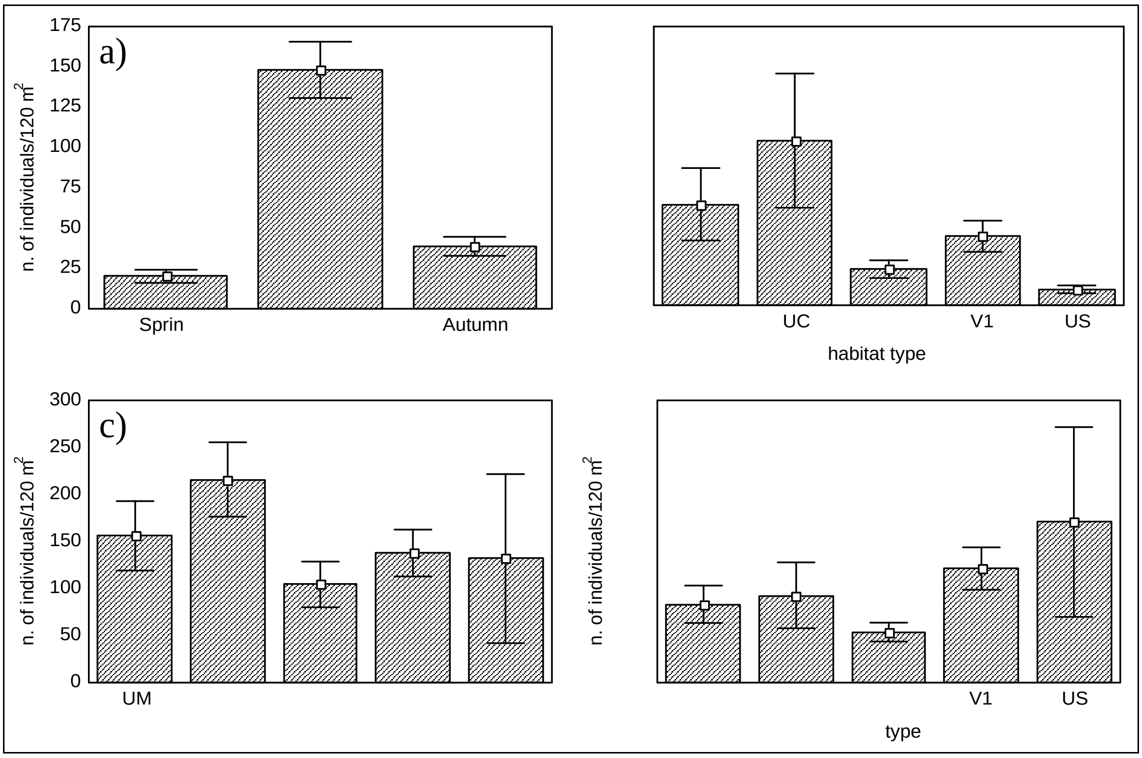

Fig. 2 – Variations in the mean fish abundance (number of individuals/120 m^2) (mean ± S.E.) across seasons (a), and across habitat types during the Spring (b), Summer (c) and Autumn (d).

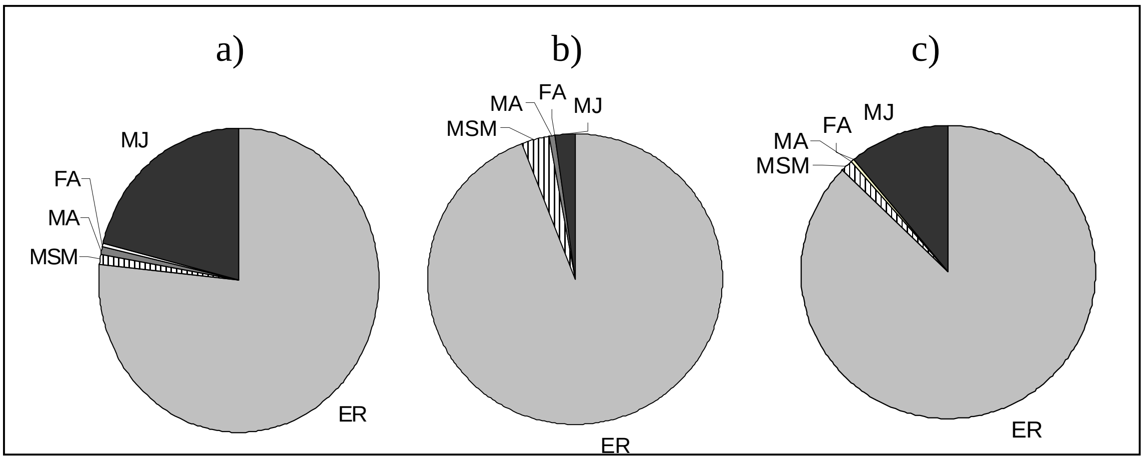

Fig. 3 – Fish assemblage composition in terms of percent abundance of functional guilds (see text for details).

3.2. GIS maps

As shown in Fig. 4, the incidence of juveniles in the lagoon during the Spring is higher within the Northern basin, than in the other basins, especially in relation to the main freshwater inlets. However, also near the fresh water inlets of the other basins, spots of higher incidence of juveniles can be detected (Fig. 4).

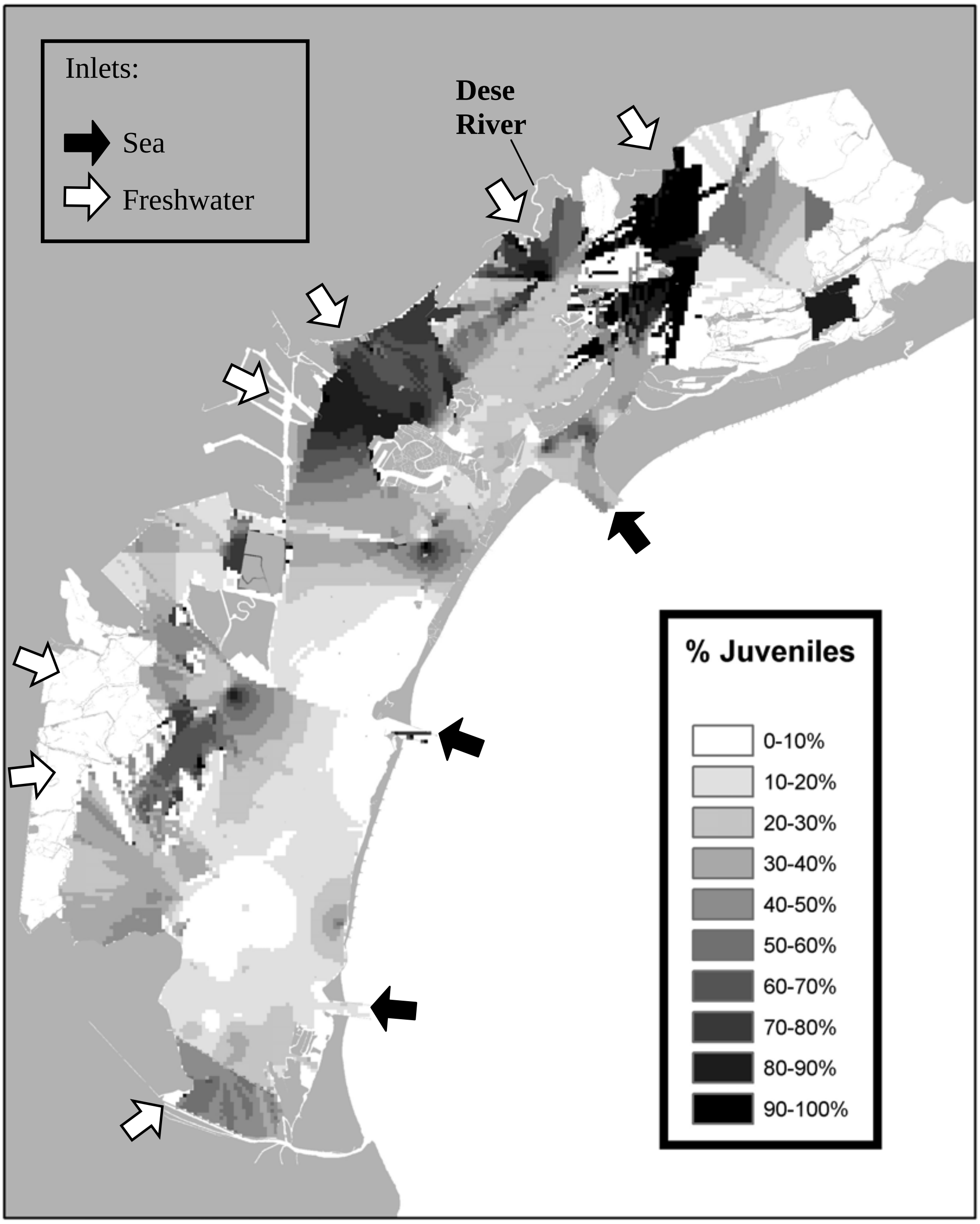

Fig. 4 – Map of incidence of juveniles (%) in the Venice lagoon during the Spring.

The distribution (based on presence/absence data) of the endangered species (Fig. 5) reveals that the stations important for the two endangered gobies (*Knipowitschia panizzae* and *Pomatoschistus canestrinii*) and for the cyprinodontid fish *Aphanius fasciatus* are mostly located in the internal areas of the lagoon, often in salt marshes and creeks (UC ad UM). By contrast, the pipefish *Syngnathus abaster* seems ubiquitous in the lagoon, although it resulted more abundant in the vegetated habitats, V1 and V2, where this species represented about the 33% and 9% of the total catch, respectively.

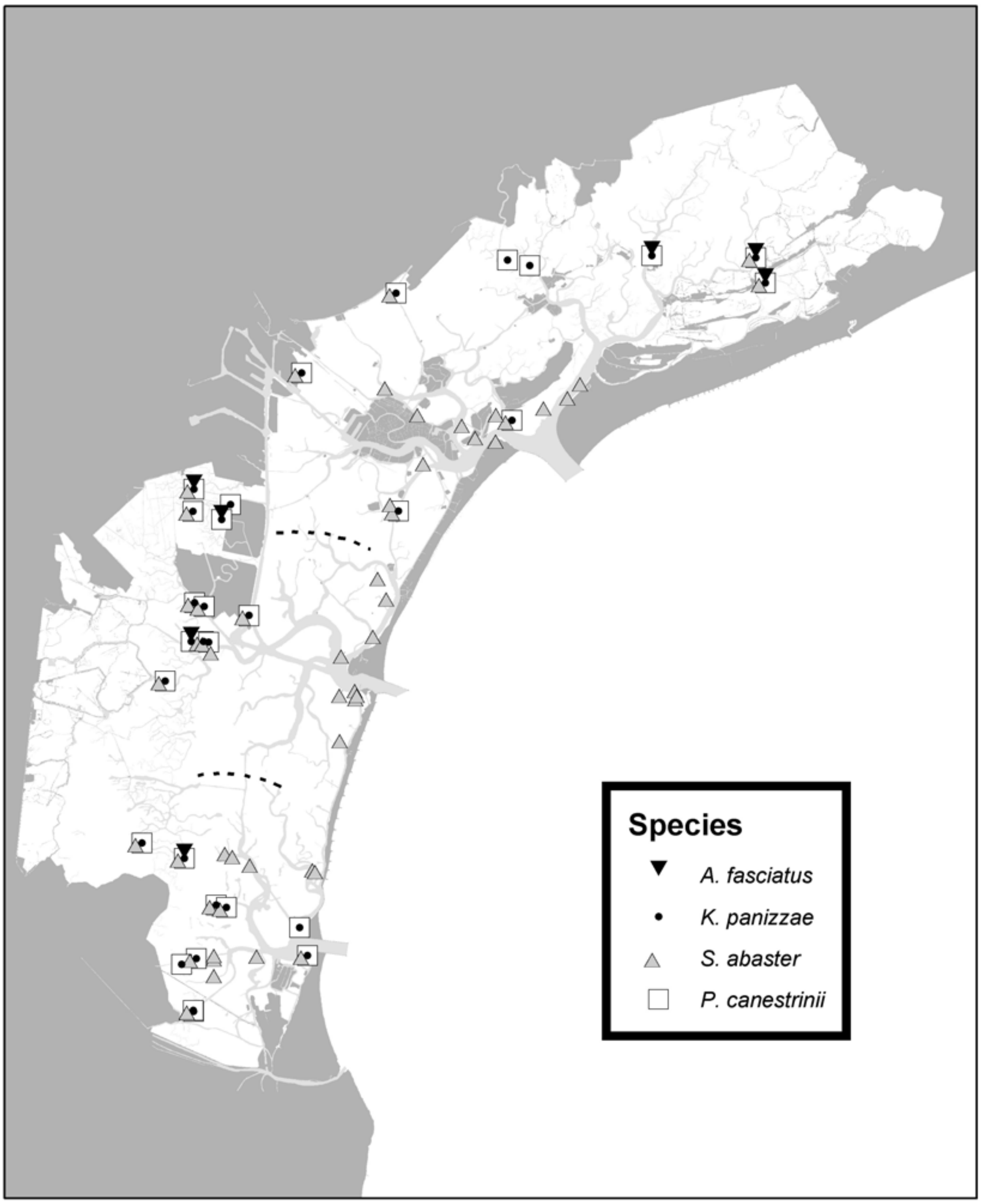

Fig. 5 – Map of the distribution of the endangered species in the Venice lagoon.

Conclusions

The results reported in the present study allow an update of the list of fish species of the Venice lagoon, previously obtained on the basis of a fyke nets survey [Mainardi et al., 2002]. By means of the active gear (beach seine), employed in the present study as sampling device, 8 new species could be added to the previous list of 52 species, giving a total of 60 species. However, if the list of species collected by means of the fyke nets [Mainardi et al., 2002] is compared to that obtained with an active gear [present study], it appears that the two methods are rather complementary. The active gear, in fact, allows the catching of small sized species which, in turn, are probably understimated in the fyke nets catches due to their selectivity (large mesh size). By contrast, the fyke nets allow the capture of large, highly mobile fish species, which can be rarely caught with the beach seine.

As regards the composition of the fish assemblages in terms of functional guilds, our data confirm what has been found in the other European estuaries [Elliott and Dewailly, 1995], that is a relatively high contribution of estuarine residents and marine adventitious species.

In terms of total fish abundance, our results showed a strong seasonal pattern with a major peak in the Summer, indicating a clear process of colonization of the shallow waters, which is likely to be driven by water temperature, according with other studies on fish communities of temperate estuaries [Potter et al., 1986; Nagelkerken et al., 2001; Wilson and Sheaves, 2001].

The differences in fish abundance across the habitats further explain the colonization pattern: during the Spring and Summer, the internal areas, mainly salt marsh creeks and mudflats, are colonized by a large number of fish, whereas during the Autumn the differences among habitats disappear, with a tendency towards higher abundance in the areas near the sea-inlets, suggesting that most species move from the inner areas to the external areas as the temperature declines, according with previous studies on other estuarine systems [e.g. Ayvazian et al., 1992].

The higher contribution of migrant juveniles to the fish assemblage during the Spring and Autumn, than during the Summer, agrees with the above described pattern of colonization, that is many of these shallow water areas function during the Spring and Autumn as nursery areas for different fish species.

Our results highlight the importance of salt marshes creeks in attracting a large number of fish, whereas seagrass meadows support apparently lower fish production. The GIS maps allowed the visual inspection of the distribution of certain components of the fish assemblage in the lagoon, as the juvenile incidence (n° juveniles/total number of fish) and the endangered species: a preliminary, interesting conclusion, which can be drawn on the basis of the inspection of some of these maps, is the importance of the freshwater inlets in attracting large number of juveniles during the Spring, especially within the Northern basin. On the other hand, both types of habitats, salt marshes and seagrass meadows, seem to be essential for the 4 fish species included in the Red list (Habitat and Species Directive (92/43/EEC), as the maps of their distribution indicate that three of them (*P. canestrinii, K. panizzae, A. fasciatus*) are present especially in salt marshes creeks and mudflats, whereas one (*S. abaster*), although ubiquitous, is mostly abundant in the seagrass meadows.

The application of GIS methods to other components of the fish community or to indicators of diversity, such as the diversity indices, will provide in the future additional useful information for the management and the conservation of the ichthyological resources.

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BIODIVERSITY IN THE LAGOON OF VENICE: A LABORATORY MODEL FOR THE STUDY OF THE EFFECTS OF ANTIFOULING COMPOUNDS ON SETTLEMENT AND SURVIVAL OF SESSILE SPECIES

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Riassunto

I rischi per l'ecosistema lagunare di composti antivegetativi di nuova generazione, alternativi agli stannorganici, sono stati valutati attraverso i loro effetti sull'insediamento larvale e sulla sopravvivenza degli individui usando l'ascidia coloniale *Botryllus schlosseri* come modello sperimentale. In particolare si è studiata la capacità di insediamento e metamorfosi delle larve in presenza di substrati rivestiti di diversi tipi di vernici in commercio nell'area lagunare e di diverse concentrazioni dei più usati principi attivi antivegetativi in soluzione. Inoltre, dal momento che alterazioni nella funzionalità del sistema immunitario mettono gravemente a rischio la sopravvivenza degli individui, si sono messi a punto una serie di saggi citochimici su emociti in coltura, da utilizzare come biomarkers, che hanno permesso una valutazione dell'immunotossicità dei principi attivi in questione. I risultati ottenuti indicano un'elevata pericolosità di queste sostanze per gli organismi, in alcuni casi simile al TBT, che rischia di avere gravi conseguenze per la biodiversità lagunare.

Abstract

We used the colonial ascidian *Botryllus schlosseri* as an experimental model to evaluate the risks of new antifouling compounds, alternative to organotins through the study of their effects on larval settlement and individual survival. In particular, we studied the settlement and metamorphosis ability of larvae in the presence of either substrates coated with various paints which are usually in commerce in the Lagoon area or sea water containing various concentrations of active antifouling principles. Moreover, since alterations in the functionality of the immune system represent a great risk for the survival of individuals, we set up a series of cytochemical assays on cultured haemocytes to be used as biomarkers; the latter allowed an evaluation of the immunotoxicity of these substances. Results indicate a high danger of antifouling compounds for aquatic organisms, sometimes similar to TBT, and the risk of severe consequences for Lagoon biodiversity.

1. Introduction

The Lagoon of Venice is a fragile and complex environment in the transition between fresh and sea waters, composed of a continuous series of different natural systems, in which the anthropic impact increased in the course of many centuries. In particular, although this environment was considered for long times only in relation to the activity of fishing, today the convergence of many anthropic interests and activities are cause of great concern for the future of this peculiar ecosystem. Since the variety of species maintaining the functionality of the whole ecosystem adapted to different natural systems, the assessment of the biological diversity represents a very important parameter to understand how the Lagoon is evolving and if changing of the various natural system is occurring.

Many contaminants, with various bioavailability and bioaccumulation and with deleterious (even potentially synergistic) long-term effects on the coastal marine biocenoses, have been indiscriminately introduced in the Lagoon especially during the last fifty years from both direct and indirect polluting sources, following the increase in the agro-industrial productiveness and the tourist and commercial harbour activities of the Venetian Region. The understanding of the “metabolism” of the Lagoon, including the biotic and abiotic factors, is therefore a top priority in sight of an ecological risk assessment.

Beginning from the second half of 1960s, biocides based on organotin compounds (TPT, TBT and their derivatives) were massively introduced in the formulation of the antifouling paints used for the preservation of materials used for submerged structures as boat hulls and helixes, buoys and moles from the settlement of various aquatic sessile organisms. These substances proved to be very harmful to the benthic marine biocenoses, in particular to the filter-feeding organisms, and, frequently, result persistent in the environment [Bryan et al., 1986; Henderson and Salazar, 1996; Hoch, 2001; Cima et al., 2003].

After the organotin ban on boats less than 25 m in length (1990) and the proposal of the total TBT enjoinment by the International Maritime Organization (IMO) [Julian, 1989], beginning from 2003, industries turned their attention to biocidal combinations of new synthesis or coming from either the pharmacology industry (bactericides) or the agriculture (herbicides, fungicides, insecticides) [Cima et al. 2002]. Their main request is to prevent both the settlement of spores and larvae of fouling macroorganisms, and the formation of the bacterial and microalgal microfilm, from which the ecological succession of the hard-substrate benthic biocenosis begins.

About twenty new substances (Tab. 1) are at present in commerce in the area of the Northern Adriatic Sea in various formulations of antifouling paints of new generation, in which the biocidal compounds play various roles, i.e. as alternative substances to TBT or as boosters to increase the performance of the antifouling paints against a wider spectrum of fouling organisms.

2. The experimental model

The environmental risk of antifouling compounds is a function of both their environmental concentration and their degree of toxicity. In the present study, we tried to reveal both the mechanisms through which such compounds carry out their activity at the cellular level and their effects on populations of sessile invertebrate species. With such aim, we carried out this study using an experimental laboratory model, represented by a species of compound ascidian largely diffused in the Lagoon and often dominant in the hard-substrate benthic biocenoses: the colonial ascidian *Botryllus schlosseri,* which is commonly reared in our laboratory. Wild colonies collected from the Lagoon of Venice are usually kept in aerated aquaria at 20 °C, attached to glass slides, and fed with Liquifry Marine (Liquifry Co., Dorking, England) and *Dunaliella* sp. microalgae.

Tab. 1 – Alternative/booster biocidal substances used in formulations of antifouling paints at present on the market in the Northern Adriatic Sea area.

CHEMICAL NAME	**TRADEMARK**	**OTHER USES**
Cu_2O, CuO, CuSCN, Cu	None	Fungicide
Zinc 2-pyridinethiol-oxide	Zinc pyrithione, ZnP	Bactericide, fungicide in antidandruff shampoos
2-Methylthio-4-ter-butylamino-6cyclopropylamino-s-triazine	Irgarol 1051	Herbicide
4,5-Dichloro-2-*n*-octyl-4-isothiazolin-3-one	Sea-Nine 211, Kathon 5287	None
3-(3,4-Dichlorophenyl)-1,1-dimethylurea	Diuron, Karmex, Telvar	Herbicide
2,4,5,6-Tetrachloroisophthalonitrile	Chlorothalonil	Fungicide in paints and glues
N-Dimethyl-N-phenylsulphamide	Dichlofluanid	Fungicide
2,3,5,6-Tetrachloro-4-(methylsulphonyl)pyridine	TCMS pyridine	Leather preservative
2-[Benzothiozolylthio]methylthiocyanate	TCMTB	Fungicide, wood preservative
Manganous ethylenebis[dithiocarbamate]	Maneb, Manzate, Dithane	Fungicide
Bis(dimethylthiocarbamoyl) disulfide	Thiram, TMTD, Thiurad, Thiosan	Fungicide
Zinc dimethyldithiocarbamate	Ziram, Methasan, Zimate, Zirberk, Karbam White	Fungicide
Zinc ethylenebis[dithiocarbamate]	Zineb, Parzate, Dithane, Z-78	Fungicide
α,β-1,2,3,4,7,7,-Hexachlorobicyclo-[*2.2.1*]-2-heptene-5,6-bisoxymethylene sulfite	Endosulfan, Benzoepin, Thiodan	Insecticide, acaricide

3. Immunotoxicity assays

Immune defences are important for the survival of metazoans. Generally, the immunosuppressive effects, assessable *in vitro* with short-term, acute toxicity assays, make organisms more vulnerable to both pathogenic agents and other xenobiotics with a severe spin-off on the composition and the functional structure of the benthic biocenoses [Dean et al., 1985]. We have carried out some assays on short-term cultures of *B. schlosseri* haemocytes to evaluate the alterations of the immune responses by some active ingredients employed in the formulation of antifouling paints.

The immunocytes of this species include (i) cells of the phagocytic line, rich in hydrolytic enzymes inside their lysosomes and heterophagic vacuoles, able to spread with amoeboid movements on the substrate and to phagocytise target-particles, and (ii) cells of the cytotoxic line containing the prophenoloxidase proenzyme and its polyphenolic substrates, on which the activated enzyme acts with the production of natural biocide substances in reply to the contact and the recognition of foreign molecules [Ballarin et al., 1993, 1994, 1995].

All the concentrations of antifouling biocides used in our experiments were sublethal, as evaluated by means of the Trypan Blue dye exclusion test for cell mortality. The immunotoxic effects are described by a series of biomarkers, which resulted useful, repeatable and sensitive with organotin compounds:

- Adhesion index: percentage of cells adhering to the substrate
- Amoebocytic index: percentage of cells with amoeboid morphology
- Phagocytic index: percentage of cells containing phagocytised yeast cells
- Enzymatic indexes: percentages of cells with positivity to the cytochemical assays for the detection of hydrolytic (esterase), oxidative (phenoloxidase) activities, and ion (Ca^{2+}-ATPase pump) and electron (cytochrome-c-oxidase of the mitochondrial respiratory chain) transport activities.
- Glutathione index: percentage of cells with positivity to the cytochemical assay for the GSH using the chlorobimane fluorochrome.
- Cytosolic Ca^{2+} index: percentage of cells positive to the Von Kossa's cytochemical assay which makes visible the cytosolic calcium in the form of black precipitates.
- Apoptotic index: percentage of cells in which the induced apoptosis is visible as fragmentation of the nuclear DNA with the TUNEL cytochemical detection kit.

The results obtained are reported in Tab. 2.

Tab. 2 – Toxic effect evaluation of various, common antifouling biocides on *Botryllus schlosseri* immunocytes.

BIOMARKER / **SUBSTANCE (µM)**	**TBT**	**Cu(I)**	**ZnP**	**Sea-Nine 211**	**Chloro thalonil**	**TCMS pyridine**	**Diuron**	**Irgarol 1051**
Adhesion index	-	0.01 d	0.5 d	-	-	-	-	-
Amoebocytic index	1 d	-	0.1 d	1 d	1 d	50 d	250 d	-
Phagocytic index	1 d	0.1 d	0.5 d	0.1 d	1 d	10 d	250 d	-
Enzymatic index (esterase)	0.1 d	0.1 d	0.5 d	-	-	-	100 i	10 i
Enzymatic index (phenoloxidase)	?	0.1 d	0.1 d	-	-	20 d	-	200 d
Enzymatic index (cytochrome-c-oxidase)	0.1 d	0.01 d	0.5 d	1 d	1 d	-	-	-
Enzymatic index (Ca^{2+}-ATPase)	10 d	-	-	10 d	-	-	-	-
Glutathione index	0.1 d	?	-	1 d	1 d	10 d	-	?
Cytosolic Ca^{2+} index	10 i	0.01 i	1 d	1 i	-	-	-	-
Apoptotic index	1 i	0.1 i	0.1 i	1 i	1 i	10 i	100 i	200 i

d: decrease; i: increase

Only TBT and ZnP cause the cell detachment from the culture substrate. The amoebocytic index and the phagocytic index were previously shown useful and sensitive biomarkers, related between them, to assess the environmental risks due to the TBT contamination. Both of the above indexes decrease in the presence of antifouling compounds. All the antifoulings tested induce apoptosis and, except for Cu(I) e Irgarol

1051, provoke severe effects on phagocyte morphology, which appear to be irreversible and both time- and dose-dependent. Metal-containing antifouling, such as TBT, Cu(I) and ZnP inhibit the hydrolytic enzymatic activity of the phagocytes. On the other hand, a significant increment of such enzymatic activity was observed after cell exposure to Diuron and Irgarol 1051: at a morphological level, the large release of the reaction product into the cytoplasm can be interpreted as a consequence of an alteration of the membrane stability. The exposure of the cytotoxic cells to the assayed biocides triggered a degranulation reaction, although only Cu(I), ZnP, TCMS pyridine and Irgarol 1051 are able to interfere negatively with phenoloxidase activity causing an inhibition of the cytotoxic activity of this cell line. The evaluation of the effects on cell respiration through the variation of the enzymatic index of the cytochrome-c-oxidase revealed that it is influenced by metal-containing antifoulings, Chlorothalonil, and Sea-Nine 211 probably through a direct action onto the internal membrane of the mitochondria. GSH, an important electron donor naturally present inside cells, represents a natural scavenger acting as an antioxidant and detoxifying agent against many electrophilic xenobiotics. It is oxidised to GSSG from TBT, Sea-Nine 211, Clorothalonil and TCMS pyridine, so that the cells might become more vulnerable to the oxidative stress. Many antifoulings are able to interfere with the homeostasis of the cytosolic calcium: ZnP causes a significant decrement of the cytosolic calcium contents that has not been yet explained. On the other hand, the uncontrolled and harmful increase of the cytosolic calcium might occur, in the case of TBT and Sea-Nine 211, through the interaction with calmodulin which inhibits Ca^{2+}-ATPase, or, in the case of Cu(I), through a direct interaction with the calcium channel receptors of the plasmalemma.

4. Evaluation of the larval settlement ability

We already demonstrated the effects of TBT on ascidian embryonic development [Cima et al., 1996]. In this case, we focussed on the ability of larvae to settle and metamorphose in the presence of antifouling compounds. In a first series of experiments, *B. schlosseri* larvae were collected in 200-ml glass containers, each containing, on its bottom, a plate coated with one of the various antifouling paints commonly in commerce in the Lagoon of Venice. Their effects on metamorphosis and settlement were followed and the obtained results are reported in Tab. 3.

Paints containing ZnP + Sea-Nine 211, or CuSCN + Dichlofluanid, or Cu_2O + Irgarol 1051 + Chlorothalonil prevent the larval adhesion. Paints containing Sea-Nine 211, TCMS pyridine + Diuron, or ZnP + Zineb + Endosulfan allow the larval adhesion, but prevent metamorphosis. Paints containing TBT or Cu(I) allow the adhesion and the metamorphosis, but kill the oozooids. It is noteworthy that the antifouling components generally do not act only through a direct contact: the presence of dead larvae and with partial metamorphosis, both free and adhering to the glass surrounding the painted plate, suggests a certain degree of leaching of the antifouling paints.

Tab. 3 – Settlement ability of *Botryllus schlosseri* larvae, after 16 h at 20 °C, in laboratory conditions, on artificial substrates (glass plates) previously coated with various antifouling paints and placed each one inside a glass container with 200 ml of filtered sea water. Data are reported as the percentages of the total number of larvae.

ANTIFOULING PAINT (Biocidal content)	**EXPERIMENT #1 (%)**			**EXPERIMENT #2 (%)**		
	on painted glass plate	on surrounding glass	free larvae	on painted glass plate	on surrounding glass	free larvae
1. Control paint (alkyd resin)	12^{M}	20^{M}	68^{F}	12^{M}	32^{M}	56^{F}
2. Sea-Nine 211	$16^{A\dagger}$	2^{M}	$82^{F\dagger}$	$10^{A\dagger}$	2^{M}	$88^{F\dagger}$
3. Cu_2O, Irgarol 1051, Chlorothalonil	$2^{A\dagger}$	0	$98^{F\dagger}$	$2^{A\dagger}$	0	$98^{F\dagger}$
4. CuSCN, Dichlofluanid	$2^{A\dagger}$	0	$98^{F\dagger}$	0	2^{M}	$98^{F\dagger}$
5. ZnP, Sea-Nine 211	0	0	$100^{F\dagger}$	0	$2^{A\dagger}$	$98^{F\dagger}$
6. Cu_2O	10^{M}	8^{M}	$82^{F\dagger}$	28^{M}	4^{M}	$68^{F\dagger}$
7. TBT methacrylate, CuO	$8^{M\dagger}$	8^{M}	$84^{F\dagger}$	$2^{A\dagger}$	4^{M}	$92^{F\dagger}$
8. TCMS pyridine, Diuron	$8^{A\dagger}$	$6^{A\dagger}$	$86^{F\dagger}$	0	$12^{A\dagger}$	$88^{F\dagger}$
9. ZnP, Zineb, Endosulfan	$6^{A\dagger}$	$4^{A\dagger}$	$90^{F\dagger}$	0	$4^{M\dagger}$	$96^{F\dagger}$

A: adhering larvae; F: free larvae; M: metamorphosis; †: dead individuals

In a second series of experiments (Tab. 4), we have evaluated the effects of various biocidal concentrations on settlement and metamorphosis ability of the larvae. The results obtained reveal that the antifoulings assayed are able to prevent the adhesion to the substrate, provoke severe malformations (Fig. 1), interfere with the metamorphosis (developmental delays and mortality), and all are lethal with the exception of TCMS pyridine and the herbicide Diuron and Irgarol 1051, which do not kill the larvae, but prevent their settlement on the substrate and block their metamorphosis.

Conclusions

Our studies, carried out on haemocytes and larvae of the compound ascidian *B. schlosseri*, provided new clues to better understand the danger of the antifouling compounds and enabled us to arrange them in orders of decreasing toxicity.

The comparison of our results in various experimental conditions using haemocyte cultures suggests the following order of immunotoxicity: TBT ~ Cu(I) ~ ZnP > Sea-Nine 211 ~ Chlorothalonil > TCMS pyridine > Diuron > Irgarol 1051.

On the other hand, the toxicity order obtained after the exposure of the larvae is the following: Cu(I) > Chlorothalonil > ZnP > TBT > Sea-Nine 211 > TCMS pyridine > Diuron > Irgarol 1051.

Since these new substances are in commerce for some time and, consequently, widespread in the environment, a real risk condition for the coastal biocenoses appears to be undeniable given that, in many cases, their accumulation, modality of degradation, synergistic effects and environmental fate are not yet well-known. Some of these antifoulings have been revealed as immunotoxic as TBT [Cima et al., 1995]. Therefore, we consider that many more tests of acute and chronic toxicity on various target- and non target-organisms should be necessary to carried out before leading to the market new potentially pollutants, in order to prevent the repetition of the same irreversible errors already occurred with TBT.

Tab. 4 – Settlement and metamorphosis ability of *Botryllus schlosseri* larvae exposed to various biocidal concentrations in 200 ml of filtered sea water in glass containers at 20 °C until controls, i.e. unexposed larvae, metamorphosed. Controls were expressed as 100%.

Antifouling biocide exposure	Metamorphosis (oozooids)	Adhering larvae	Not adhering malformed larvae	Free swimming larvae	Free unmoving larvae
Controls	100	-		-	-
TBT					
0.1 µM	48.48	-	-	-	51.52
1 µM	-	-	42.42	-	57.58†
10 µM	-	54.52	6.06	-	39.42†
ZnP					
0.1 µM	40.74	18.52	-	40.74	-
0.5 µM	7.40	22.22	-	-	70.38†
1 µM	-	-	11.11	-	88.89†
Cu(I)					
0.01 µM	70	-	-	30	-
0.1 µM	-	-	96.66	-	3.34†
1 µM	-	-	10	-	90†
Sea-Nine 211					
0.1 µM	96.15	-	-	-	3.85
1 µM	-	-	88.46	-	11.54†
10 µM	-	15.38	19.23	-	65.39†
Chlorothalonil					
0.1 µM	26.92	-	-	-	15.38†
1 µM	-	34.61	-	-	65.39†
10 µM	-	-	30.77	-	69.23†
Irgarol 1051					
50 µM	45.45	-	-	54.55	-
100 µM	30.30	-	-	69.70	-
200 µM	27.27	-	-	72.73	-
Diuron					
100 µM	38.46	-	-	61.54	-
250 µM	-	-	-	-	100
500 µM	-	-	-	-	100
TCMS pyridine					
25 µM	-	-	-	100	-
50 µM	-	-	-	-	100
75 µM	-	-	-	-	100

†: dead individuals

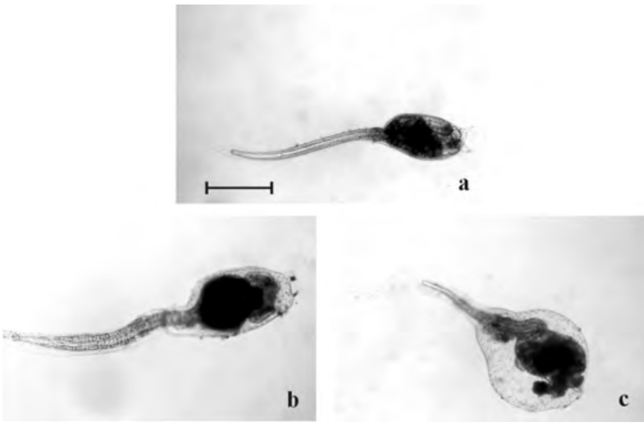

Fig. 1 – Larvae of *Botryllus schlosseri*. Normal conditions (a), and after exposure to 75 µM TCMS pyridine (b) and 0.5 µM ZnP (c). Bar length: 0.3 mm.

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ISOLATION AND CHARACTERIZATION OF MICROSATELLITES IN *ZOSTERISESSOR OPHIOCEPHALUS* (PERCIFORMES, GOBIIDAE)

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Riassunto

Il contributo riporta dell'isolamento e caratterizzazione di 12 loci microsatellite ottenuti da due librerie genomiche parziali di *Zosterisessor ophiocephalus* (Perciformes, Gobiidae), arricchite per la sequenza AC e per le sequenze AG, CAG e GATA. La variabilità dei loci è stata indagata in 200 individui raccolti nella laguna di Venezia. Sette loci sono risultati polimorfici, fornendo gli strumenti per un monitoraggio della biodiversità genetica della specie e per l'identificazione dei singoli individui.

Abstract

We isolated and characterized 12 microsatellite loci from two partial genomic libraries of *Zosterisessor ophiocephalus* (Perciformes, Gobiidae), enriched for AC and for multiple motifs. Variability was tested on about 200 specimens from the Venice Lagoon. Seven loci proved to be polymorphic and will be useful for monitoring the biodiversity of the species at the genetic level and for parentage assessment purposes.

1. Introduction

Gobiidae, with possibly more than 2000 species, is the most speciose family of marine fishes, many of which are typical of brackish waters, and includes the smallest vertebrates so far known [Nelson, 1994].

Zosterisessor ophiocephalus, commonly called "Gò", is the biggest and most abundant gobid in the Venice lagoon, where it spends most of its life cycle. The species is distributed in estuarine habitats of Mediterranean, and has been reported in the Black and Azov Sea [Miller, 1979].

Due to its benthic life style and potential exposure to xenobiotics, the species has been recently proposed as a bioindicator. This prompts for the need for an accurate knowledge of the genetic composition and temporal stability of local populations, and for the quantification of gene flow between different areas. Moreover the species presents alternative male reproductive tactics (with parental and opportunistic males, and a high degree of polygyny and sperm competition), and is therefore a good model for the study of the evolution of mating systems and sexual selection.

Here we report a set of novel polymorphic microsatellites that will be useful for monitoring the biodiversity at the genetic level and for individual identification.

2. Microsatellites isolation

Genomic DNA was extracted from fin clips (10-100 mg) using the DNAeasy Blood and Tissue Extraction kit (QIAGEN). All the polymerase chain reactions (PCR) were performed on GeneAmp 9700 or GeneAmp 2700 thermal cycler (Perkin Elmer).

Two enriched partial genomic libraries were constructed from DNA of a single specimen using FIASCO protocol (Fast Isolation by AFLP of Sequences Containing repeats, [Zane et al., 2002]), with a di-nucleotide probe, and a cocktail of di- tri- and tetra-nucleotidic probes. DNA was digested with *Ms*eI and ligated to *Ms*eI AFLP adaptor [Vos et al., 1995], using the following conditions: 250 ng genomic DNA, buffer OnePhorAll 1X (Pharmacia), DTT 5 mM, BSA 50 g/mL, adaptor 1 m, ATP 200 M, 2.5 units of *Ms*eI (New England Biolabs), and 1 unit of T4 DNA ligase (Amersham-Pharmacia Biotech); total volume was 25 L, incubation was 3 h at 37 °C.

The digested-ligated DNA was amplified in 20 L with AFLP adaptor-specific primers (5'-GATGAGTCCTGAGTAA(CATG)- 3': hereafter referred to as *Ms*eI-N). PCR conditions were [Vos et al., 1995]: *Taq* buffer 1X (Promega), $MgCl_2$ 1.5 mM, primer *Ms*eI-N 120 ng, dNTPs 200 M each, 0.4 units *Taq* (Promega) and 5 L of a 1/10 dilution of digested-ligated DNA. The PCR profile was: 94 °C 30 sec, 53 °C 1 min, 72 °C 1 min, 17 cycles. Amplified DNA was enriched using either a biotinylated $(AC)_{17}$ probe (hereafter named enrichment AC) or a mixture of $(AG)_{12}$, $(CAG)_{11}$, and $(GATA)_8$ biotinylated probes (enrichment ++).

Briefly, 250 ng of amplified DNA were mixed with 80 pmol of each biotinylated oligonucleotide in 100 L of SSC 4.2X, SDS 0.07%. DNA was denatured at 95 °C (3 min), and annealing was performed at room temperature (15 min). DNA molecules hybridized to biotinylated probes were captured by streptavidin-coated beads (Streptavidin Magnetic Particles, Boehringer-Mannheim).

One milligram of beads was mixed to approximately 10 g of tRNA (to minimize nonspecific binding of genomic DNA) and added to the DNA-probe hybrid molecules diluted with 300 L of TEN100 (10 mM Tris-HCl, 1 mM EDTA, 100 mM NaCl, pH=7.5). The mixture was incubated for 30 min at room temperature (AC enrichment) or 30 min at 40 °C (++ enrichment). The beads-probe-DNA complex was separated by a magnetic field from the hybridization buffer, which was discarded.

Three non-stringency washes were performed by adding 400 L of TEN1000 (10 mM Tris-HCl, 1 mM EDTA, 1 M NaCl, pH=7.5), followed by magnetic field application and beads recovering. Three stringency washes were performed by adding 400 L of SSC 0.2X, 0.1% SDS, and incubating for 5 min at room temperature (AC enrichment) or 5 min at 40 °C (++ enrichment). An additional wash was performed by adding 50 L of TE (Tris-HCl 10 mM, EDTA 1 mM, pH=8) and incubating at 95 °C for 5 min. Elution was performed by treating beads with 12 L of 0.15 M NaOH followed by neutralization and isopropanol precipitation.

DNA was dissolved in 50 l of water and 2 l were amplified by 30 cycles of PCR using the *Ms*eI-N primer under the conditions described above. PCR products were cloned by TOPO-TA cloning kit (Invitrogen) and recombinant clones were PCR amplified using primer on the vector. Positives at the PCR screening were purified by Exonuclease-Phosphatase (PCR Products Pre-Sequencing kit, Amersham-Pharmacia) and both strands were sequenced.

3. Results

More than 1000 recombinant colonies were obtained from the two libraries, and 45 of them were sequenced. Ten colonies from the library AC yielded 8 sequences containing repeats, whereas 35 colonies from the ++ library provided 25 sequences containing repeats. The most represented repeat was AC, which interestingly was found also in colonies from the ++ library (Tab. 1). A total of 600 colonies from the two libraries have been stored. Considering the success in the enrichment procedure (70-80% of the colonies of the two libraries are expected to contain microsatellite sequences), these colonies represent a reservoir, which can be used to easily obtain further loci in the future.

Primers for 12 loci were designed, and all proved to amplify genomic DNA of *Z. ophiocephalus*. For the sake of polymorphism testing, one primer for each pair was labelled with fluorescent dyes, which allow detection on ABI sequencers (Tab. 1).

Tab.1 - *Zosterisessor ophiocephalus* microsatellites. Reported are: locus name, fluorescent dye used, and repeat motif.

Locus name	Dye	Repeat motif
Go++2[1]	HEX	(GT)3GC(GT)6
Go++6m13	6-FAM	(AC)10
GoAC8	TAMRA	(AC)5AGCC(AC)3
GoAC3	6-FAM	(TG)6CG(TG)2CG(TG)6
Go++3	HEX	(GT)12
Go++2m13	TAMRA	TCCTCT(TCC)4(TCT)6
Go++22m13	HEX	(AC)16
Go++34m13	6-FAM	(AC)14
Go++37m13	TAMRA	(TGC)13
Go++26m13	HEX	(AC)13
Go++16m13	6-FAM	(GT)11
Go++32m13	TAMRA	(AC)18

[1] Each locus acronym refers to the species name (Go), the library used (++ or AC), and to an internal identification code (i.e. 2 or 6m13).

PCR amplifications were performed in 20 μl using the following conditions: *Taq* buffer 1X (Promega), MgCl2 1.375 mM, 160 nM of each primer, 70 μM dNTP's, 0.8 units of *Taq*, and 50 ng of genomic DNA. A hot-start touch-down PCR profile was used as follows: 1) pre-denaturation 94 °C; 2) ten touch-down cycles of denaturation 94 °C 1 min, annealing 58 °C 50 sec decreased of 0.5 °C each cycle, extension 72 °C 1 min; 3) thirty cycles of denaturation 94 °C 40 sec, annealing 55 °C 50 sec, extension 72 °C 1 min; 4) additional extension for 6 min at 72 °C.

Electrophoresis of loci was performed with an ABI Prism 3100 or 3700 automated sequencers, using standard conditions.

Two hundred *Z. ophiocephalus* individuals from the Venice lagoon were genotyped (Tab. 2). Seven loci proved to be polymorphic, with 3 to 14 alleles. Three loci were monomorphic and two yielded a complex pattern with up to 4 bands for individual, probably due to a locus duplication event.

Tab. 2 - Locus name, number of alleles, size range of alleles, and observed heterozygosity (Hobs) for *Zosterisessor ophiocephalus* microsatellites in 200 individuals from the Venice Lagoon.

Locus name	No of alleles	Size range (bp)	Hobs
GO++2	1	201	monomorphic
GO++6m13	2[1]	199-201	monomorphic1
GOAC8	1	200	monomorphic
GOAC3	3	102-122	0.021
GO++3	7	109-125	0.146
GO++2m13	4	108-129	0.042
GO++22m13	complex pattern (see text)		
GO++34m13	complex pattern (see text)		
GO++37m13	14	183-228	0.494
GO++26m13	12	113-143	0.833
GO++16m13	13	123-158	0.510
GO++32m13	10	115-133	0.552

[1] overall frequency of the commonest allele is above 99%.

The observed heterozygosity of the seven polymorphic loci ranged from 0.021 to 0.833, and no significant departure from Hardy-Weinberg equilibrium was detected. The two most polymorphic loci (Go++26 and Go++32m13) provided an individual exclusion power useful for parentage assessment. Considering that a previous allozyme survey of individuals collected in the same area revealed little variability [Bisol, 2002], our microsatellites represent a significant improvement and are a valuable tool for the genetic analysis of *Z. ophiocephalus.* Indeed, preliminary evidence for differences between localities and between age-classes has been found in this pilot survey and will be addressed in future studies.

Conclusions

This contribution reports on the isolation and characterization of microsatellites loci that will be useful for the measure of biodiversity at the genetic level of *Zosterisessor ophiocephalus*.

Six hundred colonies from two enriched libraries, which are expected to contain approximately 450 microsatellites, have been stored for future use.

Seven polymorphic loci have been characterized, from a total of twelve loci tested. The high level of polymorphism of these loci unveil phenomena that were hidden at previous allozyme analysis allowing to detect differences between samples collected in different areas of the Venice lagoon and differences between age-classes

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RESEARCH LINE 3.7
Forecasting and management models

A FINITE ELEMENT MODEL FOR THE HYDRODYNAMICS OF SHALLOW TIDAL BASINS BASED ON COUPLING OF 2D AND 1D ELEMENTS

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Riassunto

Nel lavoro è illustrato un nuovo schema per l'accoppiamento di elementi unidimensionali e bidimensionali nell'ambito dell'implementazione di un modello agli elementi finiti per lo studio del comportamento idrodinamico di bacini a marea. L'obiettivo è quello di rappresentare in modo efficace gli innumerevoli canali di varie dimensioni che caratterizzano gli ambienti lagunari dalla morfologia complessa.

Un innegabile vantaggio legato all'impiego di elementi uni-bidimensionali accoppiati è rappresentato dalla possibilità di utilizzare nella modellazione, a parità di risoluzione, un numero decisamente più contenuto di nodi e di elementi rispetto ad uno schema bidimensionale.

In letteratura sono presenti precedenti contributi a tale riguardo. L'apporto innovativo che si è voluto fornire con il presente lavoro riguarda l'attribuzione di una maggiore rilevanza all'elemento monodimensionale nell'ambito dell'accoppiamento in prospettiva di poterlo utilizzare per descrivere tutti i canali lagunari, anche quelli di dimensioni maggiori.

L'approccio consente di riprodurre più fedelmente la geometria della sezione del canale e, di conseguenza, di valutare con maggiore accuratezza le caratteristiche del moto ed in particolare le resistenze idrodinamiche offerte.

In questo lavoro è descritto in dettaglio lo schema utilizzato nell'accoppiamento ed sono riportati gli sviluppi numerici del modello.

Con riferimento ad un bacino schematico, sono poi riportati alcuni confronti tra i risultati forniti dal modello proposto e quelli che si ottengono utilizzando una schematizzazione bidimensionale tradizionale. I risultati evidenziano la buona capacità del nuovo schema di riprodurre le caratteristiche idrodinamiche del moto in un bacino a marea anche complesso.

Abstract

This paper describes a finite element model for shallow water flows in which two-dimensional elements are coupled with one-dimensional elements. The resulting 2D-1D model is a powerful and accurate tool to study the hydrodynamics of shallow tidal basins which are crossed by a very intricate network of channels generally departing from the inlets. Examples of such a type of basins are given by most of the lagoons along the North-Adriatic coast, the most famous of which is the Venice lagoon.

In the model, two-dimensional elements describe the flow over shallow areas, while one-dimensional elements are used to discretize the channels.

The main advantages of the proposed model are represented by both a reduced computational effort, when compared with fully two-dimensional models of comparable grid size, and a greater accuracy in describing the channels geometry.

The model was extensively tested against a fully two-dimensional model, and a few examples are presented in the paper. A good agreement between results of the above two models was always found confirming the remarkable capability of the proposed model to account for the presence of deep channels in an otherwise shallow basin.

1. Introduction

Most of tidal lagoons, all over the world, are characterized by typical morphologic units, namely shallows and mudflats, marshes, and channels. An example is given by the Venice lagoon (Fig. 1) in which a wide, shallow basin is crossed by a very intricate network of channels departing from three inlets, namely Lido, Malamocco and Chioggia.

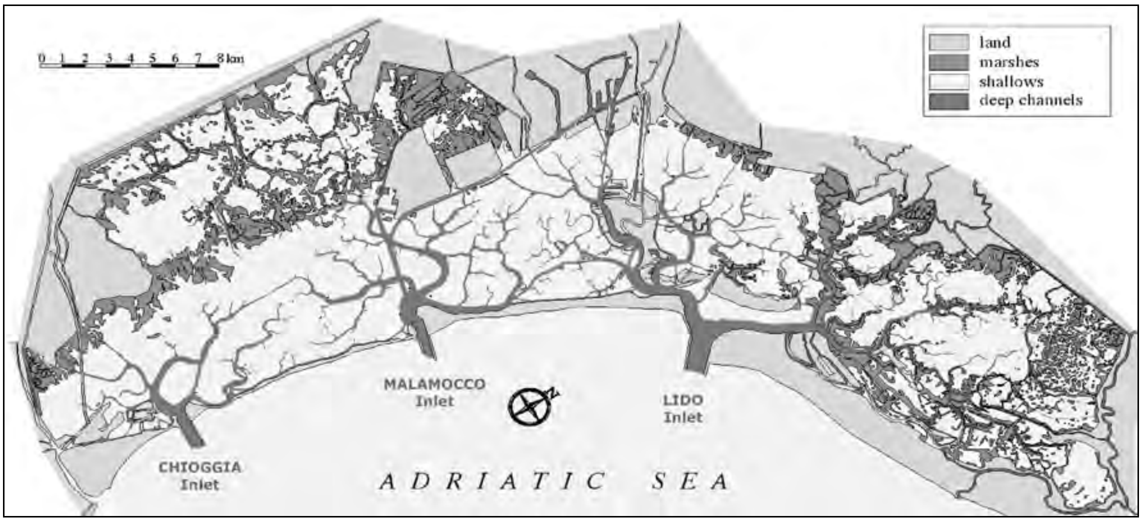

Fig. 1 – The Lagoon of Venice

This channels network plays an important role in governing the tide propagation within the lagoon. The width of the channels ranges from less than one meter to several hundred meters. However, the number of narrow channels is significant, thus their relevance is comparable to that of the larger channels.

Common numerical models based on solving depth-integrated shallow water equations by finite difference or finite element schemes do generally not include most of the minor channels due to the extremely large amount of very small computational elements required for their description.

It must be stressed that the tidal channels of the Venice lagoon have a strong one-dimensional character [*D'Alpaos and Defina*, 1993, 1995]. This fact naturally suggested the use of one-dimensional elements to represent these channels.

The considerations first outlined lead us to formulate a mathematical model based on coupling a 2D model describing shallow water hydrodynamics with a 1D model in order to simulate the flow in the channel network.

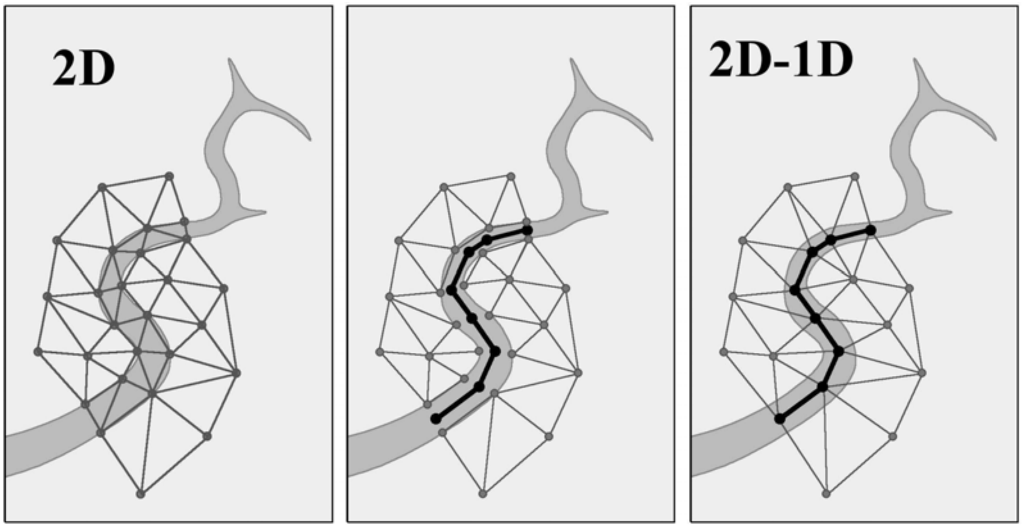

Fig. 2 – Transition from a fully 2D mesh to a 2D-1D mesh.

Among the many ways of coupling 2D and 1D elements, the one shortly described in Fig.2 was preferred for the reasons outlined below. The *transition* from a fully two-dimensional discretization of the domain to a 2D-1D discretization (Fig.2), mainly consists of two steps. Firstly all the two-dimensional elements describing the channels are replaced with one-dimensional elements. Secondly the nodes of the two-dimensional mesh neighboring the channels are collapsed into the 1D element nodes. It is clear, as shown in Fig.2, that the 2D-1D discretization requires a smaller number of nodes, when compared to a fully 2D discretization. As a consequence, the computational effort is largely reduced.

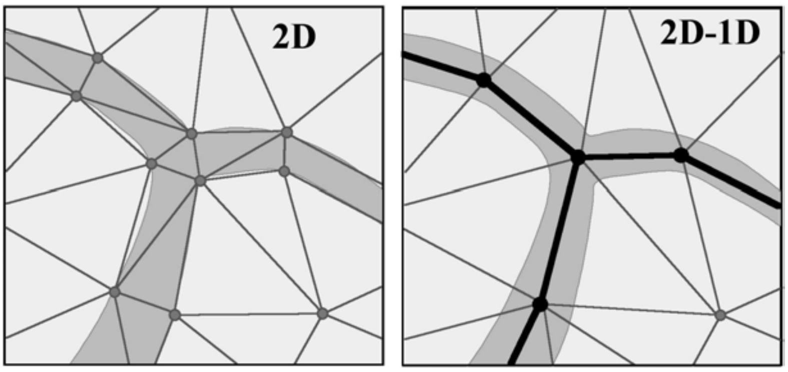

Fig. 3 –fully 2D and 2D-1D discretization of a channel junction.

Moreover a fully 2D discretization requires the use of very small elements to describe channels junctions and a consequent reduction of the integration time step.

However, the collapsing of the nodes produces an overlap region between 2D and 1D elements (see Fig. 4). This overlap has to be removed in order to avoid inconsistencies in the continuity equation.

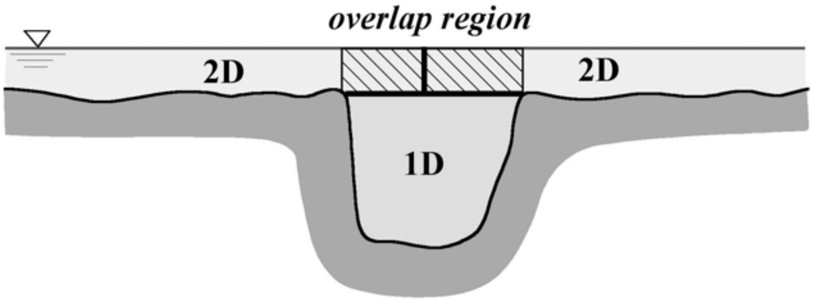

Fig. 4 – Overlap region between 2D and 1D elements as a consequence of node collapsing.

A first successful approach dealing with the overlap region was suggested by *D'Alpaos and Defina* [1993, 1995, 2004], *Defina et. al.* [1995]. They assumed that the effects due to the momentum exchange between the channel and the siding two-dimensional domain could be neglected if compared with the bottom resistance. Therefore, momentum equations of two-dimensional and one-dimensional models are maintained unaltered. The 2D continuity equation was kept unaltered as well. On the contrary, the continuity equation for the one-dimensional model was suitably modified to account for the overlapping two-dimensional flow, when the 2D elements siding the channel are wet.

In this case a reduced channel cross section (or, equivalently, a reduced channel flow rate) was introduced (Fig. 5)

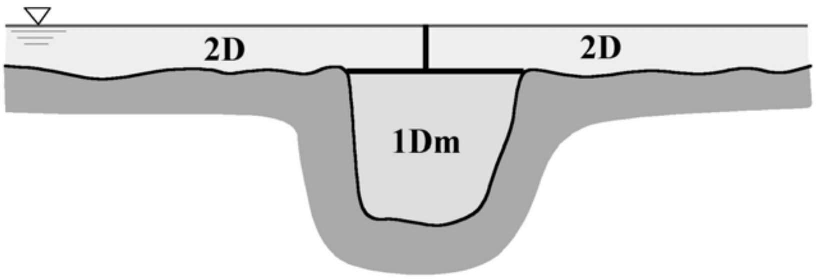

Fig. 5 – Coupling method suggested by *D'Alpaos and Defina* [1993, 1995, 2004] .

The reduced (or *effective*) channel cross section, as it depends on the flow field, was computed at each time step, based on the assumption of uniform flow along the channel axis. Moreover, in the model, the shape of the channel cross section was approximated as rectangular.

This way of dealing with the overlap region, in which some approximation was introduced in one-dimensional equations, was based on the idea that only minor channels had to be described utilizing 1D elements while 2D elements had to be used for large channels (e.g., [*Defina et al.*, 1995, Fig. 1; *D'Alpaos and Defina*, 2004, Fig. 9].

The major shortcomings characterizing the above coupling procedure are: i) a channel cross section must be approximated as rectangular or trapezoidal, ii) some approximations are introduced in the continuity equation for 1D elements in order to deal with the overlap, iii) it is assumed that the two 2D elements siding a channel have the same bottom elevations.

A new scheme for coupling one-dimensional and two-dimensional elements which overcomes the above shortcomings is described in sections 2 and 3. To validate the model many tests have been performed through comparison with the results obtained from a fully two-dimensional model. Two examples are presented and discussed in section 4. Finally, section 5 is devoted to some conclusions.

2. 2D-1D Coupling Scheme

In order to overcome shortcomings described in the previous section a new coupling scheme is here proposed. The overlap region is schematized as shown in Fig.6a: 1D elements are maintained unaltered while 2D elements siding a channel are formally reduced in extension.

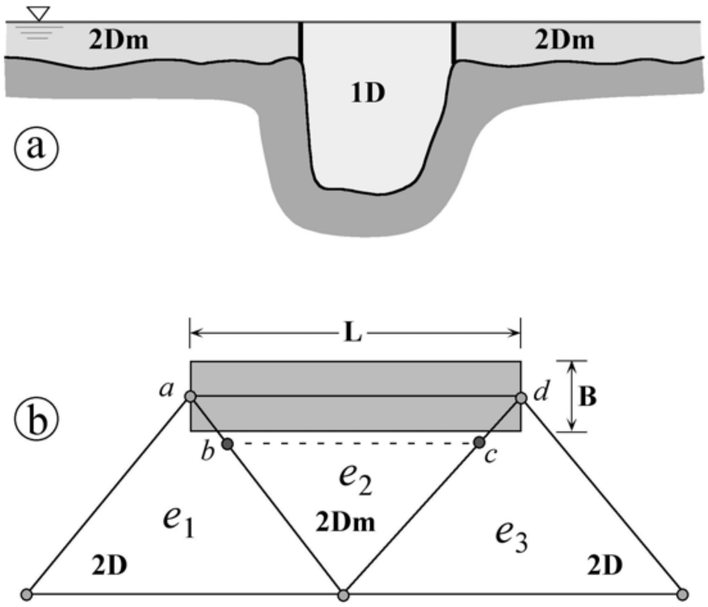

Fig. 6 – Reduction in 2D elements area for the presence of 1D elements along their sides.

It has been further assumed that only elements sharing one side with a channel (i.e., e_2 in Fig. 6b) are reduced in order to remove the overlap, while all the other elements (i.e., e_1 and e_3 in Fig. 6b) are maintained unchanged. As shown in Fig.6b, original nodes *a* and *d* of element e_2 are shifted to positions *b* and *c* so that the area *abcd* exactly corresponds to half the overall channel size: BL/2.

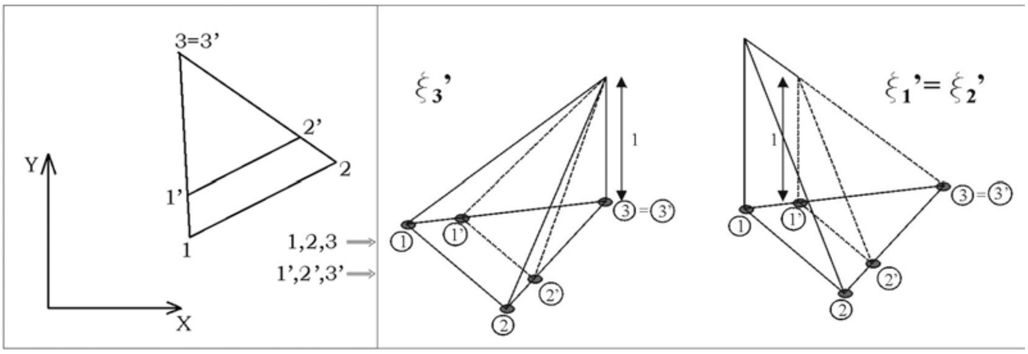

Fig. 7 – Original and reduced test function.

Considering Fig.7, coordinates of shifted nodes (denoted with prime) are simply related to the original ones through

$$
\begin{aligned}
x_1' &= x_1\lambda + x_3(1-\lambda) \qquad & y_1' &= y_1\lambda + y_3(1-\lambda) \\
x_2' &= x_2\lambda + x_3(1-\lambda) \qquad & y_2' &= y_2\lambda + y_3(1-\lambda) \\
x_3' &= x_3 \qquad & y_3' &= y_3
\end{aligned}
\tag{1}
$$

where $\lambda = \sqrt{A_e'/A_e}$, A_e is the original element area, while A_e' =A_e-BL/2 is the reduced element area.

Using (1) the expressions of the reduced test functions (denoted with prime) are easily obtained as a function of the original test functions and parameter λ:

$$
\xi_1' = \frac{1}{\lambda}\xi_1 \qquad \xi_2' = \frac{1}{\lambda}\xi_2 \qquad \xi_3' = \frac{1}{\lambda}\xi_3 + \frac{\lambda-1}{\lambda}
\tag{2}
$$

In the above discussion we assumed that each 2D element shares at most one side with a channel. Therefore, care must be taken in order to avoid situations similar to the one shown in Fig.8a. In this case the problem can be solved by dividing the element into two elements as described in Fig.8b.

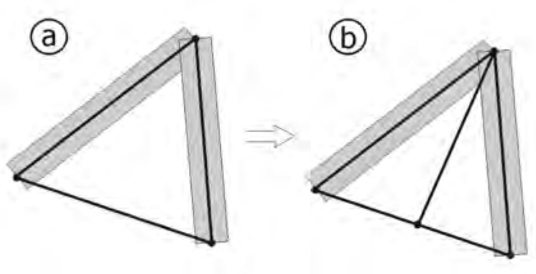

Fig. 8 – Two 1D elements siding a 2D element.

3. The Numerical Model

In the model the domain is divided into triangular and linear elements and each channel in the network lyes along the sides of two adjacent triangular elements. In this way, each channel can be added to or removed from the domain without any change in the main two-dimensional discretization. Moreover, the number of nodes in the computational mesh remains unchanged and the computational effort is only slightly increased due to the inclusion of 1D elements.

In the following two paragraphs both the two-dimensional and one-dimensional numerical models are briefly presented. They are then coupled according to the procedure described in the previous section.

Convective terms in the momentum equations have been neglected both in the 1D and 2D models.

Though it may seem that models which neglect convective terms simulate reality less accurately, due to the complex morphology of the Venice lagoon, errors introduced by neglecting convective terms are actually much smaller than errors introduced by considering these terms. In fact, convective acceleration can only be properly accounted for when considering a very detailed velocity field.

However, neglecting convective terms does not imply neglecting the effects caused by convective terms. The overall effects of convective terms can, in fact, be accounted for by suitably choosing the friction coefficient in order to produce a velocity field which is somewhat equivalent to the actual flow field, at least from a “mean” or “large scale” point of view [*Defina*, 2000b; *D’Alpaos and Defina*, 2004].

Neglecting convective terms also means neglecting horizontal exchange of momentum between elements. Therefore, from a dynamic point of view, coupling 1D and 2D elements reduces to imposing pressure congruence; this is implicitly ensured by the node collapsing procedure. From the continuity point of view, the coupling procedure simply consists in summing up contributions from both 2D and 1D elements.

For these reasons, 2D and 1D numerical models are preliminarily discussed in the following section and then the coupled numerical model is presented.

3.1. Two-dimensional Numerical Model

A full new set of two-dimensional shallow water equations has recently been developed dealing with partially wet and very irregular domains [*Defina,* 2000a].

Assuming the hydrostatic approximation, the three dimensional Reynolds equations have been suitably averaged over a Representative Elementary Area (REA) and then integrated over the depth. Neglecting Reynolds stresses and convective terms the averaged two dimensional momentum and continuity equations read:

$$\frac{\partial h}{\partial x} + \frac{1}{gY}\frac{\partial q_x}{\partial t} + \frac{q_x q_w}{Ks^2 H^{10/3}} - \eta \frac{\tau_{wx}}{\gamma Y} = 0$$
$$\frac{\partial h}{\partial x} + \frac{1}{gY}\frac{\partial q_y}{\partial t} + \frac{q_y q_w}{Ks^2 H^{10/3}} - \eta \frac{\tau_{wy}}{\gamma Y} = 0 \qquad (3)$$

$$\eta \frac{\partial h}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = 0$$

where t denotes time, q_x, q_y are the flow rates per unit width in the x, y (planform) directions respectively, $\tau_w=(\tau_{wx}, \tau_{wy})$ is the wind stress at the free surface, *Ks* is the Strickler bed roughness coefficient, γ is the specific weight of water, *h* is the free surface elevation, *g* is gravity. *Y* is the *equivalent* water depth, defined as the volume of water per unit area actually ponding the bottom, η is the local fraction of wetted domain, and *H* is an equivalent water depth [*Defina*, 2000a].

Momentum equations can be rearranged in the form:

$$q_x = -\psi\left(\frac{\partial h}{\partial x}\right) + \varphi_x \qquad q_y = -\psi\left(\frac{\partial h}{\partial y}\right) + \varphi_y \tag{4}$$

where

$$\psi = \left[\frac{1}{gY\Delta t} + \frac{q_w}{Ks^2 H^{10/3}}\right]^{-1}$$

$$\varphi_x = \left[\frac{q_x}{\Delta t} + \eta\frac{\tau_{wx}}{\gamma Y}\right] / \left[\frac{1}{\Delta t} + \frac{gY|q_w|}{Ks^2 H^{10/3}}\right] \tag{5}$$

$$\varphi_y = \left[\frac{q_y}{\Delta t} + \eta\frac{\tau_{wy}}{\gamma Y}\right] / \left[\frac{1}{\Delta t} + \frac{gY|q_w|}{Ks^2 H^{10/3}}\right]$$

The continuity equation is solved using a standard finite element approach dividing the domain into triangular elements and assuming the free surface elevation to be piecewise linear

$$h = \sum_{n=1,N} h_n \cdot \xi_n^e \tag{6}$$

where ξ_n is the basis function, h_n denotes the generic nodal free surface elevation and *N* the total number of nodes of the mesh. Moreover, coefficients ψ, φ_x, and φ_y are assumed constant within each element. Therefore it can be derived from (4) that q_x and q_y are piecewise constant as well.

Assuming, in accordance with the Galerkin method, that the basis functions are also the test function, yields:

$$\sum_{e}\int_{A_e}\left(\eta^{e}\frac{\partial h}{\partial t}+\nabla\mathbf{q}^{e}\right)\cdot\xi_m^e dA_e = 0 \qquad m = 1,\ldots,N \tag{7}$$

where the summation is extended to all the elements having a vertex in the *m* node and ξ_m^e is the basis function pertaining to element *e* of area A_e.

Applying Green's first identity to equation (7) gives:

$$\sum_{e}\eta^{e}\sum_{n=1,N}\int_{A_e}\xi_n^e\xi_m^e dA_e\frac{\partial h_n}{\partial t}-\sum_{e}\int_{A_e}\mathbf{q}_x^e\cdot\nabla\xi_m^e dA_e$$
$$+\sum_{e}\int_{\Gamma_e}\mathbf{q}^{e}\cdot n_{\Gamma}\xi_m^e d\Gamma_e = 0 \tag{8}$$

where Γ_e denotes the boundary of the computational element *e*, with normal n_Γ. In the second term, $\nabla\xi_m^e$ is constant within the generic element and the required averaged flow rate per unit width is exactly given by equation (4). The third term in equation (8), hereafter denoted with Q_m, represents the flow exiting from node *m*.

Substituting equation (4) into (8) and discretizing the time derivate using a finite difference approach yields:

$$\sum_{e}\eta^{e}\int_{A_e}\sum_{n=1,N}\frac{h_n^{(k)}-h_n^{(k-1)}}{\Delta t}\xi_n^e\xi_m^e dA_e +$$
$$+\sum_{e}\int_{A_e}\left[\psi_e\cdot\sum_{n=1,N}\left(h_n^{(k-1)}\cdot\nabla\xi_n^e\right)-\varphi_e\right]\cdot\nabla\xi_m^e dA_e + Q_m = 0 \tag{9}$$

where superscript *(k)* denotes the actual time step while superscript *(k-1)* denotes the previous time step.

The numerical model assumes that the coefficients ψ_e, φ_e and η^e are known quantities (i.e. computed at previous time step under the assumption of slowly varying flow). Therefore introducing the following definitions:

$$F_{nm} = \sum_{e}\eta_e\int_{A_e}\xi_n^e\xi_m^e dA_e \tag{10}$$

$$A_{nm} = \sum_{e}\psi^{e}\int_{A_e}\left(\frac{\partial\xi_n^e}{\partial x}\frac{\partial\xi_m^e}{\partial x}+\frac{\partial\xi_n^e}{\partial y}\frac{\partial\xi_m^e}{\partial y}\right)dA_e \tag{11}$$

$$B_m = \sum_e \left[\varphi_x^e \int_{A_e} \frac{\partial \xi_m^e}{\partial x} dA_e + \varphi_y^e \int_{A_e} \frac{\partial \xi_m^e}{\partial y} dA_e \right] \tag{12}$$

a set of N linear algebraic equations is finally obtained:

$$\sum_{n=1,N} h_n^{(k)} \cdot \left(\frac{1}{\Delta t} F_{nm} + A_{nm} \right) = \sum_{n=1,N} h_n^{(k-1)} \cdot \left(\frac{1}{\Delta t} F_{nm} \right) + B_m - Q_m \tag{13}$$

$$m = 1,\ldots,N$$

3.2. One-dimensional Numerical Model

The one-dimensional numerical model is obtained according to the same approach previously outlined for the 2D numerical model.

Neglecting convective terms the one dimensional momentum and continuity equations read:

$$\begin{aligned} &\frac{\partial h}{\partial s} + \frac{\beta}{gA}\frac{\partial Q}{\partial t} + \frac{Q|Q|}{Ks^2 R_h^{4/3} A^2} = 0 \\ &\eta B \frac{\partial h}{\partial t} + \frac{\partial Q}{\partial s} = 0 \end{aligned} \tag{14}$$

where s is the channel axis direction, Q is the actual flow rate, A is the cross sectional area, R_H is the hydraulic radius, Ks is the Strickler bed roughness coefficient and η is the local fraction of wetted domain previously discussed.

Assuming:

$$\begin{aligned} &\Psi = \left[\frac{1}{gA\Delta t} + \frac{|Q|}{Ks^2 R_h^{4/3} A^2} \right]^{-1} \\ &\Phi = Q \Big/ \left[1 + \frac{g\,\Delta t\,|Q|\,A}{Ks^2 R_h^{4/3} A^2} \right] \end{aligned} \tag{15}$$

the momentum equation can be written as:

$$Q = -\Psi\left(\frac{\partial h}{\partial s}\right) + \Phi \tag{16}$$

The continuity equation is solved by means of a standard finite element approach dividing the domain into linear elements and assuming the free surface elevation to be piecewise linear with one-dimensional basis function, ζ_n.

Assuming, in accordance with the Galerkin method, that the basis functions are also the test functions, yields:

$$\sum_e \int_{L_e} \left(\eta^e B_e \frac{\partial h}{\partial t} + \frac{\partial Q}{\partial s} \right) \cdot \zeta^e_m dL_e = 0 \qquad m = 1,\ldots,N \tag{17}$$

where the summation is extended to all elements having a vertex in the m node and ζ^e_m is the one-dimensional basis function pertaining to element e of length L_e.

Applying Green's first identity to equation (17) gives:

$$\sum_e \eta^e B^e \sum_{n=1,N} \int_{L_e} \zeta^e_n \zeta^e_m dL_e \frac{\partial h_n}{\partial t} - \sum_e \int_{L_e} Q^e \cdot \frac{\partial \zeta^e_m}{\partial s} dL_e + \\ + \sum_e \int_{\Gamma_e} Q^e \zeta^e_m \cdot n_\Gamma d\Gamma_e = 0 \tag{18}$$

where Γ_e denotes the boundary of the computational element e, with normal n_Γ. In the second term, $\partial \zeta^e_m / \partial s$ is constant within the generic element and the required averaged flow rate Q is exactly given by equation (16). The third term in equation (18), hereafter denoted with Q'_m, represents the flow exiting from node m.

Substituting equation (16) into (18) and discretizing the time derivate using a finite difference approach yields:

$$\sum_e \eta^e B^e \int_{L_e} \sum_{n=1,N} \frac{h_n^{(k)} - h_n^{(k-1)}}{\Delta t} \zeta^e_n \zeta^e_m dL_e + \\ + \sum_e \int_{L_e} \left[\Psi_e \cdot \sum_{n=1,N} \left(h_n^{(k-1)} \cdot \frac{\partial \zeta^e_n}{\partial s} \right) - \Phi_e \right] \cdot \frac{\partial \zeta^e_m}{\partial s} dL_e + Q_m = 0 \tag{19}$$

where superscript *(k)* denotes the actual time step while superscript *(k-1)* denotes the previous time step.

The numerical model assumes that the coefficients Ψ_e, Φ_e and η^e are known quantities (i.e. computed at previous time step under the assumption of slowly varying flow). Therefore introducing the following definitions:

$$G_{mn} = \sum_{e} \eta_e B^e \int_{L_e} \zeta^e_n \zeta^e_m dL_e \tag{20}$$

$$P_{mn} = \sum_{e} \Psi^e \int_{L_e} \frac{\partial \zeta^e_n}{\partial s} \frac{\partial \zeta^e_m}{\partial s} dL_e \tag{21}$$

$$R_m = \sum_{e} \Phi^e \int_{l_e} \frac{\partial \zeta^e_m}{\partial s} dL_e \tag{22}$$

a set of N linear algebraic equations is finally obtained:

$$\sum_{n=1,N} h_n^{(k)} \cdot \left(\frac{1}{\Delta t} G_{nm} + P_{nm} \right) = \sum_{n=1,N} h_n^{(k-1)} \cdot \left(\frac{1}{\Delta t} G_{nm} \right) + R_m - Q'_m \tag{23}$$

$$m = 1,\ldots,N$$

3.3. 2D-1D Numerical Model

Both the 2D and the 1D numerical models presented above are now to be coupled based on continuity condition. Combining (13) with (23) the following set of N linear algebraic equations is obtained:

$$\sum_{n=1,N} h_n^{(k)} \cdot \left[\frac{F_{nm} + G_{nm}}{\Delta t} + \left(A_{nm} + P_{nm} \right) \right] =$$

$$= \sum_{n=1,N} h_n^{(k-1)} \cdot \left[\frac{F_{nm} + G_{nm}}{\Delta t} \right] + \left[B_m + R_m \right] - \left[Q_m + Q'_m \right] \tag{24}$$

$$m = 1,\ldots,N$$

The system (24) is solved for the free surface elevation h, while the flow rate $\mathbf{q}=(q_x, q_y)$ of two-dimensional elements and the discharge Q of one-dimensional elements are computed by back substitution of h into equations (4), and (16), respectively.

It is worthwhile recalling that coefficients in (24) must be computed adopting reduced test functions when assembling contributions of 2D elements sharing one side with 1D elements.

4. Validation of the Coupling Scheme

Many tests were carried out to validate the scheme described in Section 2. The tests were performed by comparing simulation's results of the present model with simulation's results of a fully two-dimensional model, for a wide range of domain geometries and hydrodynamic conditions. In this section two test examples are presented and discussed.

A simple, rectangular basin 1200m long and 800m wide was considered in these examples. The basin is crossed by a meandering channel 60m wide and 6m deep as shown in Fig.9. A fully two-dimensional mesh and, alternatively, a 2D1D mesh were built to discretize the domain. The fully two-dimensional mesh, composed of 91 triangular elements and 57 nodes, and the 2D1D mesh, composed of 66 triangular elements, 12 linear elements and 44 nodes, are shown in Fig. 9.

The basin bottom was assumed horizontal and different depths were considered in the two examples. In example 1, the bottom elevation was set to 0.25m above the mean see level, while in example 2, the bottom elevation was set to 1.5m below the mean see level.

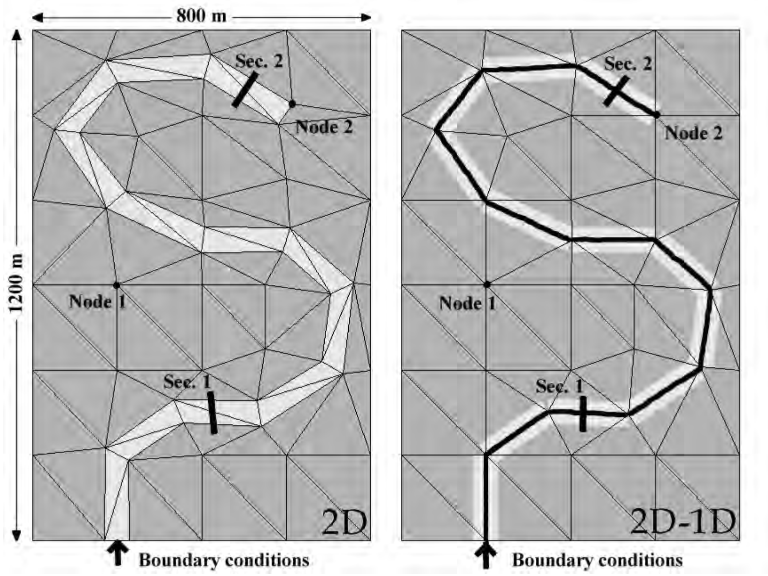

Fig. 9 – Computational domain used in the presented tests.

All simulations were performed assuming a Strickler roughness coefficient Ks=30 $m^{1/3}s^{-1}$ for the channel and Ks=10 $m^{1/3}s^{-1}$ for the remaining portion of the basin. The following boundary conditions are imposed: at the two nodes bearing to the channel, along the lower side of the domain, water elevations were prescribed which vary sinusoidally according to the law $h=0.7\sin(2\pi t/T)$, with a tide period T of 12 hours. Along the remaining part of the lower side and along the other three sides, impervious boundary conditions were assumed.

Referring to the first example, water elevations at two points far from the inlet (see Fig. 9) and flow rates at two sections along the channel (see Fig. 9) computed on the fully 2D mesh are plotted against time in Fig.10. The behavior of water elevations clearly reflects the wetting and drying processes taking place during each tidal cycle, which implies a significant reduction of tidal wave amplitude.

The resulting water elevations at the same points and flow rates at the same sections, computed on the 2D1D mesh are plotted in Fig. 10 allowing the comparison with the results obtained on the fully 2D mesh. It clearly appears that results of the two models match favorably well.

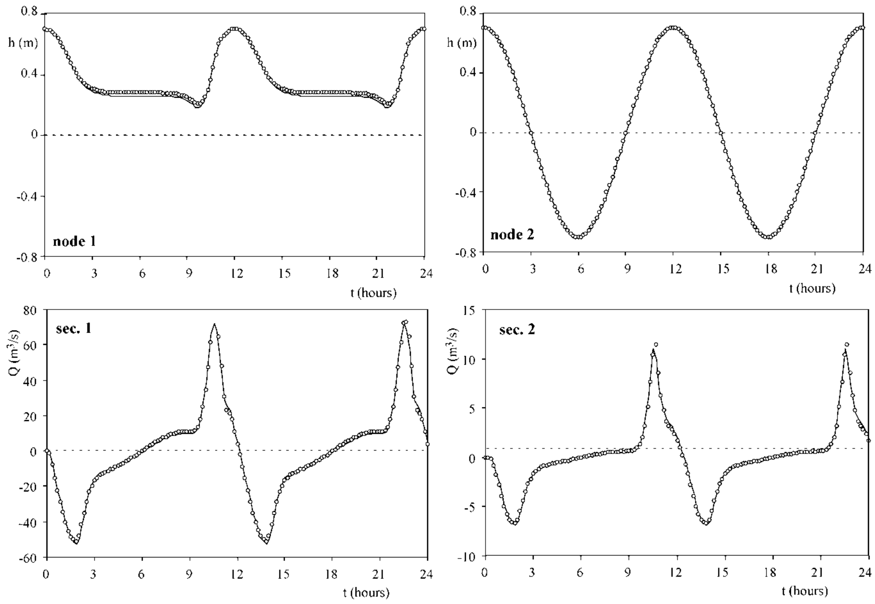

Fig. 10 – Output of the first test: comparison of levels and discharges at fixed nodes and sections between a pure bi-dimensional scheme (solid line) and the new coupled 1D-2D scheme (circles).

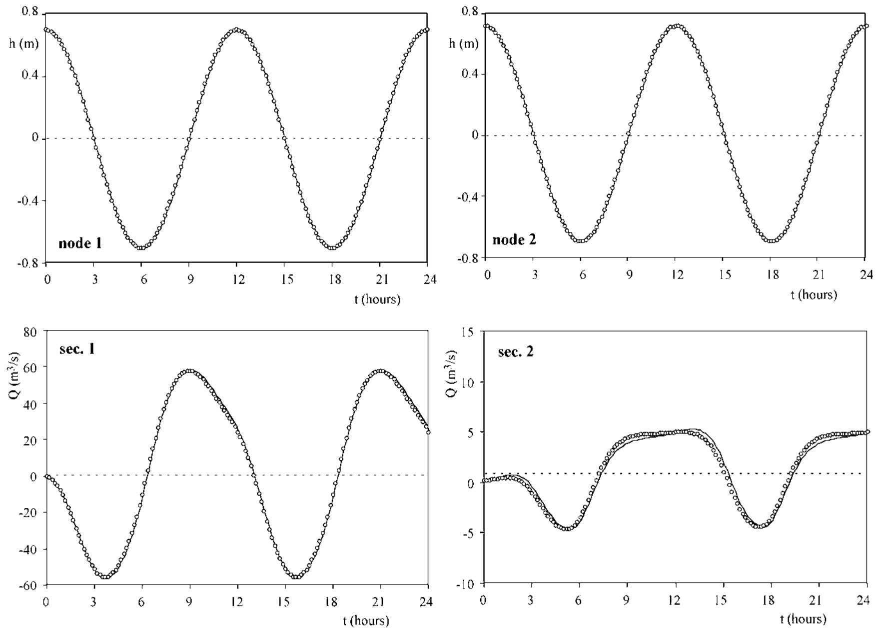

Fig. 11 – Output of the second test: comparison of levels and discharges at fixed nodes and sections between a pure bi-dimensional scheme (solid line) and the new coupled 1D-2D scheme (circles).

The same conclusions are supported by Fig. 11 showing, for the second example, the comparison between water elevations and flow rates predicted by the two different models at the same points and sections of example1.

5. Conclusions

A new numerical scheme coupling one-dimensional and two-dimensional elements in a finite element model for the hydrodynamics of tidal basins has been presented and discussed. The proposed model has been extensively tested through comparison with results from a fully two-dimensional model. All tests confirmed the remarkable capability of the model to account for the presence of deep channels in a otherwise shallow basin. To show this two examples have been presented and discussed.

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A TWO-DIMENSIONAL MATHEMATICAL MODEL FOR THE STUDY OF HYDRODYNAMIC AND SEDIMENT TRANSPORT IN THE VENICE LAGOON

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Riassunto

La laguna di Venezia è oggetto da molti anni di studi e sperimentazioni sull'idrodinamica ma poco ancora si conosce sul legame tra idrodinamica e trasporto di sedimenti e sugli effetti morfologici dei numerosi interventi che si sono succeduti e di quelli che si stanno prospettando.

Le equazioni bidimensionali delle onde lunghe in acque basse, formulate in modo da tener conto della presenza di aree parzialmente emerse, sono state risolte con uno schema agli elementi finiti che permette l'inserimento della rete dei canali minori nel reticolo di calcolo bidimensionale.

Il modello si basa su una formulazione concettuale sviluppata a metà degli anni 90 all'interno del Dipartimento IMAGE dell'Università di Padova. Il modello qui proposto si inserisce in quel filone di ricerca, differenziandosi per una nuova formulazione dei termini di accelerazione convettiva e di Reynolds, assenti nello schema originario.

Al modello idrodinamico è stato inoltre accoppiato un modulo di trasporto di sedimenti, al fondo e in sospensione, per effetto delle sole correnti di marea.

Lo schema è stato testato su alcune configurazioni geometriche per le quali è noto il comportamento idraulico (espansione laterale con separazione della corrente) o morfodinamico (formazione di barre alternate) e, per quanto riguarda la laguna di Venezia, confrontando i livelli di marea e gli andamenti di portate su alcune sezioni di misura. E' stato quindi indagato il comportamento idrodinamico delle bocche di porto nella situazione attuale e in quella dei primi del 1800 (Carta del Denaix) e dei primi del 1900 (Carta dell'Ufficio Idrografico del Magistrato alle Acque), mettendo in evidenza il loro differente comportamento in relazione alla perdita di sedimenti.

Abstract

For a long time Venice Lagoon has been investigated but the link between hydrodynamic and sediment transport is still not well understood: in particular, the morphological effects of the major interventions in the past and in the future are not known exactly.

A two-dimensional hydrodynamic model (depth averaged and full non linear), designed to simulate partially dry areas, has been developed merging a 1D network to simulate the minor channels.

The proposed hydrodynamic model is based on an existing framework developed at the IMAGE Department of Padova University in the middle 90's. The present model

follows those contributions but contains a new formulation of convective acceleration and Reynolds stresses, non considered in the existing framework. A sediment transport module, considering both suspended sediments and bed load, has been coupled to the hydrodynamics.

The model has been tested on some geometric configuration where the flow behaviour is known: the problem of a sudden lateral expansion and the formation of free bars on a straight flume. Concerning the Venice Lagoon, discharges and tide level in some sections in a boundary region has been compared with the available measurements.

We studied then the hydraulic behaviour of the three mouths in the actual situation and in the past; in particular, we examined the lagoon in the early 1800's (from Denaix's chart) and in the early 1900's (from chart of Ufficio Idrografico del Magistrato alle Acque), pointing out the differences in the tide propagation and in the sediment dynamic.

1. Introduction

While projecting the interventions for the Venice lagoon safeguarding, the mathematical models and the critical interpretation of the obtained results represent the main aspects of the planning stage and require particular attention and ability as the problem is really complex both for its social and for its environmental importance. Also the choice of the mathematical model suitable for the problem is complicated and not-unique.

Two main aspects need to be evaluated: the meaning of the hypothesis on which the equations are based (therefore the applicability limits) and the actual possibility to describe carefully the flow field geometry. The geometry complexity of the Venice lagoon requires a precise description of the principal morphologic elements and of the morphodynamic processes which happen in: this represents the only way through which the modelled problem fits with the real problem. Modelling the tide propagation in the tidal environment the 2D De Saint-Venant equations are usually utilized and are solved through various numerical techniques: finite differences, finite elements or finite volumes.

The complex geometry of the Venice lagoon, characterised by alternating channels, shoals and marshes makes more suitable the resolution method based on grids not necessarily regular, finite volumes and finite elements. Therefore, the methods based on regular grids are not very suitable.

With reference to the Venice lagoon, the advantage represented by methods based on the variable grid stands on the complexity and variability of the morphology: this impose both the necessity to describe the principal morphological elements and to adopt different refinement depending on the local morphological complexity.

The refinement limit is imposed by the computational capability but also by the geometry knowledge. Therefore, the computational limit is reached first on a uniform grid and then on the variable grid.

This concept can be explained with a simple example: the Venice lagoon discretization with a 20x20m grid requires about 1,4·106 points.

In analogy to the treatment of turbulence or mixing processes, the necessity to describe the dry/wet transition that happen at a smaller scale with respect to the grid scale leads to the formulation of specific closure schemes [D'Alpaos and Defina, 1995; Roig L.C., 1995; Bates P.D., 2000; Defina A., 2000; RMA2 WES User Guide, 2001].

In particular, as for the Venice lagoon hydrodynamic, the boundary regions of the lagoon are crossed by a dense channel network, characterised by a winding pattern, that can have a width smaller than the grid scale. Moreover, small channels (ghebi) are found into the marshes and there is not a proper lower limit to their width (Fig. 1).

These channels have the effect of promoting the tidal propagation not only during the flood, but also during the ebb phases: they represent the drainage network for the marches and they constitute a preferential path as here the resistances are smaller. Therefore, the description of these smaller channel networks is greatly required while representing the tidal propagation behind the marshes strip.

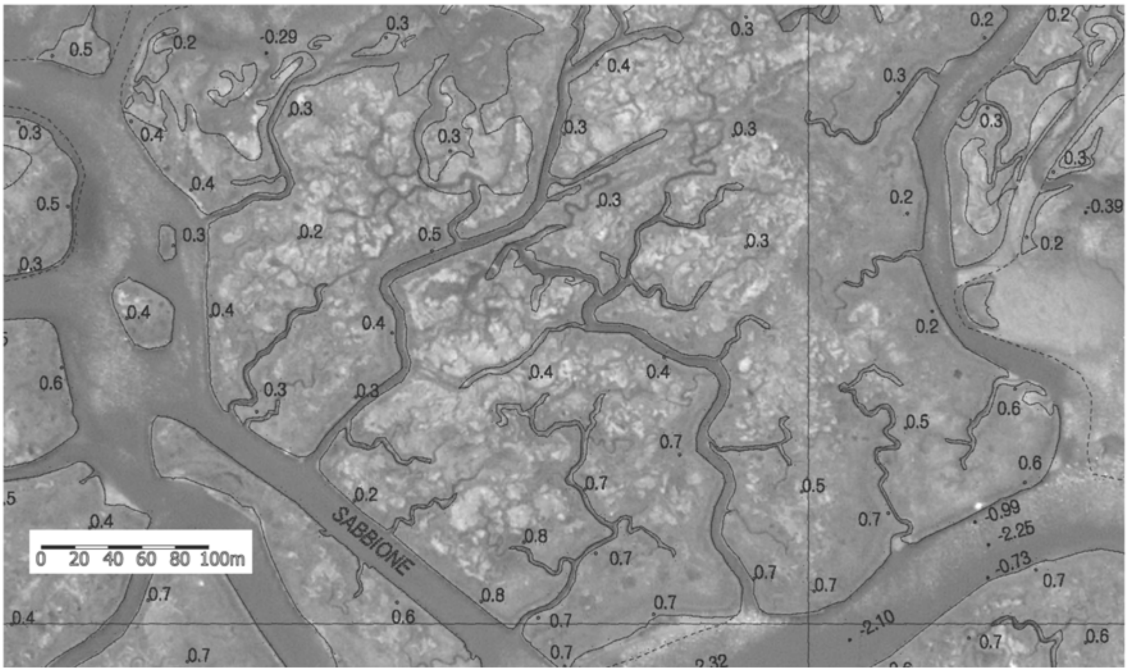


Fig. 1 – Complexity of a tidal network in a marshy area.

Another important aspect that can not be neglected is the effect of the bottom irregularities at smaller scale that the grid scale: they are totally filtered in assigning the average elevation. This irregularities play an important role during the flooding and drying processes on the marshes.

It has been noticed [D'Alpaos et al., 1994; Defina, 2000] that these irregularities can not be neglected during the tide propagation when the water depth can be compared with the irregularity length scale.

In fact, in partially dry areas, the area available for the water storage does not correspond to the geometrical area of the element and the resistances to motion are clearly spatially different. All these argumentations have led to a modified form of momentum equations, by the way of the definition of two equivalent water depths (one characterised by the effective flooding area averaged on the entire geometrical area, the second that acts on the evaluation of the bottom dissipation), and to a modified form of the continuity equation introducing a coefficient similar to the storavity coefficient utilized in the groundwater studies.

It is generally accepted that evaluating the tide propagation inside the Venice lagoon the convective inertial terms in the momentum equations can be neglected or, sometimes, accounted indirectly as an additional resistance.

Nevertheless, in the areas characterised by high velocities or characterised by separation phenomena (therefore in the area near to the Venice inlets), the convective terms and the turbulence terms play an important role and can not be neglected in the model equations, even if they promote a computational burden.

It is important to underline that the solution of the full momentum equations on a grid not sufficiently detailed can lead to some mistakes in the results: these errors could be greater than the errors obtained from the solution of simplified equations.

That said, starting from the equations valid for the partially wet domain [D'Alpaos et al., 1994; Defina, 2000] a finite element hydrodynamic model has been developed. It solves the 2D full momentum equations in the inlet areas (where the grid is sufficiently refined and the adding terms can not be neglected). The remaining areas of the lagoon are solved with the 2D-1D equations neglecting the convective and Reynolds terms. Incidentally, these terms are treated in an original way and they were neglected in the primitive scheme as described farther on.
The hydrodynamic model has been coupled with a no-cohesive sediment transport model, considering both the suspended sediment and the bed load [Van Rijn, 1984a; Van Rijn, 1984b; Van Rijn, 1984c; Talmon et al., 1995;]. This scheme simplify the grain size composition of the lagoon soils, as it has been accounted just one grain size corresponding to the silty sand. Nonetheless, this simplification should not modify the validity of the results and the conclusions about the sediment dynamic near the inlets.

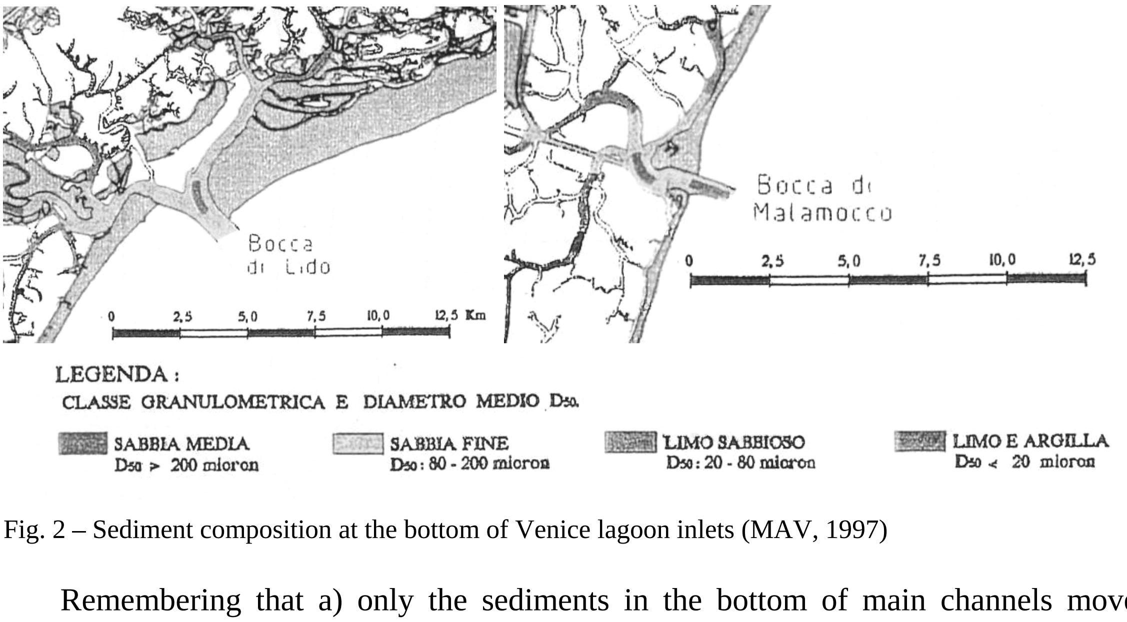


Fig. 2 – Sediment composition at the bottom of Venice lagoon inlets (MAV, 1997)

Remembering that a) only the sediments in the bottom of main channels move under the effect of the tidal oscillations, b) these sediments are almost sandy, in a first approximation it is reasonable to compute the incipient conditions basing on relationship that are derived for sand. Another problem could be the choice of the representative diameter. The prevailing presence of the non-cohesive grains let one neglect, in this analysis, the flocculation.

Some investigations have been carried out on the grain size distribution of the lagoon sediments near the inlets and the final result is a net prevailing sandy composition.

The following chapters describe briefly the previous research work and then more precisely the new activities performed. Some test cases follow and then, as far as the Venice lagoon, results on hydrodynamic and sediment dynamic are reported. Results and comparisons with the historical lagoon (1800, 1900 and 1915) are discussed.

2. Numerical modelling of hydrodynamic

The conceptual framework has been formulated in the middle 90's [D'Alpaos and Defina, 1993; D'Alpaos et al., 1994;] and it is characterized by some features that promote applications on complicated geometries and, in particular, in tidal environments where wide areas, crossed by dense channel network, are subjected to a partial and periodic drying.

We started from this framework, formulating the code in a optimised form and providing some new improvements.

The 2D domain is constituted by triangular elements that describe the geometry and the hydraulic roughness, assumed constant over the whole element area.

This representation is congruent with the numerical scheme (semi-implicit [Casulli, 1990]), as the velocity is defined at the barycentre of the triangle (averaged or constant) while the water level is set on the triangle vertices (Fig. 3).

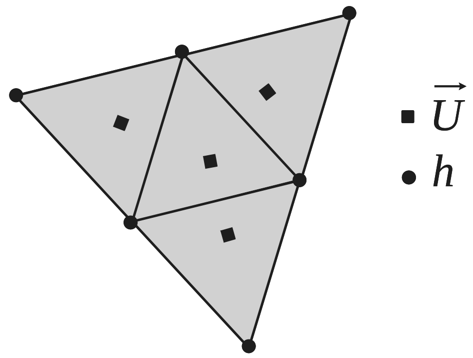


Fig. 3 – Staggered grids.

The same staggered grids are utilised in the 1D domain: its coupling with the 2D domain represents on of the main characteristics of the scheme, as it will be shown in the following.

The 2D and 1D problems, coupled, are solved by the way of a finite element method. The numerical scheme utilised in the following analysis is similar to the original one [D'Alpaos et al., 1994] but two new features are present: an original treatment of convective terms in momentum equations and the turbulent closure by the way of a diffusive/dispersive closure.

The numerical approach characterizing the last contribution lead to an accurate estimation of second derivative in unstructured and non orthogonal mesh. In the next two paragraphs a brief review of the sub-grid model for dry/wet transition and the 2D-1D coupling is described. The two new adds are the topic of the two following paragraphs.

2.1. The drying/wetting subgrid model.

The first characteristic is the sub-grid model developed to take into account of small-scale irregularities in the bottom elevation. They affect the flow in presence of small depth and flooding and drying processes, assuming a negligible effect when water depth becomes important.

Averaging the bottom elevation over a representative area, the information of small-scale irregularities are filtered out and then discarded when only the first moment is considered.

Assuming hydrostatic approximation, the three dimensional Reynolds equations are suitably averaged over a representative elementary area (weighting them with phase function) and then integrated over the depth.

The averaging and integrating operations lead to a modified form of De Saint-Venant equations, assuming again the classic form when the flooding involves the whole elementary area.

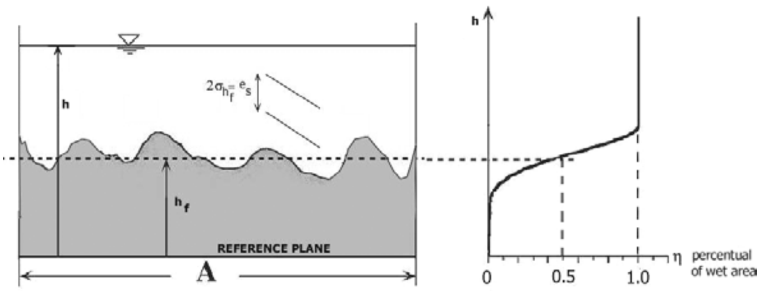


Fig. 4 – Schematic representation of irregularities over the reference area A.

Referring to the scheme of Fig. 4, the bottom elevations are assumed to be accounted by a Gaussian pdf [D'Alpaos et al., 1994; Defina, 2000] characterized by average $\overline{h_f}$ and standard deviation σ_{h_f}. On this hypothesis, having set the geometric depth as $Y_a = h - \overline{h_f}$, the percentage of wetted area, η, and the effective water depth, *Y*, (water volume per unit area) can be expressed as:

$$\eta = \frac{1}{2}\left(1 + erf\left(\frac{Y_a}{\sigma_{h_f}}\right)\right) \tag{1}$$

$$\frac{Y}{\sigma_{h_f}} = \left\{\eta \cdot \left(\frac{Y_a}{\sigma_{h_f}}\right) + \frac{1}{2\sqrt{\pi}}\exp[-(Y_a/\sigma_{h_f})^2\right\}. \tag{2}$$

The bottom shear stress in a turbulent flow is evaluated as:

$$\frac{\overrightarrow{\tau_b}}{\rho Y} = g\left(\frac{\left|\vec{q}\right|}{{k_s}^2 H^{10/3}}\right)\vec{q} \tag{3}$$

where $\vec{q} = (q_x, q_y)$ is the total flow rate per unit width, k_S is the Strickler roughness coefficient e H is an equivalent depth approximated as:

$$\frac{H}{\sigma_{h_f}} = \frac{Y}{\sigma_{h_f}} + 0.27\sqrt{\frac{2Y}{\sigma_{h_f}}} \cdot \exp[-Y/\sigma_{h_f}] \tag{4}$$

The 2D modified equations take the final form:

$$\begin{aligned}
&\frac{d\left(\overline{U_x}\right)}{dt} - \frac{1}{\rho}\left(\frac{\partial R_{xx}}{\partial x} + \frac{\partial R_{xy}}{\partial y}\right) + \frac{\tau_{bx}}{\rho Y} + g\frac{\partial h}{\partial x} = 0 \\
&\frac{d\left(\overline{U_y}\right)}{dt} - \frac{1}{\rho}\left(\frac{\partial R_{yx}}{\partial x} + \frac{\partial R_{yy}}{\partial y}\right) + \frac{\tau_{by}}{\rho Y} + g\frac{\partial h}{\partial y} = 0
\end{aligned} \tag{5}$$

$$\eta\frac{\partial h}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = 0 \tag{6}$$

where $R_{xx}, R_{yy}\ e\ R_{xy}$ are the Reynolds stresses.

When the water depth is much wider then the bottom irregularities, the expressions (1) (2) (4) state that $Y \approx H \approx Y_a$ and η=1 and the flow equations assume again a classic form.

In different words, when $h - \overline{h_f} = 2\sigma_{h_f}$ the percentage of wetted area is $\eta \approx 0.998$, while the percentage of wetted area is $\eta \approx 0.002$ when $h - \overline{h_f} = -2\sigma_{h_f}$: the range $-2\sigma_{h_f} \le h - \overline{h_f} \le 2\sigma_{h_f}$ can be defined as the one where the wet/dry transition takes place.

A similar behaviour is found in both the equivalent water depth, Y and H: they are always positive, for definition, also when the water elevation is under the averaged bottom $\overline{h_f}$, i.e. when Y_a is negative.

2.2. 2D-1D coupling

The description of small channels has an important role to correctly simulate the tide propagation on shallows and salt-marshes. Looking at the Venice Lagoon, the width of these channels, just few meters, does not advice a 2D representation, avoiding an excess in the local refinement (that can promote numerical instabilities) and saving computational resources.

It has been proposed [D'Alpaos and Defina, 1993] the coupling between the 2D domain and a 1D channel network (Fig. 5). A critical review of the original coupling is the topic of a research still in progress [Carniello et al., this book]. In the following, the original 1D scheme has been utilised.

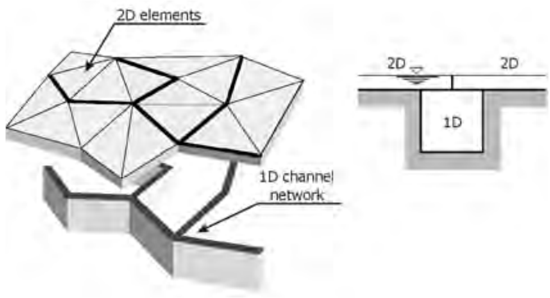


Fig. 5 – 2D-1D coupling .

Coupling together 2D and 1D elements it is possible to describe the morphology with the required details and without exceeding in the 2D discretization, as the 1D channels lie on a triangle side.

The 2D final algebraic system can be expressed as: $\{\mathbf{A}\}\{\mathbf{h}\} = \{\mathbf{b}\} + \{\mathbf{Q}\}$ where the vector $\{\mathbf{Q}\}$ take into account of flux exiting from the 2D domain (towards the 1D network or due Neumann boundary conditions) or entering in the 2D domain (from the 1D network or due Neumann boundary conditions). In a similar manner, the algebraic system corresponding to the 1D channel network is set up as $\{\mathbf{A'}\}\{\mathbf{h}\} = \{\mathbf{b'}\} + \{\mathbf{Q'}\}$.

The whole matrices are assembled together and merged in a very simple form reminding that mass conservation at a shared node requires $\{\mathbf{Q}\} + \{\mathbf{Q'}\}$ is null everywhere except where a Neumann boundary condition is superimposed.

Fig. 6 shows the coupling 2D-1D in a boundary region of the Venice lagoon.

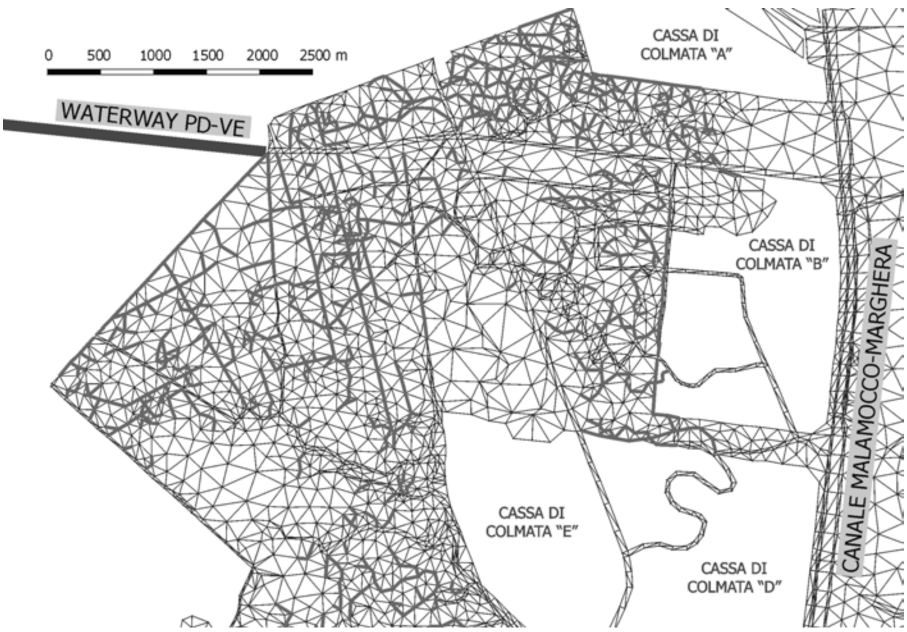


Fig. 6 – 2D-1D mesh covering a boundary region in the Venice Lagoon.

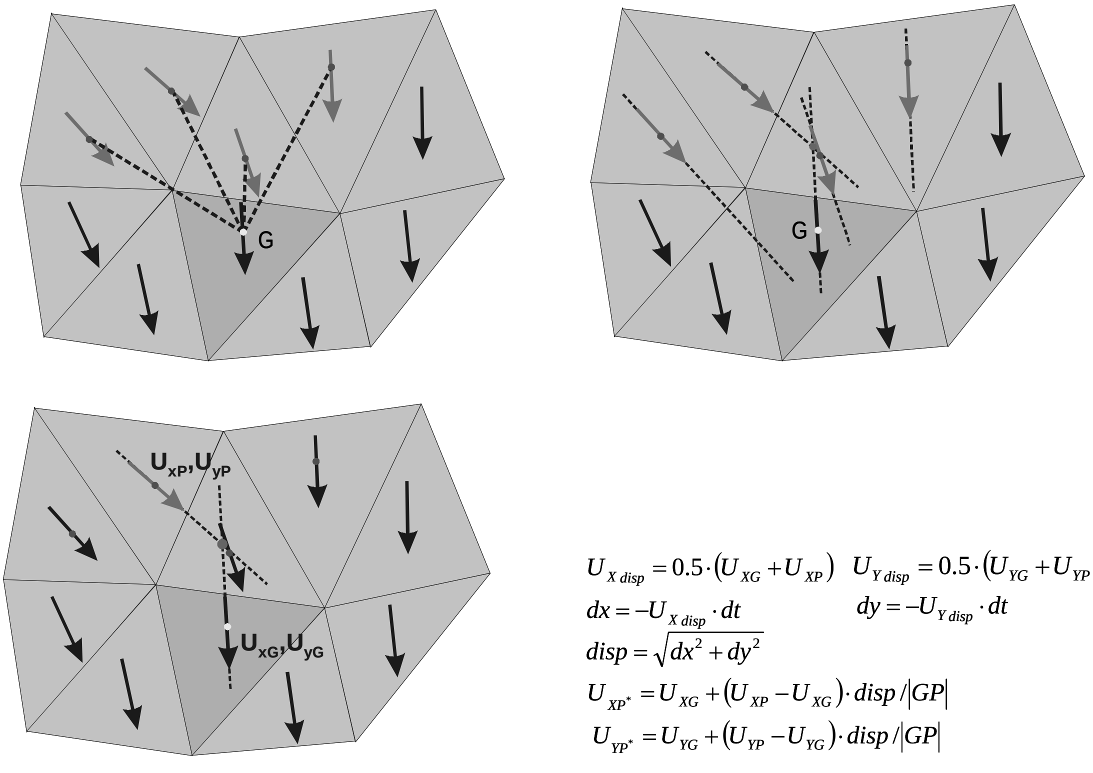
2.3. Lagrangian approach for convective terms

Total derivatives in the momentum equations are calculated following a Lagrangian approach [Casulli, 1990]. Identifying as G the barycentre of the generic triangular element, the total derivative for the velocity in G is expressed as:

$$\frac{d\left(\overline{U_x}\right)_G}{dt}=\frac{\left(\overline{U_x}\right)_G-\left(\overline{U_x}\right)_{P*}}{\Delta t} \text{ e } \frac{d\left(\overline{U_y}\right)_G}{dt}=\frac{\left(\overline{U_y}\right)_G-\left(\overline{U_y}\right)_{P*}}{\Delta t} \qquad (7)$$

where $\left(\overline{U_x},\overline{U_y}\right)_{p*}$ is the velocity in the position P* along the trajectory passing through the point G, i.e. $\left(x_{P*},y_{P*}\right)=\left(x_G,y_G\right)+\vec{U}\cdot dt$

The definition of the upstream velocity $\left(\overline{U_x},\overline{U_y}\right)_{p*}$ follows an approximated criteria based on "alignment" that has shown to be robust and applicable also to not refined mesh.



$$U_{X\,disp}=0.5\cdot\left(U_{XG}+U_{XP}\right) \quad U_{Y\,disp}=0.5\cdot\left(U_{YG}+U_{YP}\right)$$
$$dx=-U_{X\,disp}\cdot dt \qquad dy=-U_{Y\,disp}\cdot dt$$
$$disp=\sqrt{dx^2+dy^2}$$
$$U_{XP^*}=U_{XG}+\left(U_{XP}-U_{XG}\right)\cdot disp/\left|GP\right|$$
$$U_{YP^*}=U_{YG}+\left(U_{YP}-U_{YG}\right)\cdot disp/\left|GP\right|$$

Fig. 7 – Procedure for the evaluation of the departure elements in a Lagrangian approach.

The procedure follows geometric considerations and it is briefly sketched in Fig. 7. Considering the barycentre G as the arrival position, the scheme identifies the departure position(s) P and its(their) velocity. The main steps are the following:

1. the triangles sharing a vertex with the G triangle are identified; from these triangles, only those lying in a upstream position are maintained in the list as they are potential departure elements;

2. the triangles P having the velocity non sufficiently convergent to the arrival position G are removed from the list;
3. when the velocity of P element intersects the velocity of G element in a upstream position respect to the barycentre G, then P is a departure position;
4. when the departure position satisfying the previous criteria is not unique as more elements behaved as “departure elements”, it’s necessary to use averaging operations.

When the mesh is not sufficiently refined, the above procedure can be stopped before the end.

When the flow field is rectilinear, the proposed procedure leads to results not very different from those obtained following a similar approach [Defina and Bonetto, 1998], based on the alignment of $\overrightarrow{PG}$ with the arrival velocity instead of on the alignment of $\overrightarrow{PG}$ with the departure velocity.

2.4. Turbulence closure

Turbulent stresses ($R_{xx}, R_{yy}\ e\ R_{xy}$) are expressed as a linear function of the strain tensor and a Smagorinski eddy-viscosity, ν_T, written as:

$$\nu_T = L^2 \cdot \left[2\left(\frac{\partial \overline{U_x}}{\partial x}\right)^2 + 2\left(\frac{\partial \overline{U_y}}{\partial y}\right)^2 + \left(\frac{\partial \overline{U_x}}{\partial y} + \frac{\partial \overline{U_y}}{\partial x}\right)^2 \right]^{0.5} \tag{8}$$

where L is the turbulence characteristic length, $L = 0.5 \cdot A^{0.5}$, considering the turbulence taking place within the element of area A.

Considering now the x-momentum equations, the turbulence effects are then modelled as:

$$\frac{1}{\rho}\left(\frac{\partial R_{xx}}{\partial x} + \frac{\partial R_{xy}}{\partial y}\right) \approx \nu_T \nabla^2 \overline{U_x} \tag{9}$$

Averaging (5) over the A element, the Green identity allows the calculation of derivatives at a lower order

$$\nu_T \nabla^2 \overline{U_x} \approx \frac{\nu_T}{A} \int_{\partial A} \frac{\partial \overline{U_x}}{\partial n} dS = \frac{\nu_T}{A} \sum_{i=1,3} (\nabla \overline{U_x} \cdot \vec{n} L)_i \tag{10}$$

where the last equality is its discrete approximation.

As the velocity is defined at the triangle barycentre and the mesh is generally unstructured, the evaluation of the gradient leads to difficulties and approximations [Batten, 1996; Jasak, 1996].

When the mesh in orthogonal, the calculation of the normal derivative in the middle of the i-side is based on the values at the opposite barycentre, G and P:

$$\frac{\partial \overline{U_x}}{\partial n} = \frac{\left(\overline{U_x}\right)_P - \left(\overline{U_x}\right)_G}{\left|\overrightarrow{GP}\right|} \tag{11}$$

When the mesh is unstructured, this value is corrected as the i-side and the vector $\overrightarrow{GP}$ are not orthogonal (Fig. 8).

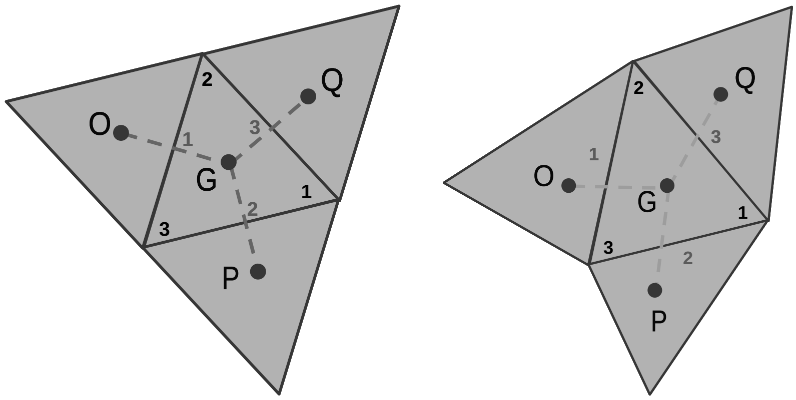


Fig. 8 – Orthogonal and non-orthogonal mesh

In this situation, the procedure for the calculation of the side gradient consists in the following steps [Jasak, 1996]:

1. Calculate the centred gradient, $\left(\nabla U_x\right)_G$ and $\left(\nabla U_x\right)_P$, for the two triangles sharing the side. Assuming a linear variation of the variable inside the triangle, the gradient is evaluated using a least-square fit;
2. Interpolate it to the face as $\left(\nabla U_x\right)^*_{i-side} = f\left(\nabla U_x\right)_G + (1-f)\left(\nabla U_x\right)_P$ with f is the interpolation coefficient;
3. Calculate the final value of $(\nabla U_x \cdot \vec{n}L)_i$ on the i-side, taking into account both the adjacent values, $\left(\overline{U_x}\right)_P$ and $\left(\overline{U_x}\right)_G$, and the value of $\left(\nabla U_x\right)^*_{i-side}$ previously evaluated.

The side gradient $(\nabla U_x \cdot \vec{n}L)_i$ is split into two parts:

$$\vec{L} \cdot \left(\nabla U_x\right)_{i-side} = \underbrace{\vec{\Delta} \cdot \left(\nabla U_x\right)_{i-side}}_{orthogonal\ contribution} + \underbrace{\vec{k} \cdot \left(\nabla U_x\right)^*_{i-side}}_{non-orthogonal\ correction} \tag{12}$$

where $\vec{L}$ is the length side vector defined as $L\vec{n}$. The two vectors, $\vec{\Delta}$ and $\vec{k}$, have to satisfy the condition $\vec{L} = \vec{\Delta} + \vec{k}$ where $\vec{\Delta}$ is chosen parallel to $\overrightarrow{GP}$.

Many possible decomposition exists. According to keep the non orthogonal correction as small as possible, by making $\vec{\Delta}$ and $\vec{k}$ orthogonal, (as it potentially creates unboundedness, especially if the mesh is highly non-orthogonal) the chosen decomposition leads to:

$$\vec{\Delta} = \frac{\overrightarrow{GP} \cdot \vec{L}}{\left|\overrightarrow{GP}\right|^2} \overrightarrow{GP} \tag{13}$$

Finally, the final form of the side gradient is

$$\vec{L} \cdot \left(\nabla U_x\right)_{i-side} = \left|\vec{\Delta}\right| \frac{\left(\overline{U_x}\right)_P - \left(\overline{U_x}\right)_G}{\left|\overrightarrow{GP}\right|} + \vec{k} \cdot \left(\nabla U_x\right)^*_{i-side} \tag{14}$$

We tested the above expression on high unstructured mesh obtaining good results and a maximum error of about 20%.

3. Numerical modelling of non cohesive sediment

A sediment transport model is coupled to the hydrodynamic module to analyse the effects of tidal currents in mobilizing and transporting the sediments. It is expecting that tidal currents play a mobilizing role only in the main channels close to the inlets where the velocity are higher. In the inner lagoon, especially in the boundary region where the tidal velocities are not high, wind-waves play the main role in eroding salt-marshes and in resuspending the sediment in the shoals. The drainage channels then convey the suspended sediments in the lagoon. We focused our attention only on the tidal forcing and on its carrying capacity of non cohesive sediments.

Both bed load and suspended sediment transport are taken into account and they are linked together by the bed evolution equation.

3.1 Suspended sediment transport.

The equation governing the 2D depth-averaged transport of suspended sediment is commonly written as

$$\frac{\partial\left(\overline{C}Y\right)}{\partial t} + \nabla \cdot \left(\overline{C}\vec{\mathbf{q}}\right) - \nabla \cdot \left(Y\mathbf{D}\nabla\overline{C}\right) = W_s\left(C_{eq} - C_b\right) \tag{15}$$

where $\overline{C}$ is the average concentration, Y is the water depth, $\vec{\mathbf{q}}$ is the discharge per unit width, $\mathbf{D}$ diffusion-dispersion tensor, W_s is the falling sediment velocity in water, C_{eq} is the equilibrium concentration at the bottom [Van Rijn, 1984] and C_b is the bottom concentration according to a Rouse shape profile $C_b = \dfrac{\overline{C}}{k(Z,\vartheta)}$. The right term represents the sediment exchange (erosion/deposition) between the water column and the bed.

As the sediment concentration and the water discharge $\vec{\mathbf{q}}$ are characteristic of the element, the equation is solved with a finite volume scheme leading to:

$$\frac{\partial\left(\overline{\overline{C}Y}\right)}{\partial t}+\frac{1}{A}\int_A \nabla\cdot\left(\overline{C}\vec{\mathrm{q}}\right)dA-\frac{1}{A}\int_A \nabla\cdot\left(Y\overline{\mathrm{D}}\nabla\overline{C}\right)dA=W_s\left(\overline{C_{eq}}-\overline{C_b}\right) \qquad (16)$$

Convective terms are treated by an upwind scheme:

$$\frac{1}{A}\int_{\partial L}\left(\overline{C}\vec{\mathbf{q}}\right)\cdot\vec{n}dL=\frac{1}{A}\sum_{sides}Q_{side}C_{upwind} \qquad (17)$$

Diffusion-dispersive terms are solved in same manner of Reynolds terms in momentum equations (cfr §2.4):

$$\frac{1}{A}\int_{\partial L}Y\overline{\mathbf{D}}\nabla\overline{C}\cdot\vec{n}dL=\frac{1}{A}\sum_{sides}Y\nu_T\,\frac{\partial\overline{C}}{\partial n}\,L_{side} \qquad (18)$$

Time integration of (16) is explicit.

3.2 Bed load transport

Bed load discharges are modelled by the Mayer-Peter and Muller formula, modified to take into account of both longitudinal ( ) and transversal ( ) bottom slope.

$$\frac{q_b}{\sqrt{g(s-1)d_{50}^3}}=8\cdot\left(\mu\vartheta-k_{long}\cdot k_{transv}\cdot\vartheta_{cro}\right)^{3/2} \qquad (19)$$

The non dimensional critical shear stress, ϑ_{cro}, is calculated according to Shields [Van Rijn, 1984] while k_{long} and k_{transv} are modelled as:

$$k_{long}=\frac{\sin(\phi+\beta)}{\sin\phi}$$

$$k_{trasv}=\left[\cos\alpha\cdot\left[1-\left(\frac{tan(\alpha)}{tan(\varphi)}\right)^2\right]^{0.5}\right] \qquad (20)$$

where φ is the internal friction angle.

The dimensionless factor μ has been introduced to account for the presence of bed forms in the bottom [Lanzoni, 2000]. The direction of the bed load transport deviates form the shear stress direction because of the presence of a transversal slope and secondary flows. We modelled the bed load direction [Talmon, 1995] as:

$$\tan(\eta) = \frac{\sin(\delta) - \dfrac{E}{0.85\cdot\sqrt{\theta}}\dfrac{\partial z_b}{\partial y}}{\cos(\delta) - \dfrac{E}{0.85\cdot\sqrt{\theta}}\dfrac{\partial z_b}{\partial x}} \qquad E=0.5\div1.0 \tag{21}$$

where z_b is the bottom elevation and δ is the flow direction near the bed. The effects of secondary flows on the direction of the stress at the bed are accounted by a simplified formula [Kalkwijk, 1986).

3.3 Bed evolution equation

The equation for bed evolution reads as:

$$(1-n)\frac{\partial z_b}{\partial t} + \nabla\cdot\overrightarrow{\mathbf{q_b}} = -W_s\left(C_{eq} - C_b\right) \tag{22}$$

where n is the porosity and $\overrightarrow{\mathbf{q_b}}$ is the bed load discharge per unit width. The right term represents the sediment exchange (deposition /erosion) between the bed and the water column.

As the sediment concentration C, the bottom elevation z_b and the bed load discharge $\overrightarrow{\mathbf{q_b}}$ are characteristic of the element, the equation is solved with a finite volume method leading to:

$$(1-n)\frac{\partial\left(\overline{z_b}\right)}{\partial t} + \frac{1}{A}\int_A \nabla\cdot\vec{\mathbf{q}}_b dA = -W_s\left(\overline{C_{eq}} - \overline{C_b}\right) \tag{23}$$

The bed load flux is modelled with an upwind scheme:

$$\frac{1}{A}\int_A \nabla\cdot\vec{\mathbf{q}}_b dA = \frac{1}{A}\sum_{lati} Q_{b,side} = \left(\vec{q}_{b,upwind}\cdot\vec{n}\right)\cdot L_{side} \tag{24}$$

Time integration of (23) is explicit.

4. Calibrations and tests

The efficacy of the 2D-1D coupling and the bottom irregularities sub-grid model has been tested in several application [Dal Santo, 1997; Magistrato alle Acque di Venezia, 2002]. We show here some results obtained in the Venice Lagoon modelling. Calibration roughness coefficients are reported in Tab. 1.

Fig. 9 shows the comparison between the calculation and the available tide level and discharges measurements in the Casse di Colmata/Lago dei Teneri region during a

1991 field campaign. The comparison is fairly good, considering the same agreement was obtained, in similar events, in other water level station located in the whole lagoon.

Tab. 1 – Strickler roughness coefficient after the calibration.

z_b>0.3m m.s.l.	ks=10$m^{1/3}s^{-1}$	C	z_b<-1.0m m.s.l. z_b>-5.0m m.s.l.	ks=30$m^{1/3}s^{-1}$
z_b<0.3m m.s.l. z_b>-0.3m m.s.l.	ks=15$m^{1/3}s^{-1}$	H	z_b<-5.0m m.s.l.	ks=35$m^{1/3}s^{-1}$
z_b<-0.3m m.s.l. z_b>-1.0m m.s.l.	ks=20$m^{1/3}s^{-1}$		sea	ks=40$m^{1/3}s^{-1}$

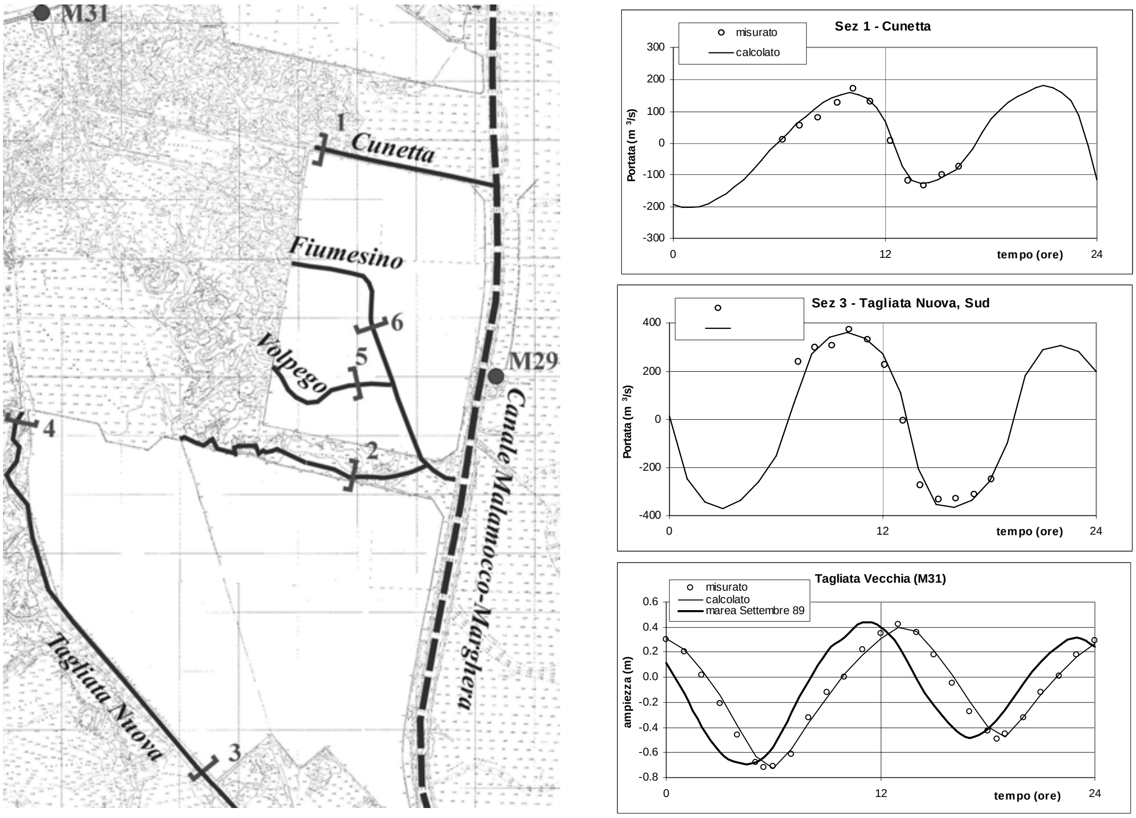


Fig. 9 –Comparison between measurements and computed discharges and tide levels.

The new features added to the scheme are tested separately. Firstly, the lagrangian treatment of convective terms and the turbulence closure are tested on a standard problem where these terms play a fundamental role. In Fig. 10 an example of a turbulent flow is represented: a sudden expansion (H_2/H_1=1.5) generates a region with separated flow. The reattachment point, for a Reynolds number $\mathrm{Re} = V_1\left(H_2 - H_1\right)/\nu \approx 100'000$, locates al L≈6·($H_2$-$H_1$). Approximately the same results were obtained in numerical and laboratory experiments for a vertical back-facing step [Codina, 1999; Speziale, 1987].

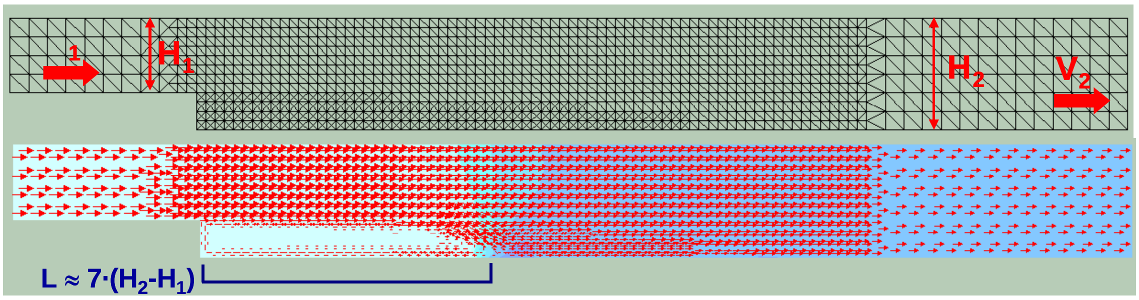


Fig. 10 – Geometry of the lateral expansion. Separated region obtained from the calculation.

The sediment transport and bed evolution models were tested reproducing the formation of free bars in a straight flume. We focused on the P1605 Lanzoni's experiment with uniform sediment. The geometric and hydraulic properties are reported below:

Flume:	Width B=1.5m	Length L=50m	
Flow:	Discharge Q=20 l/s		Bottom slope i_f=0.5%
	Water depth D=3.3cm	Velocity U_0=0.4m/s	
	d_{50}=0.48mm	d_{90}=0.71mm	s=2.65

After a 20 hours experiment, Lanzoni obtained an alternate bar configuration characterized by bar wavelength L_b≈11.0m and bar height H_b≈7.7cm.

In Fig. 11 the bed configuration after a 8 hrs simulation shows the formation of alternate bars with L_b≈10m and H_b≈6.0cm. These results can be considered in good agreement with the experiment.

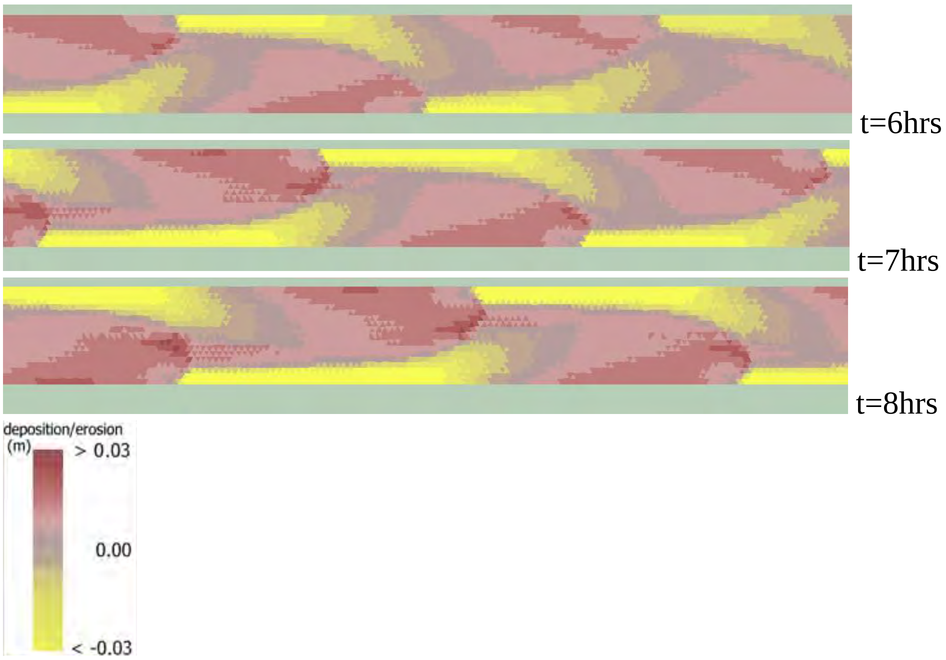


Fig. 11 – Formation of free bars on a strait flume.

While the example on the Venice lagoon proved the model ability to reproduce the tidal propagation in a very hidden area far from the inlets, the other two examples showed the model can reproduce also the small-scale characteristics of the flow field. Obviously, the domain discretization must be appropriate.

5. Some experiments on the Venice Lagoon

The aim of the present analysis is to show the capability of the numerical model to investigate the hydrodynamic behaviour and the sediment dynamic in the inlet region. We started the studies from the actual configuration (1990 bathymetry in the inner lagoon, 2000 bathymetry at the inlets) refining an existing 2D mesh in the inlet region.

Two historical lagoons have been built from the maps of Capt. Denaix (1809-1811) and from the maps of Ufficio Idrografico of Magistrato alle Acque (1897-1901), provided both by Magistrato alle Acque (by the way of Consorzio Venezia Nuova) . Morover, the 1915 inlet bathymetry (Ufficio Idrografico del Magistrato alle Acque) provide a further contribution to understand the morphological changes generated by the construction of the jetties at the three mouths. It's useful to remind that jetties at Malamocco were completed in ~1870, while jetties construction at Lido and Chioggia started in ~1880 and ~1910, finishing in ~1890 and ~1930 respectively.

Without going into details, the lagoon in 1800 (and 1901 was pretty the same) had wide salt marshes area, ~1m depth shallows, a branched channel network. The areas opened to the tide propagation was not really very different from the actual situation as the fishery farms in the boundary region were hydraulically closed. The Figs. 12a,b,c show very clearly the morphological changes occurred, especially in the Malamocco watershed.

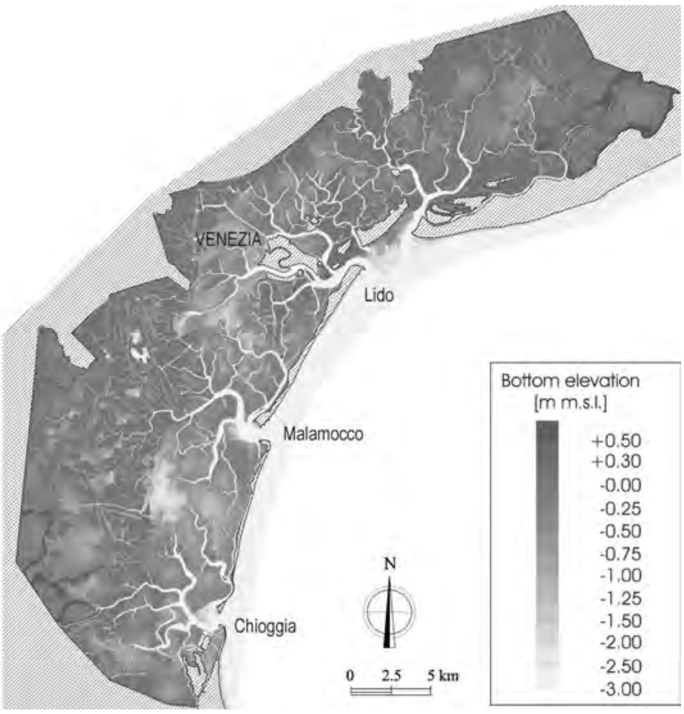


Fig. 12a – 1800 bathymetry from Denaix chart.

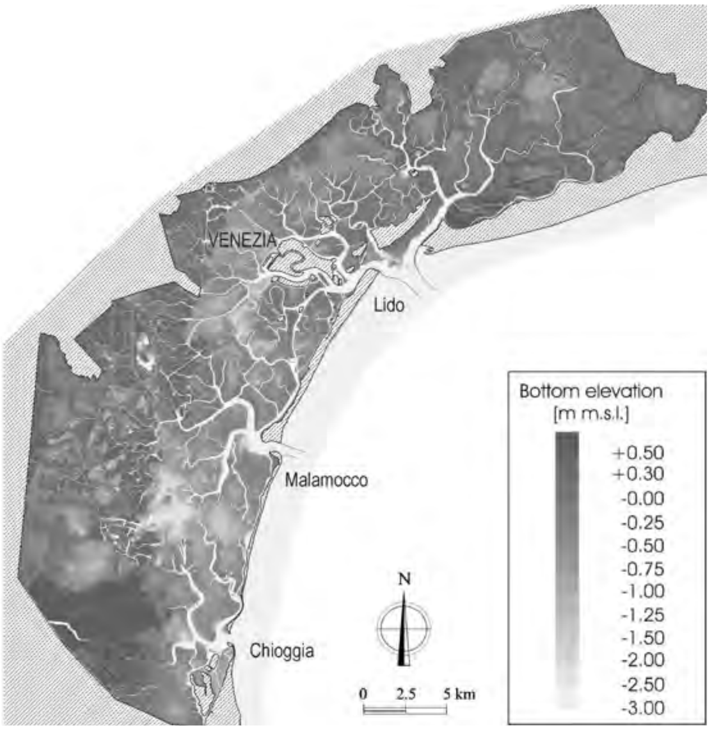


Fig. 12b – 1900 bathymetry from Magistrato alle Acque chart.

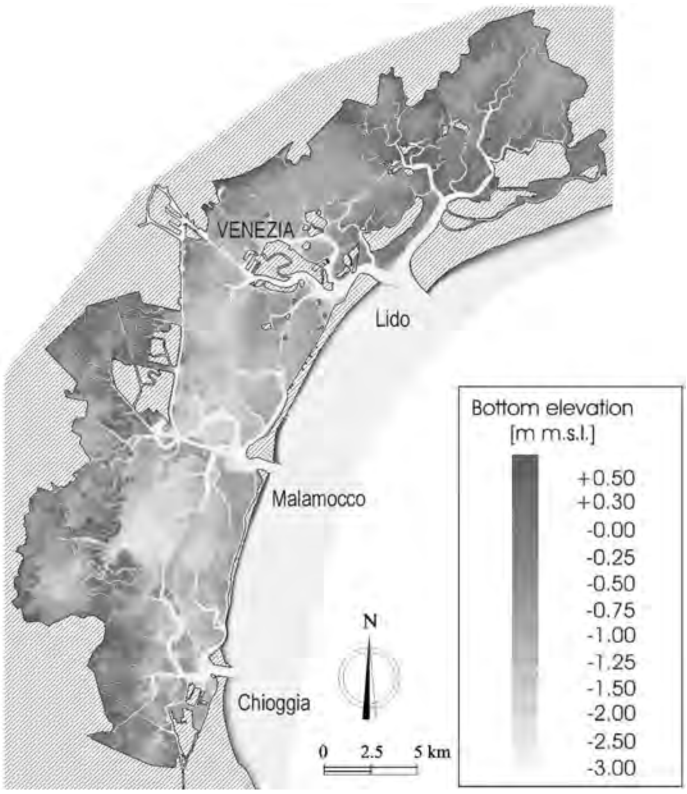


Fig. 12c – Actual bathymetry.

A sinusoidal tide, 1m range around 0.3m m.s.l., has been imposed at the sea nodes as boundary condition. The tide propagation in the whole lagoon is simulated and all the hydraulic information are extracted (velocity, depth, residual currents, tidal prism, watersheds, etc…). In Fig. 13 the Malamocco bathymetries in 1811, 1906, 1915 and in the actual situation are shown.

The construction of Malamocco jetties (finished in 1870) caused a deepening of inlet elevation in the coastal region, going the bed elevation from -6÷-8m m.s.l. to the -8÷-12m m.s.l.. The asymmetric configuration of the two dikes leaded to a localized scour in the southern breakwater head. No deepening has happened between 1906 and 1915. Very large differences exist between the 1915 and 2000 bathymetries as the bottom elevation between the two dikes is very close to the -14÷-16m m.s.l. and a big channel (Canale dei Petroli) has dredged just inside the inlet. We have to remind that not all the bottom variations are natural as in the middle 60's of last century dredging works at the inlet has been done.

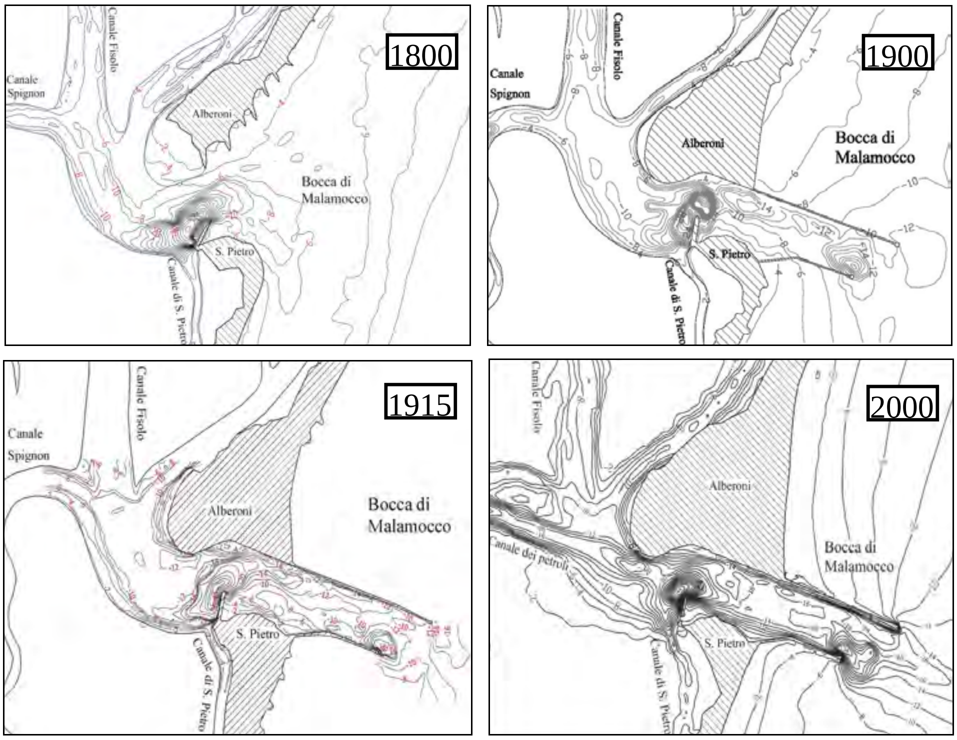


Fig. 13 – Historical evolution of Malamocco inlet.

The jetties construction caused a local modification in the hydrodynamic behaviour (as the flow was forced to flow between the dikes) and, of course, an increasing in the energy dissipation (as changes in the bottom elevation at the inlets are long time-scale processes).

In the actual lagoon, the computation shows a very different behaviour in the flood and ebb phases while in the 1800 situation an almost symmetric velocity field makes them very similar. After the inlets armouring, the ebb phase is characterised by the formation of a jet while in the flood phase the flow looks like an irrotational radial flow (Fig. 14).

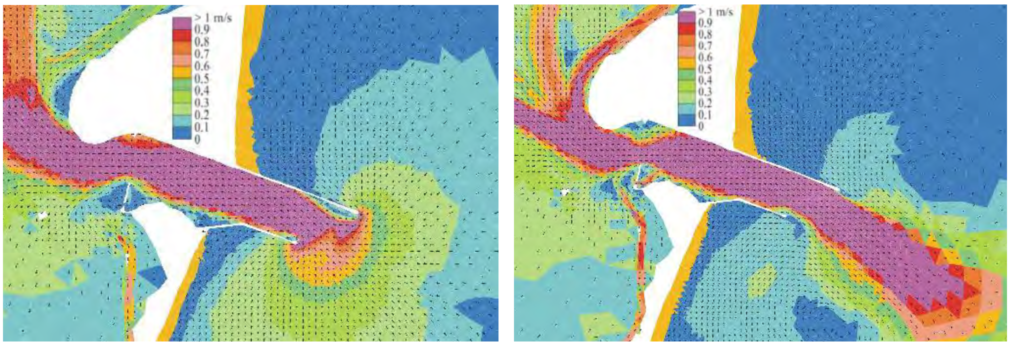


Fig. 14a – Hydrodynamic behaviour of the Malamocco inlet in the actual situation: flood phase (left) and ebb phase (right).

Separated flow are generated at the heads of the piers and inside the inlet, both in the ebb and in the flood periods. The strong contraction generated inside the inlet by the S. Pietro pier, as well the asymmetric configuration of the two piers, justifies the localized holes.

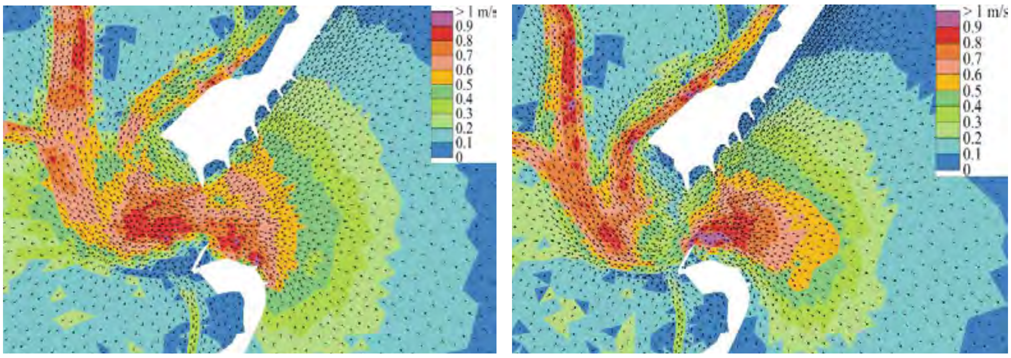


Fig. 14b – Hydrodynamic behaviour of the Malamocco inlet in the 1800 situation. flood phase (left) and ebb phase (right).

The armoured inlets in 1900 and in 1915 present the same qualitative behaviour with much smaller velocities (Fig. 15).

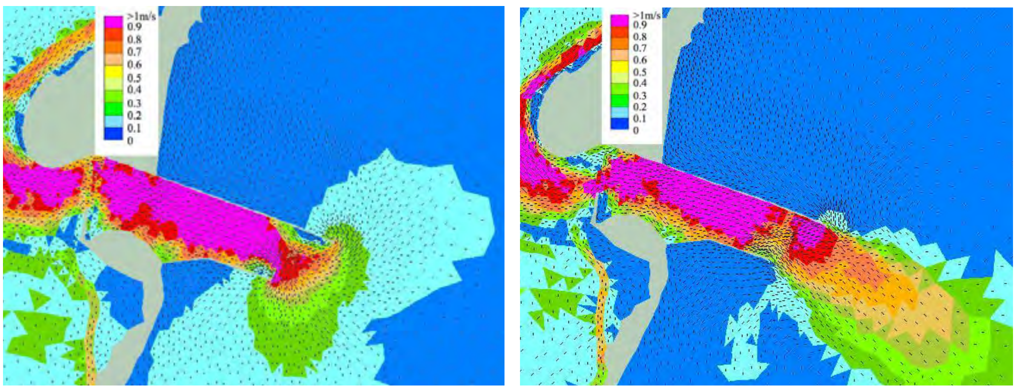


Fig. 15 – Hydrodynamic behaviour of the Malamocco inlet in the 1900 situation. flood phase (left) and ebb phase (right).

This different behaviour has also relevant consequences in the sediment dynamic as just a small amount of sediments, resuspended in the inner lagoon by wave action and tidal currents and crossing the mouths during the ebb phase, can enter again in the lagoon in the following flood phase.

We verified this behaviour simulating the transport of non-cohesive suspended sediments due the tide propagation. Assuming the lagoon soils characterized by d_{50}=50μm and d_{90}=200μm and relative density equal to 2.2 and imposing the sediment mobility, we obtained interesting results (Fig. 16). The ebb solid volume is bigger than the one in the flood phase and the net lost volume in the last cycle is ~3’000m^3.

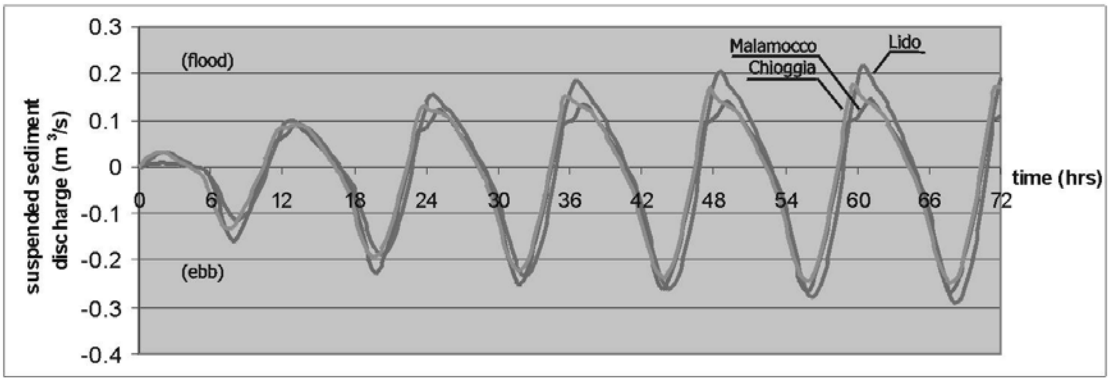


Fig. 16 – Sediment discharges at the inlets in the actual lagoon. Positive discharges refers to flood phase.

We then checked the behaviour of different diameters and tide range assuming they were incoherent and they can be represented as a fine sand (also when the chosen diameter belongs to a silt). The obtained results, different in the value as expected, are all of the same magnitude. Sediment characteristics and net loss in the last simulated cycles are summarized in the following table (Tab. 2).

Tab. 2 –Sensitivity analysis of sediment losses at the inlets.

Exp n.	d_{50} (μm)	d_{90} (μm)	relative density	Tide range (m m.s.l.)	Sediment loss (m^3)
Exp1	20	50	2.0	+0.25 / +0.95	~750
Exp2	50	200	2.2	-0.2 /+0.8	~3’100
Exp3	50	100	2.0	-0.2 / +0.8	~2’900
Exp4	50	100	2.6	-0.2 / +0.8	~1’900

Considering the experiment 4 and a frequency of 10 cycles/month, the annual amount of sediment lost is equal to 300’000m^3. Similar values can be obtained from the other experiments (2 and 3) and they have all the same order of magnitude in comparison with the values of 500’000 – 1’000’000m^3 commonly reported in literature. The experiment 1 seems to be no representative as a too much small (not realistic) roughness diameter d_{90} has been chosen.

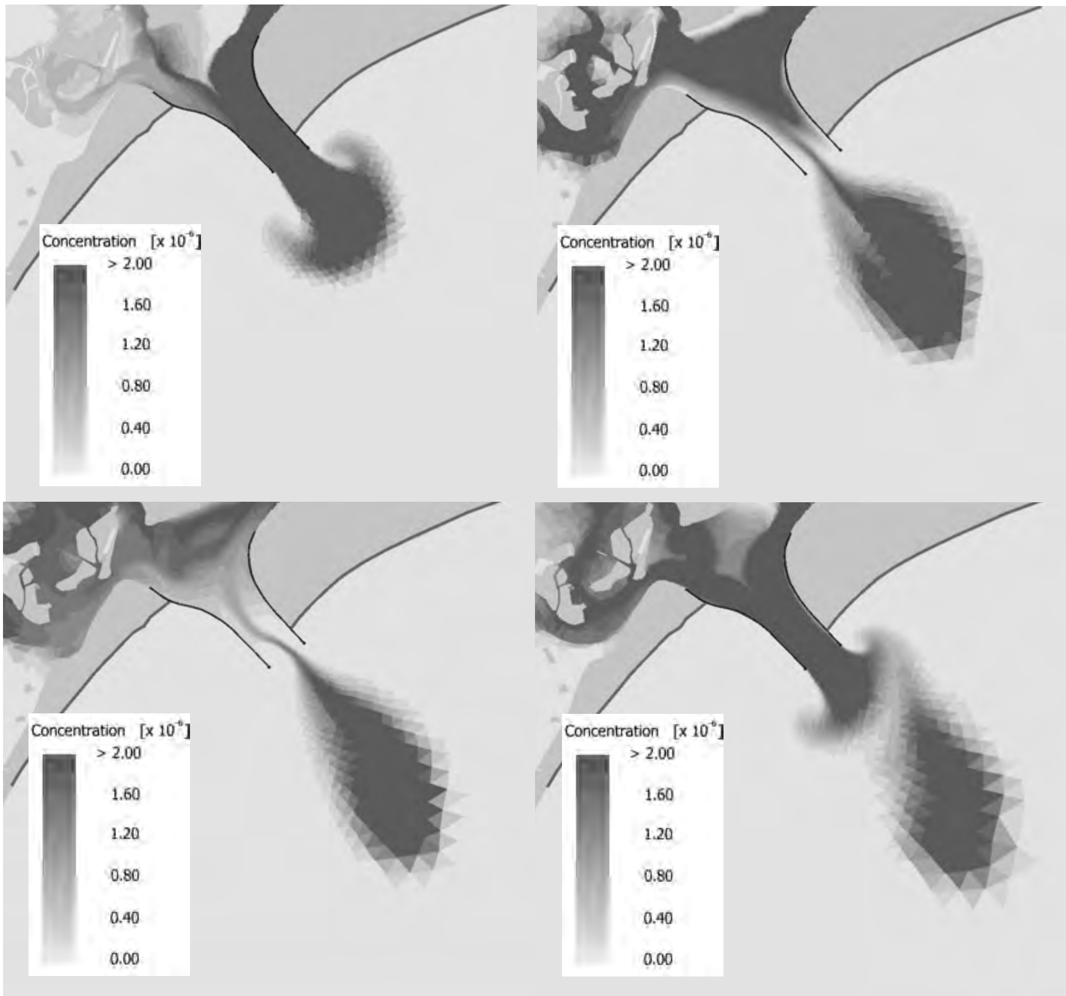


Fig. 17a – Sediment dynamic through Lido inlet. 1st ebb phase (top left), 1st flood phase (top right), inversion flood/ebb (bottom left) and 2nd ebb phase (bottom right).

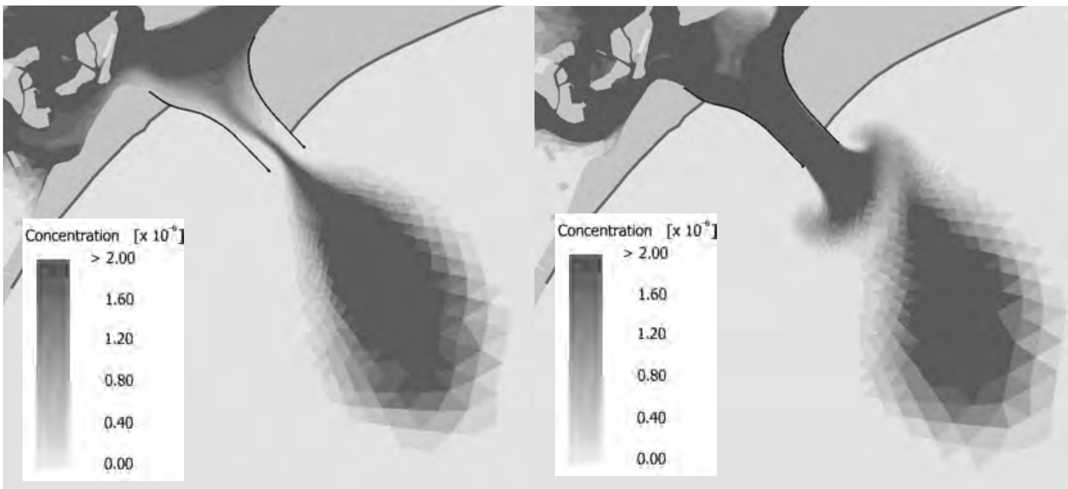


Fig. 17b – Sediment dynamic through Lido inlet. Inversion flood/ebb (left) and 3rd ebb phase (right).

Considering that the main cause of resuspension in the inner lagoon is the wind-wave acting on the bottom of shoals and shallows (so the tidal currents approach the main channels are characterised by high sediment concentration) and reminding that this process is still not considered in the model, the total expected sediment loss could be very similar to the values of 500’000–1’000’000m^3 reported above.

The cause of the sediment deficit balance resides in the non symmetric hydraulic behaviour which effects in the sediment dynamic are graphically represented in the panel reported below, where the concentration contour in six different instants are plotted (Fig. 17a,b). The sediment cloud generated in the ebb phase is pushed apart from the inlet. In the following dry phase the cloud (slowly depositing on the bottom) can re-enter in the lagoon only partially as the flow field is pretty radial (cfr. Fig. 14). In the following ebb phase the new sediment cloud superimposes to the previous one and so on. We verified that in the 1800 lagoon, for the same condition, a pretty balanced situation between ebb and flood exists. The velocity field at Malamocco (Fig. 14 and Fig. 15) clearly suggest that the carrying capacities in the 1900 and in the actual situation are totally different, being the latter very much smaller. For brevity, we do not present here those results, remanding them to a further contribution.

In the calculation we have omitted the long-shore currents, without altering the “breath” mechanism generated by the geometry of the tidal inlets.

During the ebb phases, the calculation shows that “clean” water can enter in the inlet from the lateral regions near the two dikes. In these regions, the tidal velocities can not resuspend sediments. Only during wavy sea or storms, sediments of the northern beach, resuspended by wave breaking (Fig. 18), can enter in the inlet.

As the sediment cloud has moved apart from the mouth, only the cloud region closest to the inlet can be transported again by the tidal currents. The inversion phase between ebb and dry looks very impressive as a very thin sediment thread, formed during the ebb phase, collapses with a sort of instability mechanism.

Fig. 18 – Sediment entrainment at Lido inlet in a flood phase during a wavy sea.

While the inlets are the final cause of the sediment loss from the Venice Lagoon, the causes of the morphology degradation are not so clear, especially in their relative effects. As the Venetians moved out from the lagoon the estuary of Brenta and Piave, the lack of sediment input (and fresh water) from the watershed is one of the causes of the degradation. The other causes are several: the increased energy of waves produced by wind and boat traffic; the dredging of the industrial channels (deep and large); the subsidence and the eustatism; the agricultural and industrial pollution.

In order to investigate and understand the relative effects of the main causes, we present here a brief description of the hydraulic behaviour of the historical lagoon, focusing the attention on the discharges and on the tide attenuation.

Three unreal configuration were added in the review:

- "Denaix con moli" refers to the 1800 bathymetry of the whole lagoon imaging that the jetties in Malamocco and Lido inlets were instantly built on;
- "1901+bocche1915" refers to the 1901 bathymetry of the whole lagoon where the bottom elevation at the inlets is chosen from the 1915 maps;
- "attuale+bocche1915" refers to the actual bathymetry of the whole lagoon where the bottom elevation at the inlets is chosen from the 1915 maps.

All the results are plotted in Fig. 19 and the range of the values obtained, both discharge and tide level, seems very important. Before analysing/commenting the results, some general concepts, useful to understand the following results, need to be clearly listed:

1. jetties construction usually generates a reduction of the width (as it happened in Venice Lagoon, especially at Lido);
2. jetties construction, if the bed bottom could be maintained as constant (i.e. a fixed bed), generates an increment of dissipations and local velocities;
3. jetties construction over a natural bed initiates an erosive process leading to an increment of depth, i.e. an increment of the section;
4. the degradation of the lagoon morphology (shallows deepening and salt marches disappearing, channel close to the inlets becomes deeper while boundary channels get silted due salt-marches destruction) reduces the internal dissipation accelerating the tide propagation and increasing the entering discharges.

Looking at the plots all these concepts are recognizable. All the following considerations refer to the 1m tide considered (a normal "high tide").

In 1806 the discharges through Malamocco were much less than now (approximately 50%) while those through Lido and Chioggia didn't differ very much from now.

The tide attenuation at P.ta della Salute were about 10cm, while now it is null. The unreal situation "Denaix con moli" presents a strong discharge reduction as a consequence of the instantaneous width reduction (not balanced by the bed bottom deepening) and then the increment of dissipation (20cm at P.ta della Salute).

The discharge reduction at Lido is bigger than at Malamocco as the section tightening due the jetties construction was stronger.

In the 1901 tide attenuation at P.ta della Salute (17cm at P.ta della Salute) was stronger than in 1806 as the Lido and Malamocco jetties were constructed. Nonetheless, it was weaker than the one calculated for the "Denaix con moli" configuration as, after the construction of jetties, bed erosion took place between the inlet dikes, reducing the tidal dissipation crossing the inlets.

Reduction of discharges through Chioggia inlet (revealed from the comparison of 1800 situation and 1900 situations when the piers construction were not started yet) are caused by the fact that wide areas in its watershed were appositely filled by the Brenta diversion in the lagoon, expelling a significant portion of the ancient watershed (cfr. Fig. 12a,b,c).

Comparison between 1806, 1901 and 1901-1915 shows a clear trend to reach the hydrodynamic conditions existing before the jetties construction (as they were in pretty stable equilibrium since the diversion of rivers). The bottom elevation at the inlets got deeper. As noticed before, no important variations in bathymetry occurs at Malamocco between 1901 and 1915, and both configurations have the same discharges they had in 1800. In 1900 and 1915 the approaching to the past hydrodynamic behaviour was still in progress at Lido, while Chioggia jetties was non completed jet. The quick discharge (and bottom) adaptation at Malamocco in comparison to the apparent slower variation at Lido can be promoted by the higher velocities. The fact that the jetties construction at Lido was recently terminated could also explain the apparent delay in the morphodynamic changes at Lido.

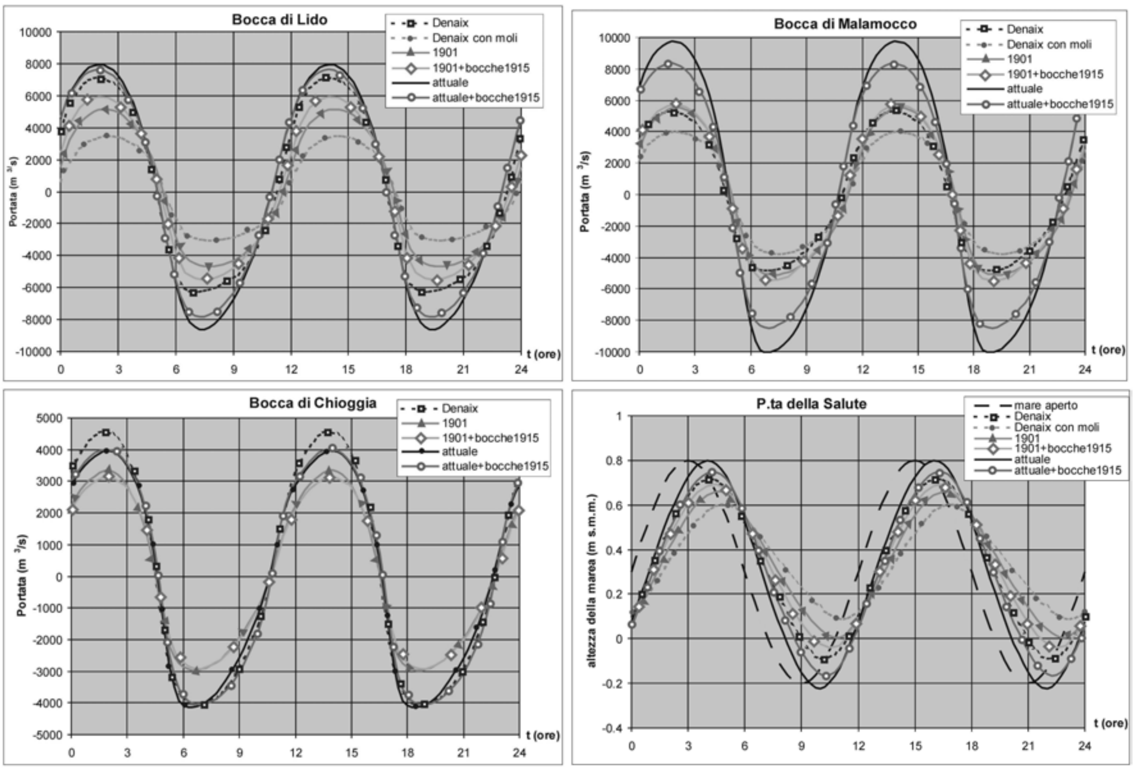


Fig. 19 – Discharges through the three inlets and tidal attenuation at P.ta della Salute in the analyzed situations.

Concluding the hydrodynamic analysis, no important wide-scale hydrodynamic variations occurred between 1806 and 1915 as it seems the jetties construction forced a new equilibrium configuration where the same discharges were obtained with different inlet depths and sections. The analysis of 1930 bathymetry will confirm (or not) this tendency. Certainly, the jetties construction has induced an asymmetric flow causing a continuous sediment loss. At the same time it's true that jetties construction can not be the only responsible of the actual lagoon degradation, especially if a sort of new section equilibrium with the same liquid discharges and very modest sediment loss was found just in the early decades of XXth century.

As the actual lagoon present very different hydraulic conditions and discharges from both the past analysed configurations, there is the realistic possibility that other circumstances verified in the XXth century (i.e. the excavation/dredging of industrial channels; the subsidence and eustatism) have given the finishing stroke to an environment in a precarious equilibrium since the river diversion.

The analysis of tide levels at P.ta della Salute in the configurations "1901+bocche1915", "actual" and "actual+bocche1915" clearly shows that only half of the tide difference between 1915 and today can be ascribed to the variation of bed elevation at the inlets, the second half being caused by variations in the morphology.

The effect of the morphology degradation in the central lagoon is easily recognizable in the following panel (Fig. 20), where for the reference tide the contours of the maximum tide elevation are plotted. The historical lagoon were much more dissipative than now, not only at the inlets but also in the inner part, where the shallows (less deeper than now) and the salt-marches (covering a considerable amount of the whole lagoon) contributed to slow sensibly and to attenuate the tide propagation.

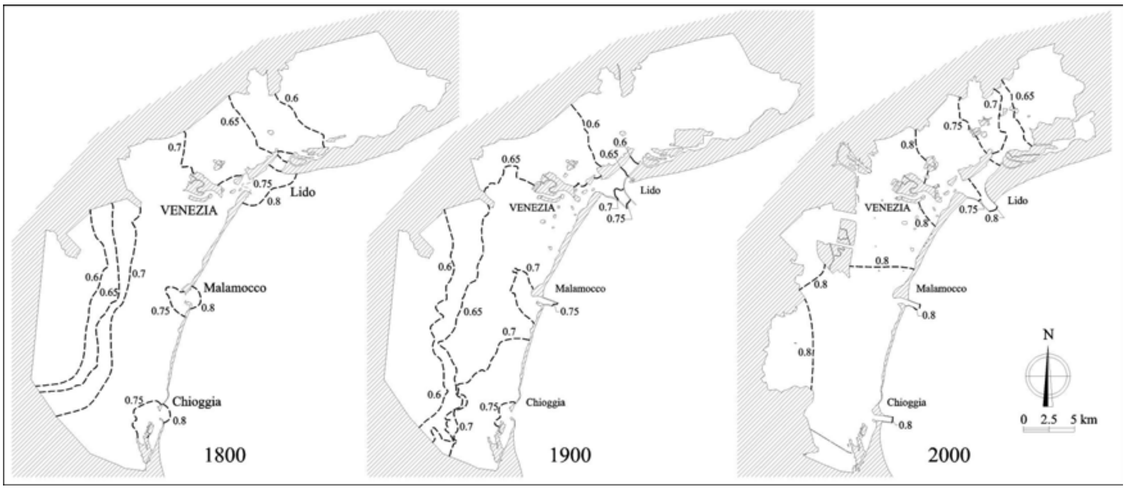


Fig. 20 – Maximum tidal level in the inner lagoon.

There is a strict link between morphology and tide propagation/attenuation even if it should not be discarded that all the analysis are done considering a normal high tide (-0.2/+0.8m m.s.l.).

The consideration here expressed can not be translated to an extremely high tide like the one happened in 1966. The Fig. 21 shows the tide propagation at P.ta della Salute in a situation where the 1806 lagoon is forced by a tide like the one in 1966. No appreciable attenuation is found.

Regulatory works to control the entering fluxes at the inlets are strictly necessary to prevent Venice from floods, while restoration of the ancient morphology and localized dissipations at the inlets act both attenuating the normal high tides in the city of Venezia and reducing the operations of fluxes regulation at the inlets.

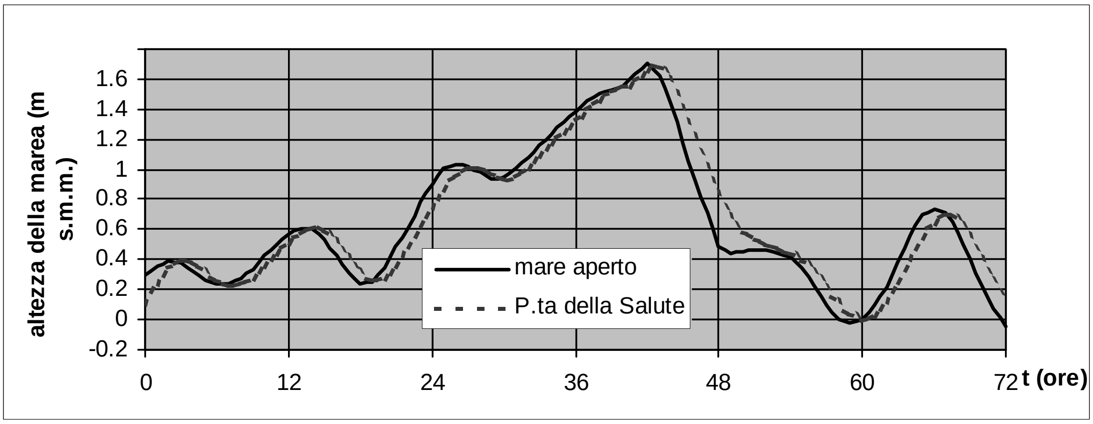


Fig. 21 – Bathymetry of 1800. Tidal levels at P.ta della Salute for an even like the one of 1966.

6. Conclusions

The review of hydraulic behaviour of actual and historical lagoon has provide new insights in understanding the causes of the morphological degradation of the lagoon. The numerical model has shown robustness, precision and user friendly pre-post processor. The computational resources are not so expensive to avoid morphological studies: the long term evolution analysis has become closer to the engineer capacities with a correct, complete but also schematic representation of the main morphological recipes and actors.

Even if the sediments have been represented everywhere as sand, the sediment dynamic at the inlets has been represented with sufficient accuracy, leading to estimate realistic values of sediment losses.

The possibility of more complete models to be ready for use in short time or their ability to be applied to the whole lagoon without approximations that would produces uncertainties, perhaps, at the same order of magnitude of those we surely made here, should suggest some critical considerations.

The analysis of the hydrodynamic has shown the variations occurred from the 1806 to 1906-1915. They are localized at the inlet regions and, by themselves, do not justify the big-scale variations occurred in the 20th century.

The total discharges and tidal prism in the historical lagoon was sensibly smaller than now, the major differences were located in the Malamocco basin, due the dredging of Canale dei Petroli.

We showed the importance of morphology in tide attenuation but not to prevent Venice from extremely high tides. For those events, regulation of the entering fluxes are obviously necessary. The sediment losses from the inlets can not be nullified, as they are induced by the geometry of the armoured inlet, but they could be sensibly reduced preventing sediment resuspention (reducing the wind-waves acting, for instance).

Acknowledgements

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AREA 4
DATA MANAGEMENT AND DISTRIBUTION

RESEARCH LINE 4.1
Distributed information system

MANAGEMENT OF SCIENTIFIC INFORMATION IN THE CORILA PROJECT: TOOLS AND TECHNICAL ASPECTS

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Riassunto

Tra i compiti istituzionali del CORILA, un aspetto essenziale riveste la raccolta e l'organizzazione delle informazioni scientifiche prodotte. A tal fine è stato lanciato il progetto RIVELA (database per le RIcerche sulla LAguna di VEnezia), strumento sviluppato appositamente per contenere, conservare e rendere disponibili le informazioni raccolte.

L'accesso alle informazioni avviene oggi tramite un canale tematico dedicato, sul sito www.corila.it, denominato appunto "RIVELA", che rende l'accesso alle informazioni facile e veloce. Il canale tematico, a sua volta organizzato in sotto–canali tipologici, consente la ricerca delle informazioni attraverso diversi strumenti.

Per ottenere un adeguato livello di performance, la rete del CORILA ha subito un insieme coordinato d'interventi hardware e software che rendono il *sistema informativo* più affidabile, efficiente e facilmente integrabile con nuove funzionalità e capacità di calcolo.

Si è mirato ad ottenere una gestione integrata delle informazioni prodotte e organizzate in diverse tipologie di formati (documenti testuali, immagini, dati alfanumerici, archivi di dati, ecc.) comunque facilmente accessibili dall'utenza scientifica.

Abstract

Considering the mission of CORILA, a really essential aspect is the collection and organisation of the information resulting from the scientific research. Therefore the RIVELA project was launched, whose goal is to receive, store and make available all data sets acquired thorugh the research activities and the related ancillary information.

A thematic channel in the CORILA web site, *www.corila.it*, named "RIVELA" makes the access to information easy and fast.

The thematic channel is divided in sub areas and the desired information can be extracted with several different instruments.

In order to achieve a proper performance level, several hardware and software coordinated modifications have been made to the infrastructure of CORILA network, which made the *Information System* more reliable, efficient and easily scalable.

The aim was to produce an integrated management system for the different types of collected information: documents, images, alphanumeric data set, data archives, etc..

1. Introduction

A really important aspect for CORILA is to collect and organise data and information produced by the scientific research, especially in its scientific program.

The different research lines produce different kinds of *information* in terms of type, structure, field of application, format and instruments used for data production.

The need for a systematic and safe information recording suggested to design a single repository, also able to share and spread the knowledge stored in it.

An integrated approach has been applied to design hardware and software structure, in order to fulfil the following main requirements:

- **Speed**: immediate display on World Wide Web
- **Capacity**: all the amount of data must be stored
- **Availability**: the information must be easily accessible
- **Security**: defending against any data loss and intrusion

2. The CORILA computer network and infrastructure

To satisfy the requirements it was needed to redesign the simple network infrastructure established at CORILA's birth. That led to a reorganisation of the web connectivity, the relocation of server resources, but also to many changes in the applications design and development and in the organisation of the work flow.

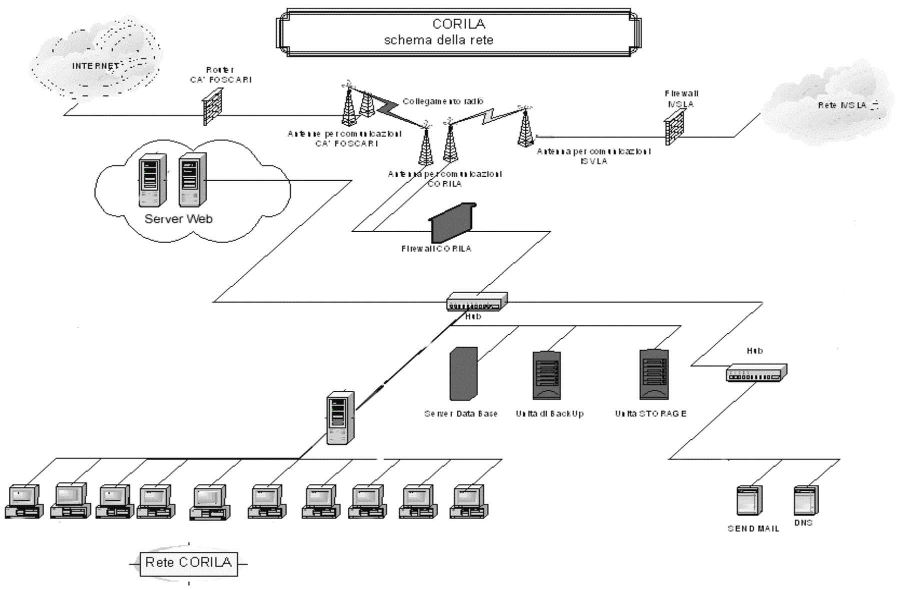

Fig. 1 – Schematic architecture of CORILA computer network.

Firstly, it was necessary to enlarge and stabilise the connection with the GARR network, realising a 11 Mb wireless link with the University of Venice Ca' Foscari, POP of the GARR network.

The next step was to improve the security, using a dedicated hardware firewall linked with some configurations and defence software.

The internal network has been completely reconfigured (fig. 1).

The entire web infrastructure was rebuilt, including the web site, a DNS, e-mail servers and other web network services, previously charged on Ca' Foscari network.

A multi-OS technical infrastructure for the development of the applications needed by the *Information System* was finally available.

The disk storage capability was enlarged, as well as the number of servers available and improving the backup and recovery system implementing proper procedure on HP Ultrim hardware.

In order to achieve a substancial fault tolerance for most critical services, RAID architecture and hot-swap disks have been used for servers. Moreover, redundancy has been applied for some selected services and network links, coping with budget constraint.

As a result of all these interventions, the service interruption has been dramatically reduced, the maintenance procedures are faster and less expensive and the overall reliability of the system has improved, while the Total Cost of Use remained substantially low.

3. The software solution

The CORILA researches are related with several aspect of the Venice lagoon: the involved disciplines range from economics to architecture, to environmental processes (biology, chemistry, meteorology, etc.). In general, there are many disciplines and studies and often the way to store, query and present data is really different.

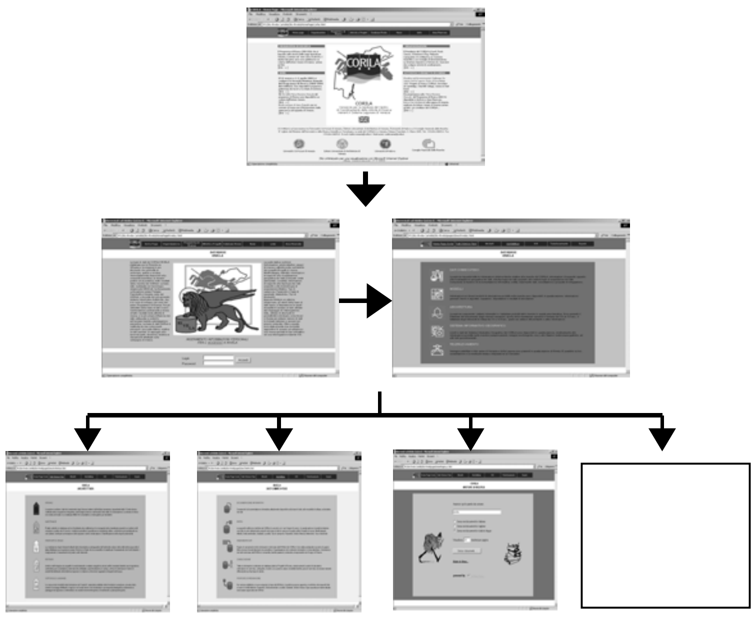

Fig. 2 – Navigation path from Corila web site to RIVELA area

To integrate all this different types of information a new thematic Channel was developed, which is accessible to registered users through the RIVELA portal on the CORILA web site.

The Channel is organised according to the thematic areas mentioned above.

The main themes are organised into different sections as follows:

- ✓ ENVIRONMENTAL DATA section which includes:
  - Hydrodynamic and morphologic data.
  - Biological data
  - Chemistry data
  - Geological data
  - Other data concerning environmental processes
- ✓ ARCHITECTURE AND CULTURAL HERITAGE includes:
  - the data base on Venetian Plaster
  - the database on workers and interventions in the Venetian area between XIV and XVI century
  - the database on the buildings restoration in the eighteen century.
- ✓ SIMULATION MODEL: numerical modelling is largely used to study hydrodynamics and ecological evaluation. Description of the models and their characteristics together with some simulation results can be found in this section.
- ✓ GEOGRAFIC INFORMATION SYSTEM: From this section it is possible to download GIS "layers" already elaborated for immediate use. Basic cartography of the Venice lagoon is available, too. In the near future a WebGIS interface will be ready for use.
- ✓ SATELLITE IMAGES: satellite and aerial images that cover the Venice Lagoon are available in this area.

One key feature of the implemented approach is the integrated management of different types of data formats (documents, images, alphanumerical data, data archives, etc.), which are all available starting from the same web interface.

Access to information is granted to recorded user, using a profiling system based on different rights level, from the researcher of the CORILA network to the generic user.

The graphic of the web interface has intuitive and immediate look and gives to the user two different navigation approaches (theme-oriented or database-centric).

Beside the navigation interface, a search engine has been developed, which facilitates information retrieval using keyword or free text search on different types of documents (web pages, pdf documents, etc.).

4. Conclusions

The hardware and software of the CORILA Information System is ready to satisfy the basic need of storing and distributing the information coming from the Research Program.

The implemented tools can be useful to spread the knowledge for the use of the Public Administration and across the scientific community and helpful for the research in progress.

The Information System has been designed with an “open” approach to be easily expandable in the near future, taking into account the information that will results from the new researches.

DATA QUALITY: AUTOMATIC PROCEDURES TO GUARANTEE QUALITY CONTROL IN DATA ACQUISITION PHASES

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Riassunto

Nei sistemi di gestione di dati, ed in particolare in quelli ecologico-ambientali, una delle componenti essenziali è rappresentata dalle procedure per l'acquisizione dati e per il controllo degli stessi (Quality Assurance/Quality Control). È necessario quindi che i dati vengano acquisiti e memorizzati dopo essere stati sottoposti ad opportuni controlli che ne possano garantire il livello di qualità e attendibilità desiderato.

In questo contesto è stato realizzato un applicativo il cui scopo è quello di filtrare i dati da inserire nel database RIVELA attraverso l'utilizzo di procedure automatiche che realizzano il processo di Controllo di Qualità.

Solo in caso di positiva verifica della qualità dei dati inviati si procede alla loro memorizzazione nel repository RIVELA, rendendo quindi le informazioni raccolte disponibili per la consultazione.

Abstract

In data management systems, and particularly in environmental and ecological archives, one of the essential tasks is represented by the procedures that collect and check data (Quality Assurance/Quality Control). Data can be stored and used only after safe check procedures, in order to guarantee the desired quality and reliability level.

Following this concept, a procedure was developed, with the aim to filter the data before filling the RIVELA repository.

Only in case of a positive result of the check, collected data are inserted in the RIVELA repository and made available for consultation.

1. Introduction

The information collected in the CORILA researches is stored in a structured repository, named "*RIVELA*".

This application is a multi layer software program, made of: user interfaces, data base structures and administration procedures, control algorithms; web based technology has been used for the user interfaces.

From the operational point of view, RIVELA interfaces are divided in two parts: the first one let the data producers send to the CORILA servers the information they want to archive; the second kind allows to select and extract the stored information, using different types of requests and queries.

This second area, called "RIVELA Portal", is available on website www.corila.it and the access is granted after user identification.

CORILA research areas cover 3 major themes: Economics, Architecture and Cultural heritage, Environmental processes. The information structure considers these main areas.

2. Data manager and quality control

In the ecological and environmental data archives, an essential task is to develop acquisition procedures able to check every single datum collected.

More generally, a proper control procedure should guarantee the requested quality and reliability level of the stored information, which is necessary to make data sets usable also for a wider audience, i.e. for people different from the producers.

This is to allow other people which study similar aspect or field to compare their results with the data sets and with information already available.

There are two main aspects to consider to reach this goal:

- *quality control procedure,* validation algorithms able to control the data consistency before filling the data base;
- *quality assurance procedure*, i.e. statistical algorithms able to control the reliability of the data sets.

At the time of writing this article the first of these aspects has been developed and implemented as described below.

To store information regarding the environmental processes area, a specific relational database has been developed, using Oracle as RDBMS.

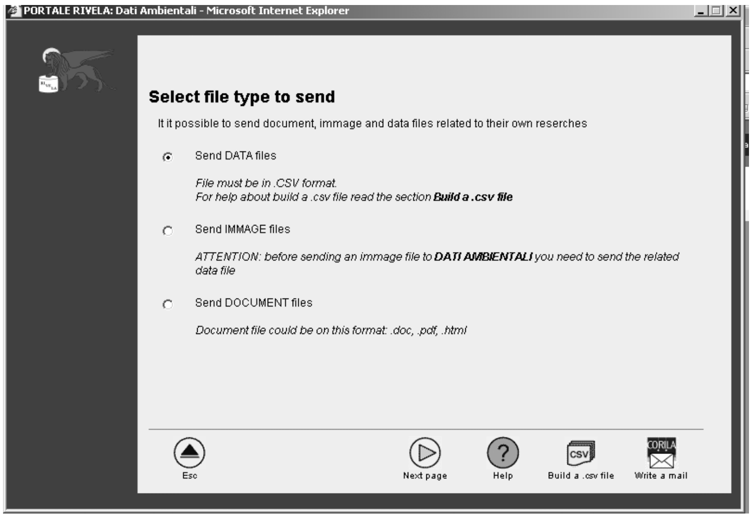

Fig. 1 user interface to send data from the web side.

The environmental and ecological data are sent to CORILA using a web based application. An authorized user who wants to send data to CORILA has to prepare on his computer one or more Comma Separated Value files (with “csv” extension). In this files the information is organised in a pre-defined tabular structure.

The files are then uploaded to CORILA via web, together with a number of ancillary information that characterizes every single file.

This upload method uses a unique approach to acquire different types of data, defining a standard that unifies all the pieces of information in a single table structure.

This method has many advantages:

- It gives non-expert users, which have no database knowledge, an easy way to represent data coming from different research fields (biology, chemistry, engineering, etc.)
- It uses a standard file format available in all operating systems
- It’s an immediate and direct transfer tool, available via web.

Moreover, it gives the data manager the possibility to apply standard procedures to check the consistency of all the data sent, before storing them in the data base structures.

An application to check data format and consistency, which is now briefly described, has been developed in Java with WebObjects technology.

Fig. 2– The administrator user interface for the Quality Control procedure application.

As first, the format file type (*.csv) is checked, and an error message is issued in case of an incorrect file format.

The next procedure validates the file content consistency.

A check is performed on the file header, comparing the information sent to the internal dictionaries of the database. In particular, the control includes:

- parameter names
- sample types
- measurement units

The dictionary of parameters in the database already counts thousands of entries and cross-references between names, sample types and measurement units are checked during this step.

Any error encountered in this phase, which is reported with a detailed description and the localisation inside the CSV file, stops the computation.

In case the file header is parsed with no errors, then every data row of the file is scanned and a number of controls is performed.

The geographical information are checked, controlling:

- measure station information:
    - station name
    - station type
    - locality
    - zones and environmental units
- geographical coordinates
    - coordinates type
    - latitude and longitude values
    - absolute and relative localisation errors

Again, any error encountered is reported in detail.

The next step concerns temporal checks. The time and date information for samples and measurements is checked and compared to the time and date ranges from the measurement campaign.

The last step consists in checking every single measurement value.

A check for misspellings is performed, then the procedure checks every value for consistency with its corresponding parameter, and values which are not within the validity range defined for its parameter produce an error message.

Non-numeric values (such as alphanumeric descriptions) are compared with values from the value dictionary for the corresponding parameter and mismatching values are reported in the error list.

If the control procedure terminates unsuccessfully, the list of the encountered errors (which is also stored in the database and can be retrieved at any time via a specific Quality Control interface) is presented to the database administrator, who can send the encountered errors list to the submitter of the examined data set.

The data sets that passed the Quality Control check are finally stored in the database and immediately available from the RIVELA Repository.

Conclusions

Quality Control is a key issue for database management, especially when dealing with data sets about environmental processes.

To assure the proper Quality Control concerning the data set of CORILA a number of procedures were developed.

The developed procedures allow data producers to send the data directly from the web and guarantee the consistency with the database schema. The stored data sets are immediately available from the RIVELA Repository.

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