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PIERPAOLO CAMPOSTRINI

30124 Venezia – Palazzo Franchetti, S. Marco 2847

Tel. +39-041-2402511 – Telefax +39-041-2402512

direzione@corila.it

www.corila.it

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"D'una città non godi le sette o settantasette meraviglie, ma la risposta che dà ad una tua domanda"

(Marco Polo in Le città invisibili *di Italo Calvino)*

INTRODUZIONE

Pierpaolo Campostrini

Direttore di CORILA

Il presente settimo volume della serie"Scientific Researchand Safeguarding of Venice" riprende, come i precedenti, i risultati delle ricerche su Venezia promosse e finanziate da CORILA nell'ultimo triennio e permette una lettura interdisciplinare più agevole dell'intenso sforzo prodotto dai ricercatori, i quali hanno saputo non solo approfondire i saperi di loro competenza, ma anche adattarli alla soluzione dei problemi concreti posti dal complesso caso veneziano.

Venezia è una città che esprime una straordinaria capacità di suscitare domande e richiedere risposte alla scienza. In questo volume ne sono state raccolte alcune. Esse sono valide evidentemente anche, ma non solo, come aiuto alla gestione del sistema lagunare veneziano. Affrontano infatti temi di attualità e di utilità molto più generale.

Ad esempio, il problema della bonifica/riuso dei siti inquinati dagli effetti di una industrializzazione poco o per nulla attenta all'ambiente è infatti tema planetario, per la soluzione del quale non esistono facili ricette. Le decisioni politiche richiedono di essere informate sui modi, sui costi, sulle conseguenze in modo da poter valutare efficacemente tutte le possibili alternative. Le strategie, le valutazioni strategiche che non siano scientificamente fondate hanno un grande rischio di essere semplicemente sbagliate e di causare grandi sprechi di risorse, se non danni peggiori all'ambiente ed alle società.

Evidentemente "globali" sono gli effetti del cambiamento del clima, che nelle lagune si misurano con maggiori sensibilità e si riflettono sia sulla matrice fisica che in quella biologica.

Le "risposte" che qui si sono trovate sono quindi davvero universali e mi auguro che tutti i lettori che prenderanno in mano questo libro potranno goderne, in qualsiasi parte del mondo.

Queste informazioni sono anche raccolti qui per essere trasferiti ai coloro che "prendono le decisioni". Risulta pertanto d'obbligo in questa introduzione sottolineare qualche precisazione. La scienza non ha modelli matematici affidabili capaci di descrivere ogni fenomeno, specie dove ai meccanismi della fisica e della biologia si associano i comportamenti individuali e sociali, e comunque qualsiasi previsione è affetta da incertezza. Questo non vuol dire

che, di fronte ad un problema complesso non si può scremare l'universo delle soluzioni a prima vista "possibili" da quelle (molte) semplicemente sbagliate. E' spesso difficile far capire la differenza tra incertezza ed incoerenza, o tra il poco probabile e l'assurdo. Tuttavia, in questo volume sono presentati dei risultati molto concreti che possono permettere ad una amministrazione sufficientemente illuminata un discernimento solidamente fondato.

In un Paese come l'Italia che attualmente non pone la scienza tra le sue priorità ed in cui il sapere scientifico è tuttora appannaggio di troppo pochi cittadini (molte volte bistrattati), in caso di decisioni su questioni controverse, spesso tutto finisce in un frullatore "democratico" nel quale il parere tecnico scientifico semplicemente non conta, perché drammaticamente minoritario.

"Minoritaria" risulta anche l'esigenza di finanziare la ricerca: il Ministero della Ricerca non ha ottenuto più finanziamenti diretti dalla Legge speciale per Venezia dall'anno 2001. I risultati che vengono qui presentati sono resi possibili da un finanziamento diretto del Magistrato alle Acque di Venezia, cui va il nostro doveroso ringraziamento e riconoscimento, e dalle analisi delle informazioni raccolte attraverso le attività di monitoraggio svolte in laguna, per conto dello stesso Magistrato alle Acque, atte al controllo degli impatti ambientali dei cantieri del MOSE. Oltre ai nostri finanziamenti, le Università e gli enti di ricerca hanno saputo far convergere su questi temi fondi provenienti da altre sorgenti, dimostrando come le domande poste da questa città siano affascinanti e stimolanti.

CORILA si pone al servizio di questi ricercatori impegnati e di questi amministratori illuminati, per sostenere l'esistenza di un filo comune che lega i loro(ed i nostri) sforzi.

Infatti, insistiamo nella pubblicazione di questi volumi poiché crediamo che l'importanza ed il significato di queste ricerche si comprenda meglio in una lettura di insieme. Per ritornare a Marco Polo/Calvino che descrive a Kublai Kan un ponte pietra per pietra, con molti dettagli, egli così risponde alla domanda su qual è la pietra che sostiene il ponte: "Il ponte non è sostenuto da questa o quella pietra, ma dalla linea dell'arco che esse formano. Kublai Kan rimane silenzioso, riflettendo. Poi soggiunge: Perché mi parli delle pietre? È solo dell'arco che mi importa. Polo risponde: -Senza pietre non c'è arco".

Senza ricerca, ci può essere salvaguardia?

"You take delight not in a city's seven or seventy wonders, but in the answer it gives to a question of yours."

(Marco Polo, in Italo Calvino's Invisible Cities)

INTRODUCTION

Pierpaolo Campostrini

Director of CORILA

This volume of the series "Scientific Research and Safeguarding of Venice", as the previous ones, presents the findings of the research projects on Venice promoted and financed by CORILA in the last three years. It allows an easier interdisciplinary reading of the great efforts given by the researchers, which have been able not only to deepen their specific scientific knowledge, but also to adapt it in finding solutions to the concrete problems of the complex venetian case.

Venice is a city which expresses an extraordinary capacity of posing questions and requiring answers to science. This volume collects some of these. They are useful for the management of the Venice lagoon system, but they are not limited to it, since they refer to topical issues and have a broader utility.

As an example from the many included in the book, the issue of reclamation/reusing of polluted areas, caused by the past industrialization and its careless attitude towards environment issues, is a global concern, whose solution is not provided by an easy and unique formula. Policy decisions need to be detailed informed about methods, costs, consequences of every alternative, in order to effectively evaluate them. In fact, those strategic evaluations which are not science-based face an high risk to be simply wrong and to cause a great resource waste and even worse damages to the environment and to the society.

Climate change is also a global concern. In lagoon systems, the effects of climate change bring measurable increasing of vulnerability and they are reflected both in physical and biological matrix.

The answers given in this book, thus, have a world-wide value and I hope that every reader who happens to handle this book could enjoy and use them, wherever in the world.

Another objective of collecting here these pieces of information is to transfer them to policy makers. Therefore, in this introduction is worth to highlight that science does not have mathematical models which are reliable to describe all the phenomena - especially when physical and biological mechanisms are

associated with individual and societal behaviors – and, besides, previsions are always affected by uncertainty. This does not mean that it is impossible to distinguish among “possible” and “wrong” solutions while coping with a complex problem. Sometimes, for the person of the street , it can be hard to understand the difference between uncertainty and inconsistency, or between probable, improbable and absurd. Science should be able to communicate these differences.

In this volume concrete results are presented, which should allow the administrators and managers to make consistent knowledge-based discernment.

In a country as Italy, that currently does not give to science a high priority, and where scientific knowledge still is a prerogative of too few citizens (sometimes mistreated), in the case of controversial decisions, it often happens that any opinion is put in a sort of “democratic blender”, where technical and scientific opinions are simply ignored because they represent the minority.

Also the need of funding research is of minority importance: the Ministry of Education, University and Research, have not received any additional fund by the special law for Venice since the year 2001. The scientific results we present here have being made possible thanks to a direct funding given to CORILA by the Venice Water Authority -to which our warm thanks must go- and from the monitoring activities of the environmental effects of MOSE construction, carried out on behalf of the Venice Water Authority, too. Beside our grants, Universities and research centres have been able to attract and to add other sources of funding on the same topics, demonstrating how fascinating and stimulating the questions posed by Venice can be.

CORILA is working in support of these researchers and these sensible administrators, in order to make more evident the common line that links their (and our) efforts.

For this reason, we insist in publishing these volumes, since we believe that the meaning of these research findings is more comprehensible when they are put together in an single reading.

Coming back to Marco Polo/Calvino in the Invisible Cities book, he was describing a bridge to Kublain Kan, stone by stone with a lot o details, when he was questioned about which stone supports the whole bridge and he answers: "the bridge is not supported by one stone or another, but by the line of the arch that they form." Kublai Kan remains silent, reflecting. Then he adds: "Why do you speak to me of the stones? It is only the arch that matters to me." Marco Polo answers: "Without stones there is no arch."

Without research, will there be any safeguarding?

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AREA 1

Economics

HUMAN CAPITAL, TECHNOLOGY INTENSITY AND GROWTH IN A REGIONAL CONTEXT

Donata Favaro[1], Eniel Ninka[2], Margherita Turvani[2]

[1] *Dipartimento di Economia M. Fanno, Università di Padova*
[2] *Università Iuav di Venezia*

Riassunto

Questo lavoro contribuisce ad una vasta letteratura sulla applicazioni a livello regionale della teoria della crescita endogena. Una caratteristica ben nota della crescita e dello sviluppo è la forte e persistente divergenza nella crescita del reddito pro capite tra le regioni. Queste differenze sono state spiegate teoricamente ed empiricamente utilizzando approcci neoclassici sottolineando rendimenti crescenti a livello regionale, con riferimento, ad esempio, allo sviluppo dei distretti industriali. La nuova economia della crescita urbana e regionale guarda alla dimensione 'locale' incentrata sul ruolo dell'economia della conoscenza come spiegazione dello sviluppo diseguale tra le regioni. All'interno di questa eterogeneità, il capitale umano e gli *spillover* di conoscenza svolgono un ruolo nella differenziazione dei tassi di crescita. Lo studio della concentrazione di un mix specifico di attività economiche e del capitale umano, con una lenta a 'grana fine' a livello locale, è un utile strumento per comprendere la crescita e le differenze territoriali. In questo studio, abbiamo sviluppato un'analisi empirica del modello di crescita della regione Veneto, focalizzandosi principalmente sul ruolo svolto dal capitale umano impiegato in settori con differenti intensità tecnologica. Per farlo, abbiamo costruito un dataset originale attraverso la fusione dei dati disponibili a livello molto locale (Sistemi Locali di Lavoro), forniti dall'Istituto Nazionale di Statistica, con le nostre elaborazioni su dati provenienti da una base dati messa a disposizione da Veneto Lavoro che contiene tutti i rapporti di lavoro nella regione Veneto. Il nostro nuovo set di dati permette sia la definizione del capitale umano di ogni lavoratore sia la classificazione delle imprese secondo la loro intensità tecnologica. Questo set di dati è usato per stimare le equazioni di crescita a livello dei 34 SLL veneti. I risultati sottolineano come la crescita nella regione è influenzata positivamente dal capitale umano impiegato non nelle industrie ad alta o medio-alta tecnologia, ma in quelle a medio-bassa o bassa tecnologia.

Abstract

This paper contributes to the vast literature on the regional application of endogenous growth theory. A well-known feature of capitalist growth and development is the vast and persistent divergence in per capita income growth between regions. These differences have been explained theoretically and empirically using neoclassical approaches emphasising increasing returns at a regional level, with reference, for example, to the development of industrial districts. The new economics of urban and regional growth look at the 'local' dimension focussing on the role of the so-called knowledge economy as an

explanation for uneven development across regions. Within this heterogeneity, the operation of human capital and knowledge *spillovers* play roles in differentiating growth rates. The study of the concentration of a specific mix of economic activities and human capital, with a 'fine grain' focus at the local level, is a useful tool to understand growth and spatial differentials. In this study, we develop an empirical analysis of the pattern of growth in the Veneto region, focusing mainly on the role played by human capital employed in sectors with different technological intensities. To do so, we built up an original dataset by merging data available at a very local level (Local Labour Systems-LLS), which was produced by the National Institute of Statistics, with our elaborations on data from an employee-employer dataset made available by the Local Labour Agency (Veneto Lavoro). The latter dataset included all employment spells in the Veneto region. Our new dataset allows both definition of the human capital content of every worker and classification of firms according to their technological intensity. This dataset is used to estimate growth equations for the cross-section of the Venetian LLSs. The results underline how growth in the Veneto region is positively affected by human capital employed not in high to medium-high technology industries, but in medium to medium-low ones.

1. Introduction

The recent world financial and economic crisis and its deep effects on the structure of productive systems in the most developed countries are posing major challenges to long-term growth capacity for both national and local economies. In Europe, even the fastest growing regions are experiencing difficulties in maintaining the targets imposed by the Lisbon strategy in terms of the development of a knowledge-based economy (European Commission, 2010).

It is well known that Europe's average growth rate has been structurally lower than that of our competitors (OECD, 2003). Economic theory maintains that a major cause of difference in economic performance is explained by different levels of investment in R&D and innovation. Empirical studies at the levels of firm and industry have established the roles of innovation and diffusion of new technology as engines of growth (Ahn, 2002; Nadiri, 1993). However, in the EU regions, persistent economic performance gaps are widespread (Armstrong and Vickerman, 1995; Cappelen, 1999). This persistence and its causes have been studied in some detail (Cappelen, et al., 2003; Dunford and Smith, 2002).

The role of education in economic growth has been recognized (Barro, 1997; Stevens and Weal, 2004); a higher quality of education works as a driver for promoting innovation and knowledge transfer among sectors and regions (OECD, 2007; Antonelli, 2002). Education is a fundamental determinant of innovation. Romer (1990), in his endogenous growth model, considers human capital as the only input for the R&D sector, where new ideas, especially for intermediate goods, are developed. Therefore, human capital is important for economic sustained growth only if it is applied where ideas are produced and where innovation eventually takes place; moreover, human capital endowment as such, and not its variation, is the trigger for growth. Romer (1990) develops

the idea of horizontal innovation, which is the creation of a larger variety of new products. On the other hand, Aghion and Howitt (1992) focus on 'vertical' innovation, which takes the form of improving the quality of existing products by creating new and different versions of goods, thus diversifying an existing innovation and transferring its benefits across the economy. International Institutions (OECD, 1996) have emphasized not only the challenges imposed by moving towards a knowledge-based economy but also the importance of providing vigorous stimulus to the accumulation of human capital, especially in those sectors which need R&D to maintain their position in a globalized and competitive market.

Among EU, the Veneto Region, the area under study in this paper, is characterized by relatively high levels of revenues per capita. However, a closer look shows a fragile economic structure, in which traditional sectors have experienced continuous economic decline and knowledge-based sectors have failed to become new drivers for growth (Regione Veneto, 2010). The resulting picture is that of a region exhibiting disparate patterns of growth in different subareas and districts and among different economic sectors. Understanding these differences is both a stimulus for our investigation and a necessity for appropriate policy-making.

The research questions we want to answer in this study point to the presence of persistent performance gaps in the economy of the Veneto Region. Specifically, our aims is to study in detail and at a sub-regional scale the origin of these gaps by looking at the role of human capital in promoting overall economic growth and by analysing its role in specific sectors, according to and in combination with differences in technological intensity.

By studying the underlying endowment of human capital and its utilization as a major determinant of the Veneto growth model, as evolved at the beginning of this century, we wish to contribute to the debate on the future of the regional economy and its position within the EU. Furthermore, we wish to provide evidence to support a vision for future growth by discussing those features of the regional growth model that may provide Veneto with the capacity to continue to maintain its potential for future growth, which is critical for its recovery from deep economic crisis.

A typical economic growth model such as that of Krugman (1995) would describe past growth patterns as the result of both industrial concentration and adaptive labour markets, and would advocate the exploitation of scale economies and the reduction of transport costs. However, the application of this model to the Veneto economy needs to be substituted. Instead, attention should be paid to those factors explaining long-term growth. The first factor is the endowment of human capital and its utilization in those sectors where growth could be maintained through time, spreading its positive effects to the overall economy. Given a certain amount of human capital and its distribution across the region – in our case the Veneto region – local and sectoral endowments are crucial for the production of new knowledge (Rodriguez-Pose and Crescenzi, 2006), which provides the foundation for differences in the capacity to grow.

For our purpose, the distinctions between modes of the diffusion of innovation benefits throughout the economy in terms of sustaining economic growth are particularly interesting and useful. Our hypothesis is that the persistence in growth-rate differences at the sub regional level is related not only to the way in which human capital endowments are present in the different sectors but more specifically are related to the way in which such capital is concentrated and applied in those sectors, which historically have proved to be the driver for economic growth and which constitute the 'core' of the Veneto Economy. These sectors happen to be those characterized by medium to medium-low levels of technological intensity (OECD, 2004), that is, not necessarily high tech or information sectors. As a matter of fact, these sectors, although investing less as a percentage of revenues than high-technology firms, do nevertheless generate new products, particularly, production processes that have considerable aggregate impact (Robertson and von Tunzelmann, 2009).

The article is structured as follows: in Section 2, we briefly summarize some economic aspects of the territory of study; in Section 3, we describe the dataset used for the empirical analysis; in Sections 4 we discuss the results of the empirical analysis.

2. The Veneto Region in the European and Italian Context: Human Capital Endowment and Technology Intensity

Veneto is one of the richest areas in Europe. In 2007, its GDP in 2007 exceeded 147 billion Euros, making a contribution of 1.2% to the EU-27 GDP. [1] In terms of GDP per capita, Veneto ranks in the top quartile among the richest regions in Europe. It ranks sixth among the Italian regions,[2] and with a GDP per capita equal to 123% of average EU-27, it holds the sixty-third position in the ranking of European regions[3]. Despite its annual GDP per capita in current prices increased from 25,900 Euro in 2001 to 30,600 Euro in 2007, Veneto lost ranking with respect to the beginning of the new millennium. If we consider the 2007 GDP per capita adjusted for purchasing power, the region of Veneto ranks forty-ninth in Europe; it was twenty-fifth in 2001 and forty-fourth in 2005 (out of 270 regions).

In Veneto, as in the most advanced economies, the share of value-added produced by industry (35% in 2007) is declining (Regione Veneto, 2010); the region is, in fact, relocating part of the activities to the service sector. Between 2000 and 2007, the share of wealth produced by this sector rose to the level of

[1] Eurostat, Regional Statistics,

http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/themes.

[2] There are 20 regions in Italy. The region with the highest level of GDP per capita is Lombardy, which reached 136.1% of the EU average and finished 37th at the European level.

[3] We refer to the NUTS 2 division.

62.6%[4].

Within the manufacturing sector, a significant proportion of the added value (30.3%) is created by machinery and mechanical; electrical and optical appliances; and means of transport. Significant contributions are also made by metals and manufacturing of metal products (18% of VA); wood, rubber and other manufacturing products (15%); and textiles and clothing (9.3%). Regarding the services sector, the most substantial contribution to added value is made by the various services to enterprises and households (31%); trade and reparations (20%); and transport, storage, and communications (11.6%) (Bank of Italy, 2009).

Although Veneto is following a sector relocation path from industry to services, a switch that highlights its dynamicity alongside the most advanced economies, at the same time it shows some aspects of weakness in long-term growth, particularly in strategic sectors such as high-tech industries and those engaged in R&D. In the period 2002-2006, R&D spending was lower than the Italian average, which is modest compared to European standards, both as a percentage of GDP and in terms of the number of people employed in research (Regione Veneto, 2010). Veneto is the seventh Italian region in absolute terms of spending in R&D – with over 776 million Euros in 2005. In terms of R&D expenditure to GDP ratio, the region falls to fifteenth place among all Italian regions. Considering that the region of Braunschweig in Germany spends 5.76% of GDP in R&D and Lombardy in Italy spends 1.8%, the 0.57% of Veneto shows the region's weakness. This weakness is confirmed by data on the employment in R&D sectors. In 2005, with only 2.2 employees per thousand inhabitants, against a national average of 3, Veneto ranks only eleventh among the Italian regions. To illustrate the gap that separates Veneto from others at the top of the list, we cite the datum of Lazio, the first region in Italy, which has more than 5.8 persons per thousand inhabitants employed in R&D positions.

Another indicator of the ability to create knowledge and innovation is the number of patents in a given time period.[5] Between 2001 and 2007, Veneto registered a discrete increase of the number of patents per capita, from 1.144 patents per one million inhabitants in 2001 to 1.353 in 2007,[6] ranking fifth

[4] The Italian average is 70.5%.

[5] The region is divided into seven provinces: Belluno, Padua, Rovigo, Treviso, Venice, Verona, Vicenza. In terms of the number of patents, there are strong differences between the provinces of Veneto. The more virtuous province is Padua (1.900 in 2007, 29% of regional total). Three other provinces, Vicenza, Verona and Treviso, contribute with similar shares between them (around 18%) while in the province of Venice were registered about 13% of patents. The remaining two provinces, Belluno and Rovigo, have insignificant shares. The differences persist also considering the number of European patents submitted to the European Patent Office – EPO. In this case, the leading province is Vicenza that in 2006 submitted 35% of patents in Veneto. Follow Padua and Treviso (21% and 22%). More detached Venice (14%) and very low values for Belluno and Rovigo (2% each) (Chamber of Commerce of Padua, 2008).

[6] Regione Veneto, Regional Statistics System Management, on-line data. Download at:

among the most successful Italian regions[7].

The ability of a territory to position itself strategically can be measured by its productive composition in terms of technological content. In terms of active high technology manufacturing firms (Regione Veneto, 2009)[8], in 2007, Veneto, at 9.4%, was the second region in Italy after Lombardy at 22%. Although the data would indicate Veneto as a centre of excellence for high technology, in fact, in 2007 more than half of the manufacturing industry in Veneto was low tech. Only 5.6% of companies were located in the high-tech sector[9] (Regione Veneto, 2009). On the other hand, an analysis of data referring to the period 2000-2008 could indicate that the number of firms in both low-tech and high-tech sectors is gradually decreasing. These companies might find it more profitable to locate in other areas of the world for different reasons such as cutting costs, or taking advantage of a higher number of skills in the most technologically developed sectors. It is therefore clear that the Veneto manufacturing industry is developed on mid-market products, which are characterized by high specialization and very high technical skills rather than technological ones (Regione Veneto, 2010).

Similarly, the Veneto region highlights the predominance of the traditional sectors, even in the aggregate of services. The tertiary sector, reclassified according to the varying degrees of knowledge, consists of mostly traditional services (61.5% of the entire sector in 2008). However, in recent years, services have shown a greater dynamism compared with the industrial sector. From 2000 to 2008, firms that dealt with market services, namely business consulting firms, transportation, and real estate grew by 65.8%, constituting 22.5% of the whole sector, while those engaged in technology services, that is telecommunications firms, IT, and R&D reached 3.5% (Regione Veneto, 2010).

The theoretical literature and empirical evidence point to the strong link between the ability to innovate, the productivity of labour, the dissemination of new technological knowledge, of products and processes, and the human capital of a territory. We therefore look at the educational level of the population of Veneto in 2001[10] (which is the year of the last census and the reference year for the econometric analysis), in order to determine whether there is a link between the reduced propensity to innovate and the availability of human capital. The percentage of Veneto inhabitants who have a tertiary education qualification[11] (only 6.5%) is lower than the Italian average by one percentage point. In the

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http://statistica.regione.veneto.it/dati_settoriali_economia.jsp.

[7] Once more, the first Italian region is Lombardy with 2,066 patents per million inhabitants while the Italian average is 1,164.

[8] There follow Piemonte (8.8%), Lazio (8.7%) and Emilia-Romagna (8.4%).

[9] 52.8% in Low Tech, 26.9% in Medium-low Tech, and 14.7 in Medium-high Tech sectors.

[10] Resident Population aged 6 or older.

[11] University degree or non-university tertiary diploma.

Veneto population, one in four holds a secondary school diploma (in line with the national average). The rest of the population, approximately 59%, has a lower secondary school diploma (*scuola media inferiore*), professional training (*avviamento professionale*), or an elementary school diploma (*licenza elementare*). About 9% of the population ages 6 years and over does not hold a diploma (analphabetic or without study title) (ISTAT, 2001).

A comparison of regional data helps us to better understand the situation in Veneto, which has one of the lowest percentages of graduates in relation to the population aged 6 and over out of twenty Italian regions, placing it in the lowest quartile. The regions with the highest number of graduates are Lazio (10.6%), Liguria (8.6%), Umbria and Emilia Romagna (8.1%) and Lombardy (7.8%). The placement improves noticeably for the percentage of the population holding a high school diploma. This finding raises Veneto to the middle position on the list of regions. The combined data show that of the percentage of the population that holds a secondary school diploma or a university degree (approximately 32.4%), among the Centre-North regions of Italy only Piedmont and Valle d'Aosta are positioned lower than Veneto. Moreover, some Southern regions, such as Abruzzo (35%) and Basilicata (32.6%), surpass Veneto.

If the data of 2001 depict a region with a low human capital stock, the latest data show a region that does not keep pace with the rest of the country. Indeed, if we look at the ratios of students enrolled in the university in the age group 19-26 years in two moments in time, that is, the academic years 2001/2002 and 2007/2008, we can make two observations. Firstly, the percentage of enrolled students increases over time both in Veneto (from 26.6% to 29.4%) and in Italy in general (from 30% to 34.6); secondly, the increase is smaller in Veneto than in the rest of Italy. Therefore, the gap that separates the Veneto region from the rest of the country widens during this period. Further confirmation comes from data on new graduates in the year 2007. The Italian average reaches the level of 5.0 new graduates per thousand inhabitants, while Veneto averages 4.5 new graduates per thousand inhabitants. On the other hand, many Southern regions rank among the highest. The better performance of the regions of Southern Italy, however, must be interpreted in light of the local labour market. In the South, the choice between work and higher education is very often conditioned by the lack of job opportunities.

3. The Dataset and a First Descriptive Analysis

The study required the construction of an original dataset, both for the territorial level of reference and the variables that were created. In fact, by merging data from different sources and using a matched employee-employer database that contained detailed information on working spells in the Veneto region, we were able to recover information on human capital and technology contents of the Local Labour Systems (LLSs) of Veneto.

Regarding the definition of the territorial unit of analysis, it is necessary to remember that the Veneto region is characterized by strong territorial and productive differences. However, it has a highly developed and articulated

infrastructural network and a workforce that presents a high degree of inter-communal mobility. The mobility of the workforce makes the definition of the territorial unit of reference very important. In fact, very often the sub-regional administrative divisions (municipalities and provinces) do not coincide with the territorial areas where the supply and the demand of labour are satisfied. Therefore, in order to have a better knowledge of the effective labour supply and of the workforce's human capital, it is essential to take into consideration the territorial unit that best satisfies this necessity. For this reason, our analysis has been carried out at the level of LLSs, which are aggregations of municipalities that identify homogeneous labour markets. The LLSs were built on routes of commuting between home and work identified during the population census of 2001. As a result, our dataset consists of 34 LLSs.

Some of the variables we used in the study were obtained or constructed using the information provided by ISTAT. We refer in particular to data on value added expressed in industrial prices[12] (2001-2005), the resident population, and the number of employees in the industry and service sectors. Using ISTAT data we were able to calculate the per capita value added produced by industry and service sectors separately, as well as the growth rates of value added per capita and what we call the Production Concentration Index, which will be explained in Section 4. Unfortunately, although the information available from ISTAT allowed a sector disaggregation of the workforce, it did not allow qualitative analysis of the workforce (at the local level), that is, in terms of human capital and professional content. Therefore, in order to overcome this lack of information and to carry out the study of the relationship between growth, human capital availability, and technological intensity, we merged ISTAT data with information retrieved from the database *Giove*,[13] which was provided by the Labour Agency of the Veneto Region*, Veneto Lavoro*.[14]

This original database contains matched employee-employer data, including all employment spells in the Veneto region in the period 1995-2007. The distinctive feature of *Giove* is its uniqueness in the Italian scene. Indeed, this database contains information on educational attainment and professional levels that allow definition of the workforce's human capital content. Moreover, considering that all the registered firms are classified according to their production sector at a very high level of disaggregation (5 digits), *Giove* allows classification of firms according to their technological intensity. To the best of our knowledge, this

[12] To adjust for changes in the price level we use an industrial price index.

[13] The Database *Giove* is the result of a corrective and integrative work on micro-data extracted from the databases managed by the Regional Employment Centres –REC (in Italian *Centri per l'Impiego - CPI*) in the Veneto region. The first version of *Giove* was released in 2004. The version used in the present paper contains information updated to the end of December 2007. Giove stands for Jupiter. For a lengthy discussion on *Giove* and its precursors please refer to Maurizio, 2006)

[14] Veneto Lavoro, established in 1998, is a technical agency of *Regione Veneto*, with organizational, accounting, administrative and financial autonomy.

paper is the first to make use of this database in order to build human capital and technology intensity indicators at such a disaggregated level.

Giove consists of three main archives that include original information on employment relationships, workers and companies, and several tables of support and decoding. The employment relationships archive includes information, on the type of contract – permanent, fixed-term, apprenticeship, part time or full time – the start and the expected end of the employment spell, and the employees' qualifications. The information on workers includes their tax code[15], place and date of birth, sex, citizenship, place of residence, and educational level[16]. The information on the firm includes its tax number/code[17], the municipality where its units are located, and the sector classification adopted by the Italian Institute of Statistics, ATECO.[18]

To have an idea of the size of *Giove*, one must remember that the December 2007 release registers more than 8 million working relationships between nearly 2.7 million workers and approximately 570 thousand local units of Veneto companies or companies that have employee workers that reside in the Veneto region.

Although *Giove* is very rich in information, it must be used with caution because its database has some limitations. Indeed, the registered employment spells are those derived from the obligatory recruitment communications that firms are supposed to deliver to the Regional Employment Centres. Therefore, *Giove* does not include information on those spells for which communication to the Regional Employment Centres is not compulsory, such as in the case of public servants and the self-employed. In addition, employees hired prior to the computerization of obligatory communications – which became systematic in the second half of the 1990s – and still working in the same company on the date of observation are not included in the dataset[19]. The first limitation of *Giove* was not a problem in our study since our analysis was conducted on the private sector alone. Regarding the second limitation, we performed some controls by comparing the consistency of *Giove* with official ISTAT data and the results indicated that the weakness is insignificant to this study.

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[15] In Italian *Codice Fiscale*.

[16] Data on attainment level of circa 20% of the workers are missing. To remedy this lack of information we performed standard imputation techniques on missing data. However, estimations presented in Section 4 were performed on the complete case data.

[17] It is the Value-Added Tax number called "Partita IVA" which is the acronym of "Imposta sul Valore Aggiunto" in Italian.

[18] ATECO is the Italian classification of the economic activities. Its class level corresponds to the NACE classification (at 4 digits level) while its division level corresponds to the ISIC classification (at 2 digits level).

[19] There are absences also among the firms. It is the case of firms without employees or firms that have not changed their structure since the beginning of the computerization era.

With regard to the measure of human capital that we created, the starting point is taken from the information on the highest education level attained by each worker. The education levels we consider are the following: no education[20], elementary school, professional training, upper-secondary diploma, and university degree (Bachelor, Master, Doctoral Programme). Given this classification, which is supported by the structure of the Italian schooling system and the actual use of different qualifications in the labour market, we have obtained for each LLS the percentages of workers with a given level of education. Next, we constructed a measure of human capital for every LLS, given the number of workers with a diploma of secondary school or university. Subsequently, the measures were refined by intersecting the information on the human capital with the sector where it is used.[21]

Using the strengths of the *Giove* database, we created a second measure of the potential human capital embedded in the experience gained in the workplace, based on information relating to the professional qualification of the workers. To do this we reclassified the categories contained in *Giove* according to the ILO classification, which divides the occupations into nine main categories[22]. However, we have not used that classification at this stage of the empirical analysis although we intend to use it to complete the study.

One of the limitations in using the number of workers to measure employment is the fact that many employment relationships last less than a year. As a result, if such short contractual arrangements are more frequent among workers with higher levels of education, then our measure of human capital would overestimate this productive factor. To overcome this limitation, a different measure of human capital was adopted by recalculating all the variables described above in worker-months[23] weighting each contract for its actual length in months.

We consider now more concrete aspects of the study. However, before discussing the empirical model, we propose a brief descriptive analysis of the region's growth in relation to factors of human capital and technological innovation based on the data we have constructed and discussed in the previous section. This exercise, conducted at the LLS level, allows us to highlight the variety and diversity entrenched in Veneto's territorial composition and its endowment of human capital and innovation.

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[20] Probably it would be more appropriate to say no diploma.

[21] Firstly considering the two macro-sectors of Industry and Services sectors and subsequently disaggregating into subsectors according to varying degrees of technology.

[22]The nine categories are: legislators, senior officials and managers; professionals; technicians and associate professionals; clerks; service workers and shop and market sales workers; skilled agricultural and fishery workers; craft and related trades workers; plant and machine operators and assemblers; elementary occupations.

[23] The rule that we adopted in contract duration calculation in year 2001 consisted in assigning a full month if the employment spell lasted at least 15 days and zero otherwise.

Evidence of this heterogeneity is presented in Table A1 in the Appendix. Consider, for example, the percentage of workers with a an upper-secondary school or university diploma in 2007 among the LLSs. There is a wide gap between the minimum of *San Giovanni Ilarione* (20.6%) and the maximum of *Padua* (nearly 42%). Consider now the percentage of workers in each of the four divisions of economic activity according to the technological intensity in 2007. While the figures are uniformly low as far as the high technology sector is concerned (the highest level is reached in *Belluno*, at 2.1%), the differences are striking if we consider the other three sectors: we begin from minimum levels very near to zero and arrive at figures near 34% in medium-high tech (*Agordo*), 32% in medium-low tech (*Pieve Di Soligo*) and 36% in low tech (*San Giovanni Ilarione*).

The relationship between growth and sector distribution (in terms of macro-sectors and subsectors) of the workers will be the topic of the following paragraph. We begin the analysis considering the industry and service sectors. Figure 1 represents the relationship between the growth in the Veneto LLSs in the period 2001-2005 and the percentage of workers employed in the industry and service sectors. It clearly depicts a strong and positive correlation between the growth of Veneto and the relative importance of the service sector in terms of employment. In contrast, it shows a strong and negative relationship between the weight of the industrial sector and growth.

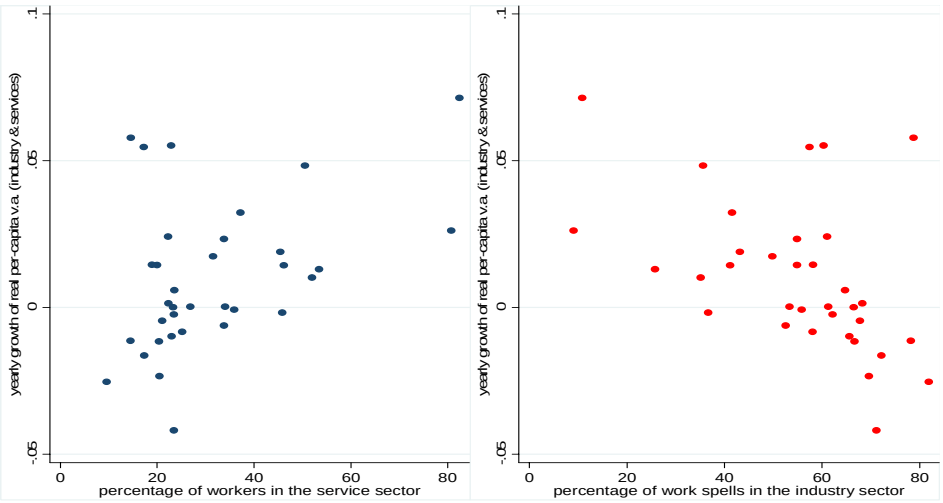

Fig 1. Growth rate of per capita value added (2001-2005) and percentage of workers employed in Industry (left-hand side) and Services

Note: Whole Industry and Services

Figure 2 shows the industrial sector as unbundled or disaggregated according to the OECD classification on technological intensity.

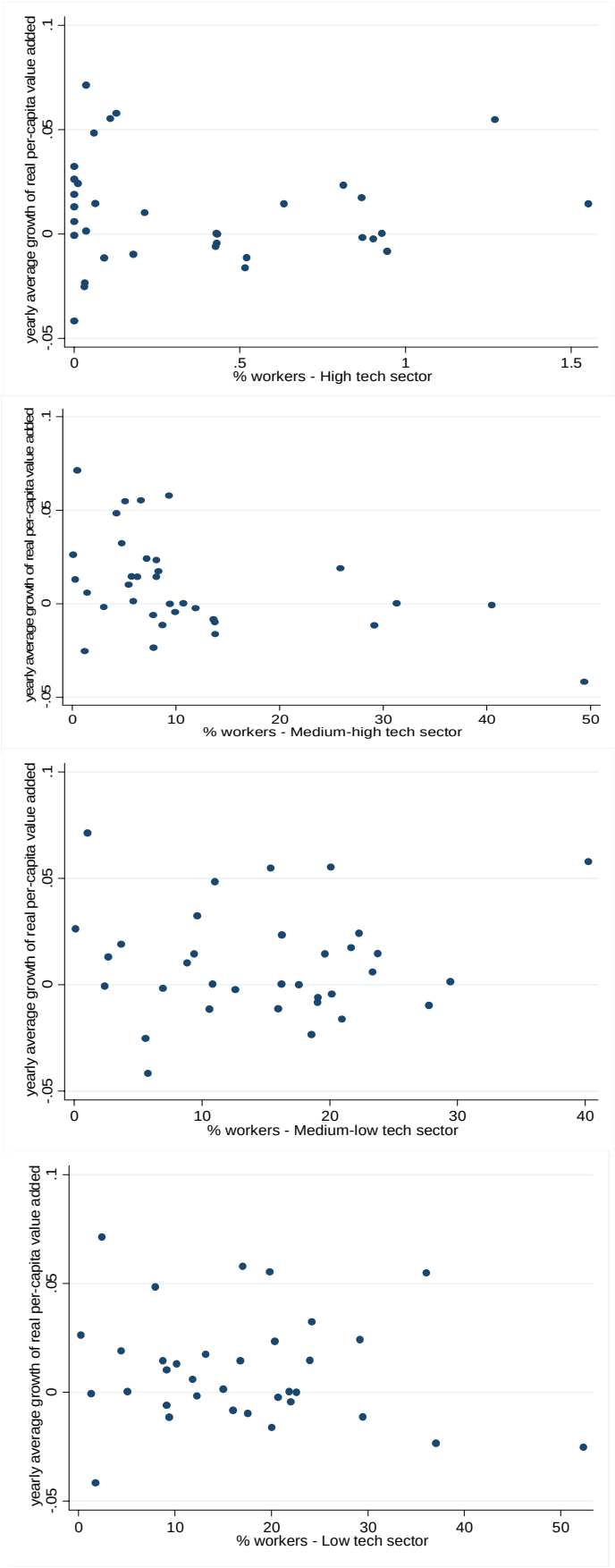

Fig 2. Growth rate of per capita value added (2001-2005) and percentage of workers in industrial sectors by technology intensity.

Note: Whole Industry and Services

The graphical analysis suggests that the high-tech industries have a positive impact on the growth of the area, even though several LLSs do not have industrial activities in their territory, and therefore, there are many null values. Instead, the relationship between economic growth and the relative territorial importance of the medium-high and low technology sectors is not clear. Finally, with regard to the correlation between growth and the medium-low technology intensity sectors, the data seem to follow a positive trend.

The figures below represent the relationship between growth and human capital employed in various sectors, including a technological content disaggregation. We want to verify that human capital plays a role in stimulating growth, conditional to the sector where it is employed. Human capital is measured in terms of the percentage of workers holding a high- school diploma or university degree, that is, post-compulsory education.

Figure 3 partly confirms what we described in Figure 1, albeit in terms of use of the labour force with high levels of human capital. The service sector is clearly positively influenced by the large number of workers with high human capital employed therein.

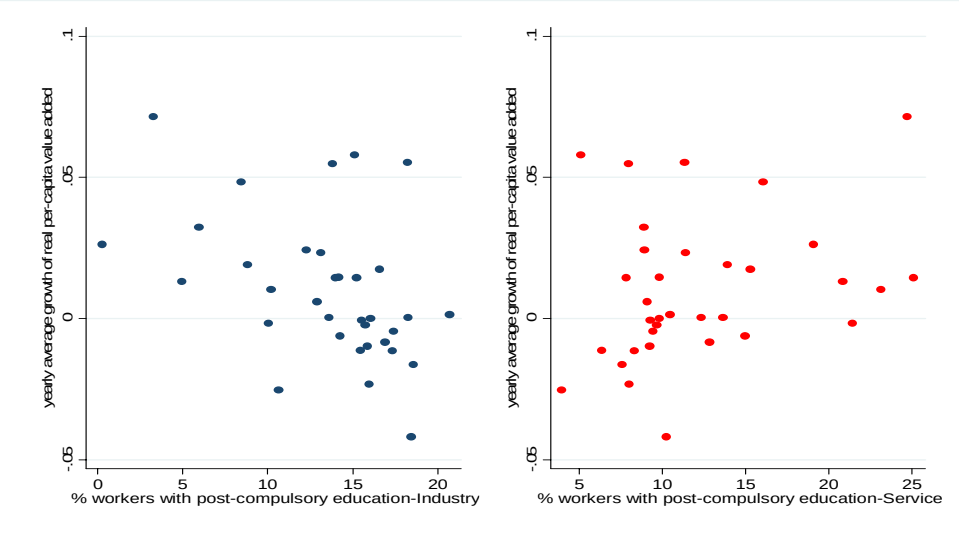

Fig 3. Growth rate of per capita value added (2001-2005) and human capital in Industry (left-hand side) and Services.

Finally, Figure 4 show the relationship between growth and human capital intensity in the industrial sectors with high/medium-high/medium-low and low technology intensity. The growth data represented in this case are net of the convergence component. This exercise aims to highlight the relationship, net of the convergence factor, which might explain much of the pattern of growth. Figure 4 shows a certain positive relation between growth and human capital employed in high-technology intensive sectors (top left) and in medium-low technology (lower left). The relationship seems to have a negative trend in the medium-high technology sectors but is non-existent for the low-tech ones. In the next Section, we will see that these intuitions are confirmed by regression analysis in which we verify these relations simultaneously and including other variables.

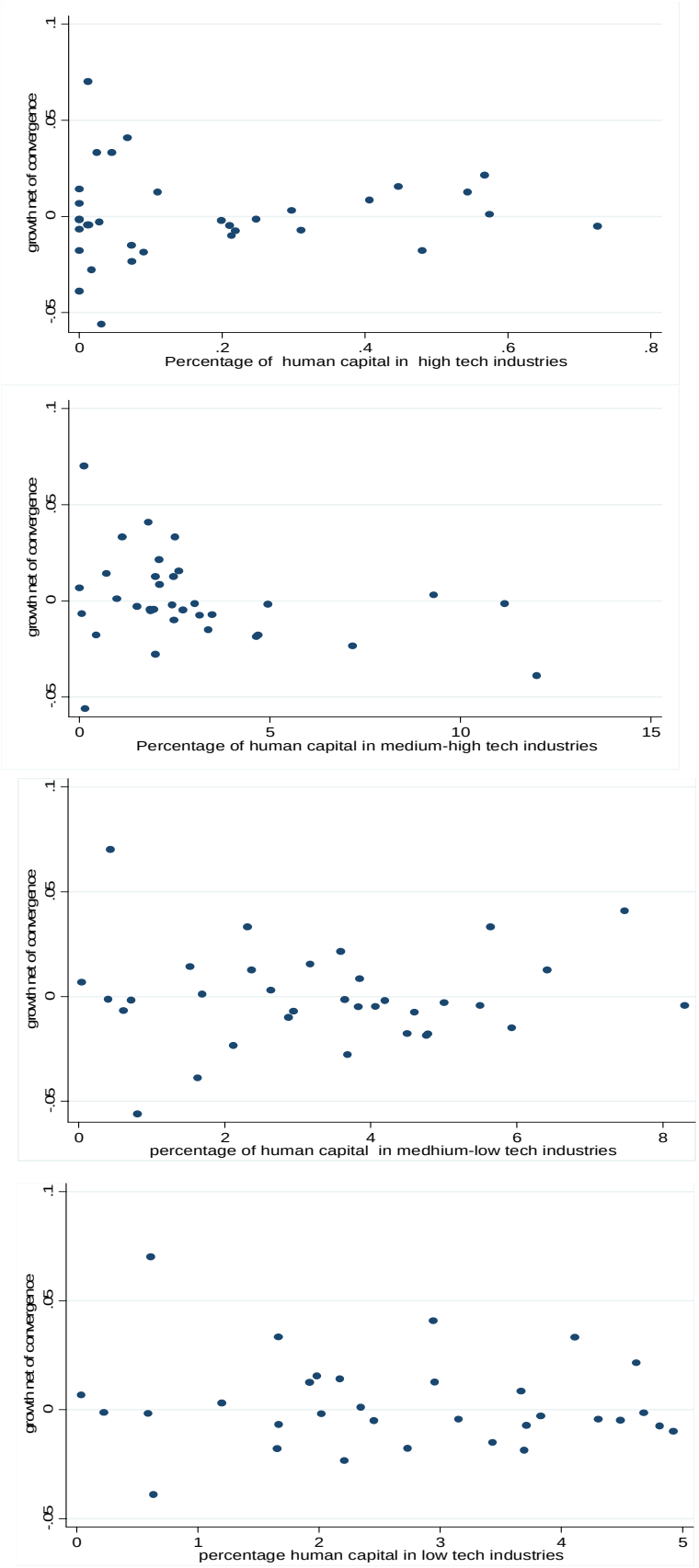

Fig 4. Growth and human capital in sectors by different technology intensity.

4. Theoretical model and empirical specification

The theoretical model on which we base our empirical analysis is the model of endogenous growth driven by sectors engaged in innovation and, to this end, using human capital. The main model of reference goes back to Romer (1990), which describes an economy with several sectors, one of which carries out innovation activities whose output in terms of new ideas is sold to the intermediate goods production sector. The innovative contribution of the Romer model, with respect to the relationship between human capital and growth, consists primarily in the formalization of the dependence of innovation on the amount of human capital employed in this sector – the only factor of production – and thus on the availability of human capital in the economy, and secondly, in the specification of the correlation between human capital employed in R&D and growth of per capita income. Therefore, growth is highly dependent on the size of the R&D sector and, consequently, on the amount of human capital employed in it.

Our purpose is to verify the validity of this model at a sub-regional level by going through the breakdown of sectors according to their intensity of research and development, in a productive context, the Veneto region, which appears to be characterized by not particularly high rates of schooling and limited diffusion of high-tech sectors. The literature on empirical testing of the hypotheses of the Romer model, developed also at a regional level, does not deal with human capital employment across sectors. Due to limited availability of data and lack of information on the content of human capital of the workforce among the sectors of economy, the Romer hypothesis has been only partially verified. These models include, among the explanatory variables, the dimension of human capital and the activity of R&D – usually measured by the number of patents – carried out in the territory of reference. Therefore, these models fail to test the hypothesis that human capital is crucial for growth when used in sectors that are engaged in R&D.

The model we propose attempts to fill this gap. By using matched employer-employee data on employment spells occurring in Veneto starting from the year 2000, we are able to determine, for each territory of analysis, the number of workers with a certain level of education working in a certain sector. This allows us to work at a higher disaggregation level with respect to that proposed by the literature. Moreover, it makes feasible a deeper investigation of the relationship between human capital, intensity of research and development activity, and development of different sectors. As described in the previous section, we can calculate not only the share of workers employed in different sectors (we have a 5-digit breakdown) and percentages by level of education but also the measure of worker-months – that is, the number of workers weighted by the proportion of the year in which they have actually worked.

The classification we take into account is the one developed by the OECD

(2004), which classifies industry in sectors characterized by high, medium-high, and medium-low and low technology[24]. This classification is based primarily on the intensity of R&D, that is, the expenditure on R&D[25], and therefore, it indicates the diverse propensity to spend on R&D; this allows a growth analysis by means of a theoretical model with several sectors that differ in the intensity of R&D they perform. Moreover, the OECD classification incorporates an index of the technological content in terms of the usage of the technology. That index weighs the intensity of technology embodied in intermediate goods and capital goods purchased by the sector itself. Therefore, the final rating in sectors of high, medium-high, medium-low and low technology derives from direct indices (based on the intensity of spending on R&D) and indirect indices (use of technology) that are both in the same category; industrial sectors that are placed in a higher level have higher technological indices, both direct and indirect, with respect to the categories below.[26]

The OECD classification may well represent, in our opinion, the differing propensities to perform R&D. In fact, as can be seen from a survey on patents held in Italy (Trigilia and Ramella, 2008), innovative activity is particularly common in sectors that incorporate a medium-high technology. More than a half of patent applications registered at the European Patent Office in 2008 (50.4%) fall in this OECD category. The remaining half is shared by high-tech industries (23.87%), medium-low-tech (18.13%), and low-tech firms (7.57%).[27] As for the sectors in which technology applied to production is generally at lower levels (the *Made in Italy* sectors), patenting activity is distributed mainly among

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[24] High-technology industries: Aeronautics and Aerospace, Pharmaceuticals, Office machinery and computers, radios and television and communications, medical, surgical and orthopaedic instruments and machines of precision and control, optical instruments and photographic equipment . Areas to medium-high technology: machinery and apparatus n. e. c (not elsewhere classified), motor vehicles, trailers and other transport equipment n. e. c, chemicals and synthetic fibbers (not pharmaceuticals), machinery and equipment n. e. c. Areas to medium-low technology: shipbuilding, rubber and plastics, coke, refineries, nuclear fuel processing, products non-metallic mineral processing, metal products and processing and other alloys. Low-tech sector: manufacturing n.e.c., recycling and recovery, wood pulp, paper, publishing and printing, food, beverages and tobacco manufacture of textiles, leather products, leather and footwear.

[25] The data used by the OECD are built considering the expenditure on R & D for the period 1973-1995, disaggregated by industrial sectors for 15 OECD countries (*Analytical Business Enterprise Research and Development* –ANBERD data).

[26] This is not surprising, given that the companies that channel greater percentage of value added to the R&D are also the most intensive users of advanced intermediate goods and machinery.

[27] Among high-technology industries, those with the highest concentration of patents are pharmaceuticals, medical apparatus and orthopaedic surgery, radio, television and communications and, finally, manufacture of machinery and precision instruments and control. In the category of medium to high technology companies stand out for their patenting firms in the sector of machinery and mechanical appliances (with 31.1% of total patents), followed, with much lower performance, but not less negligible, the chemical and automotive industries (both around 7% of national patents). These percentages are also registered among the best sectors in terms of patenting, companies to medium-low technology: the fields of rubber and plastic processing and metal and other alloys.

furniture, musical and sporting equipment, jewellery, tools in the textile industry, footwear, and leather tanning.

Without doubting the validity of the OECD classification and the importance of sectors with greater technological intensity, it is important to note that the industrial activity of medium-low technology industries, which is particularly relevant in the context of Veneto, supplies more than ninety percent of the EU output. In addition, many firms in this sector survive and grow through technological upgrading, skills in design, and intensive use of knowledge for innovation. These sectors often have unique forms of industrial organization and knowledge creation, complex linkages with the infrastructure of scientific and technological knowledge, and important regional dimensions (Kreinsen-Hirsch, et al., 2003). For this reason, such macro group production contributes substantially to aggregate growth. The medium-low technological intensity sectors, in the same way as high-tech industries, generate new products and, in particular, production processes that have a significant impact. Moreover, high and medium-low technology sectors are not independent from each other. Growth of high technology sectors derives, at least in part, from growth in other production contexts that are less R&D intensive (Hauknes and Knell, 2009).

In light of these considerations, the analysis of growth and its relationship to technology intensity in Veneto appears particularly interesting. As we shall see, the results of our study seem to emphasize the peculiarities of the Veneto system in terms of the important role played by medium-low technology sectors and the role played by human capital employed in them.

Before discussing the specifications of the empirical model, we would like to clarify what we mean by ‘human capital’. Our concept of human capital refers uniquely to the education endowment of workers and not to the incremental component of the same stock that is normally generated during the working life of the individual or by means of continuous vocational training.[28] Furthermore, we refer to workers with a medium-high education, that is, an upper-secondary school diploma or a university degree –such as a university graduate or postgraduate diplomas –, which corresponds to levels 3 to 7 of the International Standard Classification of Education (ISCED).[29] Actually, in the first empirical model we controlled also for lower levels of education, corresponding to vocational training[30]. As expected, these levels proved not significant and we subsequently excluded them from the analysis. Therefore, the analysis focuses

[28] Data do not allow identifying other components of human capital.

[29] In international terms, this corresponds to ISCED 3-7 educational levels.

[30] In Italy, at the end of compulsory schooling (when they are between 13 and 14 years old), individuals can choose between different educational paths: professional, technical or scientific-humanistic. Whatever the case may be, if they complete the whole cycle of studies, they are allowed to enter university. On the other hand, if the professional path is chosen, individuals have the chance to attend the first three years only and obtain a “vocational diploma” that does not allow to take the path of higher education.

mainly on human capital constituted by workers who completed at least the upper-secondary school cycle.

The territorial unit of reference is the Local Labour System (LLS), which is an area not defined by administrative criteria. Rather it is defined by individuated grouping of the areas where the labour demand and supply match[31]. The LLSs, in fact, as defined on the basis of individual mobility of the labour force by place of residence to workplace, delineate areas where local labour demand meets supply. Such areas are substantially different from administrative municipalities and permit assessment of the actual availability of labour and human capital.

The empirical analysis was conducted using linear regression models; the model specifications are several: from the simplest, where the territorial dimension of human capital is kept distinguished from the sector dimension, to more complex ones, where the human capital content of employment is defined for every single sector.

In all the specifications, the dependent variable is defined as the growth rate of per capita value added for the period 2001-2005. The focus of the analysis is on industry and services (I&S); the agriculture and public sectors were excluded. In accordance with the traditional scheme used in empirical growth analysis, we included among the explanatory variables of every specification the logarithm of value added in 2001. Since production and growth capacity of a local context depend also on externalities – positive and negative – linked to the concentration of activities, we include an index, referred to as the "I&S concentration index" from here onwards, calculated as the ratio between the number of employees in the I&S sectors and resident population, by each LLS[32].

The results that we are about to discuss are shown in Table 1 below. The table also includes the estimates of the simplest models, from which we began our empirical analysis and helped in defining the more detailed specifications. The models do not show correlation problems between the explanatory variables; therefore, the significance level is reliable[33].

The starting model (Model 1) is a simple specification to check how growth is affected by human capital availability and proportion of employment in the service sector. The result of all variables was significant, and the model explains 47% of growth rate variability. Veneto LLSs follow a path of convergence, the concentration of production creates positive growth externalities, and a greater specialization in services boosts growth. Finally, and

[31] The LLS are groups of municipalities identified from the information on commuting (movement of individuals between municipalities for working) in the questionnaire of the census.

[32] The data used to calculate the index are from ISTAT, Census of Population and Industry 2001.

[33] The models, whose results are discussed here, are the ones that have a correlation between the regressors lower than 0.5 (in absolute value). Upon request, we can provide the correlation matrices.

most importantly, the use of human capital determines significantly the growth capacity of the area. In Models 2 and 3, we added interactions between macro-sector intensity (Industry kept distinct from Services) and variables of human capital use. In Model 3, we also added a variable measuring the proportion of workers with vocational training education in order to determine whether this kind of education can be strategic for growth.

Estimation results show a greater explanatory power of these models than the basic one. On the one hand, they confirm the presence of a convergence path of per capita value added and the presence of positive externalities of production increasing local capacity to grow. On the other hand, growth does not seem to be influenced in any way (neither positively nor negatively) by the use of the workers endowed with vocational education, regardless of the macro-sector of employment. Instead, human capital shows its ability to stimulate growth when used in services rather than in industry. The last result suggested proceeding towards a further sector breakdown, following the theoretical idea (discussed above) that human capital employed in sectors at least partially innovative may be a key driver of growth.

Following the OECD sector classification mentioned above, we enriched the model specification by including the percentage of workers in high, medium-high, medium-low and low technological intensity (Model 4) and successively by specifying the intensity of human capital employed in each of these sectors and in services (Model 5). The results clearly show how, in the Veneto region, the sector that significantly explains the growth path is the medium-low technological intensity one. On the other hand, the productive “specialization” which has potentially the greatest impact on LLSs growth is the one in high-technology sectors, with an estimated coefficient (in Model 4) equal to 0.54, against 0.06 in the medium-low technology industries. However, although the high technology-intensive sector is significant as a whole, the human capital employed in it does not explain growth significantly (Model 5), unlike what happens with the intensity of human capital employed in the firms in medium-low sector. This result seems to be indicative of an insufficient use of highly educated workers in this sector. Moreover, observing the results of Models 4' and 5', in which variables are built considering worker-months rather than simply the number of workers, this sector seems to lose in terms of the ability to explain growth. This result indicates that high technology industries are strongly characterized by the use of temporary labour. This can have dual effects on productivity: firstly, temporary employment can cause the employee to commit less to achieve good results; and secondly, firms using mainly temporary employment may have no incentive to invest in specific training, which negatively affects system productivity.

Conclusions

In this article we study in detail and at a sub-regional scale the origin of gaps in value added growth by looking at the role of human capital in promoting overall economic growth and by analysing its role in specific sectors, according to and in combination with differences in technological intensity. The results clearly show

how, in the Veneto region, the sector that significantly explains the growth path is the medium-low technological intensity one. On the other hand, the productive "specialization" which has potentially the greatest impact on LLSs growth is the one in high-technology sectors. However, although the high technology-intensive sector is significant as a whole, the human capital employed in it does not explain growth significantly, unlike what happens with the intensity of human capital employed in the firms in medium-low sector. This result seems to be indicative of an insufficient use of highly educated workers in this sector.

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	Estimates with heads of workers					Estimates with man-months	
Dependent variable: growth rate of per capita Value Added in Industry and Services (I&S) - 2001-2005	Model 1	Model 2	Model 3	Model 4	Model 5	Model 4'	Model 5'
Log per capita Value Added. Industry and Services 2001	-.442 (-5.40)	-.442 (-5.39)	-.436 (-4.38)	-.315 (-5.13)	-.369 (-3.53)	-.352 (-5.77)	-.445 (-5.60)
I&S concentration index	.004 (3.71)	.004 (5.02)	.005 (3.23)	.003 (3.93)	.005 (5.83)	.004 (4.14)	.005 (6.66)
% workers in Services	.003 (3.08)			.004 (2.12)		.004 (1.91)	
% workers with at least upper-secondary education	.006 (2.25)						
Sectors' technology intensity							
% of workers in high tech sectors				.054 (1.73)		.046 (1.52)	
% of workers in medium-high tech sectors				.000 (0.16)		.001 (0.36)	
% of workers in medium-low tech sectors				.006 (2.74)		.006 (2.56)	
% of workers in low tech sectors				-.000 (-0.16)		-.001 (-0.35)	
Interaction between workers' educational level and macro-sectors of work							
% workers in Industry with a professional diploma			-.012 (-0.76)				
% workers in Services with a professional diploma			-.004 (-0.18)				
% workers in Industry with at least upper-secondary education		.006 (1.30)	.008 (1.28)				
% workers in Services with at least upper-secondary education		.012 (3.09)	.012 (2.25)		.008 (1.83)		.010 (2.39)
Interaction between workers' human capital and sectors' technology intensity							
% of workers in high tech sectors with at least upper-secondary education					.089 (1.33)		.077 (1.49)
% of workers in medium-high tech sectors with at least upper-secondary education					.002 (0.15)		.002 (0.29)
% of workers in medium-low tech sectors with at least upper-secondary education					.027 (1.91)		.024 (2.35)
% of workers in low tech sectors with at least upper-secondary education					-.005 (-0.47)		-.010 (-1.16)
Observations	34	34	34	34	34	34	34
R2	0.47	0.56	0.54	0.69	0.69	0.67	0.69

Tab. 1. Growth, human capital and sector intensity. OLS regressions.

Note: t-statistics in parenthesis. All models include constants. Robust estimates.

Local Labour Systems	% of Human Capital			% in High Tech.			% in Medium-high Tech.			% in Medium-low Tech.			% in Low Tech		
	2001	2005	2007	2001	2005	2007	2001	2005	2007	2001	2005	2007	2001	2005	2007
Adria	21.2	20.1	26.9	0.0	0.0	0.0	7.2	8.2	6.9	22.3	16.9	18.6	29.2	29.8	18.5
Agordo	24.8	27.1	27.6	0.0	0.0	0.0	40.5	33.3	34.3	2.4	1.4	1.2	1.3	1.4	1.0
Arzignano	21.8	24.7	25.8	0.5	0.4	0.3	8.7	8.3	8.2	16.0	13.2	13.5	29.5	24.2	22.0
Asiago	25.8	29.1	27.1	0.0	0.0	0.0	0.3	0.2	0.2	2.7	1.8	1.7	10.2	6.0	5.9
Auronzo Di Cadore	22.7	22.9	23.1	0.0	0.0	0.0	25.9	13.3	10.7	3.7	3.4	3.2	4.4	4.7	5.0
Badia Polesine	21.8	23.4	30.6	1.3	2.4	1.3	5.1	7.2	3.7	15.4	17.7	13.5	36.1	25.7	22.0
Bassano Del Grappa	31.2	38.2	39.6	0.0	0.1	0.1	5.9	5.2	5.1	29.4	23.7	21.2	15.0	11.2	10.2
Belluno	30.6	32.6	32.6	0.9	1.8	2.1	31.3	24.7	23.8	10.8	10.5	8.7	5.1	4.3	3.3
Bovolone	21.8	25.4	26.9	1.6	1.1	0.8	8.1	6.5	5.8	19.6	17.2	15.1	16.8	11.8	11.0
Castelfranco Veneto	25.9	28.4	29.7	0.4	0.4	0.3	9.4	7.8	7.2	17.6	14.2	13.6	22.6	17.4	15.0
Conegliano	25.1	26.9	27.2	0.2	0.1	0.1	13.8	10.7	10.3	27.8	21.6	20.8	17.6	13.6	11.7
Cortina D'ampezzo	28.0	26.5	26.3	0.0	0.0	0.0	0.5	0.5	0.4	1.0	1.1	1.4	2.5	2.5	2.6
Este	29.6	32.4	32.4	0.1	0.1	0.1	6.6	7.0	7.1	20.1	18.6	18.0	19.8	12.2	10.2
Feltre	25.7	27.5	28.3	0.1	0.1	0.1	29.1	24.5	23.0	10.6	8.5	8.5	9.4	6.1	3.9
Grezzana	22.0	27.6	29.4	0.0	0.0	0.0	1.4	1.1	1.3	23.4	17.8	18.9	11.8	8.3	7.9
Legnago	29.7	30.6	33.2	0.9	0.6	0.6	13.6	13.1	12.5	19.0	15.0	14.5	16.0	11.1	9.4
Malcesine	19.3	22.4	20.7	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.3	0.3	0.3	0.4	0.4
Montagnana	24.0	26.7	28.4	0.1	0.0	0.1	5.7	5.9	5.7	23.8	19.7	18.2	24.0	17.8	16.5
Montebelluna	24.0	27.5	28.7	0.0	0.0	0.0	7.8	6.6	6.9	18.6	16.9	15.2	37.0	26.9	24.2
Padova	40.3	40.1	41.7	0.6	0.8	0.5	6.3	6.8	5.3	9.4	10.2	8.0	8.8	9.0	6.0
Pieve Di Cadore	28.7	31.0	31.1	0.0	0.0	0.0	49.4	38.7	32.3	5.8	3.2	3.5	1.8	2.7	3.1
Pieve Di Soligo	20.2	24.2	25.4	0.1	0.1	0.3	9.3	6.1	4.9	40.2	32.5	31.7	17.0	12.5	11.2
Porto Viro	14.8	17.8	23.0	0.0	0.0	0.1	4.8	5.1	2.6	9.6	13.9	10.8	24.2	23.1	16.9
Portogruaro	24.5	25.7	25.8	0.8	0.3	0.3	8.1	4.3	3.8	16.2	13.9	12.8	20.4	15.2	13.7
Rovigo	31.9	27.9	39.9	0.9	1.1	0.9	8.3	13.2	8.3	21.7	20.3	16.4	13.2	9.7	8.0
San Bonifacio	25.4	26.7	28.7	0.9	0.9	0.8	11.9	8.7	8.4	12.6	11.8	11.9	20.7	14.7	11.5
San Donà Di Piave	24.5	26.5	26.7	0.1	0.1	0.1	4.3	4.3	4.0	11.0	9.2	7.9	8.0	5.9	5.1
San Giovanni Ilarione	14.6	17.2	20.6	0.0	0.1	0.0	1.2	0.9	1.6	5.6	5.2	6.3	52.3	40.6	36.0
Schio	26.1	29.5	31.1	0.5	0.3	0.6	13.8	14.4	14.6	21.0	19.4	19.5	20.1	13.4	11.0
Thiene	26.8	29.8	31.6	0.4	0.4	0.3	9.9	8.4	9.3	20.1	19.1	18.8	22.0	15.8	14.9
Treviso	27.3	30.6	31.9	0.4	0.5	0.4	10.7	8.0	7.7	16.2	13.4	12.3	21.9	15.8	13.0
Venezia	33.3	34.0	34.6	0.2	0.3	0.2	5.4	3.7	3.0	8.9	7.1	6.6	9.1	6.8	6.0
Verona	31.5	34.2	36.0	0.9	0.6	0.6	3.1	2.8	2.8	6.9	5.7	5.5	12.3	9.4	8.0
Vicenza	29.2	32.8	33.4	0.4	0.7	0.5	7.8	6.6	7.0	19.1	14.9	13.5	9.1	7.5	6.7

Tab A1. Technological and human capital intensity in Venetian LLSs

THE RECOVERY AND REBIRTH OF PORTO MARGHERA: SHORT AND LONG TERM PERSPECTIVES FOR SUSTAINABLE DEVELOPMENT

Margherita Turvani[1], Ilda Mannino[2], Donata Favaro[3] , Eniel Ninka[1]

[1] *Università Iuav di Venezia*
[2] *TEN Centre - Venice International University*
[3] *Università degli Studi di Padova*

Riassunto

Questo studio considera il recupero e la riqualificazione di Porto Marghera nel contesto delle vaste trasformazioni produttive e sociali che hanno caratterizzato l'area, sotto la spinta dei processi di globalizzazione da un lato e il rafforzamento di una nuova sensibilità ambientale dall'altro. Lo studio considera le esigenze poste da un sistema produttivo in trasformazione, non solo alla scala locale, e le specificità dell'area che, per le particolari condizioni ambientali, culturali e storiche, vedono nella salvaguardia del sistema lagunare, con la sua evoluzione ed unitarietà tra sistema naturale e antropico, condizione imprescindibile per uno sviluppo sostenibile.

Lo studio inquadra le trasformazioni avvenute nell'area nel quadro delle tendenze socio-economiche di medio-lungo periodo, alla scala vasta, al fine di evidenziare i potenziali sentieri di sviluppo, secondo le modalità e i modelli che sembrano caratterizzare i territori più dinamici in termini di crescita economica. Presenta inoltre le recenti dinamiche e le problematiche produttive, con riferimento alle problematiche ambientali e di regolazione che investono l'area, con informazioni e valutazioni raccolte grazie a due questionari somministrati alle imprese operanti nell'area nel 2010 e nel 2011. Sono esaminate inoltre le condizioni di sostenibilità ambientale dell'insieme di cicli produttivi che hanno per lungo tempo costituito il nucleo centrale l'economia dell'area, sviluppando uno studio delle filiere presenti ed operanti, in un'ottica di ecologia industriale.

1. Introduction

This study considers the recovery and the rehabilitation of Porto Marghera in the context of the vast productive and social transformations that have characterized the area under the pressure of globalization, on the one hand, and the strengthening of a new environmental sensitivity on the other. The study takes into consideration the demands placed on by a production system in transition, both at the local and regional scale, within the framework of the specificity of the area, characterized by the co-evolution of natural and man-made systems; within this framework, the lagoon safeguard is a requisite for a sustainable development.

The study was designed according to two coherent and integrated objectives:

firstly, the identification of the role played by high quality public goods (such as adequate human capital, R&D funding, physical and intangible infrastructure, efficient education system, good environmental and institutional quality) in promoting a sustained and durable local economic growth; secondly, the identification of potential options for the provision of such public goods, in particular environmental quality and infrastructures, investigating the problems and the expectations of firms operating in the area, and studying the environmental report of the area.

In the following sections we present an overview of the main results. In section 2 we follow the Industrial Ecological approach and study the sustainability of the industrial site of Porto Marghera following the approach of the Material Flow Analysis. The calculation of several environmental performance indicators allowed for punctual considerations and individuating temporal trends of variables of interest. In section 3 we analysis the endogenous growth model for the region and for Venice within it, specifically the role of qualified labour and human capital, the sectoral composition and the mobility of skilled labour among sectors to highlight the potential for innovation on economic growth. Finally, in section 4 we summarize the results of the survey administered to firms in Porto Marghera. Conclusion follows.

2. The sustainability of the productive reality of Porto Marghera

The environmental sustainability of an industrial area is closely related to the impact that its activities have on the environment: all the industrial activities consume resources and land and produce waste, hence, having an impact to the external environment. For too long, however, these impacts have not been considered with due attention, as the industry was more focused on meeting its own economic needs, rather than on the externalities it produced.

Now the awareness that there can be no long-term economic development without preserving the environment, and the ultimate goal is the sustainable development of society is widespread. A new approach which takes into account how industrial systems are not isolated from surrounding systems, but integrated, thus forming a single system has been developed. The systemic approach lays on the basis of the Industrial Ecology, a recent discipline that brings together a range of concepts, tools and approaches with the aim to drive the industrial systems toward sustainable development. These perspectives and models are quite appropriate for the area of Porto Marghera, located in a very sensitive environment such as the lagoon of Venice, with its intimate and close relations between natural and anthropic systems.

The work in this study aimed to apply the concept of sustainability to Porto Marghera, building a bridge between the real economy and the sustainable models. Hence, we tried to make talk together conflicting needs: on the one hand those related to the economic and industrial development and, on the other, those related to the protection of the environment and natural resources.

The industrial ecology, i.e. the idea of a circular economy and the application of ideas and techniques of material flow analysis to the various production cycles,

provided the theoretical support for this study. In fact, the industrial ecology has the objective to represent and to promote the organization of industrial systems based on rules derived from the processes taking place in the nature. The industry and its supply chains are studied and designed as a complex, but closed system, as opposed to a more traditional perspective that considers industrial processes like individual ones and linked in a linear fashion. It follows a radical revision of the concept of value chain and the eco-industrial development leads to a 'minimization' of the environmental impacts.

This approach has been applied to Porto Marghera, looking at its environmental performance over time, in order to derive possible future development scenarios that take into account the environmental impact of productive cycles.

The revitalization of the area, in fact, needs ideas, projects and alternatives that, in addition to ensuring sustainable economic and social development, do not impact negatively on the environmental quality and the life of local populations. On the contrary, to set the goal of sustainability implies to pursue the improvement of the life quality and environmental quality, while preserving the prospects for economic development, something the area desperately needs.

The current economic conditions, both at the local and the global scale, do call for caution in imagining scenarios for a virtuous and sustainable development. Nonetheless, this challenge can not be eluded.

The study has accepted such a challenge. Using the available information (ARPAV, 2009) it has developed a process of quantitative analysis, referring to concepts such as the industrial symbiosis (where different companies benefit from the exchange of materials, energy or information having a collective benefit greater than the sum of individual benefits that could be achieved by acting alone) and eco-industrial parks (those areas that create industrial symbiosis, using as a reference model the development of a circular use of resources) and using tools such as Material Flow Analysis and the calculation of environmental performance indicators. Besides the quantitative analysis, a more qualitative research was associated to the study in the form of interviews with stakeholders and field surveys.

In particular, we used data from the Environmental Report 1998-2007. These data were collected for a period of ten years by ARPAV (the regional Environmental Protection Agency), for the preparation of the Environmental Report for the Area of Porto Marghera, as agreed in the Framework Program for the Chemistry at Porto Marghera, which was signed in 1998. The Environmental Report contains a wealth of information on input and output flows, in terms of matter and energy for each company; there is information about the quantities of materials used in the production cycles of each company, the source of the main materials, the amount of finished products and their destination, both within and outside the area in question. Moreover, the Report contains information on the amount of water withdrawals, on the production of waste, on the production and the consumption of energy, on air emissions, etc..

Analyzing this information it was possible to recover the major flows of matter

and energy in the area and their evolution over time producing several diagrams that summarize these flows. It was also possible to evaluate the transformations occurred in the production activity, in terms of environmental performance of Porto Marghera, through the construction of indicators.

The diagrams of matter, energy and by-products flows on the one hand, and the indicators of environmental performance on the other, allow us to highlight a few salient facts concerning the actual production of Porto Marghera. At the end of the 90s it was possible to observe a good level of integration between the industries in the area, in terms of exchanges of both finished products and by-products, energy (electricity and steam) and industrial gases. Over the next decade the area went towards a progressive loss of integration. This was mainly the result of relocation decisions of major companies and the subsequent closure of entire production cycles. The study of the indicators highlights the net loss of integration within the area. Such a loss had economic consequences, as pointed out by the indicator on the efficiency in the use of raw materials.

The indicators cover important aspects of sustainability, ranging from waste to discharges of waste-water into the lagoon and the emissions of pollutants into the atmosphere. They certainly illustrate the impact of industries in the area of Porto Marghera, but in their construction we tried to represent in a concise - and comparable over time - manner, the impact or the environmental performance of the entire area. These indicators, by design, are sensitive to the fact that some industries have left the area of Porto Marghera. The analysis of the indicators showed a general reduction of the environmental impact of production activities in the area: for example, the indicator measuring the impact of the production on the environment, in terms of waste generation, referring to the traditional industries of petrochemical, has a decreasing trend over time. This means that has been reduced the impact of the outputs (in terms of solid waste, waste-water discharges and air emissions) per unit of raw material. However, in front of the reduction of waste created directly from the production process, there has been an increase of waste due to land remediation, reconstruction or new investments, leading to an increase in total waste. Moreover, in front of a decrease of the amounts of incinerated waste (that are mostly hazardous), a change in the origin of such wastes has taken place. In fact, there has been a significant increase in the incineration of waste from outside the area that reached a share of 50% in 2007.

Waste-water discharges have shown a decreasing trend over time. A similar trend characterizes the emissions into the atmosphere concerning both carbon dioxide and polluting gases. The causes of this reduction can be identified in the closure of some of the heavily polluting cycles, or in industries that have ceased entirely their production in Porto Marghera, as well as in the continuous improvements in the pollution abatement systems over the years. However, one must keep in mind the fact that, in the case of Porto Marghera, the atmospheric emissions of pollutant gases and of CO2 - with potential effects on human health, ecosystems and climate instability - are largely associated to three main groups of economic agents: the power production cycles, the industrial activities

that will remain in the area, and the port operations. In the medium term, any improvement is related to the ability of these economic operators to develop initiatives and investments designed to reduce such impacts.

Among the industries that will continue to operate in Porto Marghera the cracking, the refining, and the power production, are considered to have a greater impact on the environment. In addition to the later industries we may cite the coastal deposits and the manufacturing of metal and glass. These industries will continue to exert strong pressure on the area. The cycles of cracking-refining processes are standardized and therefore have stable waste production in time, which are dependent on trading volumes. Any increase in hazardous waste will depend on ancillary activities, such as plant maintenance or future expansion. The waste (classified as non-hazardous) produced by Thermo Electric Plants are declining, but they are closely linked to changes in production and therefore to the energy demands related to market trends and consumption. The plants are also major contributors to discharges of waste-water and gas emissions into the atmosphere, especially the two ENEL power-plants that use coal and treated waste as fuel. Therefore, any improvement of the situation in the future will depend heavily on further possible improvements in the production of energy needed in the area. It is important to note that the effectiveness of certain investments in the production of innovative and low-impact energy, such as the one based on hydrogen, are structurally related to the functioning of other production processes.

Port activities, which are part of the hypothesized medium-term outlook for Porto Marghera, have a number of important environmental impacts, not specifically considered in this study, since they are not considered in the ARPAV Report. The environmental impacts associated with port activities may be particularly critical in an area such as that of Venice and its lagoon, characterized by a considerable environmental, economic and cultural value, but in the same time by a very high fragility. The presence and persistence of these activities in Venice can be closely linked to the reduction of such impacts and, not surprisingly, many of these issues are addressed in the Operational Plan of the Port Authority of Venice. From the realisation of such initiatives or others going in the same direction depends the environmental sustainability of port activities and the hypothesized medium - long term scenario of the area.

In conclusion, the industrial area of Porto Marghera centred on some chemical plants that until a few years ago showed favourable characteristics for a renewed development as an eco-industrial park, to the benefit of sustainability, finds itself today in an uncertain situation in terms of production and impacts on the environment. The closure of many of the major production facilities and the uncertain future of some of the remaining undermines the diversity that, based on biological analogy, would give the system the ability to adapt to industry changes.

Building a path of sustainability in Porto Marghera, thanks to a circular use of resources, means to implement new projects, some of which have already been proposed in recent years, aimed at reducing the environmental impact of

existing activities, through the energy efficiency, renewable energy use, water treatment, and efficient use of resources. Furthermore, it is extremely important to introduce new types of production activities with low environmental impact, as well as activities characterised by a high content of human capital that would create opportunities for a durable economic growth.

3. The structural conditions for long term economic growth

Porto Marghera appears to face in the future additional, strong and substantial transformations of its industrial structure. The study of these transformations can not prescind from reckoning the economic growth dynamics at the wider regional context. Therefore, it is necessary to consider the structural conditions that could sustain the long-term growth of the area.

The economic literature, and more specifically the endogenous growth theory, identifies two main driving forces behind economic growth in the long run. Firstly, the human capital which requires an efficient system of education and training and, secondly, the sectors that perform research and innovation which require, in addition to public funding, a competitive environment in which human capital is employed. This theory has been applied to various contexts and different world regions and has proved successful in modelling the development dynamic of those areas which have shown a stable and sustained economic growth through time.

Moreover, there exist a strand of literature based on empirical evidence and supported by theoretical models that suggests that long-term growth and development is boosted by industrial sectors characterized by a high content of technology adopted in the productive processes and/ or built in the final products. Other sectors of economic activity that have seen a dramatic growth in the last decade are the knowledge based sectors better known as Knowledge Intensive Business Service or KIBS. In the present study we aimed to identify the aforementioned sectors in the Veneto region and to test whether they are the real gears of regional growth.

Considering the models of endogenous growth, which are based on the knowledge based industry and on innovation, implies an examinations of the conditions for economic growth at a larger than the local scale. Therefore, it was necessary to test empirically the relationship between knowledge - innovation and economic growth in the Veneto region at a sub - regional level.

The project aimed to verify some models of growth for the territory of the Veneto and to analyse the mobility flows within the region, between the Local Labour Systems, and between the Municipality of Venice and the rest of the region, in order to achieve a better understanding of the development dynamics and the role of qualified labour force in it.

To this aim, it is essential to take into consideration the territorial unit that best satisfies the necessity our study. For this reason, our analysis has been carried out at the level of LLSs, which are aggregations of municipalities that identify homogeneous labour markets. The LLSs are built on routes of commuting

between home and work identified during the population census of 2001.

As for industry, we take into account the classification developed by the OECD (2004), which classifies industry in sectors in terms of high, medium-high, medium-low and low technology content. This classification is based primarily on the intensity of R&D, that is, the expenditure on R&D, and therefore, it indicates the diverse propensity to spend on R&D. Moreover, the OECD classification incorporates an index of the technological content in terms of the usage of the technology. Therefore, the final rating in sectors of high, medium-high, medium-low and low technology derives from direct indices (based on the intensity of spending on R&D) and indirect indices (use of technology) that are both in the same category.

The study required the construction of an original dataset, both for the territorial level of reference (the LLSs) and the variables that were created. In fact, by merging data from different sources and using Giove, a matched employee-employer database that contained detailed information on working spells in the Veneto region, we were able to recover information on human capital and technology contents of the Local Labour Systems (LLSs) of Veneto.

The empirical analysis of growth models highlighted some shortcomings of the Veneto territory which do not yet manage to exploit its potential for long-term development. Our results show a strong correlation between the growth of Venetian LLSs and the relative importance, in terms of labour force, of both high and medium-low technology sectors. The latter, however, assumes a greater significance than the high-tech sector, although its impact in terms of growth is about a tenth of that of the high-tech sector.

This result is confirmed if we observe the relationship between growth and human capital endowment of different sectors. Human capital employed in medium-low technological content sectors is (statistically) significant in determining the growth of Venetian LLSs. Moreover, its towing function of the growth is not influenced by different econometric specifications we adopted. Human capital employed in sectors with high technological content, however, can not yet play a significant role in determining the Venetian model of growth. Although the human capital employed in such sectors has a much higher (circa three times) effect on growth with respect to human capital employed in medium-low technology sectors, its significance is still weak.

Our results confirm the predictions of the theoretical models of endogenous growth. That is, human capital, even in the Veneto region, would give its best contribution to the economic growth if it could be employed in research and development intensive sectors.

Moreover, this statement is confirmed by the simulation exercises that have been carried out only for the LLS of Venice. The results of the workforce - with any level of education - mobility scenarios are very clear and suggest how to make relevant policies of technological upgrading of the production system in Venice. The SLL of Venice could benefit from increased growth of at least 4% every five years if a very small percentage of its workforce could be moved from

lower technology sectors towards higher technology ones. In annual terms, this corresponds to an increase in value added growth of 0.8%. Such increase would be lower if the labour force moved from low technology sectors to medium-low or medium-high technology sectors: 0.68% and 0.15% in five years respectively. However, even these changes, in long term context could lead to a virtuous circle. Our forecasts indicate clearly that the medium-high technological intensity sector is not a key sector for promoting growth in Venice. Although the mobility of labour from low tech. sector to the medium-high leads to a positive change in the rate of growth of the per capita value added, this variation is very small (0.15%). The variation is even negative if the mobility to the medium-high technology industry is fuelled by workers from the medium-low technology sector (-0.53%).

The growth potential increases if the mobility concerns specifically workers with a high education level (high school or university), that is human capital. In this case, the mobility of human capital from low technology sectors to high technology ones would result in an increase in growth of 8.7% in five years. The increase in growth would be equal to 7.53% if the workers came from medium-high technological intensity sectors and equal to 5.34% if the mobility originated from medium-low technology sectors. Again, mobility towards the medium-high tech means relatively low increments or even negative changes.

The important and strategic role played by human capital in innovation is confirmed when we analyse the relationship between innovation activities (using the number of patents as proxy) and human capital endowment. The Venice LLS shows a good performance of patenting in relation with its human capital endowment. It is clear, however, the need for a sectoral repositioning towards activities with higher technology content in order to achieve higher levels of innovation.

Part of the study has been devoted to the study of labour mobility, specifically in Veneto, in its LLS and in the municipality of Venice, in order to verify if there is an upgrading in the use of the labour force. Such upgrading could be towards higher technological sectors or towards knowledge-intensive service sectors. Results show that, in the decade 1998-2007, Venetian industries have undertaken a process of gradual upgrading of production that has been implemented through the mobility of labour from lower-tech industries to more technology intensive sectors, following a path of “contiguity”.

As for the single municipality of Venice, we observed a general improvement of the economic reality as an attractor of the workforce. All sectors of activity in Venice appear to gain in terms of employees relatively, over the period, when compared to the rest of the region. The indices of the inflows and outflows ratio show, however, that the sectors which have a net "significant" gain are the smaller ones in terms of employment, such as the shipbuilding sector (with an index of 1.41) the refining (1.87) and chemistry (1.27). The indices for logistics and KIBS are respectively 1.18 and 1.127. The indicators that we built show, among other things, a positive balance to the municipality of Venice (relatively to the rest of the region) in those Industry and Service sectors that are of

interest to professionals with a high content of human capital. In particular, the balance of the flows in the 1998-2007 period, shows an increase of intellectual and technical professionals in chemistry, shipbuilding, logistics and KIBS sectors.

In conclusion, there are positive trends in terms of technological and human capital upgrading. These trends have taken place 'autonomously' showing an evolutionary capacity of the system. Stable policies and targeted interventions, as shown in the simulation exercises, could affect positively this evolutionary path.

4. The results of the survey "Doing business in Porto Marghera"

The survey "Doing business in Porto Marghera" was conducted jointly by the University Iuav of Venice and *Ente della Zona Industriale di Porto Marghera* in the period March 2010 - January 2011. It was designed to explore and understand the current situation on the productive activity, giving voice to the actors who operate in the area. The aim of the survey was twofold: firstly, to provide an overview of the production activities that take place in the area and secondly, to identify the demand for services and public goods that companies express and the possible forms of their supply and production.

The questionnaire allowed to obtain additional information concerning the working conditions in Porto Marghera, the reasons for locating in the area, the outlook, the difficulties related to the context or to the global crisis. Moreover, it was possible to investigate the relationships between companies in the local area, in Veneto and in the rest of the world analyzing their market shares. Similarly, we considered the interrelationships between customers in order to understand the strength of ties between companies, the transformations in progress and the prospects of opening up to a wider context.

The survey consisted in two successive phases and used two different questionnaires which were characterized by two different levels of detail. In the first phase a short questionnaire was distributed to almost all of the firms operating in Porto Marghera. In the second phase a longer questionnaire was sent to a small sample of firms. The survey allows for a description of the firms operating in Porto Marghera. It gives important insights on the constraints and opportunities arising from being positioned in the Porto Marghera site. Moreover, information on firms' business characteristics and their presence in local, national and supranational markets was collected. We are also able to highlight the complex relationships with general and specific environmental regulations and the opinions about the possible forms of public intervention in the area, as well as to outline some features of the demand for public goods and services expressed by the interviewees.

The analyze of such a quantity of information collected through the two questionnaires makes us aware of the complex framework of the industrial site both in historical and sectoral terms; the results is that analysing firms answers and opinions it is not easy to identify neither a prevailing vision about the vocation of the area, or about future scenarios, nor a shared perspective by the

companies that would suggest “winning” interventions for the revival of the area.

Respondents handed us a rich framework characterized by a high awareness of the complex nature of the production network of Porto Marghera and the high interdependence among firms and between them and the infrastructures or the regulatory system.

There are some strategic factors on which the demand for intervention for the benefit of the enterprises and of the whole area, was shared by most of the respondents. We may cite the need for action on the tax system since it affects the competitiveness. Another example of shared views are the environmental and safety regulation which are considered onerous, but in the same time represent new opportunities for growth, particularly with regard to remediation, environmental protection activities and recycling.

Among all, one of the major problems is undoubtedly linked to the networks, i.e. to the possibility of real exchanges that can support the ability to provide and maintain a fast and easy connection to the external environment; supra local flows of people, goods and information are generally recognized as decisive elements in order to achieve that competitiveness capacity which is necessary to the development. This belief is supported by all types of firms - which differ from each other in terms of business sector, company and market size - contacted in the second phase of the survey.

Firms in the industrial sectors are obviously more demanding in terms of efficient functioning of the transport system for the supply / delivery of goods. Also companies related to services consider very important the presence and the accessibility of networks as it enables them to establish and easily maintain contacts with the outside world. Networks affect many elements that interact with the productivity of firms, whether they produce goods or services and knowledge. For all, the existence of networks and their quality affects the transportation and distribution costs, the marketing in distant markets costs, and the opportunity costs of travel time for individuals. Moreover, networks influence the costs related to long distance communication and interaction, the loss of essential information and, in general, the loss of value of information over time.

The demand for networks takes the form of a “physical” demand for transportation infrastructures at the local scale such as the *Mestre* bypass or the *Nuova Romea* commercial route. These infrastructures would ensure greater openness of Porto Marghera and create new local opportunities. Moreover, the demand for networks regards also fast communication networks and to the connections with the advanced training institutions and professional consulting.

Among the infrastructural interventions in the transport sector the intervention on the *Romea* commercial route is considered important as confirmed by the datum on the willingness to pay for this infrastructure. Among the production factors which are important for the development of the firms and the are itself we may cite the quality of work and the professional and consultancy skills.

Lastly, the companies did not show a marked propensity to request for direct aid

from the Government, although we underline the role of national public taxation in support of infrastructure costs. The respondents demand for a reform on the tax system and there is a certain attitude favourable to the private investment, either directly or through forms of public & private partnerships in the supply of public goods such as the infrastructure.

Conclusions

The potential of transformation and renewal of the industrial area of Porto Marghera was studied looking at a perspective of sustainability over time, both from the economic and the environmental point of view.

The study outlines the socio-economic transformations that have taken place at a regional scale in order to highlight medium to long term potential paths of development. In so doing, the study adopts those models that seem to characterize the most dynamic areas in terms of economic growth. Moreover, the study presents some of the most recent production dynamics and problems of Porto Marghera, in the light of specific environmental and regulation issues. Short term perspectives and long term expectation are studied relying on the results of two ad-hoc questionnaires, which were administered to firms operating in the area in 2010 and 2011. Furthermore, the study considers the conditions for the sustainability of the whole production processes that have characterized the economy of Porto Marghera for a long time. It aims to shed light on the potential sustainability of the area investigating the currently active sectors in a perspective of industrial ecology.

The economic theory has identified human capital and innovation as two of the most important determinants of long-term growth: the study of the empirical evidence in the Veneto region confirms that theoretical predictions by showing that the high technology sector has potentially the greatest impact on growth; the analysis of utilization of human capital endowment of the region shows that it could be better addressed with gains for economic growth . As a matter of fact, the study of the mobility within the region evidenced some positive trends in terms of technological and human capital upgrading. These trends have taken place 'autonomously' showing an evolutionary capacity of the system and well addressed and stable policies and targeted interventions could affect positively this evolutionary path.

Yet, the future of the industrial area of Porto Marghera is nowadays characterized by some uncertainty. Although it had some favourable characteristics as an eco-industrial park for the benefit of sustainability in the late nineties, the great transformations of the 2000s, consequence of the globalization, vanished such opportunity. The closure of many of the major production facilities and the unsure future of some of the remaining activities undermines the diversity that, based on biological analogy, would have allowed the system to adapt to industrial changes.

Projects aimed at reducing the environmental impact of existing activities through the use of renewable energy, water treatment, and in general, through a better and efficient use of resources are indispensable the future of the area.

Moreover, it is extremely important to introduce new types of production activities characterized by a low environmental impact, as well as activities characterised by a high content of human capital that would create new opportunities for economic and sustainable growth. Soft and hard infrastructures contributes substantially to these paths of development, supporting the use and services provided by local public good, segnately an improved environmental quality.

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THE STRATEGIC ENVIRONMENTAL ASSESSMENT (SEA) OF MORPHOLOGICAL PLAN OF VENICE LAGOON

Giuseppe Magro[1], Stefania Pellegrini[2], Stefano Scarpanti[2]

[1] *Department of Energy, Nuclear engineering and Environmental Control (D.I.E.N.C.A.) - Università di Bologna*

[2] *IAIA Italia (Sezione italiana della International Association for Impact Assessment)*

Riassunto

In questo articolo viene presentata la metodologia adottata per la realizzazione del processo di VAS del Piano per il Recupero Morfologico della Laguna di Venezia, definita in termini funzionali alle peculiarità specifiche del contesto lagunare ed in relazione alle esperienze di analisi e valutazione ambientale in ambito internazionale. In particolare, la metodologia Dynamic Computational G.I.S. (DCGIS) adottata per la VAS del Pmlv (1) prevede che le azioni costitutive del Piano, relative ad usi e interventi, vengano definite coerentemente rispetto alle dinamiche evolutive dello stato lagunare (SL) considerato e (2) consente di evidenziare l'interazione tra gli obiettivi di sostenibilità ed i potenziali effetti del Piano.

Abstract

In this paper is presented methodology adopted for the implementation of SEA of Morphological Plan of Venice Lagoon taking into consideration specific peculiarities of Venice Lagoon and experiences of analysis and environmental assessment in the international context. In particular, Dynamic Computational GIS (DCGIS) methodology adopted for the SEA is defined in terms of interaction factors with indicators describing valuated environmental components (VECs) of Lagoon.

1. Introduction

Strategic Environmental Assessment (SEA) of Morphological Plan of Venice Lagoon provide to build systematic and structured dialogue, between planners and environmental assessors with compliance requirements for consultation in order to guide and harmonizing technical and scientific issue at different stages the evaluating and planning process. The actions and strategies for achieving the main objective of Plan, "morphological objective", should be defined in respect of general conditions of sustainability, taking into consideration site-specific issues related to environmental quality, water quality, sediment quality and ecological Lagoon conditions, and related to factors contributing to its protection.

2. The SEA process and DCGIS methodology

Strategic Environmental Assessment (SEA) is the process for integration of environmental considerations into the plans and programs and promotes (1) sustainable land development and (2) new land use planning tools (Directive 2001/42/EC).

SEA should intercept, dismantle and systematize conflict dynamics to explore and identify the best operational scenarios to be taken just during Plan preparation. Sustainability targets should be applied to systems to highlight critical issues through analysis of their interactions and their level of contrast with Plan objectives and other environmental vulnerability of Plan context. Planning requires territorial and environmental context to be characterized in terms useful for analyzing and evaluating impacts caused by different plan alternatives. The level of characterization of impacts in SEA is different from that of EIA (Directive 85/337/EEC and following modifications), for that reason it is useful to adopt specific languages expressing significant components of *impact frame* and exploring actual complexity of anthropic-environment interactions associated to different Plan alternatives on which decisions have to be taken.

2.1 The SEA process

SEA process should be able to addresses complex environmental issues and communicating them into simple language for every stakeholders potentially involved by Plan application. GIS have an important role both in analytical phase and in communicating its significant results.

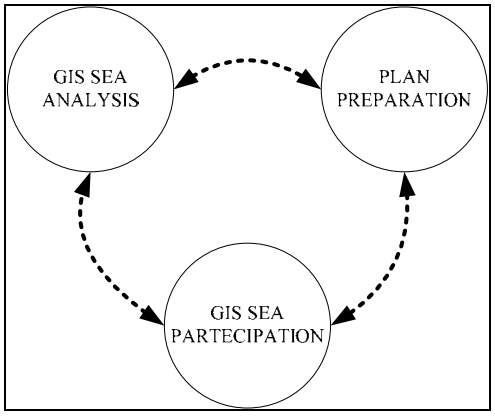

Fig 1. GIS SEA/Plan process

There are several way of supporting SEA processes with GIS, from simple qualitative geo-location of objectives and/or actions to more structured quantitative representation of environmental impacts through simulation models. Effective analytical detail level of GIS application depends on specific SEA purpose and availability of resources.

During planning processes effective knowledge of plan actions frame increases, so that analysis should be undertaken in an iterative way. This approach has

two important advantages:

- Possibility of building planning scenarios according to the results obtained by previous GIS Stressor-Vulnerability Interaction Frame analysis;

- Possibility to compare different simulations over time, verifying consistency of conceptual analysis model, describing effective plan actions on plan objectives.

2.2 The DCGIS SEA methodology

DCGIS system allows the characterization of (1) human pressure and (2) environmental vulnerability in specific factors (indicators) of pressure and vulnerability. The system determines potential scenarios of environmental impact based on correlations between pressure attributes and vulnerability attributes.

In the case of SEA, both stressor elements and also Plan actions are considered.

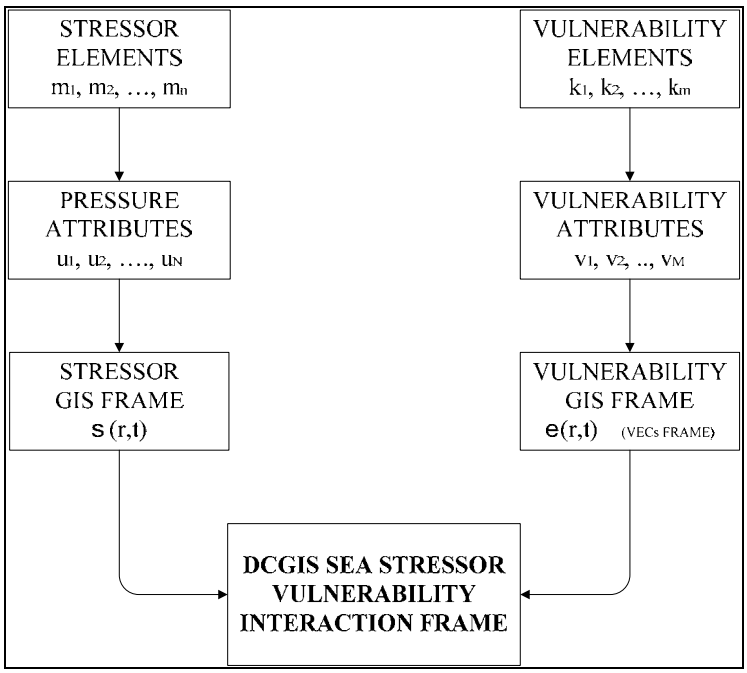

Fig 2. DCGIS SEA stressor-vulnerability interaction

Expressing (1) *stressor elements* through their pressure indicators and (2) *environmental elements* in terms of vulnerability indicators, in a GIS spatial time frame, it is possible to analyze systematically impact scenarios defined by their interaction. Adopting *conservative* approach in defining analytical *forms* of indicators allow to obtain different *tiering* characterization of potential impact of Plan actions, once defined actions through pressure indicators compliant to DCGIS SEA stressor frame

In the following table is represented the DCGIS algebra:

$m(r,t)=\sum_{j=1}^{n} a_j(r,t)\hat{u}_j$	Vector representation of stressor elements: m: stressor element $a_j(r,t)$: stressor environmental pressure function related to pressure attribute j-th u_j: basis linked to the emissive component j-th
$\sigma(r,t)=\sum_{i=1}^{N}\sum_{j=1}^{n} a_{ij}(r,t)\hat{u}_j=\sum_{j=1}^{n}\alpha_j(r,t)\hat{u}_j$	Matrix of stressors $\sigma(r,t)$ a_j: cumulative contributions of all N stressors elements acting inside area of analysis
$k(r,t)=\sum_{k=1}^{m} b_k(r,t)\hat{v}_k$	Vector representation of vulnerability elements: k: vulnerability element $b_k(r,t)$: environmental function related to vulnerability attribute k-th v_k: basis linked to the environmental component k-th
$\varepsilon(r,t)=\sum_{h=1}^{M}\sum_{K=1}^{m} b_{hk}(r,t)\hat{v}_k=\sum_{K=1}^{m}\beta_k(r,t)\hat{v}_k$	Matrix of vulnerabilities $\varepsilon(r,t)$ b_k: cumulative contributions of all M vulnerability elements acting inside area of analysis
$i(r,t)=\sigma(r,t)\cap\varepsilon(r,t)$	Impact matrix: represents all possible interactions between stressor and vulnerability indicators
$i(r,t)=\sum_{j,k}^{n,m}\alpha_j(r,t)\cap\beta_k(r,t)\cdot\vartheta_{jk}$	Weight stressor-vulnerability interaction; θ_{jk} (Correlation matrix) represent the type of interaction between pressure and vulnerability indicators in terms of level of correlation

Tab. 1. DCGIS algebra

3. DCGIS SEA methodology applied on Morphological Plan

Potential impact assessment due to Pmlv realization has been made by means of DCGIS system, which, through information structured income from CORILA, allows (1) Plan action suitability (or idoneity) level characterization in order to be in contrast with main Lagoon system degradation causes and (2) environmental assessment computation of different planning scenarios.

DCGIS methodology is a basis for :

- degradation condition characterization related to anthropic and/or natural causes in each lagoon state considered;
- list and analysis of action typology suitable for main degradation cause reduction and quantification of degradation contrast degree;
- bias for monitoring action suitable for Lagoon system evolution verification with respect to planned targets and objectves and suitable for possibile action changes

Pmlv SEA process has been undertaken in order to define customized action clusters consistent with different Pmlv scenarios, and in particular in relation to:

- Lagoon uses (critical issues list about which Pmlv may address or guide in order to decrease impact levels)
- Morphological actions (territory and environmental typological or specific scope characterization in terms of action suitability and land and environmental vocation with respect to general objective frame)

In particular, analysis methodology is based on determination of actions suitable for Lagoon actual degradation cause contrast (such as hydromorphological , ecological, of water and sediment quality).

1. Characterization of lagoon system in indicators
2. Correlation analysis between degradation indicators and causes
3. Identification of Plan actions and determines Plan suitability

Tab. 2. SEA phases

3.1 The step of analysis

Indicator cluster for Lagoon system characterization allows first specific territory and environmental assessment, suitable for next analysis stage and whole analysis frame definition.

Lagoon System is constituted by the following states:

SL = [SM, SE, SQA, SQS]

where:

SL: lagoon state;

SM: hydromorphological state;

SE: ecological state;

SQA: water quality state;

SQS: sediment qualità state.

From Lagoon System general indicator set it is possibile to select indicators for each above state; on state indicator basis, it is possibile to identify indicators representative of degradation conditions.

Analysis methodology adopted requires at this stage degradation cause (C) identification, to bring to action able to oppose degradation evolution.

Venice Lagoon actual degradation causes can be splitted into two typologies: natural and anthropic ones.

Identified causes are linked to degradation indicators by means of correlation matrix $\theta_{C\text{-}D}$.

Ability of action to be in contrast with degradation causes comes out from matrix identifying correlationships between Plan actions and degradation causes: that is correlation matrix, named $\theta_{C\text{-}A}$.

Computation of suitability (idoneity) about being in contrast with degradation causes is made by means of correlation between actions (georeferenced on the specific territory) and causes (their georeference is possible through cause indicators), that is made by use of G*eoreport* operator.

Such analysis allows to get from each considered actions territory specific vocation with respect to degradation cause decrease criterion and it is possible making the assumption that Plan actions are able to be in contrast actively against degradation causes.

3.2 Application example

In the following it is presented an application example of correlation between Plan actions and cause indicators to determine suitability Plan.

Let's suppose to have 2 action plan (A_i) and three causes indicators (x_C) generically correlated in this way:

Actions/Causes		X_{C1}	X_{C2}
A_i	A_1	3	0
	A_2	2	1

Tab. 3. Correlation matrix $\theta_{C\text{-}A}$

Based on correlation level indicated, have been determined the following suitability maps:

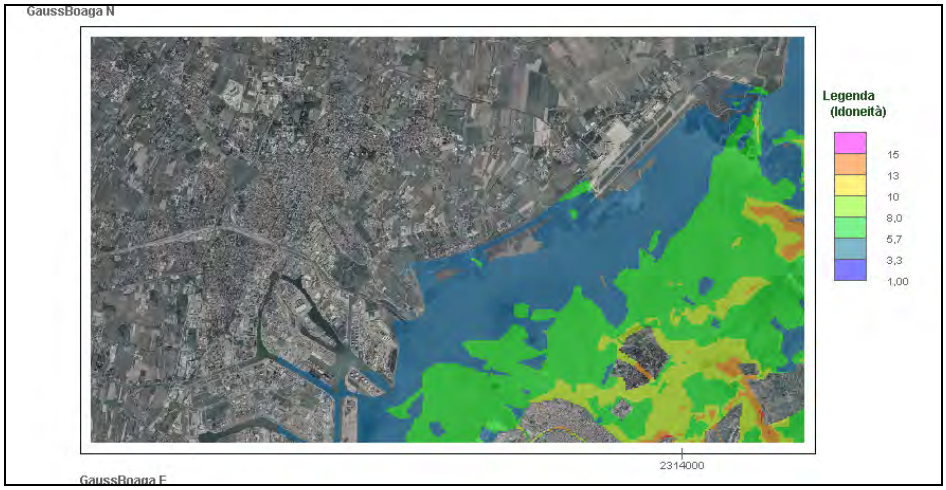

Fig 3. Suitability map of action A_1

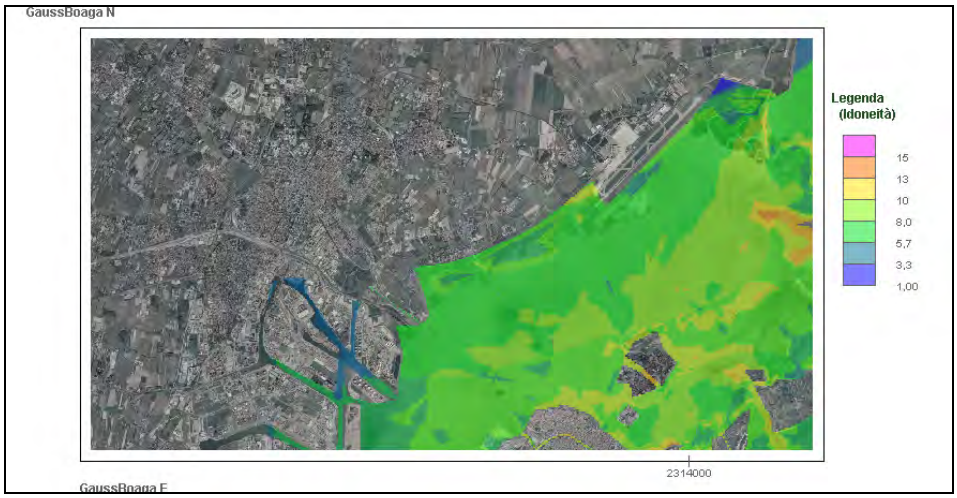

Fig 4. Suitability map of action A_2

In legenda it is represented the suitability level; the maximum level (15) represents the highest suitability.

Through the application of Georeport operator it is possible to identify areas for which it is shown same level of suitability for both actions considered.

Georeport operator is able to express on a space-time basis any interaction between maps and its application determined by the interaction matrix; in our case, in the rows there is suitability levels of A_1 and in the columns the suitability levels of A_2. Along the diagonal there is the number of cells represented by the same suitability level of both actions.

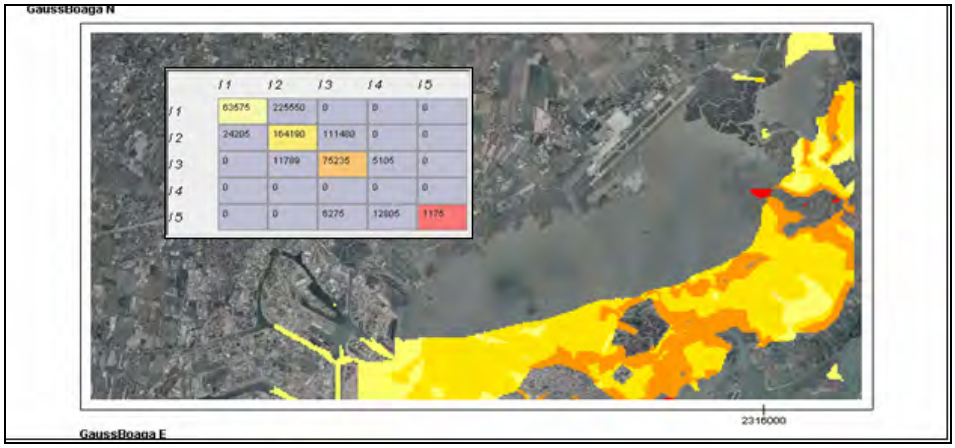

Fig 5. Georeport application

Conclusions

This paper has described methodology adopted for the implementation of SEA of Morphological Plan of Venice Lagoon, taking into consideration specific peculiarities of Venice Lagoon and experiences of analysis and environmental assessment in the international context, and an example of determination of suitability levels of territory to receive the Plan actions

The correlation analysis between suitability maps allows to identify the areas with highest suitability levels.

DCGIS SEA application is able to support the planner in the selection of actions of the Plan during Plan preparation phase.

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THE SOCIO-ECONOMIC IMPACT MONITORING OF THE MOSE PROJECT: METHODOLOGICAL NOTES

Marco Della Puppa[1], Lara Boldarino[1], Maurizio Balestrieri[2], Marco Mazzarino[1]

[1] Università IUAV di Venezia, [2] Università di Padova

Riassunto

Il monitoraggio degli impatti potenzialmente esercitati dalle fasi di cantiere del progetto MOSE su una serie di attività economiche risulta rilevante in quanto è soprattutto nelle fasi di cantiere che esse potrebbero risultarne interessate. E' per questo motivo che per ciascuno dei settori considerati - porto, turismo e pesca - è stato predisposto un impianto metodologico di monitoraggio che, caratterizzato da un filo conduttore comune seppur in presenza di specificità, consente di catturare e misurare i principali fenomeni che li interessano, di individuarne le cause e l'eventuale grado di connessione con i cantieri alle bocche. Nel presente lavoro saranno descritti i caratteri salienti dei tre impianti metodologici e riassunte alcune delle evidenze derivate dalla loro applicazione.

Abstract

The monitoring of possible impacts produced by the construction of MOSE project over a selected number of economic activities is particularly important during construction phases. For this reason a methodological framework has been prepared for each of the considered areas – port, tourism and fishing - having both common elements and specific ones; it allows capturing and measuring the main characteristics/issues, highlighting the causes and their potential relations with construction sites. The paper describes the three implemented approaches and some of the main obtained results.

1. Introduction

The monitoring of the effects produced by MOSE construction sites over three economic activities – port, tourism and fishing – is based on a framework integrating both common and specific elements and issues. Monitoring was conceived from the consciousness that the construction phases of this infrastructure can affect a number of economic areas potentially determining a decrease of offered services and, as a result, on the respective required levels. More in detail the negative effects could consist in terms of port throughput decrease, tourism demand decrease (with a possible increase in competing markets) and fish market decrease, thus having a system able to provide alerts in case of problems is important in order to minimize their negative effects.

The paper summarizes the monitoring plan structure highlighting the common issues and, for each one of the three economic activities, the specific ones. Main results obtained through the application of the framework to the port sector monitoring are provided as an illustration.

2. The monitoring framework

2.1 Data sources, types and common features

The monitoring plan for the three selected economic activities is based on the following common fundamentals:

- data sources;
- type of used data;
- “benchmark” definition.

Beginning from data sources two main categories have been identified, direct and indirect. While the direct sources are from the field activities (i.e.: measurement campaigns), questionnaires, interviews, focus groups with strategic opinion leaders (such as players involved in the sectors under scrutiny), the indirect sources are publications, studies, official data provided both by public authorities (i.e.: Port Authority) and operators (i.e.: tourist offices).

The information and data obtained from these sources can be quantitative and qualitative. The quantitative data are used to see how the monitored phenomena evolve over time and allow the evaluation and the comparison among data pertaining to different periods. Qualitative information/data are very important too as they mainly concern opinions, perceptions and strategies of the players involved in the economic activities. Monitoring this kind of information is very important because frequently players’ decision processes are not only based on concrete evidences but also on perceptions or thoughts even if they are incomplete or incorrect.

The last one of the common elements is the “benchmark” definition where, for each one of the three sectors, a certain year has been chosen as a benchmark for comparison. In other words the year before the beginning of the construction activities (year 2004) is assumed to be the one when everything “was running normally” and it is used as comparison term in order to verify if there are changes due to MOSE project construction.

2.2 The monitoring framework for the port sector

For the port sector the designed monitoring methodology considers four categories of possible effects, namely direct, indirect, induced and competitive effects. Indirect and induced effects are difficult to measure because they are not directly connected to port operations as they concern firms’ activities, workers, etc. in terms of regional GDP, duties, that can be affected by port problems. Direct effects are the ones strictly linked to port operations and they concern the quantity of goods handled within the port and the quality of the service provided to ships in terms of transit time, waiting times, scheduling, frequency, reliability, etc. Effects on competition are, at end, related to the possibility that parts of cargoes handled within the port are lost (they are shifted to another place) because operators choose other ports.

Starting from the identified possible effects it has been decided to monitor the following parameters that can be related to direct and on competition effects:

- traffic parameters:
  - goods traded by Venice port disaggregated by “strategic” maritime service type (liner services as motorways of the sea, container, passengers) and type of goods (liquid and dry bulks, general cargo);
  - selected goods/flows traded by a number of “competitor ports” that are Ancona (ro-ro/ferry and passengers), Ravenna (dry bulks), Trieste (ro-ro/ferry, containers and passengers), Genoa (containers and passengers) and La Spezia (containers);
- service quality parameters: ships’ delays, transit and waiting times classified by “strategic” service type, namely ro-ro, containers, ferry and cruises;
- economic parameters: cost of port operations such as mooring, tugs, pilotage, port duties, etc. Since these parameters are not variable over time because subject to changes introduced with specific regulations, it has been decided to point out variations only when these happen;
- quality parameters: viewpoints, perceptions and strategies of a selected number of representative players involved in port operations (opinion leaders).

2.3 The monitoring framework for the tourism sector

It has been chosen that the monitoring plan for the economic activities should be aligned because of their common area of use. However going on with the more detailed description, for the tourism sector direct and indirect effects have been identified too.

Speaking about direct ones, they can be divided in micro and macro indicators. Micro indicators can be further divided between demand and supply side as they are linked with tourists behaviours, in terms of tourists’ expenditure and arrivals/attendance number, and with services offered. Macro indicators are the sum of micro ones in order to identify sector’s consumption, investment and workforce levels.

Indirect effects are instead defined in order to determine the amount and the effects played by tourist’s expenditure on regional GDP.

In order to have the most complete point of view, after defining the summarized effects it has been decided to monitor a certain number of parameters, the ones thought to be the most relevant and strictly connected to direct effects:

- tourists’ arrivals and presence in Cavallino Treporti, Lido and Chioggia (overall and average number);
- tourists’ expenditure;
- tourists’ perception in Cavallino Treporti and San Nicolò;
- Front Office’s perception;

- accommodation availability (accommodations and beds number);
- maritime traffic;
- trends, strategies and perceptions of decision makers and opinion leaders (quality table).

2.4 The monitoring framework for the fishing sector

Monitoring the effects of MOSE project on the fishing sector is done to verify if the construction activities impact fish (with a production decrease) or fishery-related markets.

A comprehensive monitoring plan should consider a large number of different factors such as fishing boat flows (type of fishing fleet), fishing techniques, enterprises number, fished quantities, prices, etc., so it has been necessary to choose a number of relevant factors to be monitored. The criteria followed has been that of focusing on specific areas and those aspects relevant both from an economic (e.g.: growing trends and overall volumes) and an environmental point of view (e.g.: species included in the “red list”) . This has led to the definition of the following variables:

- short term variables. These include the analysis of price-trends for seven key species, selected because of their economic and biological significance for the Venice lagoon system, and the monitoring of fish quantities sold on Chioggia wholesale fish market, useful to better understand price-trend anomalies.
- long term variables include:
    - the fishing fleet organization;
    - the enterprises directly involved in the lagoon-based fishing activity;
    - the fishery direct employment level.

3. Some empirical evidences from the port sector

At present the implemented monitoring plan has highlighted no impacts of construction sites on Venice port activities. The monitoring plan has led to a number of significant evidences that enabled having a more precise understanding of this important sector. Following the briefly described structure the main obtained results can be summarized as follows.

Venice port is experiencing a transition process (started years ago) which transforms it from an industrial to a commercial port. In this general situation it can be generally considered as a healthy one because, even if in very recent periods the global economic crisis produced a general decrease in traded goods, it has shown stability trends, which is particularly important for the already mentioned “strategic flows” as containers, motorways of the sea and passengers. The port good health is also linked to “traditional” goods as the bulk ones, goods frequently characterized by seasonal and/or market fluctuations.

Looking at “competitor ports” first of all the trends related to the global economic crisis are confirmed. Their trade flows analysis also showed that there have been some interdependencies among them and Venice port, but it has been possible to understand that the causes were not MOSE-related, but due to external, occasional and/or limited in time events (e.g.: some dry bulks have been shifted to Ravenna port for infrastructural maintenance at Venice terminals, a shipping company decided not to sail Trieste any more and placed its ships in Venice, etc.).

One of the most interesting evidence is the one related to the quality of the maritime service offered. The monitoring plan pointed out that not only MOSE project construction sites are producing no negative impacts on port operations, but that more than once there has been an increase in quality because ships’ average transit times not only decreased (navigation operations are getting faster) but also became more constant and reliable over time (services are even more on time). The implemented monitoring plan also allowed investigating delay causes and pointed out that these were not linked to construction sites but mainly to weather conditions (fog, wind, tides, etc.), terminal congestion and so on.

The trends coming out from quantitative analysis have been completed with qualitative ones. As already mentioned a number of relevant players have been interviewed in order to have information about their perceptions and thoughts. What appeared is a general good feeling concerning both construction sites and port of Venice condition; on the other side one of the most relevant critical issues, that can be defined as “traditional”, is the one linked with Venice port overall structure and position because within the lagoon there are problems mainly with space availability and canals depth that need to be solved as soon as possible in order to enable growing trends.

Conclusions

The paper described the monitoring framework implemented to monitor the possible effects produced by MOSE project construction sites on three economic activities. The monitoring plan is based both on a common background and on specific elements.

The refinement performed on it during the monitoring activities has led to a framework that is able to provide a complete picture of the examined economic activities, pointing out how these evolve during time and to show if there are problems or anomalies, also highlighting the causes.

AREA 2

Architecture and Cultural Heritage

PRELIMINARY STUDY ON THE BEHAVIOUR OF THE WOODEN FOUNDATIONS IN VENICE

Guido Biscontin[1], Francesca Caterina Izzo[1], Claudio Bini[1], Enrico Rinaldi[2], Nicola Macchioni[3], Benedetto Pizzo[3], Chiara Capretti [3], Giuliano Molon [4], Michele Regini[4], Alberto Lionello[5], Ilaria Cavaggioni[5], Zeno Morabito[6]

[1] *Università Ca' Foscari di Venezia, Dipartimento di Scienze Ambientali*
[2] *CORILA. Consorzio per il Coordinamento delle Ricerche sul Sistema Lagunare di Venezia*
[3] *CNR-IVALSA*
[4] *Insula SpA*
[5] *Soprintendenza per i Beni Architettonici e Paesaggistici di Venezia e Laguna*
[6] *Arcadia Ricerche Srl*

Riassunto

Questa ricerca ha consentito di stabilire una serie di informazioni sul comportamento del sistema delle fondazioni veneziane, che possono essere considerate un punto di partenza per una conoscenza scientifica sulle condizioni e le caratteristiche delle palificazioni lignee dell'edilizia veneziana.

Il sistema complesso costituito da legno, acqua e terreno forma la struttura delle fondazioni di Venezia. Le condizioni chimico-fisiche e biologiche nelle quali il legno della palificata viene a trovarsi non sono tali da provocare un rapido decadimento del materiale ligneo, poiché gli agenti del degrado biotico più aggressivi (insetti, funghi, organismi marini) non trovano un ambiente idoneo al loro sviluppo. Ciononostante dopo alcuni secoli il legno, in condizioni di costante imbibizione e di sostanziale anossia, può andare incontro anche ad un significativo degrado da parte di batteri anaerobi. Dietro il luogo comune dell'inalterabilità nel tempo delle fondazioni lignee degli edifici veneziani si cela in realtà una conoscenza superficiale e sporadica dello stato di conservazione dei pali su cui "poggia" la città.

La ricerca, basandosi sui pochi casi indagati in passato e sui limitati campionamenti che è stato possibile effettuare, ha messo in evidenza la presenza di un degrado delle palificazioni, con differenze anche significative tra diversi edifici e diverse specie legnose adoperate. Le indagini eseguite hanno, infatti, confermato che il materiale legnoso è soggetto a processi di degrado con cinetiche apparentemente lente, che dovranno essere ulteriormente studiate. Con le conoscenze acquisite non è ancora possibile, infatti, mettere in relazione l'intensità del degrado con il fattore legato al tempo di messa in opera del materiale ed infine, cosa più importante, con le effettive condizioni statiche del sistema di fondazione. Le specie legnose individuate sono state il larice, il pino silvestre, la quercia e l'ontano; il degrado è risultato essere prevalentemente di natura biotica ad opera di batteri da erosione. Inoltre, sono state trovate le prime correlazioni tra i parametri che caratterizzano il sistema palo-terreno-acqua, ciò che rappresenta l'inizio della conoscenza del reale stato di degrado del legno che potrà permettere di effettuare anche previsioni sulla stabilità nel

tempo dell'intera fabbrica. In particolare nei siti di campionamento sono stati registrati valori di pH basici e valori di potenziale ossido-riduttivo negativi, indicando una condizione riducente di giacitura del legno.

La ricerca ha individuato alcuni indicatori significativi del sistema (come il massimo contenuto di acqua, la densità basale, il contenuto di lignina e di olocellulosa,la percentuale di ceneri, il pH, il potenziale ossido-riduttivo, la percentuale di sostanza organica, la presenza di calcare) che potranno in ulteriori sviluppi indicare la condizione di stabilità del materiale, requisito indispensabile per la sicurezza del costruito in Venezia.

Si ritiene necessario, oltre ad un approfondimento delle competenze, l'impiego di ulteriori metodi di indagine non distruttiva, valutando altre esperienze a riguardo, e la possibilità che riescano a fornire risposte alle problematiche individuate.

Abstract

This research has allowed to find some information about the behaviour of the wooden foundations in Venice: this could be considered the starting point for a scientific knowledge on wood conditions and characteristics under Venetian buildings.

The complex system composed of wood, water and soil forms the wooden foundations structure. The chemical, physical and biological conditions in which the wood exists are not such as to determine the quick deterioration of wood, because the environment is not favourable for the biodeterioration agents (like insects, fungi, sea organisms). Nevertheless, after few centuries, wood subjected to constant imbibition and almost anoxia conditions could be deteriorated by anaerobic bacteria. So, the fallacy that wood under water is strongly resistant hides the lack of a scientific knowledge of the state of conservation of foundations, underlining the necessity of in-depth and accurate surveys.

The research has underlined the presence of degradation, considering also the different buildings and the different wood species.

Larch, pine, oak and alder have been detected; their biodeterioration is due to erosion bacteria. It has been possible to find the correlation between parameters which describe the entire system (wood, water and soil): this is fundamental to reckon the stability of Venetian buildings. In particular, soils are characterized by basic pH values and negative redox potential that indicate reducing conditions.

This study has recognized some meaningful parameters (as Basal Density, Maximum Water Content, organic extractives, lignin content, holocellulose amount, ashes content, pH, redox potential, organic content, carbonartic content) which could be useful for determining the material stability.

1. Introduction

1.1 The foundation system in Venice

The foundation soils in Venice are composed of sand, silt, clay and peat which are often mixed in different proportions; all these layers are relatively compact and show a low bearing capacity.

The poles used in the foundation system were made of larch, oak, alder and elm with diameters varying from 10 to 25 cm: normally there were 9 poles per square meter, planted proceeding from outside to the core of the foundation. Poles length ranged from a maximum of 3.50 m to less than 1 m. Once the poles were planted, the heads were sawed to get a regular surface on which two or more layers of wood boarding (zatteroni) were set. These were made of planks or beams, called madieri, and their thickness depended on the weight they had to bear. Considering the specific case of bell towers, the total planks thickness was 50 cm or more: the interposition of cross-planks on the palisade favoured homogeneous behaviours of the entire foundation system.

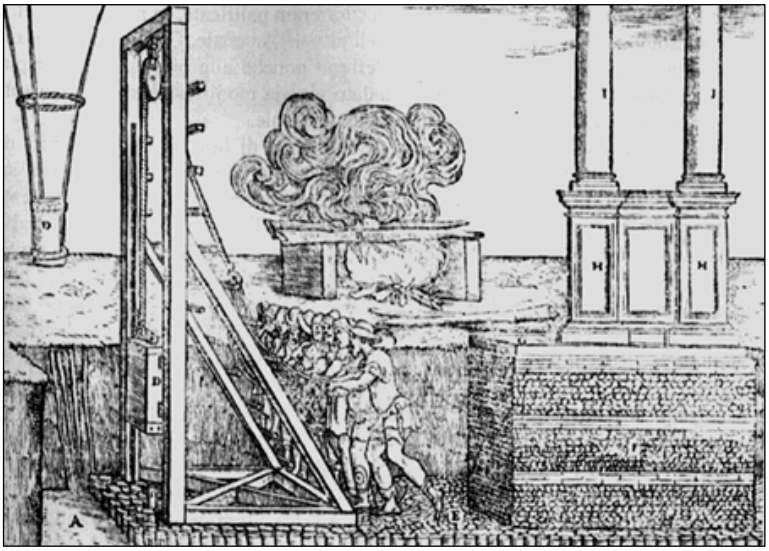


Fig. 1. Poles-Beatmachine, G. A. Rusconi, Dell'Architettura secondo i precetti di Vitruvio, Venice, 1590

Recent surveys on the Venetian bell towers of the Basilica of Santa Maria Gloriosa dei Frari and Santo Stefano highlighted that the structural characteristics and the state of preservation of the foundations are fundamental for the equilibrium of the entire building [2].

1.2 The state of preservation of foundations in Venice

The basic knowledge of the foundation building system of Venice is quite well known [3, 4]. However, despite this fact scientific investigations on their effective state of preservation are substantially missing. For a long time it was thought that wood immersed in water was not subjected to any forms of decay. It was common to think that: if wooden foundations sustain Venice since a thousand years, then wood immersed in water does not decay… In fact, the

situation of complete imbibition and the chemical-physical and biological conditions in which wooden piles are preserved still today represent circumstances in which wood does not decay rapidly, because the most aggressive biotic degraders do not easily act in such conditions. However, recent investigations carried out on wooden foundations evidenced a more complex situation. Analogously to what found in the Netherlands [5], a situation of decay emerged from a series of analyses executed on the wooden poles of two ancient Venetian tower-bells [6], although with a certain extent of variability between the two cases. These occurrences, together with the relevant variability observed, put some questions on the effective behavior of the whole foundation system (i.e. the combination of wood, soil and water).

Present research project was planned starting from these points. Although its outcomes do not allow to answer all questions, it establishes a milestone to which it will be possible to refer in the future.

2. Experimental

2.1 Sampling

Over the past decade, some areas of the historic center of Venice have been included in the “Progetto integrato rii” ("Project Canals") promoted by the company Insula S.p.A to assure the channels continuous maintenance and monitoring.

The sites chosen for the sampling were those where Insula S.p.A. was performing interventions: two sites in the insula of San Felice, in the Cannaregio district (at the confluence of Rio delle Acque dolci and Rio dei Gozzi) and one site in the insula of San Martino di Castello (Rio Ca’di Dio) (Figure 2).

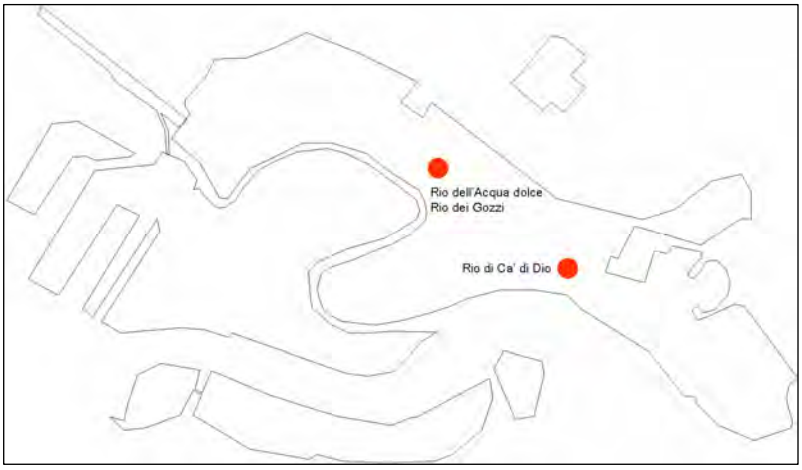


Fig. 2. Sampling sites

Fig. 3. Poles and boarding- Rio delle Acque Dolci

Fig. 4. Poles and boarding- Rio San Martino

Site	Wood samples	Typology	Soil samples	Depth of soil sampling
Ca' di Dio	A	boarding	C1_1	0-10 cm
	A	boarding	C1_2	10-20 cm
	B	log	C1_3	25-40 cm
	B	log	C1_4	40-55 cm
	C	pole	C1_5	55-70 cm
	D	pole	C1_6	70-90 cm
	D	log	C1_7	90-100 cm
	E	log	C2_1	0-15 cm
	F	log	C2_2	15-30 cm
	G	log	C2_3	30-45 cm
			C2_4	45-60 cm
			C2_5	60-75 cm
			C2_6	75-80 cm
Acque dolci	H	boarding	C3_1	0-17 cm
	H	boarding	C3_2	18-30 cm
	H	boarding	C3_3	21-45 cm
	H	boarding	C3_4	46-60 cm
	J	boarding	C3_5	61-75 cm
	L	pole		
	L	log		
	M	pole		
	N	pole		
	P	pole		
San Martino	R	pole		
	S	pole		
	T	pole		

Tab. 1.Wood and soil samples taken from foundations of various sites

2.2 Analyses on wood and soil

Analyses carried out on wood were focused to evaluate its characteristics at the moment of the extraction from excavation, according to what provided in standard UNI 11205:2007 [7]. Characterization of waterlogged archaeological wood consisted in the:

- analysis of anatomical characteristics, by means of optical and electronic microscopy (SEM and ESEM),

- measurement of: basic density (Db, g/cm3), Maximum Water Content (MWC,

%), total substances extractable in organic solvents and in water (%), ash content (%), acid lignin (%) according to the methodology described by standard TAPPI T222 [8], and calculation of holocellulose (%).

Concerning the soil analysis, organic carbon, total lime content and texture were determined [9], and Fourier-Transform Infrared Spectrometry (FT-IR), thermo-gravimetric analysis coupled with differential scanning calorimetry (TG-DSC), X-ray fluorescence (XRF) and X-ray diffraction (XRD) were carried out.

3. Results and discussion

3.1 Wooden elements in foundations

There was an elevated uniformity in species used in each foundation (Table 2): in the Rio Ca' di Dio site every analyzed element, independently on the typology, was in larch (*Larix decidua Miller*) whereas in Rio delle Acque Dolci there was a difference according to typology: all poles were of alder (*Alnus glutinosa* (L.) Gaertn.) and boards above piling were made of oak (*Quercus sp*.). Finally, all poles analyzed in Rio San Martino were in Scots pine (*Pinus sylvestris L*.).

Anatomical analyses also allowed evaluating the state of preservation of cell walls as related to the eventual typology of biological attack.

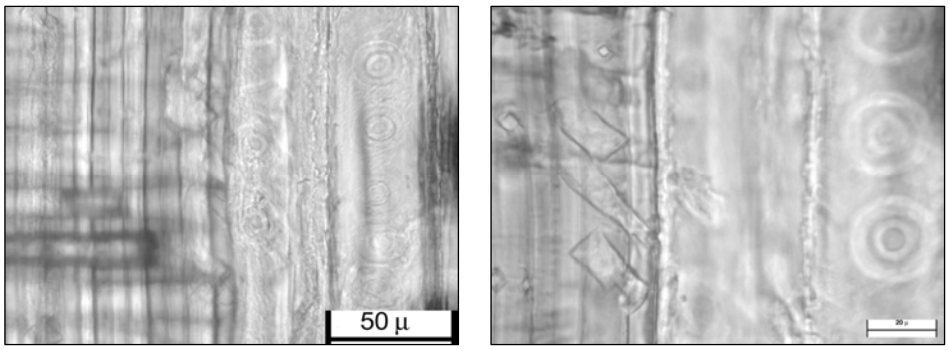


Fig. 5. Rio Ca' di Dio. Left, radial section of sample C. Right, radial section of sample D. Both samples were larch (Larix decidua Miller). Arrows indicate signs of bacterial attack.

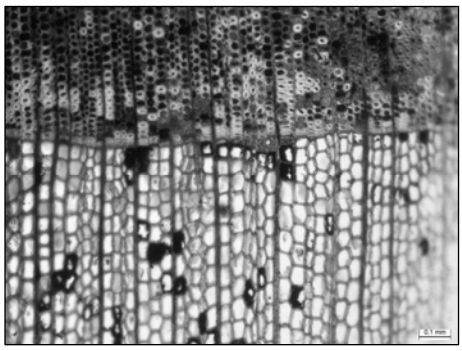


Fig. 6. Rio Ca' di Dio. Transversal section of a sample from the boarding in larch.

In Figure 5 arrows indicate clear traces of erosion bacteria attacks. This fact was confirmed from both the presence of diamond-shaped grooves (longer arrow) and thin erosions around border pits (shorter arrow). Traces of erosion

bacteria attacks were also visible on transversal sections of softwoods. Figure 6 shows a ring of sample A in transversal section: latewood of the previous ring in the upper part and earlywood of the subsequent ring in the lower part. Latewood, thick walled, allowed to better observe the presence of attacks in darker cells.

In alder, a diffuse porosity hardwood, the entity of attacks is more difficult to detect in low magnification images as those shown in Figure 7.

However, when decay became particularly intense wooden structure was no more able to sustain loads even of little entity and it collapsed in a generalized manner. This caused the substantial loss of readability of the wooden tissue (Figure 7, right).

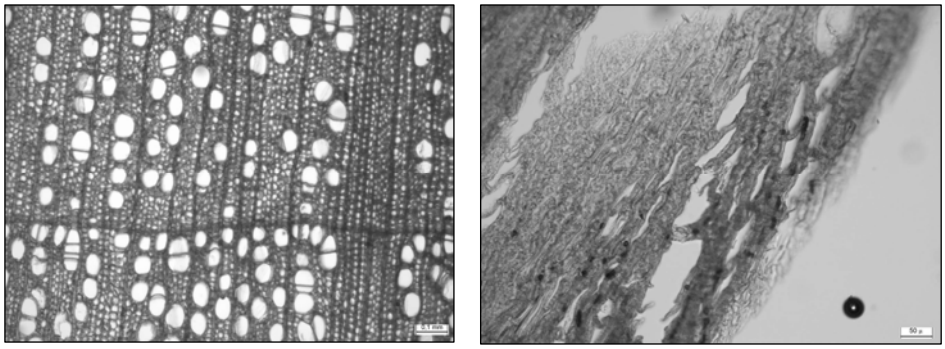


*Fig. 7. Rio de' Gozzi. Both photos evidence transversal sections of alder (*Alnus glutinosa (L.) Gaertn.*). The state of preservation of cell walls evidenced on the left-side photo is much better than that shown on the right one. In this latter the strong compressions caused the disappearance of most lumen cells.*

Some substantial differences were observed in wood samples taken in the considered sites. In Rio Ca' di Dio, where all samples were of larch, the state of preservation is on average quite good, mainly if compared with values often found in archaeological excavations. Measured average basic density was 0.35 g/cm3 against a literature average value of 0.56 g/cm3 for non-degraded wood, and values of holocellulose-to-lignin ratio (H/L) for samples taken from poles ranged from 1.6 to 2.4 (Figure 8), corresponding to approximately 60-80% of the analogous value for non-degraded wood. Instead, samples from boarding were in a worse state of preservation, with H/L of the order of 40% of that for non-degraded wood, associated with an elevated variability among the analysed portions. A similar occurrence was also found for another larch sample, also taken from a board in Rio delle Acque Dolci site. This let suppose an effect of the different lying position in which samples have been preserved in service conditions (horizontal for boarding, vertical for poles).

In any case, it is important to evidence that the mechanical behavior of a material even with such a limited extent of decay has to be considered as reduced, mainly bearing in mind the specific use of the objects.

In the Rio delle Acque Dolci site more wood species were used. In this case a clear differentiation in the state of preservation of different species was observed. Concerning oak, the analyses evidenced an acceptable durability, with H/L ratio of 60% of that for non-degraded oak wood. Conversely, alder samples appeared generally decayed: the one in better conditions was

comparable to that reported on the right in Figure 7. In these cases the low measured values of MWC (thus apparently indicating materials in good conditions) were imputable to collapse of cells, which in fact increased the basic density of samples. This occurrence demonstrated the importance of a multidisciplinary approach for a correct diagnosis. Indeed, both the microscopy observations and the chemical evaluations evidenced the effective bad state of preservation of samples.

	Species	Typology	MWC %	Db (g/cm^3)	Db res (%)	Ashes %	Total extractives %	Lignin %	Holocellulose %	H/L
Ca' di Dio										
A	larch	boarding	281	0.28	49.5	54.7	10.5	21.6	13.2	0.61
A	larch	boarding	153	0.47	83.7	7.2	3.4	43.3	46.1	1.07
B	larch	log	406	0.21	36.8	6.5	8.3	37.9	47.3	1.25
B	larch	log	169	0.42	74.5	29.4	17	20.0	33.6	1.68
C	larch	pole	197	0.37	65.8	8.1	4	33.4	54.5	1.63
D	larch	pole	272	0.28	50.8	11.3	5.9	31.2	51.6	1.66
D	larch	log	416	0.2	36.1	6.7	6.4	32.6	54.3	1.67
E	larch	log	202	0.36	64.5	2.0	9.3	27.4	61.3	2.24
F	larch	log	160	0.44	77.8	1.7	6.6	26.7	65.0	2.43
G	larch	log	151	0.46	81.5	7.7	7.6	26.8	57.9	2.16
Acque Dolci										
H	larch	boarding	325	0.25	44.0	8.1	5.2	41.1	45.6	1.11
H	larch	boarding	64	0.91	162.5	68.4	2	14.1	15.5	1.09
H	larch	boarding	133	0.51	90.3	14.5	5.4	41.1	39.0	0.95
H	larch	boarding	64	0.91	162.5					
J	oak	boarding	148	0.46	69.2	4.1	6.9	30.7	58.3	1.90
L	alder	pole	519	0.17	42.3	2.4	12.9	42.6	42.1	0.99
L	alder	log	519	0.17	42.3	1.7	7	56.7	34.6	0.61
M	alder	pole	204	0.36	89.6	4	3.5	66.9	25.6	0.38
N	alder	pole	603	0.15	37.5	2.9	9	63.5	24.6	0.39
P	alder	pole	703	0.13	33.1	5.4	5.6	50.9	38.1	0.75
San Martino										
R	Scots pine	pole	482	0.18	39.0	8.5	9.6	58.3	23.6	0.40
S	Scots pine	pole	483	0.18	39.0	34.1	6.8	49.8	9.3	0.19
T	Scots pine	pole	429	0.20	42.9	14.7	6.1	51.6	27.6	0.54

Tab.2. Results of analyses on wood samples taken from foundations of various sites.

Finally, in Rio San Martino site all samples, in Scots pine, were in a uniform state of preservation, corresponding to a basic density of 0.2 g/cm3 (40% of that for non-degraded wood), which evidenced an appreciable level of decay.

However, the limited availability of species distribution in a same site (i.e. only a few different species were present in each site) could appreciably affect all of these considerations, and hence a more extensive campaign of analyses is required in order to confirm these observations.

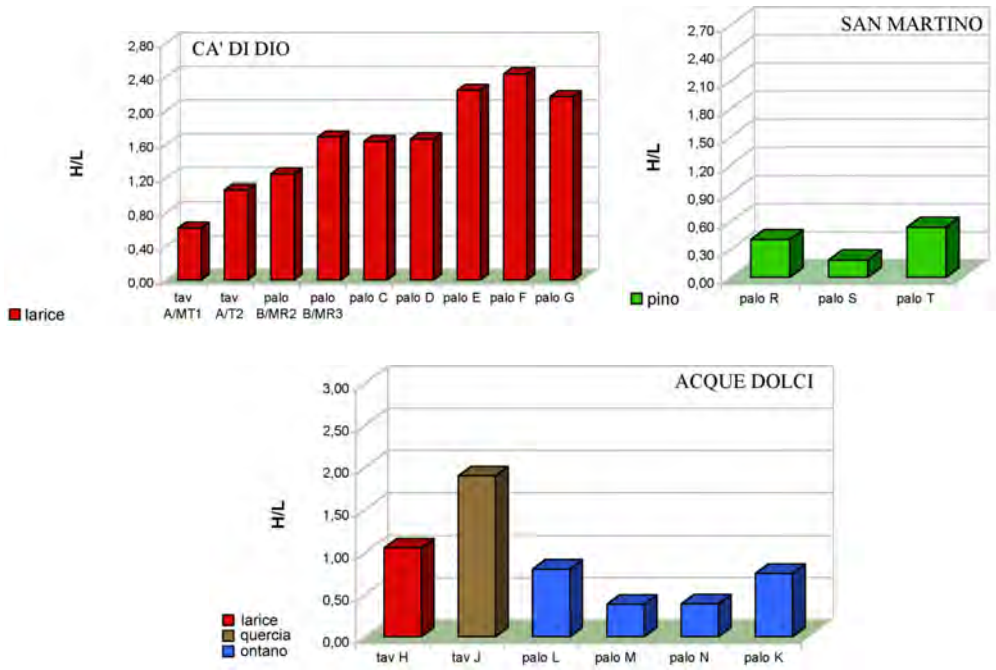


Fig. 8 a,b,c: values of Holocellulose-to-Lignin ratio (H/L) for samples taken from the considered sites. The maximum values in the y-axes correspond to the H/L ratio for non-degraded wood of the considered species.

3.2 Foundation soils

During sampling, pH and redox potential (Eh) measurements were performed in situ on foundation soils.

The pH values were typical of the slight alkalinity condition: pH values tended to decrease slightly as the depth increased. In the foundations system, soil is completely immersed in water and therefore the absence of oxygen leads to reducing conditions. Eh measurements confirmed the status of strong reduction in soils in contact with foundation poles: the Eh values were all negative, between -16 and -90 mV (Table 3).

The percentage of organic matter in soil samples was around 3-4%. This value increased with increasing depth and this was probably due to the lagoon sediments that are rich in organic matter and their accumulated layers in the canals.

All samples contained between 8 and 15% of carbonates: as shown for the organic matter, the quantity of limestone seemed to be correlated with the sampling depth. Consequently, big amounts of limestone influenced directly the increase of pH values up to 8.5 (as recorded in situ).

According to the triangle of soil texture by USDA (United States Department of Agriculture), foundation soil textures have been classified by the fractions of each soil separate (sand, silt, and clay) and they were on the average all included in the classes sandy clay and sandy clay loam (Figure 9). In particular, while the depth increased, the percentage in the amount of sand increased too and the percentage of clay and silt, which were the smaller fractions in soil, decreased.

Soil sample (sampling depth)	pH	Eh (mV)	Organic carbon %	Total limestone%	sand %	clay %	silt %
C1_1 (0-10 cm)	8.43	-90	3.90	13.40	34.9	41.9	23.2
C1_2 (10-25 cm)	8.39	-90	1.20	9.90	32.8	43.5	23.7
C1_3 (26-40 cm)	8.20	-68	2.90	13.30	33.8	41.4	24.8
C1_4 (41-55 cm)	8.20	-78	3.80	13.80	34.6	40.8	24.6
C1_5 (56-70 cm)	8.25	-81	4.30	14.30	37.2	40.9	21.9
C1_6 (71-90 cm)	8.16	-83	4.50	12.90	50.4	35.8	13.8
C1_7 (91-100 cm)	8.05	-77	4.80	13.80	51.9	36.9	11.2
C2_1 (0-15 cm)	nd	nd	3.20	11.20	40	40.1	19.9
C2_2 (16-30 cm)	nd	nd	3.50	11.60	38.9	38.7	22.4
C2_3 (31-45 cm)	nd	nd	3.60	14.80	39.3	37.5	23.2
C2_4 (46-60 cm)	nd	nd	3.80	15.20	37.5	37.6	24.9
C2_5 (61-75 cm)	nd	nd	3.20	14.70	43.7	31.2	25.2
C2_6 (75-80 cm)	nd	nd	4.40	13.80	46.3	39.9	13.8
C3_1 (0-17 cm)	7.40	-21	1.90	8.50	40.9	36.6	22.5
C3_2 (18-30 cm)	7.46	-27	2.00	10.30	38.4	35.5	26.1
C3_3 (31-45 cm)	7.35	-31	2.20	8.10	39.8	36	24.2
C3_4 (46-60 cm)	7.30	-20	2.40	9.40	45.6	34.8	19.6
C3_5 (61-75 cm)	7.26	-16	3.20	10.70	49.8	32	18.2

Tab.3. results of the analysis on foundation soils.

The presence of calcium, iron, silicon, potassium, aluminum, sulfur and traces of titanium, chromium and manganese were detected by XRF analysis (Figure 10). FT-IR and termogravimetric analysis results showed that carbonates (in particular calcite, dolomite and siderite), silicates and clay (as illite and albite) were present in the soils samples (Figures 11-12). It's important to underline that the formation of siderite, FeCO3 and pirite, FeS, occur only when redox potential values are negative (reduction condition): that was the case for the Venetian sites as already shown.

These results were confirmed by XRD analysis which evidenced the presence of calcite, dolomite, albite, sepiolite, illite and quartz in foundation soils (Figure 13).

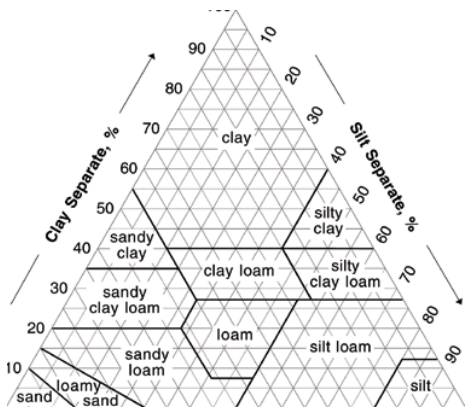


Fig. 9. the USDA Soil texture classes: the red circle shows the identification area for the samples (sandy clay/sandy clay loam).

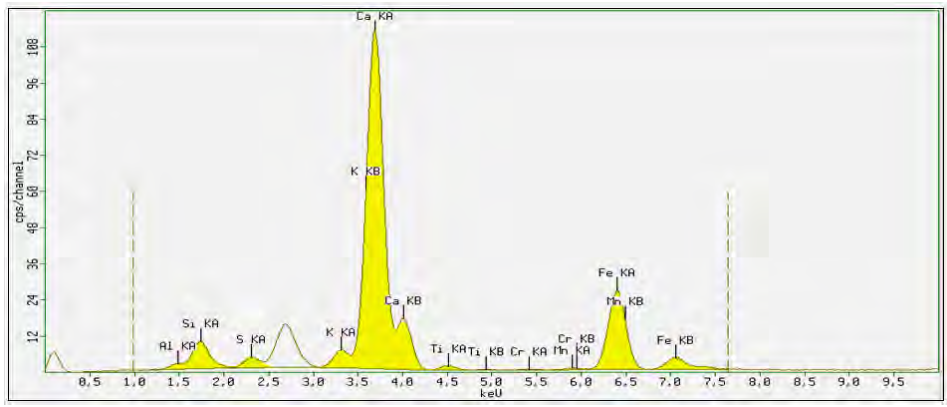
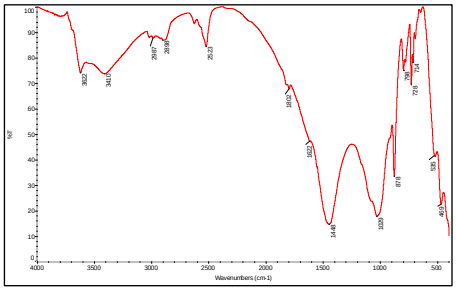


Fig. 10. XRF spectrum of sample C1_1.



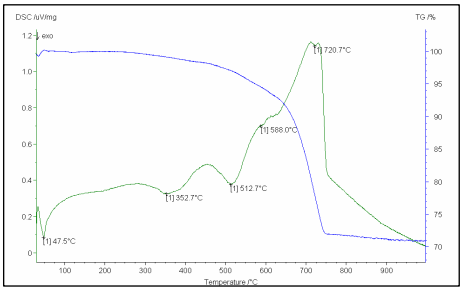


Fig. 11. XRF spectrum of sample C1_1.

Fig. 12. thermogram of sample C 1_1

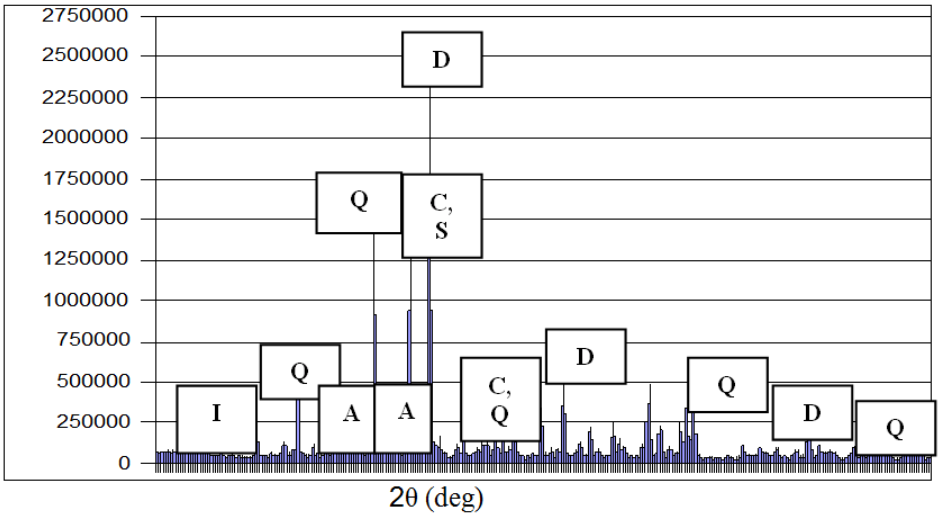


Fig. 13. XRD spectrum of sample C 1_5

A= albite
C= calcite
D= dolomite
I= illite
S= sepiolite
Q= quarzt

Conclusion

This research allowed for the first time to get a range of information on the behaviour of the Venetian foundation system: this can be considered the beginning of a scientific knowledge based on the conditions and characteristics of the wooden foundations of buildings.

The developed sampling protocol has been set up and has led to important results in situ and in laboratory analysis, both for wood and soil samples. The parameters for studying the complex system (i.e. wood, soil and water) were chosen in order to evaluate the degradation of wood, thus obtaining a diagnosis on the overall condition of the wooden material.

The results were reliable and significant.

The analyses carried out on wood samples confirmed that, in the service conditions of foundations, the material was subjected to decay processes. However, kinetics of decay were apparently slow, although this aspect needs to be further evaluated. Moreover, it is still not possible to correlate decay intensity and exposure time (i.e. time of use of elements) and, more important, to correlate decay level of wooden poles and effective static conditions of the whole foundation system.

The identified wooden species (namely larch, Scots pine, oak and alder) are in agreement with those found in previous investigations carried out for tower bells of Frari and S. Stefano, in Venice [6], and also with those reported in the Bacpoles Project [10]. Decay was essentially of biotic origin, and more specifically it was imputable to the action of erosion bacteria, identified by means of microscopic analyses. These organisms attack wood in almost total absence of oxygen. In these conditions other mechanisms of decay, such as attacks by soft rot, can be highly difficult to develop. Natural durability of wood against bacterial attack seemed to be dependent on wood species. In fact, it is known that generally hardwoods are more susceptible to bacterial attack in comparison to softwoods, very probably thanks to the different structure of their lignin.

The analyses on foundation soils allowed defining the most significant parameters for the characterization and the comprehension of the behaviour of soils in contact with wooden foundation. In particular, the state of slight alkalinity, the negative redox potential, the significant amount of organic material are fundamental to understand the state of preservation of Venetian foundations.

Acknowledgements

This research was funded by Corila (Consorzio per il coordinamento delle ricerche sul sistema lagunare di Venezia) and it was included into the “Secondo Programma di ricerca” of Corila (Architecture and Cultural Heritage).

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PLANNING AND RESTORATION OF THE AREAS FACING THE VENICE LAGOON INLETS CONCERNED BY THE TIDE REGULATION INTERVENTIONS

Domenico Patassini[1], Laura Zampieri[2], Elena Gissi[1], Laura Mosca[2], Endri Orlandin[1]

[1] *Dipartimento di Pianificazione, Università Iuav di Venezia*
[2] *Dipartimento di Architettura, Università Iuav di Venezia*

Riassunto

La presente ricerca si pone l'obiettivo di prefigurare scenari di trasformazione a breve e lungo termine riferiti al territorio costiero della laguna di Venezia, che possano orientare l'elaborazione di ipotesi di riqualificazione dei contesti interessati dalla realizzazione degli interventi di regolazione delle maree.

Il raggiungimento di tale obiettivo presuppone la definizione di un quadro conoscitivo in cui fare convergere l'articolato panorama degli strumenti di pianificazione, tutela e gestione del territorio costiero e lagunare, nonché gli studi riferiti agli assetti morfologici, paesaggistici ed ambientali, che saranno utilizzati per la redazione degli scenari di trasformazione a scala vasta. Tali scenari prefigureranno simulazioni del palinsesto delle concertazioni decisionali che, ai vari livelli di governo, possono condurre alla realizzazione delle trasformazioni stesse.

I risultati attesi riguardano la redazione di scenari trasformativi d'area vasta, derivanti dall'applicazione degli strumenti di pianificazione, tutela e gestione del territorio, attualmente in essere, e riferiti al quadro normativo europeo in materia di gestione integrata delle coste, quadri di sintesi delle trasformazioni previste dalla messa in esercizio degli interventi di regolazione delle maree e l'evidenziazione di fattori di criticità.

L'elaborazione di ipotesi trasformative localizzate è finalizzata ad ottenere scenari di trasformazione delle aree adiacenti gli interventi di realizzazione delle maree, che saranno il risultato delle seguenti valutazioni progettuali: interventi di riequilibrio ambientale, riprogettazione paesaggistica, possibilità di sviluppo di turistico compatibile con la trasformazione dei territori interessati, valutazione della compatibilità degli interventi con gli assetti paesaggistici ed ambientali degli ambiti marini, costieri e lagunari interessati.

La ricerca è organizzata in fasi di lavoro, che dovranno necessariamente intersecarsi: la prima approfondisce la raccolta degli aspetti conoscitivi, ed occuperà la prima parte del biennio di ricerca (2009-2010), la seconda sviluppa verifiche degli assetti di pianificazione e progettazione degli scenari ipotizzati, e concretizzerà, nel secondo anno, (2010-2011), gli esiti prefigurati nel primo arco temporale.

Abstract

The study of the Venice lagoon coastal system requires a multidisciplinary approach. Planning practice, protection and design, at different scales, therefore need constant interchange, to compare and evaluate the various issues and operational choices made by each party.

In this sense our research strives to investigate the different scenarios produced by the interaction of tidal management, complex governmental framework, and the actions of several actors and stakeholders operating within the Lagoon ecosystems.

The focus went to the implications and the possible relations between landscape design, tourism development and environmental compatibility of the Venice Lagoon coastal areas, considered a continuity of the Veneto Region's coastal system and as an interface between the Lagoon and the Adriatic Sea.

Landscape design, that complies with recently recognized European and national statutes, seems to be a suited instrument to tackle the complex scenarios analysed herein.

The expected results point to the identification of large-scale transformations scenario that arise from the application of planning tools and land protection elaborated at various administrative levels, and the design of landscape restoration's hypotheses, localized around tidal management.

The present research is part of the M.A.V. (Venice Water Authority) study program developed through the CO.RI.LA (Consortium for Coordination of Research Activities Concerning the Venice Lagoon System) entitled "The Venice Lagoon under the climate change framework, with respect to actions of mitigation and adaptation, and to territorial practices evolution", line of inquiry n° 7, "Planning and restoration of the areas facing the Venice Lagoon inlets concerned by the tide regulation interventions".

1. Introduction

The purpose of the present research is to foresee short and long term scenarios to the Venice lagoon coastal area to direct further development of the areas affected by tidal regulation interventions.

They will be analyzed the existing planning tools, the protection and management of the coastal and lagoon land, along with the studies on the morphological, landscape and environmental structure. A preliminary cognitive framework will be evaluated as a simulation of the concerted decision-making programmes at the various levels of government, can lead to the realization of the transformations.

The expected results concern with the definition of transformation scenarios at a large scale. Those scenarios will consider the enforced planning instrument forecasts. They will also comply with the European legislation on integrated coastal management and with the transformation changes foreseen when tidal regulatory intervention will be put at work.

Transformation projects on areas affected by tidal management interventions entail the following evaluations: checking the compatibility of the interventions in relation to environmental balance; landscape development; promoting tourism that is compatible with the transformations foreseen, assessing the compatibility of interventions with the surrounding landscape, sea, coast and lagoon areas involved.

The research is organized into different work phases that will have to intersect. The initial phase of the two year research (2009-2010) entails collecting cognitive data. The second serves to test the plans or projects conceived and will run from the second year (2010-2011), formalizing the expected results.

2. The coastal landscape of the Veneto Region, a study by themes

The first stages of this study strive to identify the reading strategies on the main structural elements of Veneto's coastal land. An analysis of the current state is drawn from existing planning instrument and policies.

The goal is to offer an interpretive key to favour data entry and a better understanding of the on-going transformations, especially with regard to the tourism sector, to see how it interacts with the territory. Environmental, social, economic and cultural components contribute to qualify complexity and wealth of the region.

At this stage of the research it seemed fundamental to reflect on a logic centred on the *land and water mechanisms* as guiding elements to govern Veneto's coastal landscape (Vallerani, 2004). According to this logic, the research verifies the correspondence of the actions towards protection foreseen by territorial authorities (municipalities, provinces, regions) with those made by bodies working in the environmental sector and in tourism (consortiums, associations, parks, etc.).

Transformations of Veneto's coastal areas are part of a global process that started forcefully back in the days of the Serenissima Republic (leaving noteworthy traces of "territorial control"). What prevailed back then had to do with hydraulics and hydrogeology. Afterwards, the past two centuries have witnessed problems related to production pressure, intense anthropic use and tourism. The rise of tourism along the coasts, and their great concentration on the insular city of Venice, is the main threat and pressure to the landscape, nowadays. Its environmental components can be said to have been already partly compromised, degraded, and depleted.

In 1987 Geographer Marcello Zunica[1] had already denounced "the beaches in Veneto as examples of makeshift tourist facilities that had sprouted starting in the 50s". The region, compared to its northern counterparts, has been in the forefront for the phenomenon of illegal building.

1 Zunica, M. (1987), Lo spazio costiero italiano. Dinamiche fisiche e umane. Valerio Levi, Rome

An absence of regulatory measures and policies has promoted the predominance of tourism industry, which after World War II grew significantly, and in fact, ended up partially depleted the landscape and the coast's heritage (Goula, 2008). The current crisis in the development of mass tourism has led to questioning new models which must meet the standards of environmental quality and protection of coastal landscapes (Macchia, Mazzanti, 2004).

Constraint policies whose goal was to protect some unique areas have not managed to avoid widespread violations to the areas, as in the coastal area that stretches from Jesolo, Caorle and Bibione, between the Sile and Tagliamento river. Active protection and integrated landscape planning towards a sustainable development of tourism, were awarded increasing space in international debates[2], becoming a basis on which new theories on planning coastal landscapes (Calcagno Maniglio, 2009) can be conceived.

Macro orientation systems that fall under the theme of cities-nature-tourism must be identified to investigate on Veneto's coastal landscape.

2.1 Built Landscape and human pressure

The morphology of built space and a large scale connection network point to the high urban density along the South Eastern coast of Veneto which stems from anthropic pressures, demographic impact, the economy, ecology, and primarily from the development of tourism.

The existing and planned infrastructures, in tandem with the dynamics of land use have disrupted the space configuration, alterating the morphology, particularly in the areas that stretch from Cavallino Treporti, Jesolo and Bibione. Regional planning[3] forecasts confirm this trend, placing Chioggia, Venice-Lido, and the long coastal stretch from Jesolo to Bibione as major tourist destinations, giving Veneto's territory the vocation of a large, linear, multipolar coastal city.

An in-depth look at coastal landscape, extended to the regional scale, offers insight on human use of coastal land. The Po Delta area, for instance, because of little tourist pressure, is more integrated with natural dynamics of lagoons and valleys.
The built coastal landscape can be structured towards several systems, which are:

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2 For more information see: Sustainable Tourism, the Lanzarote Charter, the World Conference on Sustainable Tourism (WTO, UNEP, UNESCO, EU), Lanzarote, Spain. 1995; Manila Declaration on the Social Impact of World Tourism (WTO, General Assembly), Manila, Philippines. 1997; Rimini Charter, International Conference on Sustainable Tourism (Province of Rimini, Region of Emilia Romagna), Rimini, Italy. 2001.

3 The Regional Territorial Coordination Plan points to a growth and enhancement of'tourist and tourist related activities.

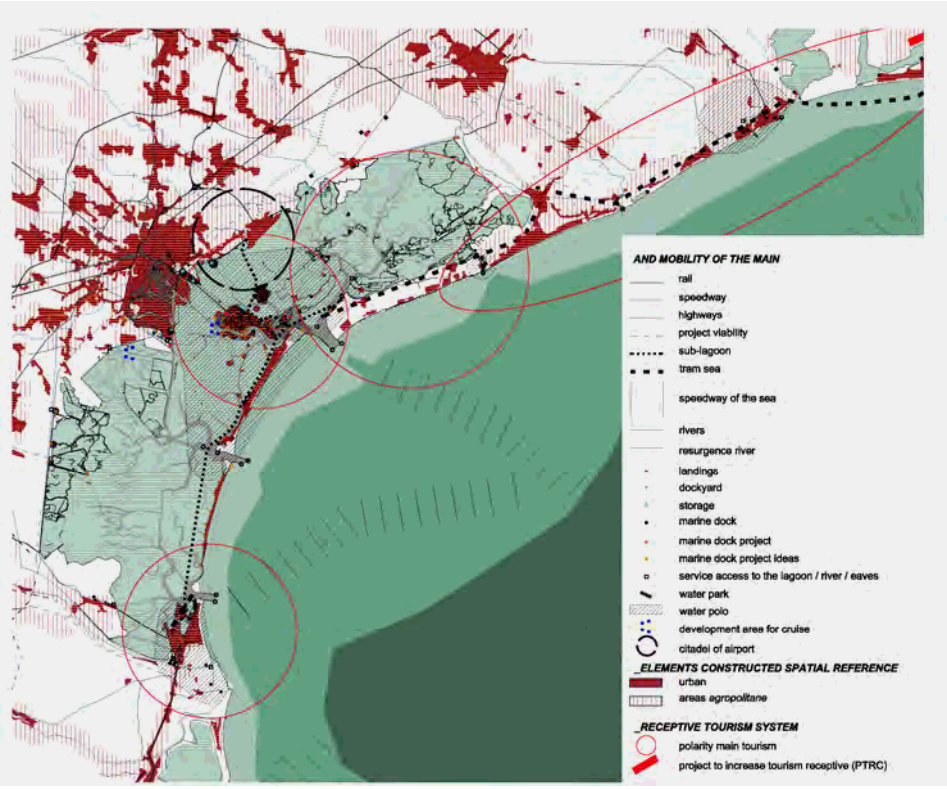

Fig 1. Built landscape and human pressure

- The transport system, parking and mobility, by rail, road, water and air. In particular, connections to the beaches, with the line expected to link the lower lagoon, thus Tessera to the Lido and Chioggia; the new Subway[4] which runs along some coastal areas, etc. The mapping of ports and marinas (river, fishing vessels, and cruise) deserve mention as they are a reference point for territorial planning, as is large nautical terminal system of Chioggia, Venice-Lido, and Caorle. Recreational boating has in fact become the new "driving force" of economic activities found throughout the coastal and surrounding areas. Difficulties arose in respect to the location management, and in managing and controlling water traffic that produces waves. Covering land and water, these phenomena upset the coastline's natural continuity, becoming one of the major causes of deterioration to the delicate morphology of the lagoon;

- The fabric of urbanized and *agripolitan* areas (in the strip above the mean sea level, houses developed along rivers and roads, with settlements on the coast having a *comb pattern*). *Agripolitan* areas are vast specialised farming areas where the territory is significantly used by infrastructures, residence and the productive system. They are a sort of "urban continuum of the countryside" (Bernardi, 2004) which would explains why, when it comes to services, mentality and customs, the residential sprawl in Veneto no longer distinguishes between town and countryside, and it is "(...) the constructed landscapes that

4 Note that the Regional Territorial Coordination Plan and the Provincial territorial coordination Plan report two different profiles.

reconciles nature and culture "(Bernardi, 2004), and " the megalopolis that swallows open space "(Turri, 2004);

- *Tourist facilities*, according to the types of tourism (ecotourism, rural, historic heritage, culture and traditions, exhibitions and conferences, spas, seaside, and sports). The pattern on the economic-productive is reported in the figure no 2. An outline of the tourism sector underscores the theme of urbanization pressure alongside with the demographic impact of coastal municipalities. Data was provided by the Urban Planning Department of the Veneto Region for the "Strategic Project for the conservation and protection of the coasts"[5] in Veneto and refers to tourist accommodation (hotels, campsites, tourist residence, and other), beach services and equipment (the establishments, cabins, umbrellas, data, people accommodated), and marinas (docks and berths).

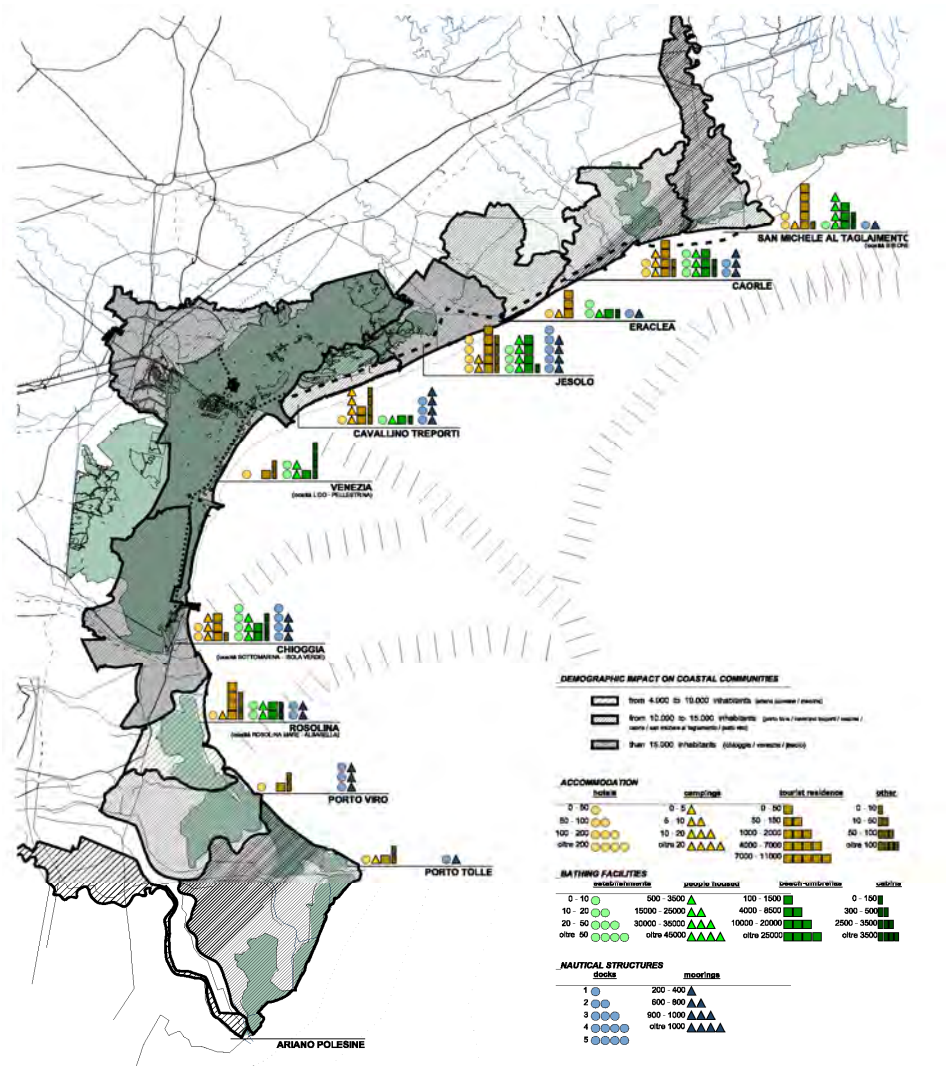

Fig 2. Demographic impact on coastal communities and tourist activities

5 The data source is Mavian L, Operti I. (2008), "Il sistema dei litorali. Elementi per la tutela e la valorizzazione degli ambiti lagunari", Urban Planning Department, Veneto Region, Vol2

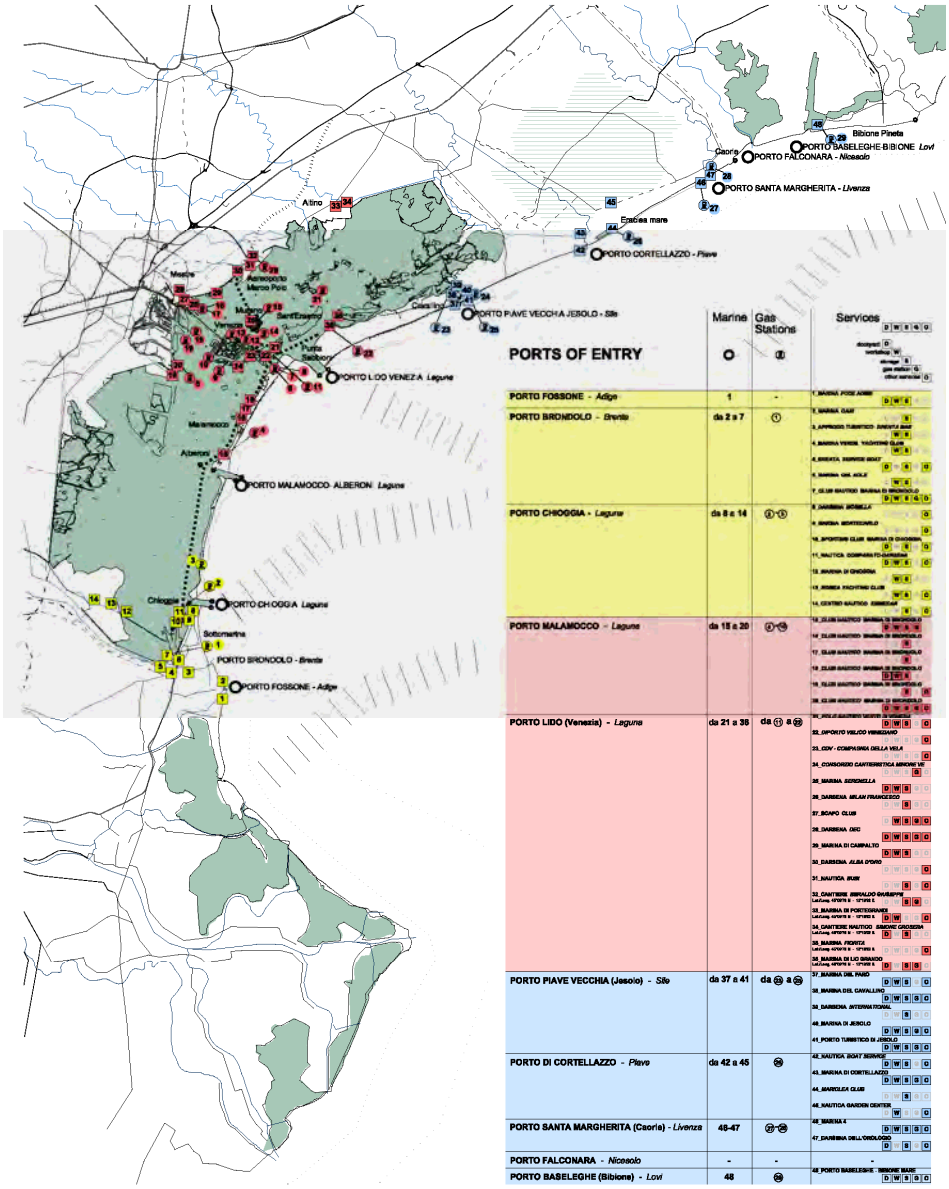

Fig 3. Navigation

2.2 Natural, environmental and socio-cultural values

Distinctive features of open space, read from the scale of the Veneto and North Adriatic coast, offer a extremely rich and complex cognitive framework of the critical areas as well as their great potential. In Veneto Region, more than anywhere else, the landscape comes from man's work on earth which *has been taken away* from the water. Its socio-cultural value is tied to the geomorphological evolution, where natural and man-made aspects are extremely interconnected.

The research approach monitors coastal systems. Its broad research scope helps in organizing, into a continuous geographic sequence, all of the fragments and heterogeneity of the natural and semi-natural landscapes. Moreover this

work serves to underline the need or the opportunities that have to be undertaken for environmental requalification and recovery so that ecological processes can be preserved and favoured (applying the concept of Ecological Network).

One of the great potential opportunities is offered by Venetian coast line, the so called *Litoranea Veneta*, a water mobility system which links Venice to the Gulf of Trieste. It traces the lagoon's ancient internal connection which probably extended to the Adriatic coast reaching the Po Delta (at the back of the fossil dune belt). Nowadays it can re-emerge as a tourist route to navigate inside the lagoon, parallel to the coast. The canals along Veneto's coast could thus become a network of *slow mobility* that connects the different landscapes along the coast and inland. The major rivers would therefore be linked to the lagoons and sea (the route was already announced in regional and provincial plans which are currently discussed to evaluate them as European programmes and projects)[6] .

'Continuity' of the elements of the system are attributable to the following eco-environmental systems:

- A highly natural coastal belt system that goes from the coast to the hinterland. It comprises sandy beaches, dunes, coastal forests, structured vegetation, reclaimed and cultivated marshland. This system includes the marine water surface, the sandy bottoms and 'tegnue' (marine habitats on rocky outcrops that are currently examined by European projects and programmes)[7]

- The system of natural elements - land and water- including lakes and valleys, which define the whole development of Veneto's amphitheater (Turri, 2004), and the uniqueness of its hydrogeological system which have the lagoons inlets to communicate with the mouth of the river and the deltas. This system, along with a dense drainage network, characterise the rich and complex belt that moves inland from the coast about 15-20 km, below mean sea level. This is a fragile landscape as it releases any negative impact of the hinterland onto the lagoon. This land area is the most unstable lands, and is therefore drained artificially with pumps and pumping stations, being in continuous tension between the land and water mechanisms.

In this belt, which this study identified as having added potential to develop a new sustainable dimension of coastal tourist, the elements of design and construction of the inland coastal landscape intersect: reclaimed areas, fishing

6 For more information see *Progetto Acque Antiche. Il percorso della Litoranea Veneta*, as an initiative of INTERREG IIIA Phase CBC Italia–Slovenia 2000–2006 – Province of Venice, Department on EU Policies.

7 For more information see: ARPAV - Area Tecnico Scientifica Osservatorio Alto Adriatico – Polo Regionale Veneto, (2007) LE TEGNÙE: a study of areas of particular environmental interest to enhance local fish resources and to protect nature.

valleys, rice fields, salt marshes[8], vegetable gardens[9], unique examples of historic crops related to this reclaimed marshland environment. Then there are the artefacts that witness the land formation and use, like the lighthouses, fortifications, the *Casoni di Valle*[10], windmills, dewatering stations and navigation locks. There are also artefacts of historical and architectural significance as the Villas that belonged to noble Venetian families, located along the river or just in the surroundings, which could still be reached from Venice by motorboat.

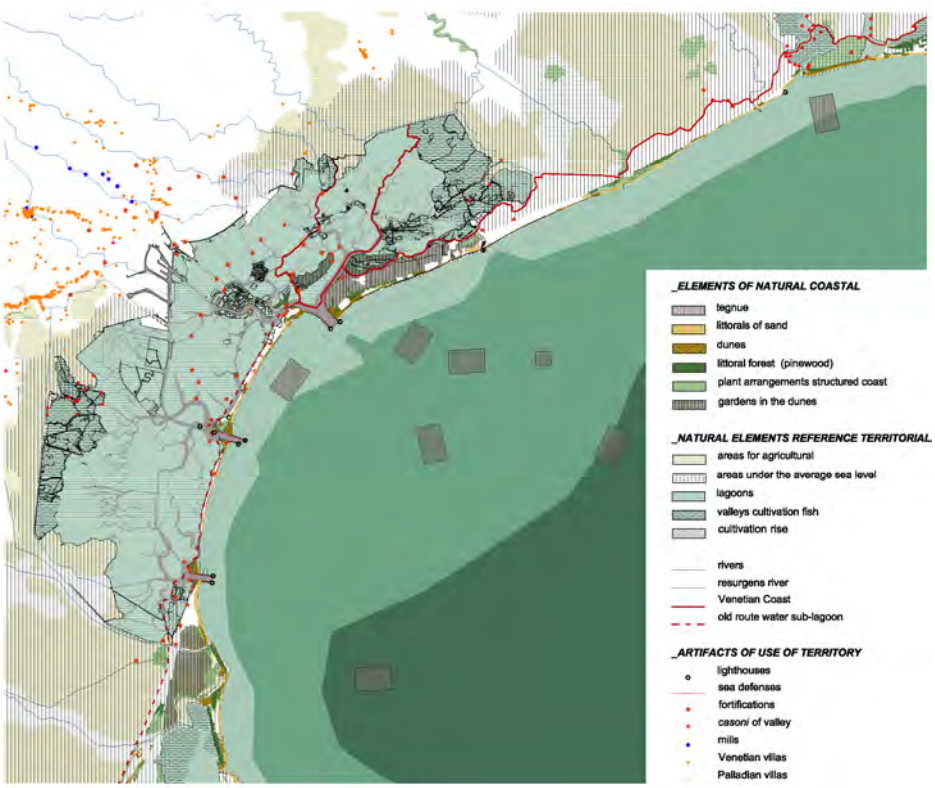

Fig 4. Eco-environmental and socio-cultural values

2.3 Tourism and thematic itineraries

In relation to what was previously mentioned, this study illustrates the potential development of tourism along coastal landscapes by examining the patterns and signs found on the territory, and the existing physical traits. And to facilitate river transport that also connects to the coast, a sustainable tourism model is defined to assure a continuity that provides the dynamics of a slow mobility.

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8 On the topic of salt marshes see J-C.Hocquet, Le sel et la fortune de Venise, Université de Lille 1978, J-C.Hocquet, Chioggia, capitale del sale nel Medioevo, Il Leggio, Sottomarina (VE) 1991

9 Especially those in Chioggia, Venice-St.Erasmo and Cavallino Treporti.

10 The 'Casoni di Valle' are the typical fishing huts of the Venice Lagoon, see Franzin R. (ed). *Casoni: dalle lagune di Caorle e Bibione a Cavarzere.* Ediciclo, Portogruaro.

Our starting point consists in assessing the infrastructures that are already available and the potential of the planning instrument. Maps that are centred on natural resources and tourist use[11] are then compiled. The latter are then divided into thematic itineraries and the different nuclei are organized hierarchically.

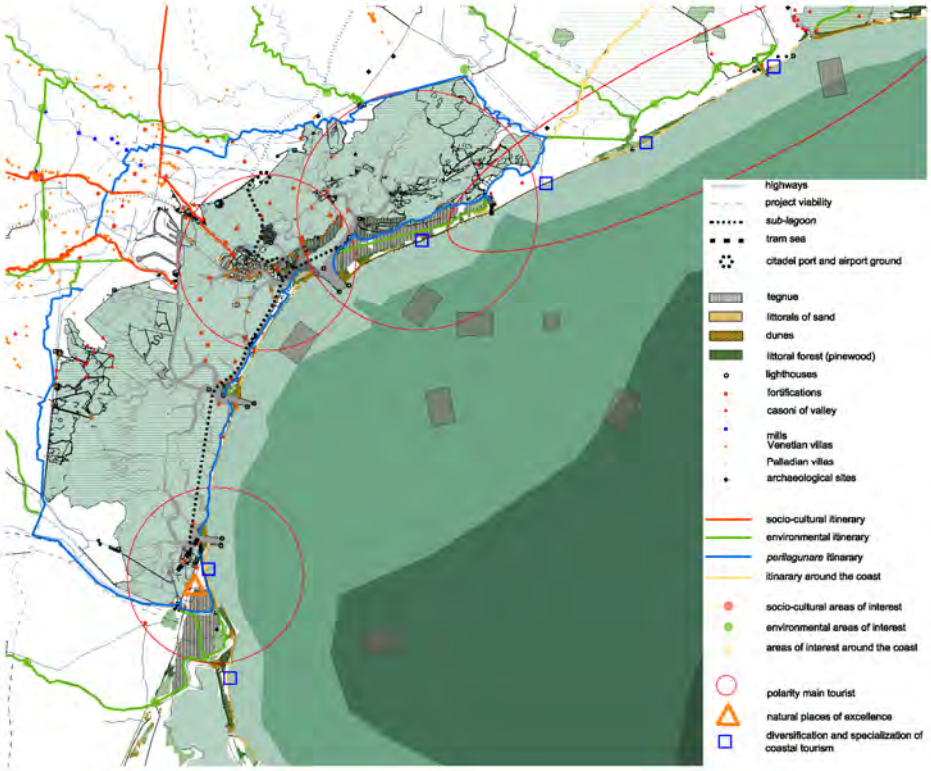

Fig 5. Tourist attractions and thematic itineraries

The maps are created based on the following criteria:

- A historical-cultural itinerary; environmental itinerary, lagoon itinerary and coastal inland itinerary;
- Secondary itineraries on horseback, cycle routes;
- Relevant nuclei related to individual primary routes;
- Main tourist attractions and destinations of excellence.

Our report can therefore be regarded as a base onto which a geography of tourism development and trends of land use can be developed, departing from an analytical approach. Articulate elements comprising tourism, the environment and cultural heritage, with the aid of such approach, can be organized. The nautical theme of marinas can also include the theme of

11 From the Coordinated Territorial Plan of the Venice province, table no 5 on Environmental, historical, cultural and touristic itineraries (scale 1:100.000)

protection and enhancement of the landscape.

2.4 The coast, a comparative analysis

Considering the recent actions and initiatives implemented by the Veneto Region[12] to protect and promote the development of coastal areas, and European experience on the theme of Integrated Coastal Zone Management[13], a comparative analysis of the coast can be formulated. A sequence of themes are found across all of Veneto's coast (covering roughly 113 km). Herein constraint mechanisms, functions and permitted uses defined in local planning instruments were compared and specified. When redefining the coast's special role, beaches were in the forefront from the environmental perspective of reclaimed land.

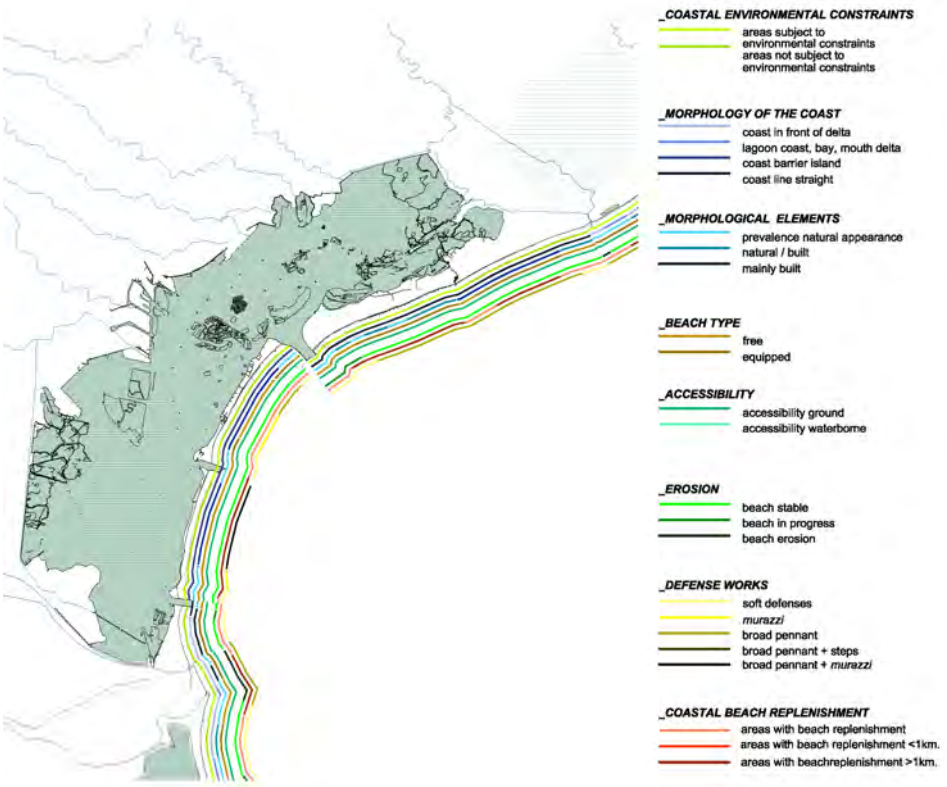

Fig 6. A comparative analysis of the coast

The Figure 6 outlines the gaps found at lagoon inlets and in coastal cities that have had a significant tourism development. Conversely, the Po Delta area represents a clear continuity of the landscape where there is the longest stretch of coastline in Italy which so far has remained untouched by man.

In conclusion the present analysis helps to observe the state of policy

12 Ibidem, Mavian and Operti, 2008

13 See paragraph 3 of this article

implementation along coastal areas and to propose operative guidelines for the redevelopment and enhancement of the coastal area, from a development perspective that is centred on environmental and socio-economic issues. Whereas in the planning phase, it will serve to check the effectiveness of the actions produced by transformation scenarios.

3. The regulatory framework of the Veneto Region and European measures on emerging coastal landscape

Coastal landscape, in this section, is examined in order to re-establish its regulatory framework and discuss the actions that the Veneto Region undertook in accordance to the prescriptions set out by the European Union.

3.1 The status of implementation of European water legislation

The Veneto region plans and programmes the coastal landscape according to the prescriptions contained in the Water Framework Directive and Marine Strategies. This recently established process adopts experimental measures on fishing and on the protection of marine ecosystems, enforced by the Regional Law 15 of 12/07/2007.

The aim of the Water Framework Directive 2000/60/EC deserves attention for its efforts to preserve and improve the water environment of the Community through measures on water quality integrated with measures on quantitative aspects. This EU framework directive provides for the management of the Community's inland surface water, underground water, coastal and transitional waters, classifying the water in order to prevent and reduce pollution, promote a sustainable use of water, protect the environment, improve the conditions of aquatic ecosystems and mitigate the effects of floods and droughts.

The recent Marine Strategy Directive[14] (2008/56/EC) pursues an innovative approach based on ecosystems. It prescribes that all countries monitor the pressures and impacts on the ecosystem, as well as adopt state-of-the-art scientific knowledge on the issue, prior to establishing the priorities and goals.

Marine Spatial Planning (MSP) seeks to ensure that every Marine environment is endowed with a general plan that embodies different activities and interest groups working with the sea. Moreover its goal, when considering the entire land-water ecosystem, is to support decision-makers to adopt integrated policies. The MSP also strives to mitigate the conflicts related to its use, taking into account the marine and terrestrial relationship.

Veneto, with its Regional Law 15 of 12/07/2007 to preserve, protect and

14 The EU marine policy dates back to 2002 when marine protection was one of the seven thematic strategies of the Commission, currently the 6th environment action plan, and after six years, in June 2008, after having consulted all Member States and participating actors, the EU finally adopted the Marine Strategy Directive, enforced on 17 June 2008. It will become the Comunity's environmental pillar in terms of integrated marine policy.

repopulate fish resources, has implemented a system of measures and provisions that establishment Zones of Biological Protection – that correspond to Special Marine Protected Areas (SMPA) - and proted diversification, enhancement and conversion of fishing companies to shellfish farming and the developing tourism. Intervention was programmed through a plan that passed on "Integrated management of coastal area" (DGR n. 3730 of 2/12/2008).

The Regional Council is particularly committed to increasing environmental protection of marine areas; protecting and optimising biological and geomorphological resources of zones in which fish is being repopulated; promotion a socio-economic development that is compatible with nature, and the activities of institutions, bodies or associations, that offer guided tours, scuba diving for scientific purpose, tourism and recreational activities.

A body that deserves mention is the marine Committee[15]. Established as a permanent body, it must be consulted when coordinating and managing the activities affecting coastal landscapes. Its task is therefore to help coordinate intervention and shape regional policies on action programmes.

Contributions for operations considered eligible for funding by the LR 15/07[16] are awarded to the initiatives that are compatible with the national fish plan, with existing national and EU legislation, and with the laws on tourism and education. In the year 2007-2008, 27 projects, with funds amounting to a total of about 12 million Euros were assigned/approved.

Regional Law 15/2007 also foresees that an integrated management plan of the coastal area be laid out within 180 days after the publication of the aforementioned Act. Yet this plan has still not been drawn up. A Regional Decree has however been issued, DGR n. 3730 on the "Initial steps towards an integrated coastal management plan L.R 15/2007". It is a first step towards an overview of the current coastal areas. The goal being to show the extension of Veneto's coastal area (considering knowledge of the physical system of coastal areas, human pressures, the level of pollutants, the management of water resources, as well as high risk and vulnerable areas linked to port activities, maritime transport, tourism, fisheries and aquaculture), the relevant legislation on the different sectors, and other necessary information required for a complete picture of the various activities that affect Veneto's coastal region with

15 Instituted according to L.R. 15/07, art. 3, with D.P.G.R. n. 221 of 22/11/2007, the Advisory board includes the President of the Regional Council (chairing the sessions), the Regional Municipal Councillors as experts on fishing, the President of the competent regional advisory Commission, the President of the Managing Body/Authority, the Comnanders of the Harbourmaster's Office in Veneto, a representative of each trade associations that are part of the local consulting commission on fishing and aquacolture, a representative of sportfishing organization, the President of the Provincial council of Venice, the President of the Province of Rovigo, the Mayors of the municipalities along the coast, a representative of the pleasure craft associations.

16 L.R. 15/07, art. 6

specific reference to hunting and fishing[17].

The DGR 3730 focuses on fishing and on the quality of northern Adriatic coastal waters. Particular attention goes to the emergence of artificial rocks ("tegnue") and on fishing and the quality of northern Adriatic water.

Finally, it should be pointed that since 2006 several initiatives have centred on integrated coastal management in designing sectoral policies such as the one on fish production. The Cooperative League – Veneto's Regional Committee, in a document of 2006[18], proposes itself as the authority that implements a series of measures on the management of fish production. It will also integrate the problems on coordinating fishing activities with other activities, both on land and at sea, covering an area of roughly 150 km from the mouth of the Tagliamento, north of the Po, south of Goro, extending from 3 miles from shoreline.

Additionally, this project is connected to another one that works on similar lagoons problems in the Veneto Region[19]. For a number of reasons these projects are inevitably linked on issues like fishing communities, a co-presence of numerous trades within a category, the interaction of fish resources in the sea-lagoon, and sectoral socio-economic issues.

3.2 Development Prospects: difficult integration of land and water

The first critical problem to emerge from the previous section involves how coastal landscapes are defined and identified as the subjects of integrated programmes and plans. In fact, the Regional Law 15/07 focuses primarily on the sectoral work carried out on marine waters which is oriented and distinct from coastal activities.

Integrated management takes coastal land and waterscapes and it integrates marine and inland waters[20] and landscapes. A good example - though at a different scale and under different legislation - is the Nature Park of Camargue[21]. The park management plan extends its jurisdiction to the coastal areas in front of the Nature Park, and urban planning decisions are integrated to examine the effects caused on the marine areas and vice versa. Note that the coastal landscape extends well beyond the simple shoreline.

Coastal landscapes have seen the increased involvement of the European

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17 The DGR 3730 refers to the Hunting and Fishing Design Unit of the Regional office for Environmental Protection.

18 DGR n. 1134 of 23/04/2004 on the approval notification DGR n. 3974 of 10/12/2004 on the approval of the ranking Measure 4.4 – Actions for Project n. 01/AO/2004

19 A.G.C.I. Del VENETO, Integrated Plan to manage small-scale fishing in lagoons in the Veneto Region, 2006

20 As defined by the Water Framework Directive 2000/60/CE, paragraph 3.1

21 For more information on the Regional Nature Park of Camargue, France, see "Charte Objectif 2022, Parque Naturel Régional de Camargue", Volume 1 and Volume 2, 2009

Union as it promotes policies that extend inland, consider inner coastal landscapes, and landscape that extends towards the water and comprises the marine activities and ecosystems as well as the management of sandy shores.

In alignment with the above, one of the "great" goals of the European Commission, currently under discussion by EU Member States[22], is contained in the Recommendations to the European Parliament and to the Council (COM/00/545), of September 8th, 2000, to establish guidelines that encourage Member States to draft the national strategies on integrated management of coastal areas[23].

Integrated Management of Coastal Zones (IMCZ) aggregate various policies that influence coastal areas because of a dynamic process that is destined to last and evolve in time. And, to implement the instrument, the participation of all stakeholders becomes a benchmark of the methodology. IMCZ is not only an environmental policy. Protecting natural ecosystems is one of the main objectives of the strategy[24] though it also works to promote the economic and social wellbeing of coastal areas so as to favour a modern and dynamic community. Results[25] from the review and evaluation process of the experience to implement IMCZ recommendations adopted by member states, which were promoted the Commission in 2006 and 2007, point to the principles that contribute to the "positive" Management of Integrated Coastal Zone (IMCZ):

1. An ample perspective that does not only focus on isolated aspects, but considers the various interconnected issues is required. Many of the problems involve different spatial-time scales. But all the factors that influence coastal zones, including human activities and natural phenomena must therefore be considered;

2. Adopting a long-term perspective that considers the precautionary principle

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22 Member State did not implement a National Strategy on IMCZ as encouraged by European Recommendations on the issue. Seven countries (Finland Germany, Malta, Portugal, Spain, Romania and Great Britain) are working to establish a national Strategy on IMCZ; another six States (Belgium, Cyprus, France, Greece, Holland and Slovenia) have drafted documents that compare to the national IMCZ Strategy, or integrated management of coastal zones has become an integral part of territorial planning processes; eleven States (Bulgaria, Croatia, Denmark, Estonia, Ireland, Italy, Latvia, Lithuania, Poland, Sweden and Turkey) have not had any IMCZ type of national Strategy implemented. They have only had fragmented experience on issues relating to coastal zones. Source: COM (2007)308 “Address in European Parliament and at the Council: the Evaluation of integrated management of coastal zones (IMCZ) in Europe”

23 The Recomandation was adopted from the European Council and from the European Parliament on May the 30th (2002/413/CE).

24 The European Commision promotes a strategic approach based on environmental protection and on valorization on local resourses toward an integration management between land and water targets.

25 Communication of the European Commission, COM (2007)308 “Address in European Parliament and at the Council: the Evaluation of integrated management of coastal zones (IMCZ) in Europe”

and current and future needs of generations;

3. Set up sufficiently flexible management systems to face the evolution trends of coastal areas and the process of acquiring knowledge;

4. Decisions must be based on accurate and thorough data. The specificity of coastal areas and the variety of European coasts must be taken into account, according to the principle that no preset solutions exist, and that systems and principles must be calibrated each time;

5. Natural forces and the load capacity of ecosystems must be considered when promoting sustainable and socially responsible human from the economic perspective;

6. All stakeholders involved must interact with the stakeholders and encourage involvement in the management process;

7. To coordinate different territorial policies, all levels of government need to be involvement to promote the contacts of different administrations (local, national) and partnerships;

8. A variety of instruments that favour coherence between the goals of sectoral policies and programme and management instruments are needed.

In particular, Integrated marine spatial planning combines the instruments and the procedures of territorial planning with IMCZ principles. The domains of application of territorial planning and IMCZ at sea must be extended with the goal of reaching a balance between the economic, social and environmental dimension of sustainable development and the analysis of the interaction between different sectors in order to develop common tools and enable synergies thus avoiding conflicts. IMCZ and IMSP are complementary instruments for a sustainable coastal and marine development a new and integrated European maritime policy.

A critical outlook on the themes and issues raised by the framework presented herein was adopted in his research. Ample room was dedicated to defining coastal landscapes in order to offer future support to projects, by competent bodies, on integrated planning and management.

4. Planning instruments for the lagoon

The present research examines the coastal areas facing the Venice lagoon and the way the lagoon itself has become a part of the inland area from the perspectives proposed by our research, including the territories of the lagoon shoreline. To develop the transformation/transitional trend scenarios of the territory it is essential for the planning to cross beyond the local dimension (noting that the instruments were adopted just recently) and to be local as well.

4.1 Regional and provincial planning forecast

The new Coordinated Regional Territorial Plan known as PTRC, treat the theme of planning of the Venice lagoon in a very conflicting way. On the one hand the Lagoon "basin" and some adjacent mainland areas are identified as one of the

39 landscape zones[26], defining a highly articulated set of landscape quality objectives and guidelines, and on the other identifying[27], when the plan is first implemented, some strategic projects that are not oriented towards protection and preservation but which instead set up/represent a marked artificialization of the lagoon and its surrounding area.

An initial strategic projects foresees that environmentally conscious and recreational boating areas are likely to expand and thus to increase the number of berths in the macro-areas of the Venice lagoon, in Chioggia, the eastern shore of the Po delta, Lake Garda (north and south) [28].

Logistics of the new Padua-Venice port authority are expected to encompass an area of direct access to the lagoon, a large urban area with infrastructures, water transport that connects Padua to Venice, converting riverside roads into a “truck” road to thus become a multimodal axis.

Finally, to assure transport connections between the airport towns of Venice-Treviso and Verona with Veneto’s mobility network , decisions on the development of Tessera’s Master Plan (see the following paragraph) were fully supported by the city of Venice.

The Territorial Plan for the Coordination of the Province of Venice, known as PTCP, approaches the planning of the Venice lagoon between light and darkness. Even if the Provincial Plan has placed the environmental balance of the lagoon as one of its main priorities by seeking to curtail the degradation of its landscape, it also foresees at the same time an enhancement of port and related activities alongside greater nautical policies, as outlined by the PTRC provisions.

Based on such premises, it must however be highlighted that in order to reach to afore mentioned objectives the plan aims at a general reduction of environmental and landscape degradation, with particular focus on land and water relationship. This goal can only be reached, on the one hand, by having a unified vision of the complex Venetian lagoon that systematizes the different uses and interests, including hydraulic management and the effects derived from the new arrangement in progress, recovering the longitudinal continuity that extends along the northern part of the lagoon. And on the other hand, to help reconsider the current fragile balance and vulnerability of the upstream coastline, and towards an organic plan of "flooding" areas at a lower altitude, which are harder to keep dry and less interesting from an agricultural perspective. Both responses foresee an organic requalification of the entire environmental system, by placing the provincial ecological network in the forefront.

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26 Landscape Ambit, issue 31, under the Decree 42/04

27 Art. 5 related to technical Laws

28 Coordinated Regional Territorial Plan, art. 54 on Technical rules and Regulations

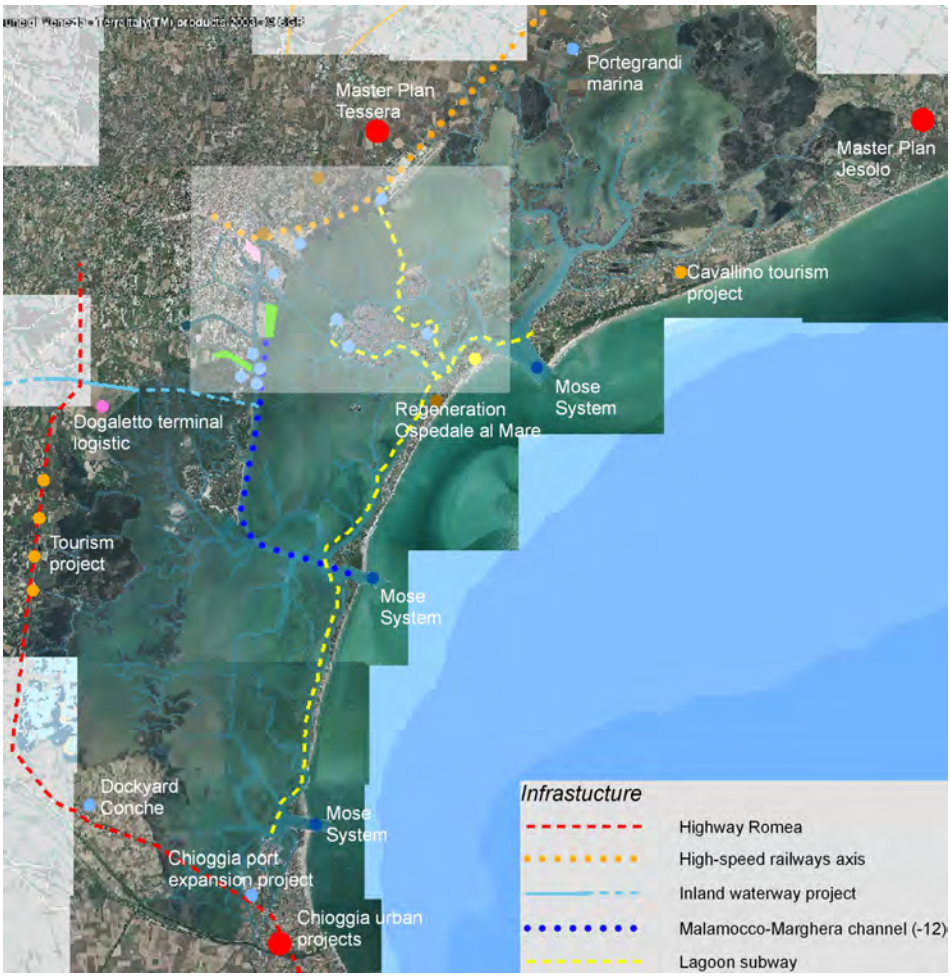

Fig 7.Projects in the Venice lagoon

4.2 The Local Planning

Following a presentation of the planning instruments on a territorial scale (especially regional and provincial), the three conditions for development that emerged from the municipal planning system[29] can now try to be defined in brief.

The highly urbanized coastal area must cater predominantly to residential functions and tourist activities. The current planning process are designed to make the coastal front even more rigid and with infrastructures that include both a coastal apparatus[30] (many tourist related activities, especially geared towards bathing), and an adjacent area to the beach where transformation projects have

29 Nine municipalities (Chioggia, Codevigo (PD), Campagna Lupia, Mira, Quarto d'Altino, Musile di Piave, Jesolo, Cavallino Treporti and Venice) were referred to as their territory opens onto the Venice lagoon.

30 Si veda ad esempio l'insieme delle trasformazioni introdotte dal Master Plan di Jesolo, e recepite dalla Variante al Piano Regolatore Generale del 2003, nell'ampia porzione di territorio compresa tra Jesolo Paese e Jesolo Lido

significantly altered the landscape of zones that used to be a predominantly agricultural or scarcely urbanized. As an example, we can refer to the changes set by Jesolo Masterplan, included in the variant to the Piano Regolatore Generale (town planning scheme) of 2003, concerning the wide area situated within Jesolo Paese and Jesolo Lido, as well as to those set by the Progetti Speciali (special projects), included in the variant of 2007 in Chioggia Municipality. See, for example, the conversion of the docks trading area in Saloni island; the increase of residential and tertiary areas in the historical centre; carrying out a 18 holes golf pitch in Isola Verde; the rising of dockyards, not only at the main waterstreams mouths.

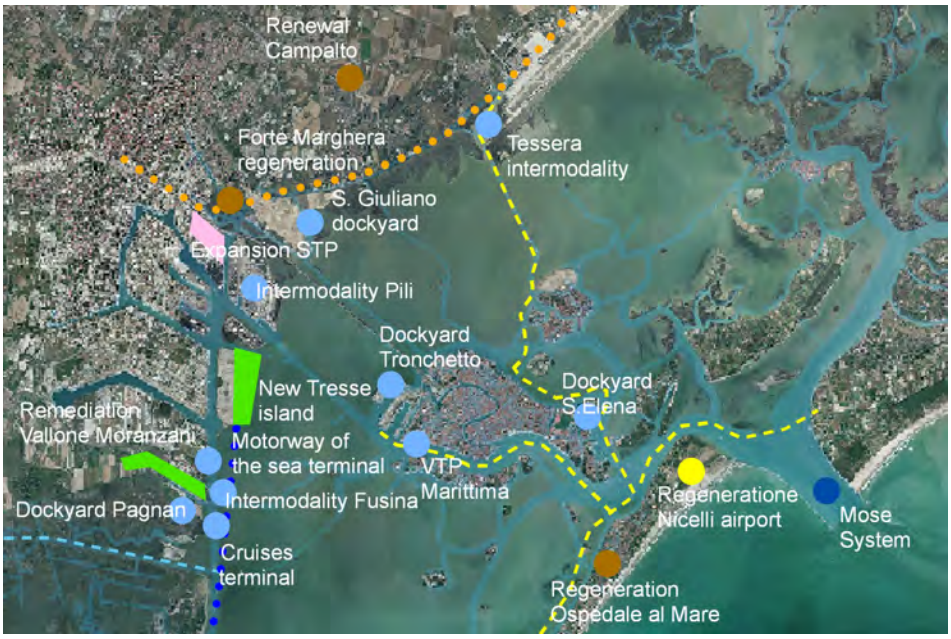

Fig 8. Projects in the Venice lagoon, Central Lagoon

The Mestre lagoon area is the urban centre with the greatest artificialization, a 15 Km long waterfront including the industrial area of Porto Marghera, a tradeport, a ramification of urban dwellings in Mestre, and the international Marco Polo airport. New forecasts[31] of the Venice Municipal Administration on this domain enable SAVE (the airport managing body) to proceed with the expansion of airport infrastructures, to create adequate services and urban functions[32] that support the airport's development process (especially the business park) of the areas which the city has vacated, resulting in greater rigidity of the sensitive front and agricultural hinterland around Campalto, which includes archaeological sites of Altino.

As concerned with the remaining strip just around the Lagoon, the urban

31 These guidelines are part of the 2008 Tessera Master Plan

[32] Within an area of 17 hectares, 8% is for the economic activities area and 18% for the sport facilities, as in Tessera Masterplan, 2008.

settlements are located next to the Venice-Trieste axis (SS 14), near Riviera del Brenta (Brenta river shore) (SR 11) and all along the way connecting Mira to Piove di Sacco (SP 13). However, it is possible to find smaller settings as Pontegrandi and Caposile in the northern area, and Lova in the southern one. Regarding the latter area considered, though there are no remarkable urban settlements, there are two highly important axes: the SS 309 Romea, running along Canale Novissimo and the Lagoon shore, and SR 43, which skirts Taglio del Sile, situated on the Lagoon border as well.

Even the remaining strip around the lagoon seems have a prevalence of important infrastructure axes. In fact current planning instruments and the ones in progress are progressively determining new heavy urbanization. Consider for instance what is foreseen by the Municipality of Campagna Lupia in terms of buffer zones, the new Variation for adjustments to the Venice Lagoon Area Plan (known as PALAV) – In valley zones (2008), which foresee approximately 58,000 sqm of building surface destined to tourism and tourist services, in areas along the Romea, along the lagoon margin. Moreover, in Piruea "Conca di Pontegrandi", situated in Quarto d'Altino Municipality, both residential and recreation structures are being carried out.

Regarding the recreational navigation infrastructures system, existing within the Lagoon area, a study, carried out in 2002 by Coses, foresaw 6,000 new boat park places according to the planning tools of the nine Lagoon municipalities, compared to the already existing 19,000. (It is important to consider that, because of the existing unauthorized boat places, the above quantity is surely underesteemed). Such forecasts will affect the Lagoon environmental structure and will result in an increasing water traffic.

Municipality	*Current boat parking places (water and land)*	*New boat parking places foreseen (water and land)*	*Total*
Chioggia	1.033	1.225	2.258
Codevigo	10	350	360
Campagna Lupia	440	Nd	440
Mira	1.127	500	1.627
Quarto d'Altino	110	294	404
Musile di Piave	0	0	0
Jesolo	848	1.712	2.560
Cavallino Treporti	718	190	908
Venice	14.230	1.303	15.533
Total	*18.516*	*5.574*	*24.090*

Tab. 1. Recreational navigation in Venice Lagoon. Source: "La cantieristica minore nel Comune di Venezia". Coses. 2002.

Conclusion

The goal of the study is to evaluate the impact of potential development of coastal tourism activities. Tourism here follows different local demand patterns thus requiring appropriate intervention to the land, sea, and the coastal and lagoon areas affected by the intervention that must comply with the latest rules and regulations in force on tidal management and on lagoon entrance that include the Community law referred above.

Investigation has so far centred on defining the scenarios that generate the transformation of vast areas, by identifying the important theme of “nature - city – tourist” relations, which deserves further expansion, and on the opportunities the territory offers to set a potential plan or reuse of an area close to the lagoon entrance can be set.

Work will therefore involve the drafting of a 'work in progress' scheme which shows, by approximation, the transformative actions foreseen from the application of the planning and protection instruments of the territory and the opportunities offereb by the land resources, the landscape and the environment.

Two main scenarios are foreseeable, one derived from the future trend, and the other from planning strategies oriented to the management and conservation of the project areas. The above will have to be subjected to a summative evaluation.

The first are aimed detecting the main factors of compatibility and criticality of Veneto’s coastal land, in particular the coast along the lagoon. The concurrence of man-induced pressures are also evaluated in the components that refer to the development, the transformation or conservation of the infrastructure forecast system, of the settlement and cultural system, and of tourism and in the pleasure craft system.

The latter strive to identify elements and opportunities of environmental continuity of coastal development. These include the coastal landscapes and its inland, illustrating interpretation patterns that feature the following landscape components: landscapes and tourism, landscapes and navigation , landscapes the productive use of land and water, landscapes and nature.

In particular, the study examines the territorial context in question that will undergo the implementation of interventions to manage the tides that serve to identify the ways to redesign the landscape of the areas affected by the above-mentioned potential scenarios.

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CLIMATE CHANGES IN VENICE LAGOON, MITIGATION MEASURES AND EVOLUTION ADAPTATION IN TERRITORY USES
Requalification and redesigning of some land areas facing Venice Lagoon

Stefano Rocchetto[1], Monica Bosio[1], Tommaso Fornasiero[1] , Valentina Gambelli[1]

[1] *Dipartimento Unico della Ricerca, Facoltà di Architettura, Università Iuav di Venezia*

Riassunto

La fase conclusiva della ricerca è finalizzata ad evidenziare le criticità generate dalla interpolazione tra le condizioni al presente e le previsioni dei cambiamenti climatici al 2100, con particolare riferimento alla Laguna centrale, in quella porzione che va da Venezia al Canale dei Petroli e sulla quale si affaccia il waterfront di Porto Marghera e delle Casse di Colmata.

Viene innanzitutto costruito un quadro dello *stato di fatto* che assume come fattori significativi quelli relativi alla morfologia e alle opere di salvaguardia dell'ecosistema lagunare da un lato e i progetti di sviluppo e riconversione della portualità veneziana dall'altro.

Mentre questi ultimi sono stati analizzati e descritti nelle fasi pregresse della ricerca (fatta eccezione per alcuni recenti aggiornamenti come il porto d'altura), viene in questa fase dedicato un capitolo specifico ai momenti salienti della storia della **morfologia** della Laguna di Venezia e alla descrizione sintetica delle problematicità registrate al presente.

I dati relativi alle previsioni dell'innalzamento del livello del mare al 2100 desunti dagli scenari dei cambiamenti climatici alle varie scale vengono messi in relazione con i dati relativi al fenomeno naturale delle maree proiettato anch'esso al 2100.

Questo quadro complessivo evidenzia come alcune criticità attuali siano di proporzioni tali per cui l'assunzione di previsioni di cambiamenti climatici potrebbero (in riferimento soprattutto all'innalzamento del livello del mare) acuire i problemi, più che generarli: ci si riferisce, per esempio, al deficit di sedimenti che da decenni sta trasformando la laguna centrale in braccio di mare.

Alcuni aspetti sono invece più strettamente legati all'assunzione di uno o l'altro estremo della forbice di previsione di innalzamento: è il caso dell'**accessibilità** a Porto Marghera dal mare Adriatico e viceversa, (attualmente garantita dal canale dei Petroli la cui navigabilità deve comunque essere continuamente ripristinata e/o conservata con l'escavo del tratto nord-sud) che vedrebbe più o meno compromessa la sua funzionalità, in ragione della prioritaria e imprescindibile salvaguardia di Venezia attraverso il funzionamento delle paratie mobili alle bocche di porto.

Questo quadro analitico e critico costituisce la base di partenza per la definizione di uno scenario intermedio al 2050 e due scenari tra loro alternativi al 2100, che indagano le possibili trasformazioni di questa porzione di territorio lagunare tra terraferma e mare, assumendo come prioritari gli obiettivi di salvaguardia dei centri storici della laguna e, quindi, verificando le possibili soluzioni adattive delle politiche di sviluppo economico programmate o annunciate in area portuale (logistica, crocieristica e attività produttive in genere) e ricettive in aree di bordo.

Una ricognizione storica dello sviluppo lagunare dai primi insediamenti umani ad oggi, evidenzia l'incongruità della distinzione tra *habitat naturale* e *habitat umano*, e la necessità di parlare invece di un *sistema laguna* come palcoscenico di azioni antropiche e ripercussioni "naturali" o di eventi naturali e risposte antropiche, in un continuo e reciproco rapporto di *causa e effetto.*

Infine, ma non ultimo, è stato costruito un regesto di progetti realizzati, e non, soprattutto in altri luoghi del pianeta, e ritenuti pertinenti per affinità contestuali e tematiche con l'ambito della ricerca e gli scenari approntati.

Tali progetti sono concepiti come strumenti di misurazione delle scelte progettuali, necessari per verificare la fattibilità delle ipotesi a scala territoriale e capaci di far immaginare alla dimensione umana le relazioni tra natura e artificio, tra l'abitare e il lavorare, tra la contemplazione e l'azione , tra terra e a acqua.

Abstract

The research final phase is finalized to found critical problems generated from interpolation between today's Lagoon conditions and climate changing forecasts at 2100. The site we concentrate our research is the Central Lagoon, between Venice and The Petroli Channel, where Porto Marghera waterfront and Casse di Colmata face.

Initially the current situation picture has been built that assumes as significant factors the ecosystem morphology/safeguard, and development/conversion projects for Venice harbour.

These ones have been discussed already in the previous research phases; one of this research phase is dedicated to morphology history in Venice Lagoon and to brief description of present condition problems.

Data related to rising seawater forecasts at 2100 picked up from climate changing scenarios at various scales, are interpolated to the natural tide phenomenon at 2100.

This complex picture detects today's problems are already such critical that climate-changing forecasts could just make them worst: for example, from decades the sediment loss phenomenon is constantly changing Venice central Lagoon in a sea gulf.

Some other aspects are strictly connected to the choice between the worst and the best seawater rising forecast: for example accessibility to Porto Marghera

from Adriatic sea. This accessibility would be more or less compromised by seawater rising level, because of the priority of Venice safeguard by the mobile dyke system rising at Lagoon entrances.

This critical and analytic picture is the starting point of one 2050 scenario definition and two 2100 scenarios definition (these last alternatives between them). These three scenarios investigate possible transformations of this part of Lagoon, between land and sea, assuming as a priority Venice and Lagoon small historical centres safeguard, and verifying possible adaptive solutions of programmed and proposed politics of both economic development in harbour areas, and accommodation development in border areas.

Historical recognition of lagoon development from first human settlements up to today, emphasizes the need to speak about a unitary *lagoon system,* without a distinction between *natural habitat* and *human habitat,* in which anthropic actions produced always “natural” repercussions, in a continuous and mutual relation cause – effect.

Last, but not least, a similar projects (realized or not) regest has been created as a measurement-verifying instrument of Venice large-scale ipothesis fattibility. At the human scale, the regest wants to be an instrument to image relations between natural and artificial, living and working, contemplation and action, land and water.

1. Introduction and method

The Central Lagoon of Venice is the investigation territory, which means that part of the lagoon basin between the city of Venice and the port entrance of “Malamocco”, comprehensive of “Porto Marghera” and the “Casse di Colmata”. The research aims to emphasize the problems generated by interpolation of present conditions and climate changing previsions at 2100. It concludes by the definition of transformative hypothesis (project scenarios), as a possible answer to problems pointed out.

The current situation picture has been initially built and it has been configured itself as a first scenario, because it shows “as built” some projects that actually are still not built, even though they are all contingent.

A particular section is dedicated to “high waters” phenomenon data interpolation and to the rising tide level forecasting at 2100.

The *current situation scenario* is the starting point for three future project/scenario: the first one intermediate at 2050; two at 2100, alternatives between them. These scenarios are possible answers to three different macro problems: the Venice and minor historical centres safeguard, the lagoon morphological system restoration and Venice port accessibility from sea.

The historical recognition of lagoon development from first human settlements up to today, emphasizes the need to speak about a unitary *lagoon system,* in which anthropic actions produced always “natural” repercussions, in a continuous and mutual relation cause – effect.

Scenarios have been elaborated basing on this conviction.

Finally a similar projects (realized or not) regest has been built as a measurement-verifying instrument of Venice large-scale ipothesis fattibility and as a human scale prefiguration of generable relations from these ipothesis.

2. The current situation

The current situation can be resumed in three main themes:

- Development and harbour/industrial reconversion;
- Environmental requalification and mitigation interventions;
- Lagoon morphological situation and defence infrastructures for “high water rising”.

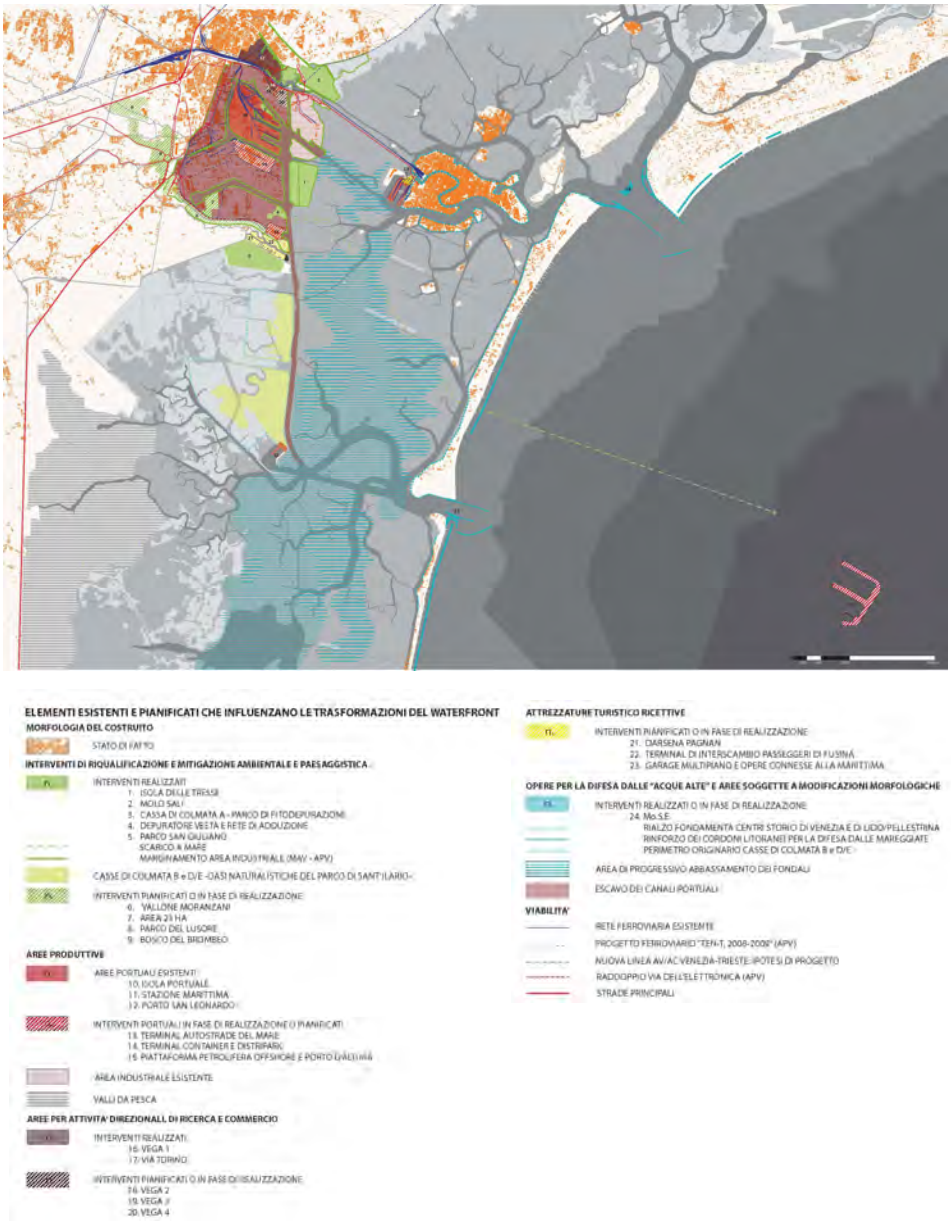

Fig. 1. “Current situation” sheet: it resumes actual themes and problems

Harbour and industrial areas development field includes both the chemical division reconversion to logistic/harbour uses (terminal “Autostrade del mare”, Terminal “Container” and Districpark), and the border areas closed down transformed to service and accommodation sectors (Vega, Terminal Fusina, Pagnan harbour).

Another important theme is the environmental cleaning up and requalification of industrial areas and front water basin: relatively to the huge problem of sludge dumping in the Lagoon, the harbour islands margining, the adduction network and the purification plants, have been almost completed; regarding soils the “Masterplan per la bonifica dei siti inquinati di P.M.-2004” is the principal planning instrument that aimed, as first, to the characterization of soils. (Objective almost reached).

Fig. 2a. Principal projects in building phase or provided along Central Lagoon border (sheet T_01).

A lot of these border projects can’t be reduced to solve just one of previous themes. This is the case of dredging industrial channels: it aims to restore the internal lagoon navigability for big ships (that was no more possible from 2004), but it produces the polluted soil purification and collocation problem. Realized and future dumping areas planned in the “S.I.N.” (national importance site) of Porto Marghera (Tresse island enlargement and Vallone Moranzani) are, as a matter of fact, green parks in their “superficial façade”[33].

[33] In the 2010 P.O.T. (2008-11) revision Venice Port Authority points Tresse Island as the most significant site to install an extension of 212.000 squared meter of photovoltaic panels.

Lagoon morphology is characterized by a huge sediment exchange with the sea and results are evident especially in central lagoon basin. In the last 100 years the huge hydrodynamic changes, make worse erosive processes and produced a progressive reduction of area of Barena and the constant lagoon-bed lowering. This process is so strong in the Central Lagoon, that this part of the lagoon basin is assuming the characteristics of a sea gulf.

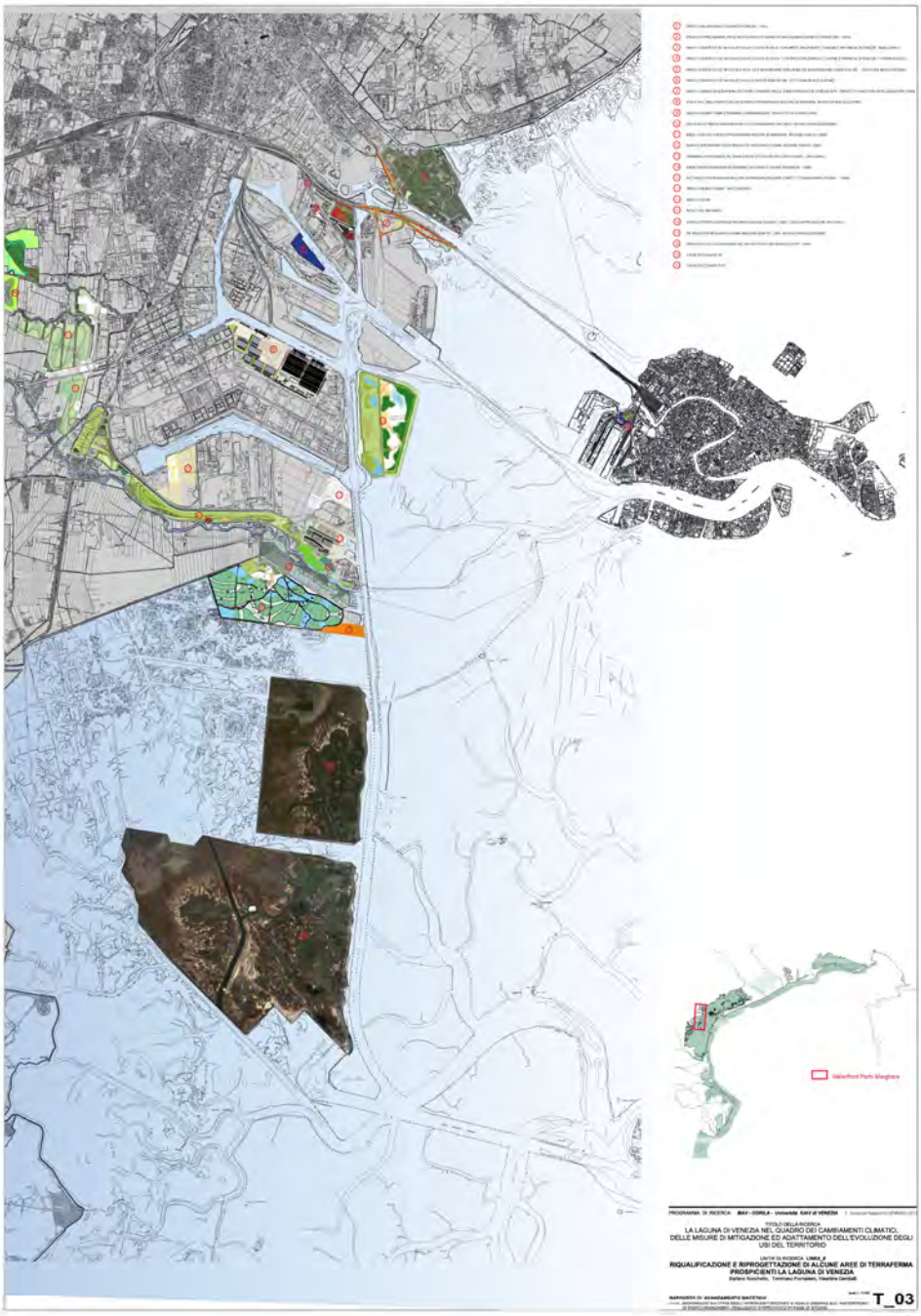

Fig. 2b. Principal projects in building phase or provided along Central Lagoon border (sheet T_02).

The causes that determined this process are various and they are principally derived by the human necessity to maintain lagoon accessibility and navigability. Some of these causes are from past centuries (rivers deviation of XVII century) and some others are more recent (XIX century lagoon entrances modifications and XX century realization of artificial channels Vittorio Emanuele and Malamocco-Marghera).

Morphological interventions are still possible to contrast the degradation phenomenon: to reduce the fetch and the wave motion due to wind and to boat crossing, Barene rebuilding, the reinforcement of Barene borders, the raising of Barene level (referring to new medium sea-level), the plantation of halophilous plants capable to retain the sediment fine components, and also the fishing and traffic regulation have been planned. [34]

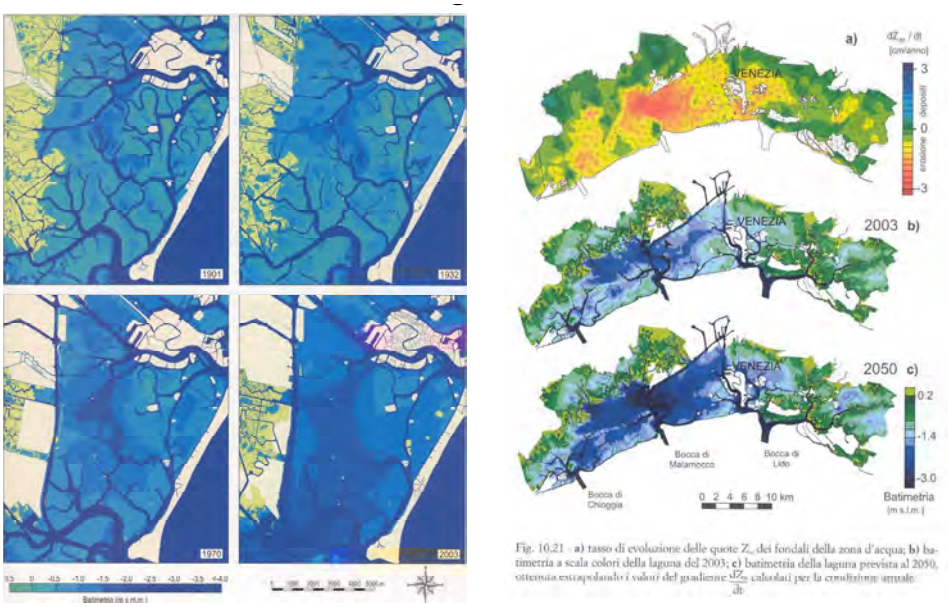

Fig. 3. Lagoon Morphological evolution: lagoon bathymetry from 1901 to 2003, and forecasts to 2050 .

"High water" phenomenon is strictly linked to morphological and hydrodynamic Lagoon conditions, and it will be more frequent in the future, caused by forecasted climate changes.

From decades Venice and minor islands Safeguard, is the starting point of

[34] In "Attività di aggiornamento del Piano degli Interventi per il Recupero Morfologico in applicazione alla delibera del Consiglio dei Ministri del 15 Marzo 2001". For a synthesis see "Stato dell'ecosistema lagunare veneziano-Strumenti del magistrato alle Acque di Venezia" – Marsilio . july 2010, in particolar the chapter "L'evoluzione morfologica" authors Luca De Nat (Thesis Spa) , Alessandro Bergamasco (CNR –IAMC-Messina), Andrea Rismondo, Martina Cazzin (SELC), pages 95-97. That other studies are "Su alcuni possibili interventi di riequilibrio morfologico della laguna " in Luigi D'Alpaos, *Fatti e Misfatti di idraulica lagunare. La laguna di Venezia dalla diversione dei fiumi alle nuove bocche di porto,* Istituto Veneto di Scienze, Lettere ed Arti, Memorie 44, Venezia 2010.

research and investments: the most important investment is the **Mo.S.E.,** the mobile dyke system designed for Venice and lagoon "high water" defence. Its construction started in 2006 and it will be completed in 2014.

It will work with tides ≥ 110 cm a.m.s.l. and it will protect up to 3 meter high tides. The needed time to activate the system (rise dykes, maintain in position during high tide and lower them at the end of the high tide) is calculated in 4-5 hours; the false alarms are valued in the order of 30-50%. The seaside reinforcement and the rising level of some Venice borders, complete the protection system.

3. Tides ≥ 110 cm calculations referred to 2050 and 2100 scenarios.

Data of sea level rise forecasts at 2100, picked from climate changes scenarios at various scales, synthetically listed in the following table, are related to natural tide phenomenon 2100 projections.

Some of actual morphological problems can make just worse, whatever will be the sea level rise. In the other hand, other aspects are strictly connected to a choice that needs to be taken: Porto Marghera Accessibility from Adriatic Sea is one of these aspects. Porto Marghera, in fact, won't be able to work properly, because the priority Venice safeguard will be the first choice by closing Mo.S.E. dykes.

SEA LEVEL RISE FORECASTS AT 2100 *Isostatic and tectonic local movements (subsidence) are added to I.P.C.C. forecasts.				
FONTI	**I.P.C.C. 2007 cm**	**E.N.E.A. 2007* cm**	**C.N.R. VE 2008* cm**	**Min.Infr.e Trasp.- M.A.V., C.V.N., 2010[35] cm**
valore minimo	18	36	17	4
valore massimo	**59**	**108**	**53**	**50**
VALORE MEDIO	38,5	72	35	27

Tab. 1. sea level rise forecasts at 2100.

Now the following question seems proper: how many times mobile dykes at the lagoon entrances will work in the next years, if we assume different sea level rise forecasts data, at local and global scale?

If we consider the sea level rise forecast at 2050, made by I.P.C.C. in 2007 of

[35] SAL.VE. Salvaguardia Venezia,site: http://www.salve.it/it/soluzioni/acque/f_avanzamento.html ,october 2010.

+29,5 cm and by M.A.V. of +25 cm, lagoon entrances will be closed (with tides ≥110 cm) between the **4,22%** to the **6,02%** of total hours/year.

In both cases, the defence system from “high water”, would guarantee the Venice and Lagoon Safeguard and the Commercial and industrial harbour could still work properly.

PREVISIONI DI INNALZAMENTO DEL LIVELLO DEL MARE AL 2100

*alle previsioni I.P.C.C. sono sommati anche i valori di movimenti isostatici e tettonici locali (subsidenza).

FONTI	I.P.C.C. 2007 cm	E.N.E.A. 2007* cm	C.N.R. VE 2008* cm	M.Infr.e Trasp.- M.A.V., C.V.N., 2010 cm
valore minimo	18	36	17	4
valore massimo	**59**	**108**	**53**	**50**
VALORE MEDIO	38,5	72	35	27

Livelli di marea	PERIODO CONSIDERATO 2000-2009 PERMANENZA ore	min	n. casi	DURATA MEDIA ore	min	FREQUENZA n. casi/anni
> = 190 cm	0	0	0	0	0	0
> = 180 cm	0	0	0	0	0	0
> = 170 cm	0	0	0	0	0	0
> = 160 cm	0	0	0	0	0	0
> = 150 cm	1	20	1	0	0	1/10 anni
> = 140 cm	10	55	5	2	11	1/3.3
> = 130 cm	25	10	9	2	48	1/2
> = 120 cm	54	25	20	2	43	2.0
> = 110 cm	131	35	52	2	31	5.2
> = 100 cm	341	25	141	2	25	14.1
> = 90 cm	873	35	336	2	36	33.6
> = 80 cm	2184	60	811	2	42	81.1
> = 70 cm	5381	50	1897	2	50	189.7
> = 60 cm	11306	15	3306	3	25	330.6
> = 50 cm	20016	40	4768	4	12	476.8
> = 40 cm	30700	50	5982	5	8	598.2
> = 30 cm	42329	40	7012	6	2	701.2
> = 20 cm	53768	55	7981	6	44	798.1
> = 10 cm	63817	30	8964	7	7	896.4
> = 0 cm	72101	30	10051	7	10	1005.1
< 0 cm	15545	35	3809	4	5	380.9
< -10 cm	9220	45	2649	3	29	264.9
< -20 cm	4929	25	1730	2	51	173.0
< -30 cm	2208	0	958	2	18	95.8
< -40 cm	775	25	404	1	55	40.4
< -50 cm	220	35	129	1	42	12.9
< -60 cm	65	30	35	1	51	3.5
< -70 cm	14	5	9	1	33	1/1.1
< -80 cm	1	0	1	0	0	1/10 anni
< -90 cm	0	0	0	0	0	0.0
< -100 cm	0	0	0	0	0	0.0

Fig. 4. Scenarios: tide calculation ≥ 110 cm, 2050 and 2100

There are different conclusions if we consider the 2100 scenario: if we assume both the worst sea level rise forecasts by I.P.C.C. /2007 (+59 cm) or the better ones by C.N.R. VE./2008 (+53 cm) and by M.A.V. (+50 cm), the lagoon entrances would be closed from the **35,37%** to the **24,53% of total hours/year.** Mobile dykes will work, in the worst scenario, almost every day and often twice a day; in the better one for the 2/3 days/year.[36]

Summarizing, listed below there are problems related to morphological degrade and to the interpolation of sea level rise forecasts and lagoon safeguard infrastructures from "high water" phenomenon:

- Central Lagoon is interested by a progressive lagoon-bed lowering that aims to transform it to a sea gulf;
- The watershed between the central/north lagoon basin and the central one[37], moved to Venice, changing water current circulation and maximum internal tide levels curves;
- It's possible to improve morphological structure and tide spread timing, to reduce sediment loss, by lagoon morphologic interventions.

Moreover, it's possible to formulate following forecasts:

- Venice Lagoon, historically always connected with the Adriatic Sea, will become a closer lagoon, with a low water changing frequency from the sea. In case forecasts will be worse than mentioned we should consider that the Venice lagoon would became a completely sea-separated ecosystem: a closed lagoon physically and environmentally different from today.
- Industrial and commercial system connected to maritime activities will need to face the future difficult accessibility from the sea.

3- Scenarios

Scenarios investigate possible transformations in this part of lagoon territory between land and sea, assuming as priority Venice and minor islands safeguard.

They will verify possible adaptive solutions for economical development politics in harbour area (logistics, cruises and industrial activities in general) and for accommodation politics in industrial border areas.

It's very difficult to forecast a future so far, but we can start from two statements:

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[36] Periods in which high water phenomenoun is more often ≥110 cm are December/March and June/September, 8 months per year. Exceptional tides are historically concentrated (75%) in November, December and October. The annual average of mobile dykes working hours would have more frequence closing periods during summer, that is the season of more cruise traffic in the lagoon.

[37] The division line between liquid surfaces fed by each Lagoon Entrance (Lido and Malamocco)

1- Maintenance and productive system development of activity sectors compatibles with territory asset and ecological and economical sustainability. That would not condemn Venice to an economical destiny connected just to tourism, making Venice a thematic Park better than a normal city.
2- Lagoon environment and Venice safeguard, in the consciousness that to obtain a so important aim it's really important to understand all transformations of the past 600 years, particularly the last century ones, and to imagine new morphological assets consistent with lagoon natural system, but also able to keep together the development reasons (also industrial and commercial) with the natural and landscape safeguard.

Scenarios start from the "current situation" by picking up from existing planning instruments, at different scales, all interesting territory development ipothesis (Waterway VE-PD completion and the environmental rehabilitation as public green area of the petrol refinery and Petrol Depot island); other indications by planning instruments have been dismissed because they contrasted with valorisation politics of agricultural areas nearby the lagoon (logistic centre ipothized by P.T.R.C. in the area of the Sant'Ilario Territorial Park in Mira district).

In projecting scenarios to 2100, we aim to change those dismantled industrial soils to parts of a complex and dense city facing the lagoon horizon, like Venice. This would mean to stop the diffuse hinterland urbanization and to drive settlement politics to the concept of soil recycle, even those soil that are compromised by decades of industrial activities, the reclaim of which would prefer the logics of abandon.

Scenario/project at 2050

For the very long time in between today to 2100, it has been elaborated an intermediate scenario/project.

The planned interventions are:

a- New urbanization politics: the petrol refinery and the petrol depot islands transformation; the first industrial area and the Naviglio Brenta waterway outlet transformations.
b- Commercial and Industrial activities transfer: Cruise port transfer in the Cassa di Colmata B; petrol refinery and depots offshore (eventual) transfer.
c- Hydraulic and lagoon morphological interventions: artificial structures settlement in the central lagoon basin and along the Petroli and Vittorio Emanuele Channels; Waterway VE-PD completion.
d- Realization of a reducing pollution system for lagoon waters.

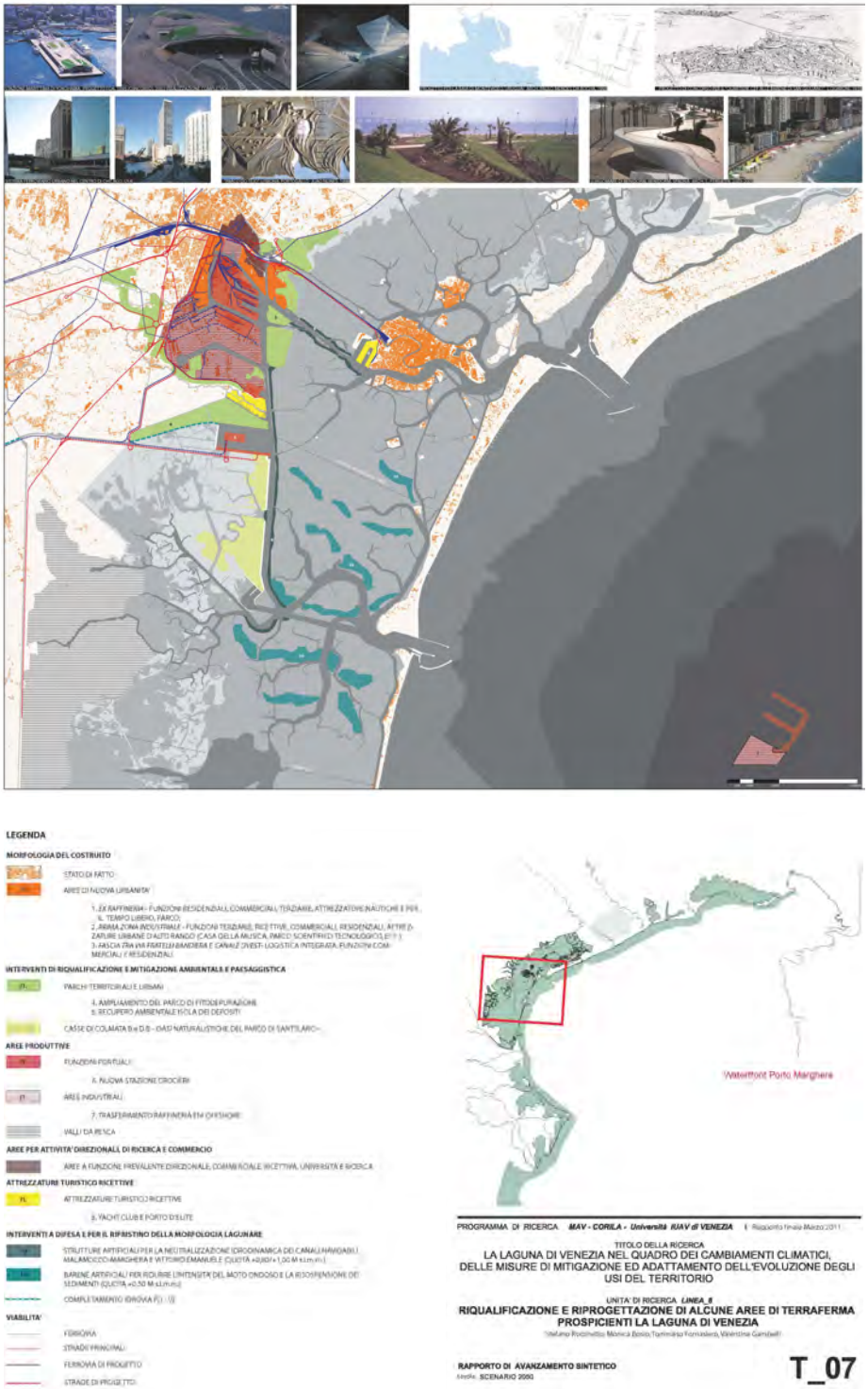

Fig. 5. Scenario at 2050

Scenario/project 2100

Both 2100 scenarios aim to a solution that allows connections between sea and lagoon to support industrial and commercial activities, which will be otherwise really compromised by dyke closures (as mentioned before).

Summarizing, the first scenario takes the sea to the internal Porto Marghera waterfront; the second one transfers part of Porto Marghera offshore.

Scenario/project 2100_1

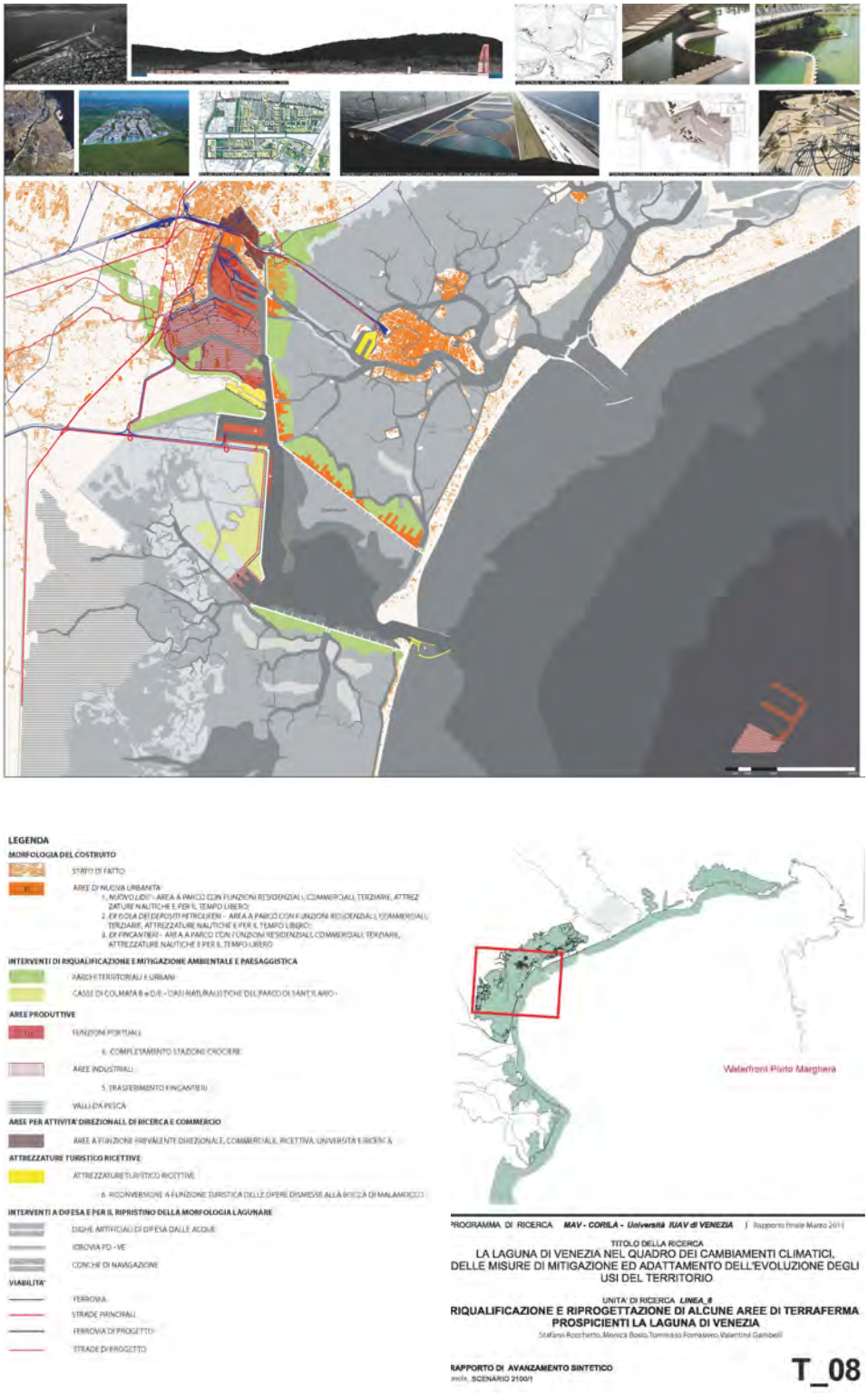

Fig. 6. First scenario at 2100

Malamocco lagoon entry will be opened and will be built a channel-basin, artificially separated from the rest of the lagoon and directly connected to the sea (also with the sea level), to allow free access to industrial and commercial area of Porto Marghera.

In the last century, central lagoon has lost its morphological specific characteristics: Barene areas disappeared and the sea level rised.

The first ipothesis/scenario chooses to “sacrifice to the sea” this part of the lagoon by transforming it definitively and naturally to a sea gulf.

The other two lagoon entrances, Lido and Chioggia, still work with Mo.S.E. mobile dykes for tides ≥110 cm a.m.s.l. The touristic cruise ships will use the Malamocco entrance, both for entrance and exit traffic.

This system permits to Porto Marghera to work, ensuring maximum access from sea. The Petroli channel, until Fusina and the Terminal “Autostrade del mare” will be enlarged to make possible the two ways ship traffic.

The channel border, facing Venice, generates a new waterfront that includes the ex Petrol depot island and the Tresse island, arriving until the Alberoni.

Scenario/project 2100_2

The separation between lagoon and sea is maintained and today’s activities located in the harbour island of Porto Marghera (239,83 ha), will be transferred to a new artificial offshore platform, in adherence with the planned and future realized one.

To make this new platform efficient, this area should be connected to Porto Marghera and all the hinterland, by a new railway and highway combined infrastructure, which can have two different developments:

- A complete raised out of water development, with a sensible approach to crossing channels along the path (channel of Valgrande-Spignon and Canale di San Pietro), to crossing lands such as Pellestrina, and at the end to crossing sea.
- An undersea tunnel from an artificial island (the entrance) nearby the New Fincantieri (in San Leonardo harbour area) to another artificial island to be realized at least at 3 miles from the seacoast, than raised out of water until the platform.

This scenario ensures a relevant sea traffic reduction inside the lagoon, (cruise ships, floating platforms, ferry boats) and it clears out all logistic activities from the harbour island areas of Porto Marghera, which are converted in “new urbanity”, with a high-density settlement logic (as Venice density). Near borders this new urbanity can melt with big public waterfront spaces.

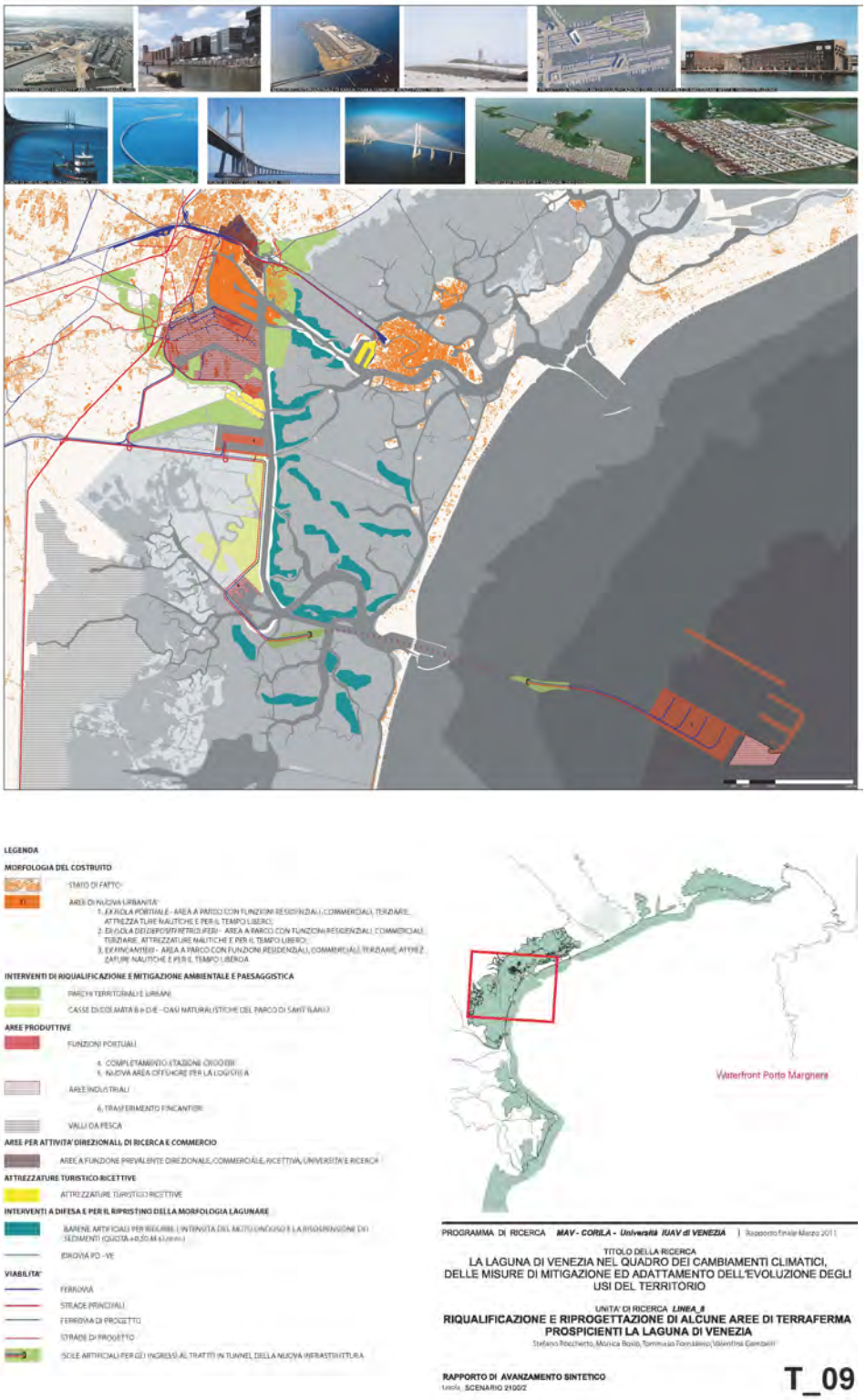

Fig. 7. Second scenario at 2100

4. Conclusions

The big and exceptional settlement system of Venice Lagoon is the result of long transformation times and of a huge anthropic modification work of natural environment; for this reason it has been necessary to go over the actual perception to find the complex historical transformation phenomenon. The progressive artificial lagoon context building, to ensure water control, is the fascinating aspect of the contradictory city, suspended between natural and artificial. The Historical City destiny is linked to the all around territory. To safeguard one means to safeguard the other too. Today and in the future, Venice Safeguard is linked to our capacity to harmonize the development idea for the hinterland and for the historical city. Moreover the concept of environment preservation cannot be separated from its capability of driving changes to realize a new stability.

We think that this is the meaning of the speech of the famous '500 century hydraulic Cristoforo Sabbadino: "essendo il principal obiecto del Stado nostro la conservazion de queste nostre lacune"[38], who to "conservare" (preserve, ndr) did not hesitate to deviate the river paths outgoing in the lagoon.

Moreover, as Manfredo Tafuri wrote: "La naturalità di Venezia, esaltata dal Sabbadino, non esclude l'ampliabilità del tessuto urbano lagunare. I nuovi terreni fabbricabili e la sistemazione delle zone cantieristiche introducono piuttosto, nel *piano* elaborato da Cristoforo nel 1557, una definizione rigida dei limiti urbani: fondamenta continue cingono la città e un sistema di canali perimetrali scorre lungo le rive, lungo le attuali Fondamenta Nuove e sul retro della Giudecca. Come è stato notato, la nuova Venezia di Sabbadino cresce su se stessa, mentre la Giudecca e San Giorgio Maggiore risultano connesse assai più alla città che alla laguna".[39]

The 2050 Scenario and more transformative 2100 scenarios, introduce urban development suggestions of a city that spread itself to the hinterland renouncing its relationship with the historical city and the lagoon.

The city idea we would like to introduce, is an urban structure that is not divided in different functional zones; it is a complex place where living, working, buying, studying and, overall, a public collective space, according to the best historical tradition of European cities, in particular Mediterranean ones.

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[38] "the principal object of the State is the preservation of ours lagoons"

[39] Manfredo Tafuri, Venezia *e il Rinascimento,* Giulio Einaudi editore s.p.a., Torino, 1985, cap.sixth, pag. 216 – translation: " Venice naturality, exalted by the Sabbadino, doesn't exclude tha possibility to enlarge the lagoon urban net. New building lands and the organization of Harbour areas introduce, in the plan of Cristoforo (Sabbadino, ndr) in 1557, a rigid definition of urban borders: continuous paths surround the city and a channel perimetral system wets borders, along the Fondamenta Nuove and along the back of Giudecca. As somebody noticed, the Sabbadino's new Venice rises on itself, and the Giudecca and San Giorgio Maggiore Island seem to be connected more to the city than to the lagoon."

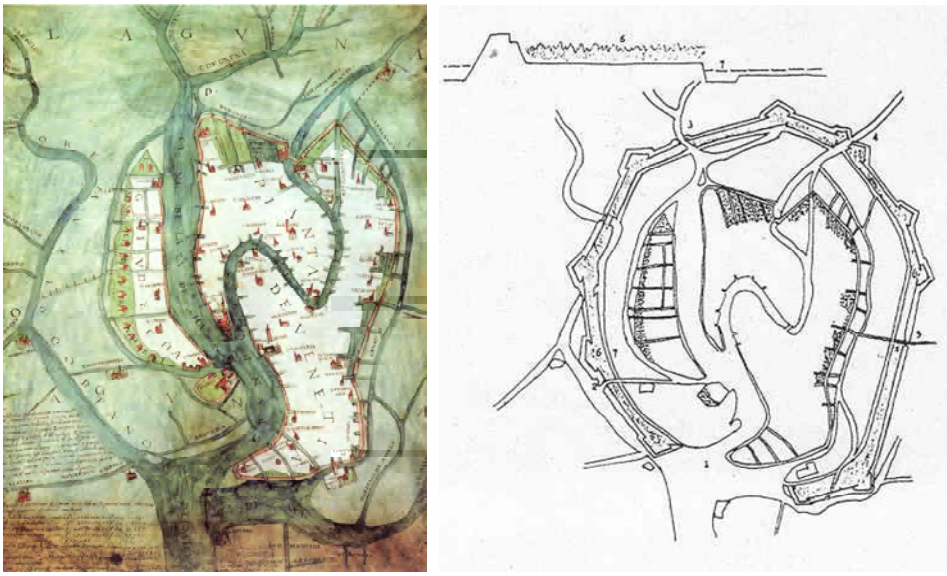

Fig. 8. development plan and hydraulic solution of Venice. Cristoforo Sabbadino. State archive of Venice (on left side); Rebuilding Venice with a water wall, by Alvise Cornaro idea .

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AREA 3

Environmental processes

BIOAVAILABILITY AND BIOTOXICITY OF LAGOON CONTAMINANTS AND THEIR LEGISLATIVE EVOLUTION

W. R. L. Cairns[1], F. Corami[1], C. Rigo[1], G. Capodaglio[1,2]

[1] *CNR-IDPA, Istituto per la Dinamica dei Processi Ambientali, Venezia,*
[2] *Dip. Scienze Ambientali, Università degli Studi Ca' Foscari, Venezia*

Riassunto

La speciazione è la differenziazione delle diverse forme chimiche assunte da un elemento in traccia nell'ambiente. Lo studio della speciazione permette la valutazione della concentrazione dello ione libero, dei complessi organici ed inorganici e dei composti organometallici. È di primaria importanza evidenziare che la speciazione di un elemento in traccia, ovvero le forme in cui l'elemento è presente nell'ambiente, ne determinano la bioaccessibilità e la biodisponibilità, influenzandone grandemente il destino, nonché gli effetti verso i vari recettori ambientali, ivi compresi quelli umani. Per molti elementi in traccia la concentrazione dello ione libero risulta essere la specie principale in grado di causare effetti tossici nei biota. Questo è in accordo con il free ion activity model (FIAM, modello dell'attività dello ione libero), che afferma che lo ione libero o lo ione "acquoso" dell'elemento in traccia sia la forma più biologicamente attiva dell'elemento disciolto.

In base a questa assunzione, i fattori chiave in grado di influire sulla tossicità nei confronti del biota sono quelli in grado di influenzare la speciazione dell'elemento in traccia in esame. L'uso dei bioindicatori e/o dei bioaccumulatori è una metodica efficiente per la valutazione delle anomalie nell'equilibrio biologico in aree soggette ad attività antropiche, più o meno intense, è l'utilizzo di vere batterie di bioindicatori e bioaccumulatori permettono di sintetizzare l'azione sinergica delle diverse componenti ambientali. In una corretta valutazione del rischio ambientale, lo sforzo analitico deve essere di tipo olistico, ovvero il biomonitoraggio e le misure chimiche devono integrarsi tra loro, considerando le diversità e le similitudini tra organismi e tra organismi ed ambiente, così da poter avere una visione la più ampia possibile di tutti i probabili percorsi di trasporto, di tutte le probabili vie di esposizione ed assimilazione, del bioaccumulo, delle dinamiche e delle cinetiche di tossicità. In diverse nazioni una attenzione sempre crescente è rivolta alla programmazione di una corretta gestione dell'ambiente, che si accompagna alla programmazione di una attenta e rigorosa valutazione del rischio ambientale e che conseguentemente permetterebbe una ponderata e precisa legislazione.

Negli Stati Uniti, le diverse sezioni della Agenzia per l'Ambiente, USEPA, hanno elaborato nel corso degli anni diversi frameworks, che hanno permesso di evidenziare, sia a livello scientifico sia a livello legislativo, i fattori chiave sulla valutazione del rischio di vari agenti contaminanti. Un importante strumento,

utilizzato per la valutazione del rischio degli elementi in traccia, è il Biotic Ligand Model (BLM). Il BLM offre un metodo quantitativo e diretto per determinare la biodisponibilità di un elemento in traccia in funzione del chimismo delle acque e della sensibilità degli organismi, fornendo pertanto un mezzo per stimare gli effetti di fattori sito-specifici sulla tossicità dell'elemento in esame. L'obiettivo di questo progetto è l'applicazione di strumenti di monitoraggio duttili, efficaci e soprattutto sinergici, che possano quindi permettere una integrazione degli aspetti ecotossicologici e degli aspetti chimici e fisico-chimici, così da poter proporre ai decision makers un adeguamento legislativo della normativa ambientale veneziana ed italiana, che risponda così ai dettami dei più recenti frameworks europei e degli Stati Uniti in materia di valutazione del rischio e ambienti acquatici.

Il progetto si propone l'inserimento dello studio della speciazione e della geospeciazione nel quadro del monitoraggio ambientale e della valutazione del rischio ambientale, in ambito scientifico, tecnico e legislativo, e l'utilizzo del Biotic Ligand Model come indispensabile strumento di valutazione della biodisponibilità e della tossicità. Si propone inoltre l'applicazione di una valutazione del rischio per inquinanti organici persistenti, che integri in maniera efficace e duttile le informazioni sulla tossicità e la concentrazione di contaminante accessibile all'organismo.

Abstract

This study aims to take modern assessment methods for environmental risk and apply them to the Venetian lagoon. The European Framework Directive was officially published in 2000, and all member and candidate states have to conform to it. The primary objective of this directive is to reach and maintain high quality levels for all European water resources. The Venetian Lagoon is an important source and sink for a number of pollutants. The application of these new study techniques will help management authorities to comply with the European Water Directive and to make informed decisions on how best to manage this precious and fragile ecosystem.

1. Introduction

Biogeochemical cycles are the summation of all the characteristic paths available to a chemical element, which determine its environmental distribution and fate. All elements, including those that are considered essential, circulate within the biosphere through various pathways. Any perturbation at any stage of the biogeochemical cycle of an element will be reflected in the entire cycle. In depth studies of biogeochemical cycles allow us to not only understand an elements pathway, but also how the pathways can be modified and if the modifications will be short or long term, or reversible or irreversible. Trace elements are unique as contaminants as they are neither created nor destroyed in the environment, they instead undergo transformation processes from one chemical species to another, passing from one point in the cycle to another moving eventually to sinks where they are less available.

The toxicity and hence environmental risk posed by an element is based on the bioavailability and concentration of the elemental species in which it is present. The aim of this project is to use modern tools for the assessment of the environmental risk posed by chemical elements and apply them to the Venetian lagoon.

2. Toxicity Bioavailability and Biotoxicity

To understand the mechanisms and factors that control the uptake and the possible toxic effects of trace elements it is often necessary to consider the competitive interactions between essential and toxic elements (1,2). To understand accumulation and transfer processes along the entire trophic web, it's essential to study the behaviour of trace elements at the chemical and biological level, considering their chemistry in concentration terms, along with variations in the chemical species in which the elements can be present. By studying closely their absorption and transport along the trophic web, the interaction levels between the various trace elements can lead to a complete understanding of the processes and mechanisms that influence them in the ecosystem. The interaction of an element with other parts of a system depends on its chemical form, so it is very important to study in depth the speciation of trace elements.

Some trace elements are micronutrients, for example iron (Fe), manganese (Mn), and also copper (Cu) and zinc (Zn), while others such as lead (Pb) or mercury (Hg) have no role in cellular mechanisms, and when assimilated by cells have toxic effects. In Figure 1 the effect of concentration on the environmental risk posed by an element can be seen.

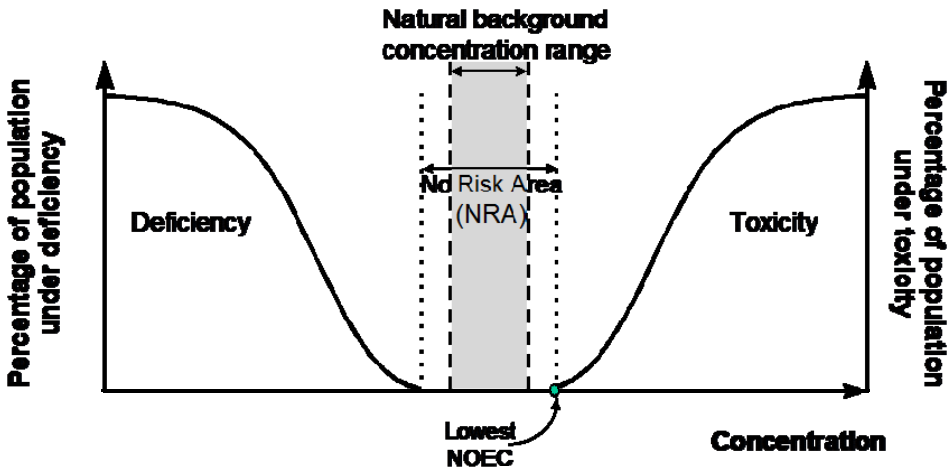

Fig 1. Concentration versus risk for a conceptual element.

In Figure 1 the curve between deficiency and toxicity for micronutrients is demonstrated. For micronutrients such as Fe, Mn, Cu or Zn, when the concentrations are below a certain level the organism is deficient in them, the no risk area, is the concentration range in which the organism can assimilate, and excrete the element with no ill effect. Once an element is present above this concentration, toxic effects can start to be seen. Some elements such as

Se have a very narrow no risk area, deficiency is at very low concentrations, and toxic effects occur very rapidly. Non essential “toxic” elements have a slightly different curve. There is no deficiency demonstrated, below a certain concentration the body is able to excrete or detoxify the element, but above this concentration toxic effect occur rapidly with increasing concentration. However, the uptake and toxicity of an element is also determined by its bioavailability.

At this point it is essential to clarify the concepts of bioaccessibility, bioavailability, bioaccumulation and bioconcentration (3). Bioaccessibility refers to the quantity of a metal available in the environment that can interact with organisms via the cell membranes and or other contact surfaces (skin, mucose membranes etc) and are potentially available for absorption and adsoption processes. It can be defined as the amount of a metal available in the environment that is exchangeable via physical, chemical or biological processes and is not sequestered inside another specific environmental matrix. Bioavailability is defined as the fraction of an element to which an organism is exposed to under defined conditions for a specific length of time, in other words how much of the bioaccessible metal is capable of being absorbed and assimilated by passing across the cell membranes of the biota. Bioconcentration is the net accumulation of a trace element inside an organism, in relation to absorption directly from the water, via passage across the gills and or other external membranes such as the skin. Bioaccumulation instead, is the net accumulation of a trace element in tissues of particular interest and or internal organs, resulting from the sum of the exposures to which an organism is subjected, such as air, water and solid materials (soils and sediments) and food, in other words it represents the net balance between assimilation and elimination of a metal.

3. Methods for assessing Bioavailability and Environmental Risk

Methods used for assessing the bioavailability of an elemental species have changed over time as demonstrated in Figure 2.

Tool	Date	Description	Comments
Total recoverable metals	Pre-1985	Dissolved metals + easily dissolved solid metals; hard mineral acid digestion	Highly conservative for metals in effluent that may become environmentally active
Acid soluble metals	1985	Less aggressive digestion procedure	Not much improvement
Dissolved metals	1993	<0.45 micron, pH 6.5-9.0, TOC & TSS	Improved approximation, but not ideal
BLM	2000	Model based on water chemistry	Continuing research focus

Fig 2. Historical methods for assessing the bioavailability of an element

The instrument we intend to use for assessing the risk posed by trace elements is the Biotic Ligand Model (BLM) (4-6). The BLM offers a direct and quantitative method for determining the bioavailability of a trace element, and the sensitivity of organisms to it as a function of its aquatic chemistry. It is useful for estimating site specific toxicity factors of the element under question. This model was developed by enclosing the characteristics of two important models on the bioavailability of trace elements: those of the Gill Surface Interaction model (7) and the Free Ion Activity Model (FIAM) (8). The BLM is summarized in Figure 3.

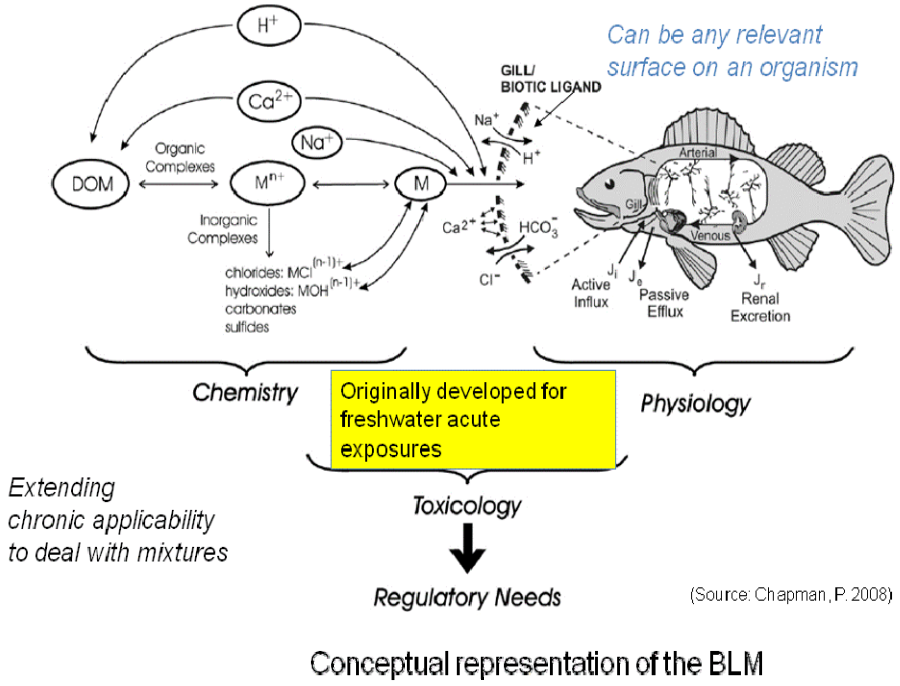

Fig 3. Conceptual representation of the Biotic Ligand Model

In the context of this model, the biotic ligand represents the accumulation site of an element or of trace elements, it can be a tissue, or an organ like the gills. The concentration of the element associated with the biotic ligand is calculated on the basis of the concentration of a trace element associated with any inorganic or organic ligands present in water. The biotic ligand competes with other ligands such as natural organic materials (NOM) and the carbonate ion for example, that can bind the available trace element and interact with other important cations in solution. Ca for example can compete with the free ion for physiological active sites present on the biotic ligand. At sufficiently elevated levels, competitive binding of calcium with the biotic ligand could inhibit the efficient accumulation of a trace element. The integration of this important competitive effect in the BLM, together with a relationship between the accumulation level of an element and its toxicity, can give important information on the decreasing toxicity of an element in relation to increasing water hardness.

The European Framework Directive was officially published on the 22nd December 2000, and all member and candidate states have to conform to it, by adjusting their environmental legislation and applying appropriate guidelines.

The primary objective of this directive is to reach and maintain high quality levels for all European water resources.

To completely apply the Water Framework, in depth studies on the environment at a morphological and ecological level to study the impact of environmental change are required, taking into account any socio-economic impacts. Of primary importance are methodological studies to develop guidelines to evaluate environmental risk that operate not just at a technical or legal level but also at scientific level resulting in knowledge improvement.

New methods are also required such as the use of Biological Early Warning Systems (BEWS), since ecological monitoring needs to take place hand in hand with chemical monitoring to gain indispensable data on the bioavailability of contaminants. All this needs to be done following homogeneous detailed protocols for every monitoring or analytical phase.

In Italy(9), the Environment Ministry has proposed quality standards for marine waters, sediments and biota in relation to the priority substances in list number 2455/2001/EC of the European Commission dated the 20th November 2001 (present in European Directive 2000/60/EC, placed in the Official Gazette of the European Community on the 15th December 2001). To protect marine areas, the Italian proposal foresees that by 2021 the total concentration of priority and dangerous substances in marine waters, and lagoons should approach environmental background levels for natural substances and zero for anthropogens. A list of quality standards has been proposed for marine waters, lagoons and coastal ponds, as well as for sediments, that for the moment are provisory but can be further modified in the future. The over-riding importance of further studies has been highlighted. The monitoring of priority and dangerous substances, to demonstrate their toxic effects related to bioaccessibility and bioavailability are vital, both from contamination sources and in the sinks. Within this Italian scenario is the Venice Lagoon, with its environmental peculiarities and its environmental and socio-economic emergency. Management and control of the Lagoon is the responsibility of the state, represented by the Magistrato alle Acque. The Magistrato all Acque is an important decision maker in the legislative field for the safeguarding of the lagoon environment, and therefore will be a future user of scientific progress in the application of emerging monitoring technologies, for environmental management.

Aims and Objectives

The objectives of this project is to monitor stress biomarkers in sentinel organisms, such as Mytilus galloprovincialis (a sedentary filtering shellfish, which is an excellent indicator of the water column) and Tapes philippinarum (a filtering shellfish, that lives in the sediments). These will be taken at sampling sites in the Venice Lagoon, that have been previously and extensively characterised. In parallel, speciation data of trace elements, such as cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn), in water, coming from previous studies in the Venice Lagoon, will be collected and reviewed thoroughly. Furthermore, in parallel to the study of stress biomarkers in biota, mercury (Hg)

speciation in waters of the Venice Lagoon will be studied.

Previous data of the geospeciation of sediments, collected in several sites of the Venice Lagoon (Giudecca, Palude di Cona, Malamocco and the industrial area of Porto Marghera) will be collected and reviewed thoroughly. When sampling biota and lagoon water at the chosen sites, sediments will be collected, as well. The geospeciation of the sediment samples will be studied in order to complete previous investigations.

Then, the experimental data obtained will be thoroughly evaluated. All the data, including those coming from previous studies and the experimental data of this study, will be inserted into the Biotic Ligand Model, a tool that is used in the American environmental regulations for risk assessment and monitoring.

For organic pollutants, such as PCBs, concentration data from previous studies in the water and sediments of the Venice Lagoon will be collected and reviewed thoroughly. Then, the corresponding total Toxicity Equivalents (TEQ) values will be compared and evaluated along with the stress biomarkers in the biota.

The project proposes the insertion of speciation and geospeciation studies into the framework for environmental monitoring, and establishing environmental risk assessment in the scientific, technical and legislative sphere and establishing the Biotic Ligand Model as an essential tool for the evaluation of bioavailability and toxicity. Furthermore, the establishment of a risk assessment for POPs (persistent organic pollutants), which encompasses toxicity, accessibility and availability towards biota is another important aim of this project.

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THE SHALLOWS PROJECT: PRELIMINARY INVESTIGATION

Luigi Tosi[1], Luca Baradello[2], Giuliano Brancolini[1], Mauro Caffau[2], Laura Carbognin[1], Maurizio Grossi[2], Federica Rizzetto[1], Pietro Teatini[1,3,], Massimo Zecchin[2]

[1] *Istituto di Scienze Marine - Consiglio Nazionale delle Ricerche, Venezia;*
[2] *Istituto di Oceanografia e Geofisica Sperimentale, Trieste;*
[3] *Dipartimento di Metodi e Modelli Matematici per le Scienze Applicate, Università di Padova.*

Riassunto

Nell'ambito del Programma di studio "La laguna di Venezia nel quadro dei cambiamenti climatici, delle misure di mitigazione ed adattamento e dell'evoluzione degli usi del territorio", il Progetto SHALLOWS "Indagini nel sottosuolo olocenico della laguna di Venezia" è stato avviato nel contesto dell'Attività: "Analisi delle componenti a scala locale del relative *sea level rise* alla luce degli scenari globali di sviluppo futuro considerati dall'IPCC".

Questo progetto prevede l'estensione all'area lagunare centrale delle indagini del sottosuolo lagunare condotte nell'area meridionale dalla Linea di Ricerca 3.16, nel precedente programma di ricerca CORILA (2004-2006).

Le indagini verranno principalmente condotte nei bassifondi attraverso rilievi sismici ad altissima risoluzione, analisi sedimentologiche e geomorfologiche. In particolare saranno investigati in dettaglio alcuni siti chiave dove sono presenti strutture geomorfologiche sepolte, ad esempio sistemi deltizi e di argine-canale.

In questo articolo vengono presentati scopi ed obiettivi della ricerca e riportati alcuni esempi di risultati relativi alle indagini preliminare effettuate nella fase di programmazione delle campagne di rilevamento geologico.

Abstract

In the framework of the CORILA Research Programme "La laguna di Venezia nel quadro dei cambiamenti climatici, delle misure di mitigazione ed adattamento e dell'evoluzione degli usi del territorio" the SHALLOWS Project: Indagini nel sottosuolo olocenico della laguna di Venezia been activated within the Activity "Analisi delle componenti a scala locale del relative sea level rise alla luce degli scenari globali di sviluppo futuro considerati dall'IPCC".

Whit this project, the investigations of the subsoil carried out in 2004-2006 (Research Line 3.16 of the 2004-2006 CORILA Research Programme) in the southern area of the Venice Lagoon, extend to the central lagoon basin. Investigations in the subsoil down to about 20 m depth below the lagoon shallows are ongoing by Very High Resolution Seismic survey, sedimentological and geomorphological analyses. In particular, the study focused on some key sites where signs of the presence of buried geomorphological features, e.g. deltas and channel-levee systems, have been preliminary detected.

At the date, only preliminary results are available. Hence, this paper describes the aims and objectives of the research and shows a few example of the recently acquired data.

1. Introduction

The Venice Lagoon originated during the Holocene transgression of the Adriatic Sea onto the northeastern part of the Late Pleistocene Po plain and its evolution has been subjected to a complex combination of natural processes and human interventions [Gatto and Carbognin, 1981].

The activity of the Po, Adige and Brenta river systems largely influenced the evolution of the central and southern Venice Lagoon during the Holocene. At present, in the watershed NW of Venice the distal margin of the Late Pleistocene Brenta river alluvial fan is exposed [Tosi et al., 2007a; Tosi et al., 2007b]. Abandoned riverbeds recognized in the central and southern catchments mainly correspond to Late Holocene courses of the Brenta River, whereas some of the southernmost traces refer to ancient systems of the Adige and Po rivers (Fig. 1). In particular, in the coastal plain near the southern lagoon margin there is evidence of the northernmost paleoriverbed of the Po River that was probably active until the Roman Age [Tosi et al., 2007b]. Signs of paleobeach ridges, extending in NE-SW direction, were identified analyzing the digital elevation model (DEM) of the lagoon bottom (Fig. 1).

The westernmost paleobeach ridge is related to an ancient shoreline found in the coastal plain south of the Venice Lagoon and likely dating back to about 4,5 Kyr BP. In the last 4 Kyr, depositional activity of the Brenta, Bacchiglione, Adige, and Po rivers filled up the back-barrier lagoon and the surrounding swamps causing the eastward migration of the littoral, presently testified by the clear evidences of a complex system of ancient beach ridges and sand dunes [Rizzetto et al., 2003]. Very High resolution Seismic (VHRS) surveys pointed out the presence of morphological features related to these systems in the lagoon basin [Rizzetto et al., 2009; Tosi et al., 2009b; Zecchin et al., 2008; Zecchin et al., 2009] (Fig. 2).

Since Roman times the lagoon has been considered a source of security against enemies because of its peculiar environmental setting, and several hydraulic works, aimed at preserving the lagoon environment, were carried out over the centuries. First hydraulic works were carried out to divert toward the sea the course of Adige, Brenta, Bacchiglione, Sile and Piave rivers flowing into the lagoon whose continuous supply of sediment threatened the gradual silting-up of the basin and the consequent risk of the lagoon conversion into a marshland. These huge works started in 1400 A.D. and concluded in 1609 with the diversion of the Po River to the South.

Starting from 1800, man again intensely altered the lagoon setting with large-scale intervention such as land reclamation and filling-in operation aimed at improving the agriculture and expanding the industrial and urban zones; new deep shipping canals were dug to serve the industrial harbour adequately, as well as changes to and reduction in the number of sea openings were carried out to

improve the efficiency of the port of the original eight inlets; the permanent closure of areas near the lagoon margin for use as fish farms. Furthermore, during the 1950's - 1960's the industrial water supply was provided by rash exploitation of artesian aquifers inducing a serious land subsidence, which, in turn, deepened the bottom of the basin further and contributed to an intensification of "acqua alta" events (a local idiom meaning "flooding").

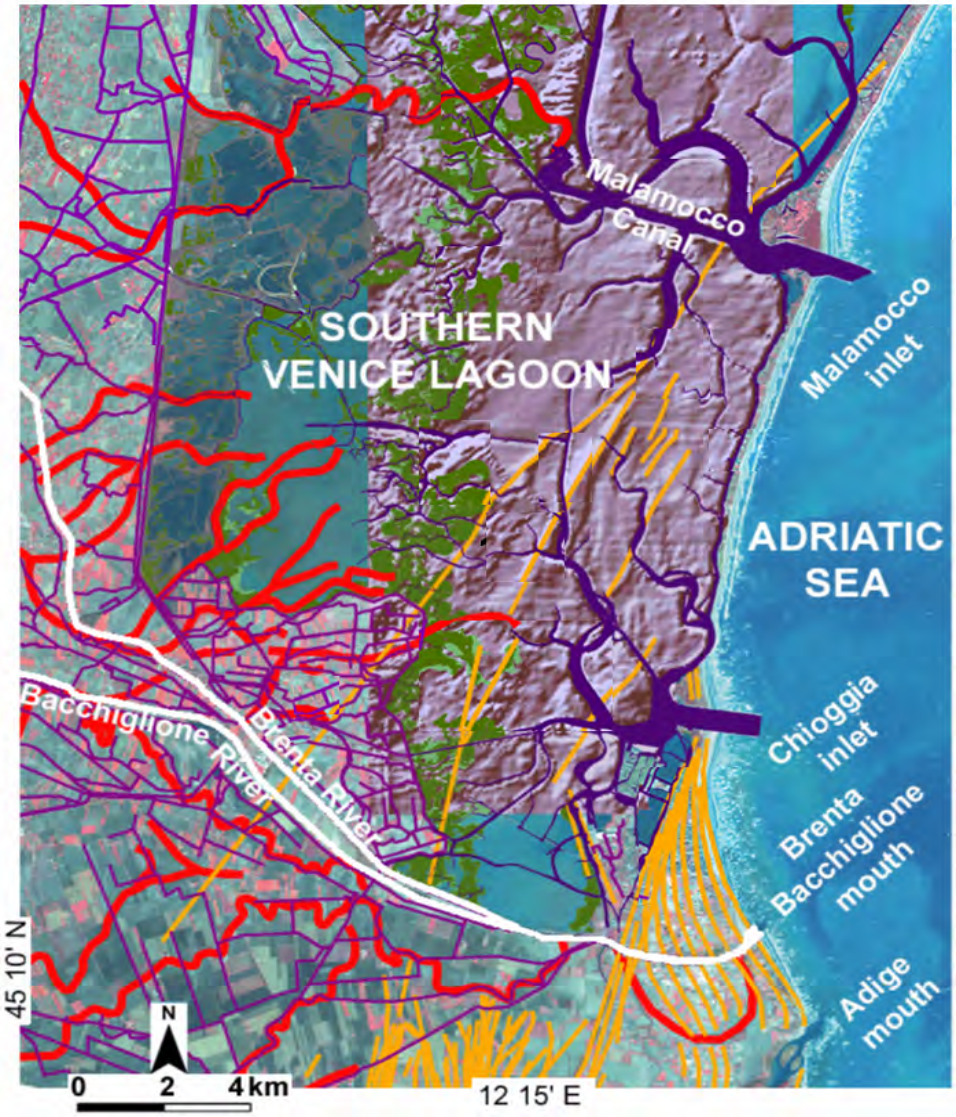

Fig 1. ASTER satellite image of the southern Venice coastland. A shaded relief map of the lagoon bottom is superimposed on the image. Red lines: paleoriverbeds; orange lines: paleobeach ridges; dark violet and light violet areas: present lagoon channels and hydrographic network, respectively; green areas: salt marshes. White lines highlight the present courses of the Brenta and Bacchiglione rivers. Modified from Tosi et al. [2009b].

Since the beginning of the 1990's a vast series of safeguard measures were implemented and are currently under way, to partly restore and defend the environment. They include the creation and/or the nourishment of beaches, the restoration of sand dunes, the reconstruction and protection of the wetlands, the local defence works in the historic city and other lagoon centres, as well as a major project involving temporary closure of the three inlets to guard against exceptional floodings in the lagoon, i.e. the MOSE (MOdulo Sperimentale Elettromeccanico) project [Carbognin et al., 2000].

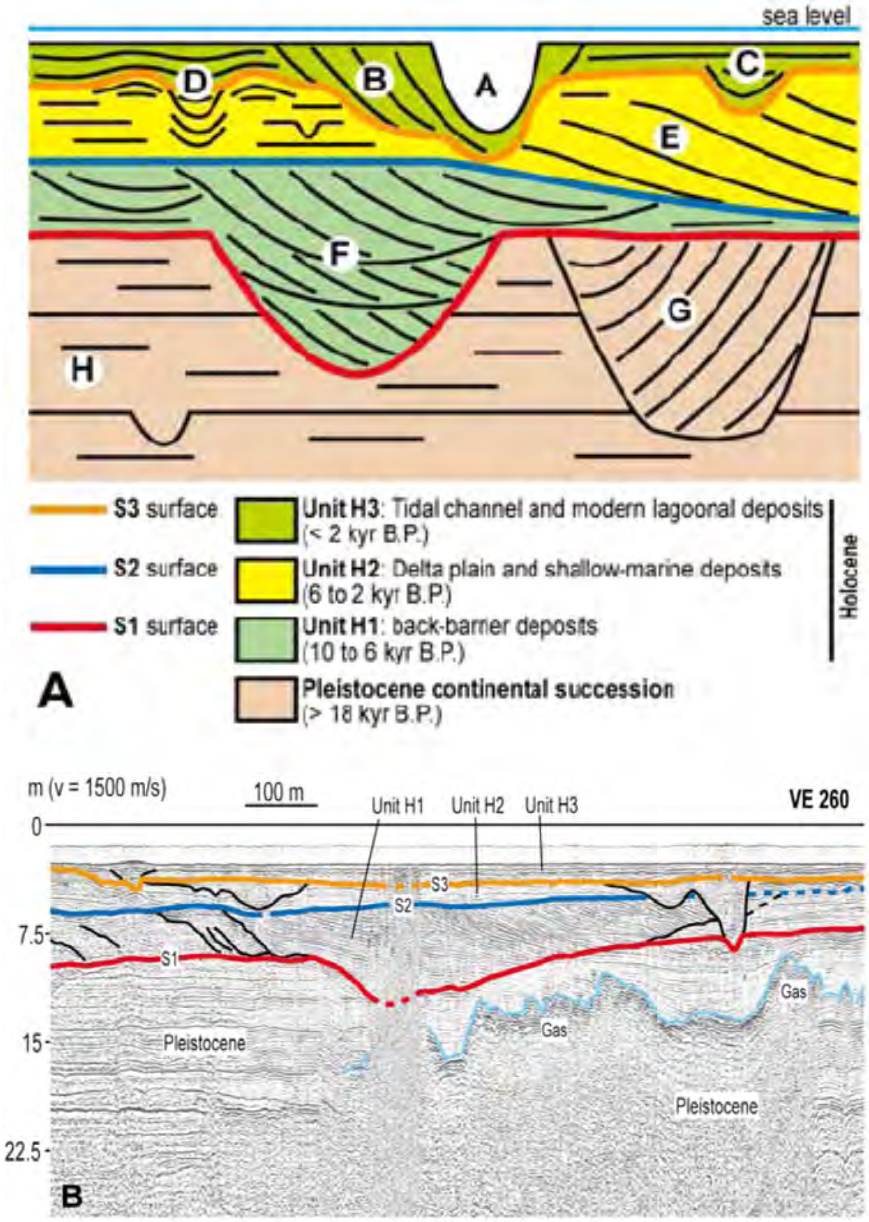

Fig 2. (a) Simplified architectural scheme of the Holocene deposits in the southern Venice Lagoon. Unit H1 represents the transgressive sequence, whereas Unit H2 is the regressive sequence. Unit H3 consists of sediments deposited during the recent human-induced transgression that followed delta abandonment. A-Active tidal channel; B-Lateral accretion; C-Buried tidal channel; D-Channel-levee system; E-Clinoforms; F-Early Holocene estuarine and fluvial channels; G-Pleistocene river; H-Pleistocene alluvial plain. (b) Late Pleistocene and Holocene complex channelized sequences. Modified from Tosi et al. [2009b].

2. The SHALLOWS Project

Seismic surveys carried by the RL3.16 Project in the framework of the 2004-2006 CORILA Research Programmes produced new insight in the evolution of the southern Venice Lagoon through the Late Pleistocene and Holocene.

In the framework of the of the CORILA Research Programme: “La laguna di Venezia nel quadro dei cambiamenti climatici, delle misure di mitigazione ed adattamento e dell’evoluzione degli usi del territorio”, and in the context of the Activity: “Analisi delle componenti a scala locale del relative *sea level rise* alla luce degli scenari globali di sviluppo futuro considerati dall’IPCC”, the goal of Sub-activity “Investigation of the Holocene subsoil of the Venice Lagoon”, i.e. SHALLOWS Project, is to complete the investigation started in the previous RL3.16 Project by widening the study area to central lagoon basin.

SHALLOWS Project will take advantage from that experience and in particular from the Very High Resolution Seismic surveys ad hoc implemented and capable to acquire data in very shallow water (about 1 m depth).

2.1 Why it is important to perform Very High Resolution Seismic surveys in the Venice shallows?

Sediment sampling allows accurate sedimentological studies of the sedimentary successions and the precise description of depositional environments, providing the base for the lateral crono-stratigraphic and main depositional environment correlations. Recently Zecchin et al. [2008], Rizzetto et al, [2009], Tosi e et al. [2009b], Zecchin et al. [2009] providing impressive images of the southern lagoon subsoil, evidenced the high complexity of the Late Pleistocene-Holocene deposit architecture, which is characterized by a high lateral heterogeneity and the presence of numerous geomorphological structures. It is then very difficult providing a high-quality reconstruction of the deposit architecture, even with the availability of a large core number.

Fig. 3 illustrates a typical geological section across the lagoon. It is clear that the record of the recent sediments is very limited or even missed in correspondence to the major channels which are not representative of the evolution of the lagoon. The same figure also include two examples of seismic profiles both crossing a small tidal channel. It is evident that the difference in the sea floor grain size (coarser in the channel and finer in the shallows) produce a strong difference in the seismic section: in correspondence to the channel, the signal is dominated by the multiple reflections while, in the shallows, primary reflections are in a good evidence.

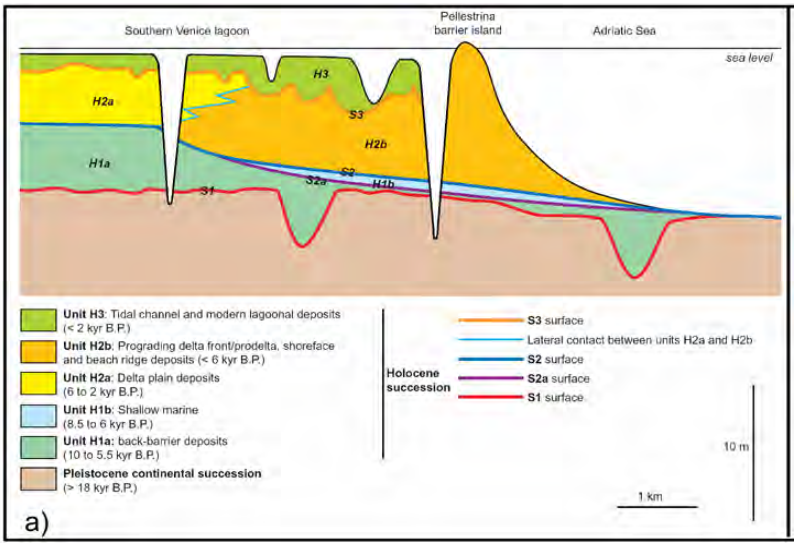

Fig 3. a) Schematic cross-section of the lagoon subsoil [modified from Zecchin et al., 2009].

Since the shallows represent the 90% of the Venice lagoon the knowledge of their geological setting is of particular relevance for many scientific and engineering issues. Only by geological and geophysical investigation in the shallows it will be possible to get a detailed tri-dimensional reconstructions of the recent evolution of the Venice lagoon and a satisfactory understanding the

rule and the interaction of the different components of the relative sea level changes.

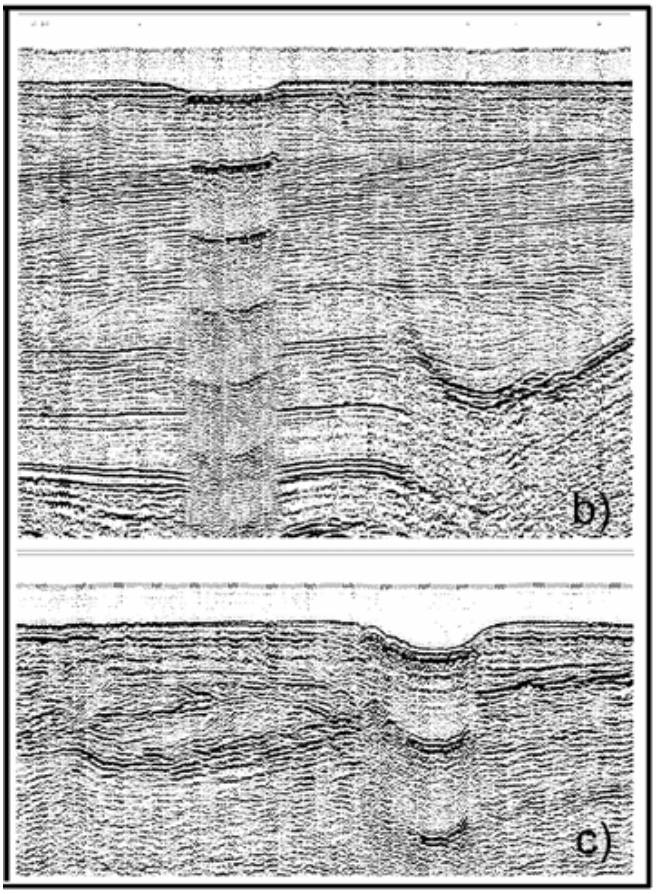

Fig. 3. b) and c) examples of VHRS profiles showing very fine detail of the subsoil below the shallows whereas bad results in correspondence of tidal channels.

2.2 Aim and objectives of the project

The aim of this study (SHALLOWS Project) is to understand the changes in the lagoon landscape over the Holocene, as well as to better distinguish natural and human-induced causes responsible for its historical evolution [e.g., Tosi et al. 2009b].

The surveys will be carried out in the shallows of southern and central parts of the Venice Lagoon. In particular, detailed investigations will be focused on some key sites where signs of the presence of buried geomorphological features, such as ancient coastlines, deltas and channel-levee systems, occur.

Specific objectives of this study are: (a) the assessment of the architecture and lateral variability of the Holocene sediments [e.g., Zecchin et al. 2009], (b) the recognition of buried fluvial channels probably related to Late Pleistocene and Holocene courses of the Brenta and Bacchiglione Rivers [e.g., Rizzetto et al. 2009, Tosi et al. 2009b], (c) the reconstruction of the evolutionary sketch of inactive and active tidal channels, aimed to understand their dynamics and their rule in the morphological evolution of the lagoon [e.g., Zecchin et al., 2009].

2.3 Materials, methods and activities

Seismic surveys, geomorphological investigations and sedimentological analyses are used in this study.

The main project activities are:

- Field acquisition and processing of a VHRS survey for approximately 100 km of sections.
- Collection, homogenization and processing of the data (sedimentological, geophysical, mapping, etc.).
- Sedimentological and micropaleontological analysis of sediment samples from available cores.
- Integration of seismic data and sedimentological data.
- Delivering of processed data and final report.

Seismic surveys are carried out by a Very High Resolution Seismic (VHRS) system optimized to operate in water depths less than 1 m [Brancolini et al., 2008]. This system consists of i) an impulsive energy source (boomer), ii) an electro-dynamic transducer mounted on a catamaran frame and iii) a pre-amplified oilfilled streamer composed of eight piezoelectric elements connected in series with a 2.8 m active array section. The boomer produces a theoretical minimum phase wavelet with an amplitude spectrum between 200 and 9000 Hz. The maximum impulse rate generally used is 8 pulses per second at 150 J and the hydrophones have a sensitivity of 63 dB/Volt/microbar and a bandwidth of 100–10,000 Hz.

After the line-drawing of the main unconformities and the geomorphological features, seismic sections are interpreted following the seismic stratigraphic models from Zecchin et al. [2009] and Tosi et al. [2009b].

Reconstruction of the seismic-morpho-stratigraphic units is generally accomplished by integrating analysis of the seismic data with both sedimentological analyses and available geological information, i.e., sedimentological, stratigraphic, geotechnical, mineralogical, textural, and bathymetric data, ^{14}C dating, satellite images, and historical maps.

New sedimentological and micropaleontological analyses are carried out in samples from cores provided by the Water Authority of Venice and ISMAR-CNR\Venice. In particular, sediment samples were collected along the cores at 20 cm intervals and at each lithological variation. A sub-aliquot of 50-60 g was taken from each sample for the micropaleontological and sedimentological analyses. The aliquots were dried at 50°C for 24 h, weighted and then treated with hydrogen peroxide (10 % vol) for 12 hours to remove the organic matter. They were then washed through a 63 µm mesh and dried. These fractions were weighted to determine the percentage of sand and silt remaining.

Foraminifers were studied quantitatively on a subsequent sub-sampling of at least 300 individuals, which are sufficient to identify the dominant taxa, according to Murray (1976).

The interpretation of the environmental meaning of the benthic foraminiferal

assemblages are inferred from the modern benthic communities [Serandrei Barbero et al.,1999; Donnici et al., 1997; Albani et al., 1991; Albani et al., 1998; Donnici and Serandrei Barbero, 2002, 2004; Canali et al., 2007; Zecchin el al., 2009].

2.4 The study area

The study area of the SHALLOWS Project is the central lagoon basin though some investigation are required south of the Malamocco Canal to integrate the previous survey carried out within the CORILA 3.16 subproject (**Errore. L'origine riferimento non è stata trovata.**).

3. Preliminary data

The activities related to the first six months were a test of the seismic acquisition system, sediment analysis from available a 25 m long core and the first VHRS campaign.

3.1 VHRS surveys

The seismic surveys program has been planned according to the existing data and the research objectives and a survey test carried out in the study area allowed the step-up of the VHRS system.

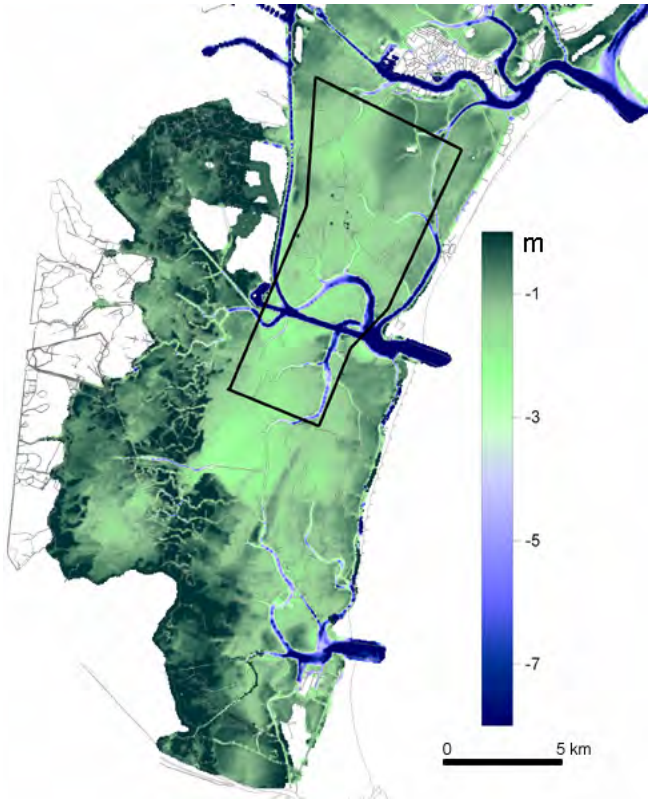

Fig 4. Bathymetric map of the southern and central basins of the Venice Lagoon showing the study area.

A test survey was performed in June 2009. Two main campaigns have been scheduled for the acquisition of seismic lines: the first one is based a coarse grid of about 80 km aimed to i) asses the architecture of the subsoil of the

central lagoon basin and to ii) identify geomorphological features of interest. The second survey follows a fine grid of about 20 km to point out the structure details of the selected active and inactive channels.

The first campaign (SHALLOWS 1) was carried out in September 2009; Fig. 5 shows the position of the seismic lines. Three examples of seismic data showing the architecture of buried channels are reported in Fig. 6, Fig. 7 and Fig.8.

Fig 5. Position of the seismic lines acquired during the first survey (SHALLOWS 1)

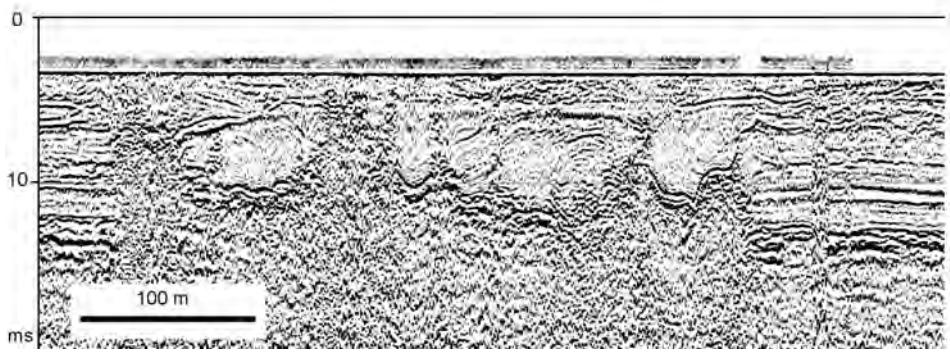

Fig 6. Example of the complexity of the subsoil architecture.

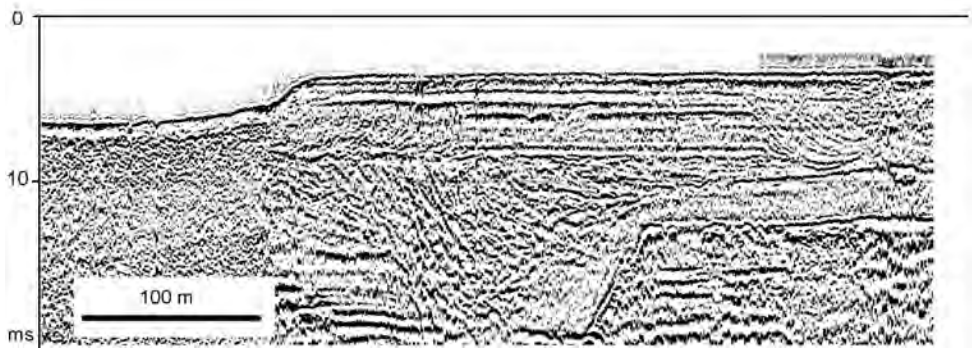

Fig 7. Example of active and buried tidal channel complex systems.

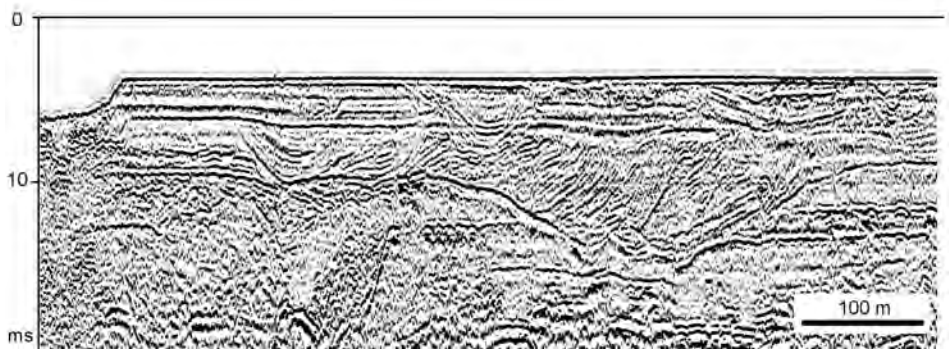

Fig 8. Example of active and buried channel complex systems.

3.2 Core analyses

Four 25 m and three 8-m long cores, available from previous researches (i.e. CARG and ECHOS projects), were sampled and analyzed.

Sedimentological analyses were carried out for the first time in the 25-m long core ISMAR-1 while an improvement of sampling and analyses were preformed in the others cores.

The preliminary stratigraphic log of the ISMAR-1 core is reported in Fig. 9. In detail, between 25 and 9,95 m depth the biogenic fraction consists of only continental gastropods, fresh-water ostracods, vegetable rests and oogons of Characeae. From 9,95 m up to the top of the core, the sediments are characterized by a organic rich fraction that is composed of benthic foraminifera, bivalves, gastropods and ostracods, typically from brackish-water.

Between the most common benthic foraminifera, individuals belonging to the species: *Ammonia beccarii*, *Haynesina paucilocula*, *Cribrononion translucens* and *Trochammina inflata* are present.

4. Conclusive considerations

After a brief overview of the main fluvial systems crossing the southern Venice area before the sea ingression, the SHALLOWS Project is introduced. Aim and objectives have been described and preliminary data have been reported. The importance to investigate the lagoon shallows representing most of the Venice lagoon basin, is emphasized.

The knowledge of the geological setting and the subsoil architecture is of particular relevance for many scientific issues. Expected results of this project are likely important to point out the evidence of radical changes triggered by human-induced river diversion of the lagoon tributaries, and others interventions as well as by climate and relative sea level changes. Engineering and hydrogeological studies would take advantage from the results of this project. For instance, relict sandy geomorphological features, characterized by high permeability, act as preferred pathways for groundwater flow [Carbognin and Tosi, 2003; Rizzetto et al., 2003; de Franco et al., 2009] and the architecture of the shallow subsoil play a fundamental role in the land subsidence process [Tosi et al., 2009a].

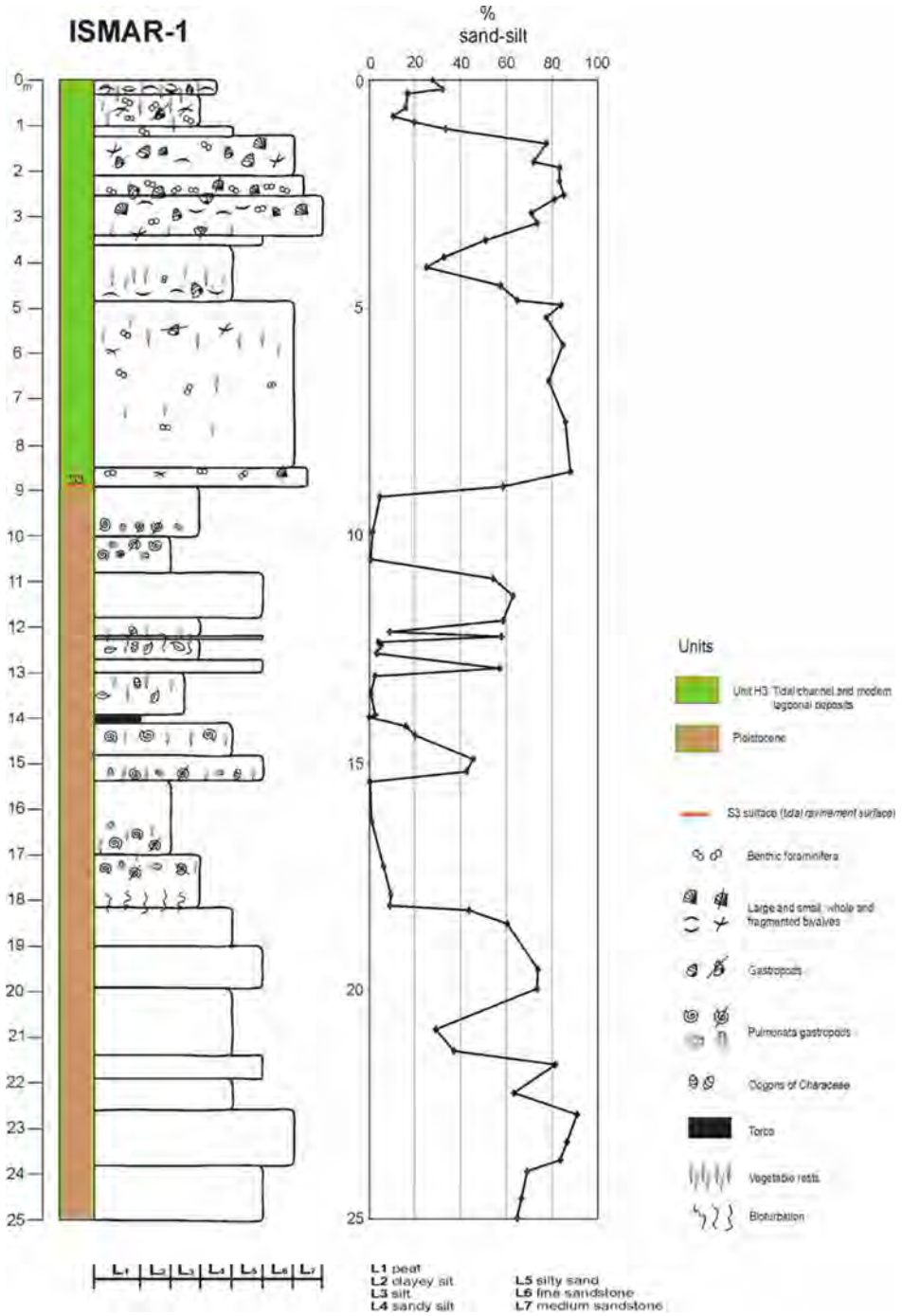

Fig. 9 - Preliminary stratigraphic log of the ISMAR-1 core

Acknowledgments

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MITIGATION OF THE EXPECTED RELATIVE SEA LEVEL RISE BY ANTHROPOGENIC LAND UPLIFT: A STRATEGY PHYSICALLY POSSIBLE?

Pietro Teatini[1], Giuseppe Gambolati[1], Massimiliano Ferronato[1], Luigi Tosi[2]

[1] *Dipartimento di Metodi e Modelli Matematici per le Scienze Applicate, Università di Padova*

[2] *Istituto di Scienze Marine, CNR, Venezia*

Riassunto

Studi modellistici condotti recentemente suggeriscono che l'iniezione d'acqua salata in un acquifero profondo 600-800 m al di sotto della Laguna di Venezia potrebbe sollevare uniformemente la città lagunare di 25-30 cm in un intervallo temporale di 10 anni. Tale innalzamento avrebbe consentito una riduzione di oltre il 90% delle acque alte verificatesi in città dal 1872 ad oggi. Inoltre, in vista dei previsti affetti dei cambiamenti climatici globali, tale strategia potrebbe integrare il MOSE nel controbilanciare l'innalzamento eustatico previsto nei prossimi decenni. Tale strategia è stata accolta da alcuni, anche scienziati, non esperti di geomeccanica in modo dubbioso: è fisicamente possibile che il terreno si sollevi di un'entità apprezzabile per mezzo di iniezioni di fluidi nel sottosuolo? Il presente lavoro propone una review di lavori pubblicati nella recente letteratura scientifica specializzata che dimostrano attraverso l'utilizzo di misurazioni di precisione condotte principalmente durante l'ultimo decennio, come l'iniezione di fluidi nel sottosuolo abbia prodotto un innalzamento del suolo fino ad alcune decine di centimetri in un intervallo temporale che può variare tra alcuni mesi e alcuni anni. Tali evidenze supportano pertanto l'idea di utilizzare questa metodologia per mitigare le conseguenze del "sea level rise" in quelle aree costiere ad elevato valore ambientale e/o culturale che sempre più frequentemente e con maggiore intensità sono interessate da inondazioni per il sovrapporsi dei processi di eustatismo e subsidenza.

Abstract

Recent modeling studies indicate that injecting seawater into a 600-800 m deep brackish aquifer underlying the Venice Lagoon might help raise the city uniformly by 25-30 cm over a 10-yr time. This would lead to more than 90% reduction of the most severe floods experienced by the city since 1872 to present. Moreover, in view of the expected global climate change, this strategy could offset the expected sea level rise, thus increasing the operative life of the mobile gates MOSE at the lagoon inlets over a significant time interval. This innovative strategy has been doubtfully viewed by some people, also scientists, not expert in the field of geomechanics: is physically possible to appreciably rise the ground surface by injecting fluids into the subsurface? This paper presents a survey of some interesting examples of anthropogenic uplift measured in the

past by the traditional levelling technique and in recent times with the aid of satellite technology. The available information shows that an heave of the ground surface up to a few tens of centimeters over a time interval that may range from a few months to a few years has been obtained by subsurface fluid injections. Such evidences support the idea of using this approach as an innovative defence from and a substantial mitigation to flooding that plagues high-value coastal lowlands experiencing land subsidence, both of natural and anthropogenic origin, and seal level rise due to climate changes.

1. Introduction

It is well known that subsurface fluid removal induces anthropogenic land subsidence. Magnitude, spatial distribution, time of occurrence, and extent of the area involved depend on a large number of factors including the location and pumping rate of each single extraction well, the pore pressure decline, the depth, volume, and permeability of the pumped formation, and the geomechanical properties of the reservoir, the overburden and the faults possibly located in the reservoir surroundings [Gambolati *et al*., 2005].

The reverse, namely land uplift due to underground fluid injection, was a much less observed and recognized event until recently. In recent times satellite technology has offered a relatively inexpensive, space distributed, and accurate methodology to detect the ground movements practically worldwide and has alerted to the process of anthropogenic uplift wherever it may prove of some interest in terms of magnitude, size of the area involved and time of occurrence. The use of Interferometric Synthetic Aperture Radar (InSAR) techniques has grown very much over the last decade thus facilitating immensely the detection and measurement of rising areas in connection with programs of aquifer storage and recharge (ASR) [e.g., Bawden *et al.*, 2001], injection of water-based solutions and vapors to enhance oil production (EOR) [e.g., Du *et al.*, 2005], CO_2 sequestration in depleted gas fields and/or saline aquifers [Vasco *et al.*, 2008], underground CH_4 storage [Castelletto et al., 2009], land subsidence mitigation [e.g., Chen et al., 2007], and geomechanical characterization of the geologic formations [Jahr *et al.*, 2008].

The present paper provides a survey of some interesting areas in the world where appreciable heave has been observed mostly as a “by-product” of fluid (water, gas, vapour) injection in geological formations. The mechanics of land rebound is first briefly addressed. Then, the case studies are presented on the basis of the injection purpose.

2. Equation governing ground heave due to fluid injection

Generally speaking, uplift is caused by the migration to the ground surface of the expansion of the geological formation where the fluid is disposed of. The deformation of the injected porous medium is mainly driven by the in situ pore pressure p and temperature T variation, with the amount of the total displacements mainly controlled by the rock compressibility and thermal expansion coefficient. Based on the classical thermo-poro-elastic theory

[Coussy, 1995], the partial differential equations governing the rock deformation read:

$$G\nabla^2\mathbf{u} + (G+\lambda)\nabla \mathrm{div}\mathbf{u} = \alpha\nabla p + \frac{\theta_s}{c_b}\nabla T + \mathbf{b} \qquad (1)$$

where ∇ and ∇^2 are the gradient and the Laplace operators, respectively, G and λ the Lamé coefficients generally dependent on the stress path, $\mathbf{u}$ is the displacement vector, α the Biot coefficient, θ_s the volumetric thermal expansion coefficient for the solid (s) phase, c_b the bulk compressibility, and $\mathbf{b}$ the vector of body forces. Different types of fluid can be pumped underground to recharge an aquifer system, arrest or mitigate the anthropogenic land subsidence occurring during the depletion of hydrocarbon fields or enhance oil production, but also and gas, e.g., CO_2 for EOR or long-term sequestration or natural gas (methane) for gas storage operations. Steam (water, vapour) is also successfully used to recover heavy oil or bitumen. If a multi-phase flow is involved the pore pressure in equation (1) must account for the presence of all phases. Pressure and temperature in the injected formation can be predicted by additional equations that prescribe the mass and energy conservation.

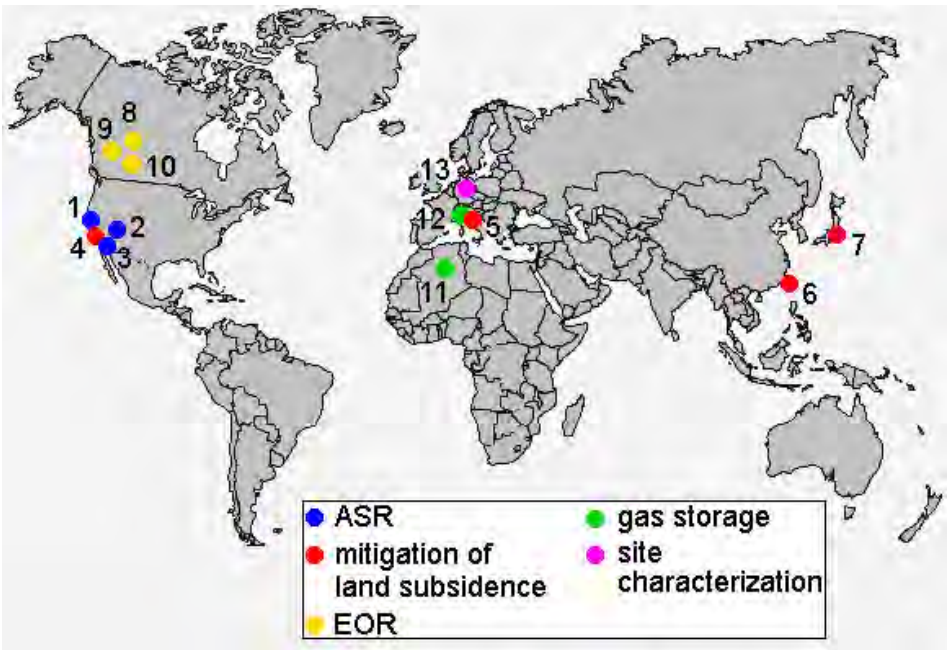

Fig 1. Case studies described in the scientific literature where ground uplift due to fluid injection into the subsurface has been measured. The sites are distinguished on the basis of injection purposes. 1)Santa Clara Valley, California [Schmidt and Bürgmann, 2003]; 2) Las Vegas Valley, Nevada [Bell et al., 2008]; 3) Santa Ana Basin, California [Bawden et al., 2001]; 4) Long Beach, California [Colazas and Olson, 1983]; 5) Chioggia Mare, Italy [Teatini et al., 2000]; 6)Taipei, Taiwan [Chen et al., 2007]; 7) Tokyo , Giappone [Sreng et al., 2009]; 8) MacKay River, Canada [Petro-Canada, 2008]; 9) Pace River, Canada [Du et al., 2005]; 10) Cold Lake, Canada [Stancliffe and van der Kooij, 2001]; 11) Krechba field, Algeria [Vasco et al., 2008]; 12) Lombardia-1 field, Italy [Castelletto et al., 2009]; 13) Upper Palatinate, Germany [Jahr et al., 2008].

3. Examples of measured anthropogenic land uplift

Regardless of the fluid injected, the basic mechanism underlying the geomechanical response is similar with the major differences restricted to the framework where the operation takes place, i.e. the basin geology, the magnitude of the p and T variations, and therefore the stress path that ultimately controls the deformation. For instance, recharged aquifers are typically shallow and wide with the p rise smaller than the previous decline, while gas/oil reservoirs are older, deeper and more consolidated with a generally lower porosity, permeability and compressibility. In this case the pressure build up can

be, at least potentially, much larger than the one experienced by an aquifer. The above factors can generate a very different land surface response in terms of both magnitude and area distribution according to the specific case at hand.

Several case studies can be found in the literature (Fig. 1). Here we shortly describe a few examples, one for each of the different purposes listed above.

3.1 Uplift in connection with ASR projects: Las Vegas Valley, Nevada

The Las Vegas Valley is located in a structurally controlled alluvial basin containing up to 1500 m of unconsolidated sediments of Pliocene through Holocene. Coarse-grained (sand and gravel) alluvial-fan deposits are laid down from the surrounding mountain ranges form broad piedmonts around the periphery of the valley, while predominantly fine-grained (silt and clay) compressible materials underlie the central part of the valley. Intervening sequences of both coarse- and fine-textured sediments give rise to a well-developed multi-aquifer system crossed by several Quaternary faults reaching the ground surface from the underlying bedrock. Most of the groundwater in the aquifer system originates from the rain falling on the Spring Mountains to the west.

Groundwater has greatly promoted the development of Las Vegas since the early 1900s when the first wells were drilled in the area. The Las Vegas metropolitan area increased in population from 0.8 million in 1990 to more than 1.5 million in 2000. Although natural springs historically provided with water this arid valley (the average precipitation in a year is about 12-20 cm), groundwater pumping was to be drastically increased to help meet the rising demand. Total pumpage reached a peak of more than 100 Mm^3/year in the late 1960s, remaining steadily above 70 Mm^3/year till the 1990s. Groundwater is mainly pumped from the upper 600 m of unconsolidated sediments. The long-term effects of the continued subsurface overdraft produced a regional decline of water levels of as much as 90 m by 1990 with more than 1.7 m of land subsidence measured by levelling surveys through 2000 [Bell *et al*., 2002].

Since 1988 the Las Vegas Valley Water District (LVVWD) implemented a groundwater recharge program in the attempt of enhancing the local water supply during periods of high demand. Water is recharged primarily in the coolest months using treated surface water imported from the nearby Lake Mead and the Colorado River. Since the artificial recharge program beginning, water levels have stabilized and recovered by as much 30 m from 1990 to 2005. Persistent Scatterer InSAR on ERS and ENVISAT datasets acquired from 1995 to 2000 and from 2003 to 2005, respectively, show not only a general reduction of the subsidence rate but also a broad area adjacent to the easternmost margin of the main artificial recharge zone exhibiting uplift velocities up to 1 cm/year (Fig. 2). Seasonal displacements of the order of 1 cm are also superimposed to the larger uplift trend, indicating that there are both short- and long-term components in the elastic response of the system. The maximum seasonal amplitude occurs during January through March each year being

closely related to the final stage of the artificial recharge [Amelung *et al*., 1999; Bell *et al*., 2008].

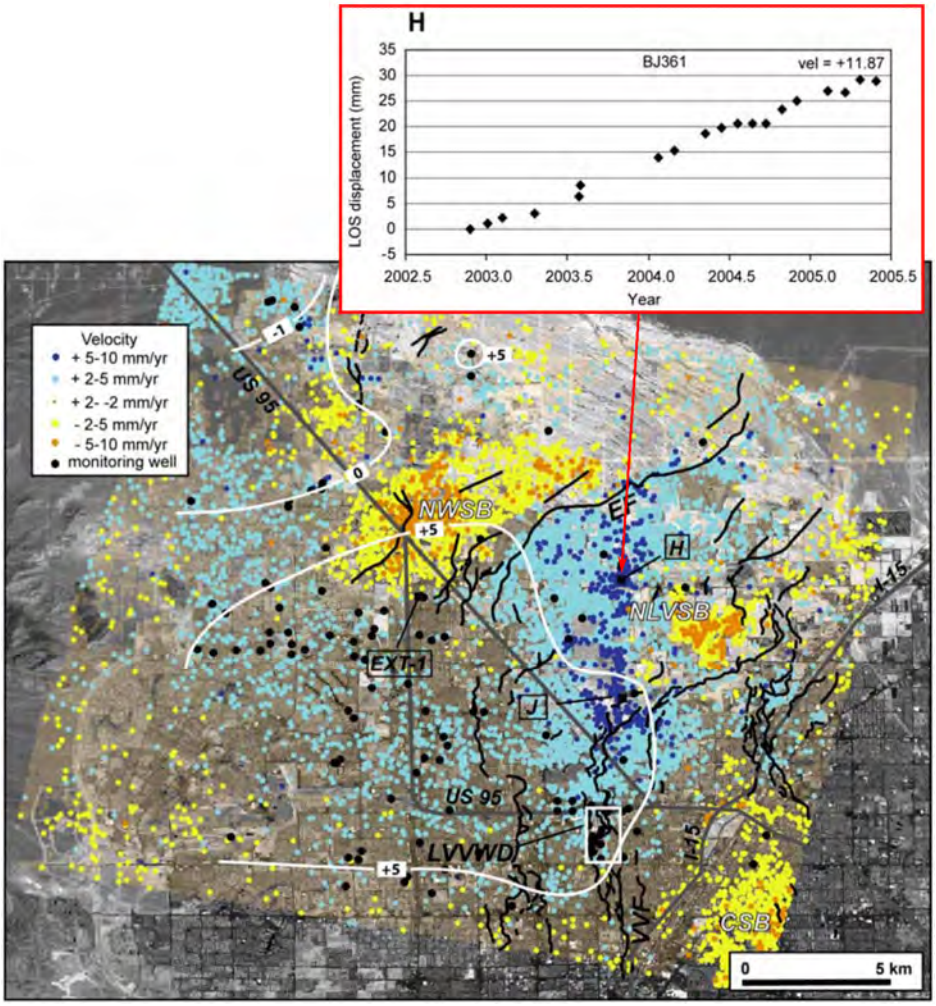

Fig 2. Velocity map for the northwest portion of Las Vegas Valley, Nevada, obtained by Persistent Scatterer InSAR from ENVISAT data between April 2003 and May 2005. The contour lines of the water-level change (m) recorded in the same interval are shown. The inset on the right shows the time series of the vertical displacement for the persistent scatterer indicated on the map (modified after Bell et al. [2008]).

3.2 Uplift due to land subsidence mitigation: Taipei basin, Taiwan

Taipei City is the political and economical centre of Taiwan with a dense population of about 3 million inhabitants plus several million people in the surrounding suburban areas. Like many other big cities in the world, early development of the city was enhanced by the development of the groundwater resources. The centre lies on 300-m thick late-Quaternary fluvial deposits laid down over a deformed Miocene bedrock starting from about 400,000 years ago.

Groundwater pumping mainly occurred from 1955 to 1970 from a confined aquifer comprised between 50 and 140 m depth below the ground surface. Piezometric head has decreased by more than 40 m with the lowest value achieved in 1975. The massive pumping was paralleled by large land settlements amounting to as much as 2.2 m in the city centre [Wu, 1977]. In order to mitigate the subsidence and prevent the possible associated damages, the government stopped the use of groundwater in the Taipei Basin during the early 1970s. The settlement rate has therefore significantly decreased with the

hydraulic head gradually recovered and stabilized since approximately the late 1990s. The establishment of a fine network of leveling benchmarks has allowed for an accurate monitoring and control of the ground movements during the aquifer recharge. The behaviour of the post-pumping ground elevation is characterized by a relatively long period of declining subsidence followed by a period of uplift from 1989 to 2003. Most surface rebound was observed in the central to eastern portion of the basin, roughly corresponding to the area of maximum subsidence. From 1989 to 2003 most of the Taipei Basin, except for the westernmost margin, experienced a rather homogeneous uplift of 7 to 10 cm with a maximum value of up to 17 cm (Fig. 3a). The largest rate of more than 1 cm/year was measured between 1989 and 1994 (Fig. 3b). The observed elastic rebound has allowed to quantify in about 10 the ratio between the soil compressibility in virgin loading and unloading/reloading conditions [Chen *et al*., 2007].

3.3 Uplift in connection to EOR projects: Cold Lake, Canada

Cold Lake is the oldest of the four developed oil sand production areas of northern Alberta, Canada. It is producing from the Clearwater sand lying at a depth of about 450 m and 15-30 m thick. The sand is primarily quartz and in the best quality area is quite homogeneous and densely packed, and exhibits dilation when sheared. Above the Clearwater is the Grand Rapids formation consisting of interbedded shale/sand sequences (often containing small gas reservoirs), and the Colorado shale group. Fresh water aquifer sands at depth of 100-150 m overlie the Colorado shale. The bitumen viscosity in the Clearwater varies between 50,000 and 100,000 cp at in-situ temperature close to 13 °C. The area was developed initially by Imperial Oil Ltd. using CSS (Cyclic Steam Stimulation) consisting of cycles of steam injection (30-40 days) at fracturing pressure followed by a production period of several months. Currently, the SAGD (Stream Assisted Gravity Drainage) process is favoured for new projects.

In CSS, the deformations from the pressure cycles (typically between 10 MPa to 2 MPa or less) and thermal expansion combine to an overall heave of 10-35 cm. Wang and Kry (1997) show the data and simulation results for an area of 3 well “pads” (each consisting of 4 rows of 5 wells) for the period between January 6 and February 24, 1989. At the beginning of this period, the injection and production was balanced, but due to previous injection, the maximum heave was already about 20 cm.

Satellite measurements of the Cold Lake project have been described by Stancliffe and van der Kooij (2001). As shown in Figure 4, large deformation changes can occur over small periods of time (2-3 months). They stated that their best data shows that the total deformation can reach 36 cm during a single month.

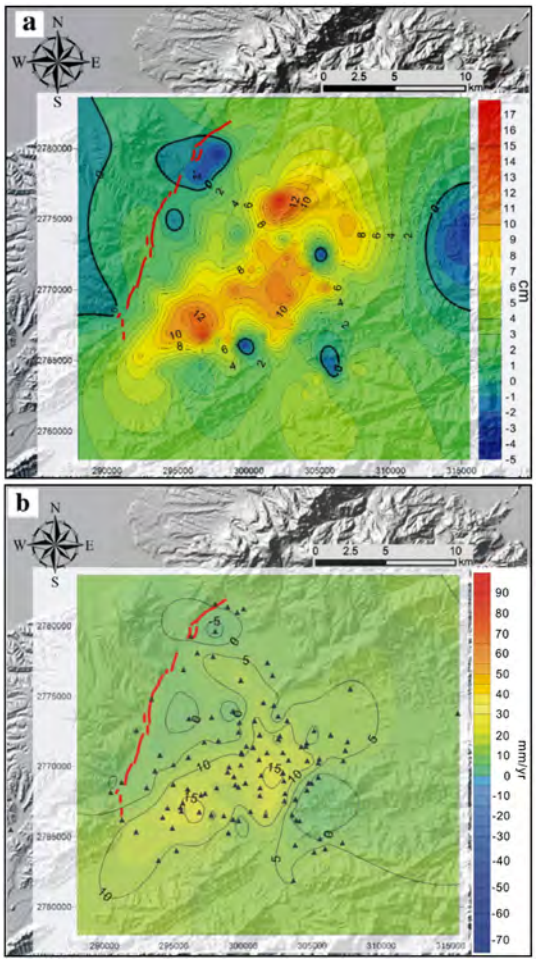

Fig 3. (a) Map of land uplift in the Taipei basin from 1989 and 2003 as obtained by interpolation of the leveling records. (b) Land upheaval rate over the period 1989-1994 (modified after Chen et al. [2007]).

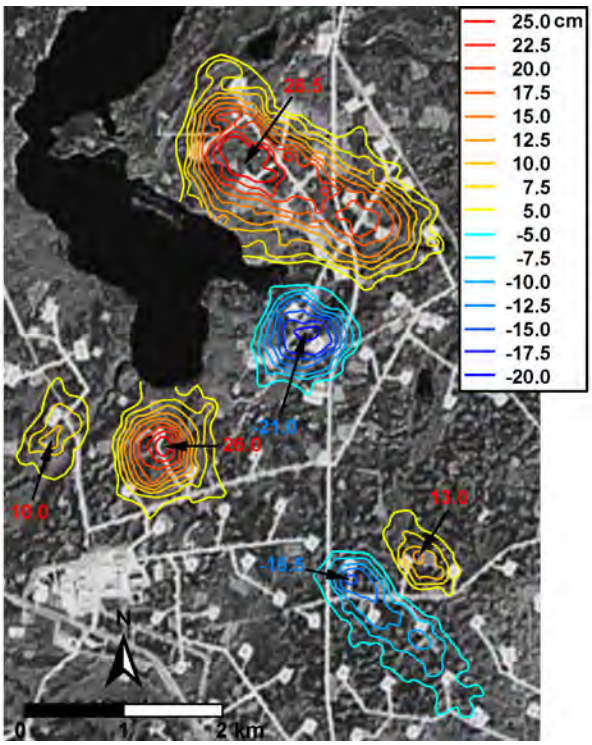

Fig 4. Deformations (cm) over a time period of 86 days (August 5, 1996 – November 1, 1996) measured by InSAR in Cold Lake CSS project [adapted from Stancliffe and van der Kooij [2001]).

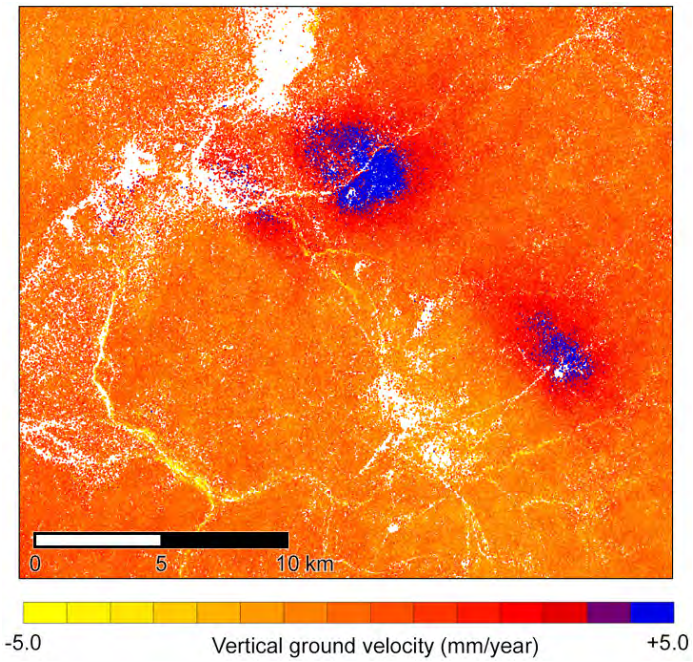

Fig 5. Mean land vertical velocity above the Krechba field, Algeria, as detected by the analysis of PSInSAR data in the period 2003-2007 [modified after Vasco et al. (2008)].

3.4 Uplift in connection with gas storage: Krechba field, Algeria

The Krechba field is a gas reservoir located in the Algerian Sahara desert at a burial depth of about 2000 m. The 20-m thick producing layer lies on a north-northwest trending anticline and mainly consists of quartzose fine-grained sandstone of the Lower Carboniferous age. The overburden is made of a sequence of alternating mudstones and sandstones. The horizontal stress field in the basin is highly anisotropic with faults on the flanks of the anticline trending on the north-northwest direction. The gas produced from the Krechba field contains a high mole fraction of CO_2 which must be separated and disposed of for both economic and environmental reasons. The CO_2 is therefore re-injected into the reservoir through three nearby wells located at about 8 km northeast of the cluster of the production wells. The well-head injection pressure varies during the operations with an average value of 15 MPa and peak values achieving 18 MPa.

As part of a CO_2 sequestration research project, the InSAR technology has been used to monitor the injection effects on the ground surface [Vasco *et al*., 2008]. The study is based on the satellite radar images obtained from the European Space Agency ENVISAT archive from July 12, 2003 to March 19, 2007 using the Permanent Scatterer (PS) technique [Ferretti *et al*., 2001]. In the Krechba field case the quality of the measurements is particularly good because of the rock outcrops in a desert area with little shifting sand. The mean vertical ground velocity for the investigated 2003-2007 time interval as provided by the PSInSAR data analysis is shown in Fig. 5. The areas with a positive velocity are increasing their elevation by more than 5 mm/year and are clearly correlated with the location of the three injection wells. The cumulative upheaval measured above the Krechba field amounts to about 2 cm with a rather uniform area distribution.

3.5 Uplift in connection to site geomechanical characterization: Upper Palatinate, Germany

A water injection experiment intended to study the upper earth crust deformation, improve the knowledge of the coupled hydro-geomechanical processes and characterize the involved subsurface porous medium was performed from June 2004 to April 2005 in the Upper Palatinate, Eastern Bavaria, Germany [Kumpel *et al.*, 2006]. Water was injected at a rate of about 290 m^3/day for a total of 84,000 m^3 through an open hole that was 3850-4000 m deep. Land deformation was monitored by ASKANIA high-resolution borehole tiltmeters installed at 5 locations at a variable 1.5-3.3 km distance from the injection well denoted as Kontinentale Tiefbohrung der Bundesrepublik Deutschland (KTB). The pore pressure increase exceeded 10 MPa at KTB over the injection time and induced a land deformation that was detected by the tiltmeter array. The measured tilts were reproduced with the aid of a finite element model based on the ABAQUS code. The results [Jahr *et al.*, 2008] reveal a maximum anthropogenic uplift of approximately 3 mm above the injection point which dissipates quickly as one moves far from it (Fig 6a). Fig. 6b shows the modelling reconstruction of the tiltmeter measurements around KTB.

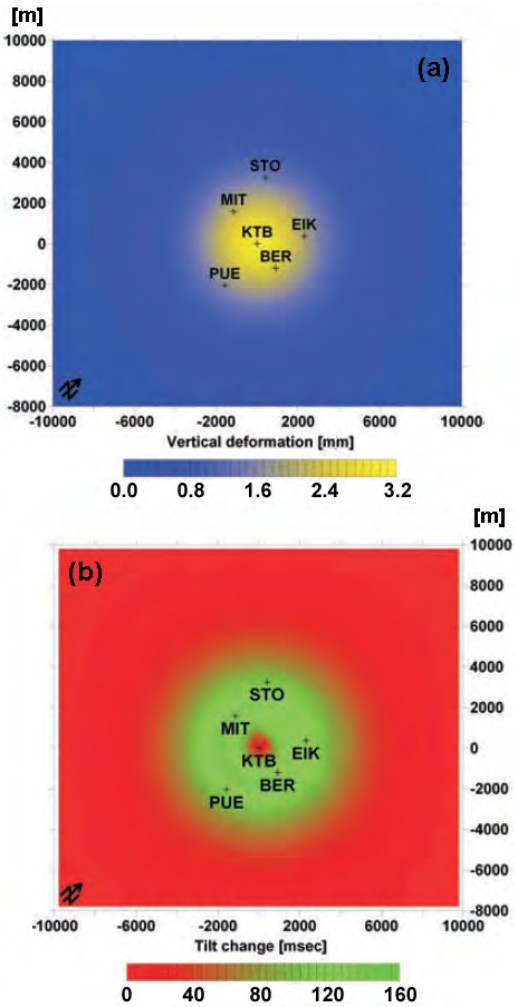

Fig 6. Results from the finite element interpretation and reconstruction of the tiltmeter measurements: (a) land uplift; (b) tilts at the land surface [modified after Jahr et al. [2008]).

Conclusions

A survey of sites worldwide where underground fluid (water, gas, steam) injection has caused a measurable land uplift (or heave) has been performed. Fluid is injected for various purposes, from enhancing oil production to storing gas in depleted gas/oil fields, recharging pumped aquifers, disposing of industrial liquid wastes and mitigating anthropogenic land subsidence. Vertical land displacement is measured by making use of traditional levelling technique, tiltmeters, or most frequently and relatively inexpensively with the aid of the satellite interferometry. Land may rise as a consequence of the migration to ground surface of the injected formation expansion which is due primarily to the release of the effective intergranular stress and secondarily to the shear dilation (or dilatancy) on condition that the induced fluid pore overpressure is large enough so as the yield surface (or friction line) is intersected by the Mohr-Coulomb circles. Thermal expansion can also contribute significantly to the observed heave. Land uplift due to anthropogenic fluid injection is therefore a strategy physically suitable for the mitigation of high-value coastal lowlands subject to high risk of flooding.

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APPLICATION OF A NEW BIOINDEX BASED ON HARD SUBSTRATE BIOCOENOSIS FOR THE EVALUATION OF THE LAGOON QUALITY

Francesca Cima, Paolo Burighel, Loriano Ballarin

Dipartimento di Biologia, Università di Padova

Riassunto

Il lavoro condotto in questa ricerca si è basato sullo studio del “fouling” nella Laguna di Venezia, volto a verificare l’attendibilità di un indice di qualità ambientale applicato a quattro stazioni della Laguna. Tale indice è stato sviluppato attraverso la raccolta di dati chimico-fisici e biotici e lo studio della loro interrelazione.

A partire da Giugno 2007 sono state immerse delle unità rappresentate ciascuna da un pannello di acciaio e uno di legno (20 x 15x 2.5 cm) in quattro stazioni diverse della Laguna, in modo da poter raccogliere dati relativi a un’area rappresentativa della Laguna seppure in un periodo piuttosto limitato – l’estate – ma corrispondente al massimo sviluppo e differenziazione delle biocenosi. A cadenza mensile sono state acquisite foto dei pannelli in modo da poter controllare la successione ecologica delle comunita a “macrofouling” di substrato duro presenti e raccolti parametri chimico-fisici relativi all’acqua, quali temperatura, pH e salinità. I dati raccolti sono stati inseriti nel bioindice per descrivere lo stato di salute delle acque lagunari nelle quattro stazioni. Il lavoro principale è consistito nell’elaborazione dei dati biotici attraverso l’analisi delle foto digitali dei pannelli per effettuare il riconoscimento delle specie, il loro numero e l’area ricoperta sui pannelli.

L’indice di qualità ambientale in esame risulta utile per poter stimare lo stato di salute delle acque lagunari attraverso un sistema poco costoso ed efficace. I risultati ottenuti sono stati confrontati con quelli ottenuti in precedenza e hanno fornito delle conferme sull’utilità del bioindice, nonostante delle differenze dovute probabilmente più a piccoli cambiamenti climatici annuali che a variazioni significative in parametri locali.

Abstract

This research was based on the study of the fouling in the Lagoon of Venice and its aim was to verify the reliability of an index of environmental quality applied to four stations of the Lagoon. Such index has been developed through the collection of physico-chemical and biotic data and the study of their interrelation.

From June 2007, panel systems, each one represented by a steel and a wood panel (20 x 15 x 2.5 cm), were immersed in four different stations in order to collect data regarding a representative area of the Lagoon in a period – summer – which, although limited, corresponded to the maximum development and

differentiation of the biocoenoses. Pictures of the panels, to control the ecological succession of the macrofouling community of hard substrates covering the panels, and values of physico-chemical parameters of the seawater, like temperature, pH and salinity were collected each month. Data were introduced in the bioindex to describe the status of health of the lagoon seawater in the four stations. The main work consisted in the biotic data processing, through the analysis of the digital photos of the panels for the recognition of the species, their number and the covered area on the panels.

The index of environmental quality under examination results useful for evaluating the status of health of the lagoon seawater by means of a cheap and effective system. Results were compared with those previously obtained and have supplied confirmation of the utility of this bioindex, in spite of differences probably due more to little year's climatic change than significant variations in local parameters.

1. The fouling in the coastal benthic biocoenoses

The coastal benthic communities are characterised by higher biomass and species diversity than the offshore ones. This difference can be due to many causes, such as the higher temperature of the more superficial layer of the water column, the considerable concentration of food and biogenetic factors, a greater number of hard substrates. In addition, in coastal environments, there is a remarkable instability of the habitats due to climatic, anthropic and predatory phenomena, which cause interruptions of the colonisation so that the biocoenoses begin to develop again from the early-phases of the succession, determining a high rate of growth [Railkin, 2004a].

In the Lagoon of Venice, the substrates interested by the fouling phenomenon are very common and are represented, for example, by boat keels, artificial moles, piping, fishing nets, platforms, signal boas. The interest towards fouling derives on one hand from the demand of preventing damages provoked by the organisms encrusting the submerged artificial surfaces and, on the other hand, from the intrinsic value of the macrofouling community as useful tool to evaluate the biodiversity status of the lagoon. Various phases succeed during the colonisation of a substrate and the animal and vegetal benthic organisms settle in succession till a final stage, called relative climax, is reached. Such progression is characterised by a temporal sequence depending on the duration of the immersion of the substrate, a seasonal sequence, and a biotic sequence [Redfield and Deevy, 1952]. The temporal sequence comprises four stage [Wahl, 1989]:

1. Biochemical conditioning, represented by absorption of macromolecules and dissolved ions in the seawater;
2. Bacterial colonisation;
3. Development of microfouling, that is the colonisation by unicellular autotrophic and heterotrophic eukaryotes;
4. Development of macrofouling, that is the colonisation by multicellular autotrophic and heterotrophic eukaryotes.

The first two phases are regulated by physico-chemical and partially biological

mechanisms, whereas the biological factors prevail in the last ones.

Initially, the virgin surface absorbs polysaccharides and proteins dissolved in the seawater. Next, the substrate is covered with a primary biofilm constituted of debris and bacteria characterised by very fast multiplication cycles [Meadows, 1964]. Microfouling represents the primary covering which includes, besides biofilm and debris, microorganisms like protozoans and diatoms, and nematodes. This layer favours the settlement of the following one, the macrofouling, represented by porifers, bryozoans, hydrozoans, anthozoans, sedentary polychaetes, molluscs, cirripeds, tunicates and microalgae; moreover, grazing invertebrates are present, like wandering polychaetes, amphipods, isopods, decapods.

The seasonal sequence varies depending on the settlement and the reproduction of animals and plants in the different moments of the year. The most intense settlement in the Lagoon of Venice occurs in summer, from June to October. The organisms of the macrofouling have different growth speed and, therefore, they can develop and grow in the biocoenosis with different times: for example, serpulid polychaetes, characterised by a rapid growth, dominate the community initially and are then replaced by mussels, which grow much more slowly.

The biotic sequence develops through structural and functional change of the community, till the final stage, the relative climax, is reached, when all the species of the community enter a dynamic balance among them. It is characterised by a stable abundance and the total number of species is reached in different times depending on the climatic zone and the depth of the substrate [Connel and Slatyer, 1977].

The substrate colonisation occurs through two principal phases, a reversible and an irreversible one. The first phase includes transport and settlement, which is initially characterised by temporary adhesion to the surface through substances secreted by organisms: this phase represents the biofouling process. Subsequently, the irreversible phase takes place and the settlement becomes permanent with the development, the growth and the release of spores and larvae. The sequence of the biofouling process is directional, since every involved process immediately activates the following one [Railkin, 2004b]. The initial stage, called primary fouling, is constituted of pioneer species like, for example, bacteria, algae and hydrozoans, highly able of colonising virgin surfaces. The primary fouling represents the ideal biological substrate for the secondary fouling, characterised by organisms with slow growth, as mussels, which develop over already settled organisms and represent the reaching of the final stage, i.e., the relative climax [Sheer, 1945].

2. Bioindexes for the evaluation of the quality of the lagoon environments

The most rapid and immediate system for the ecological evaluation of an estuarine or lagoon environment is the use of biological indexes, which can summarise a large amount of data regarding various environmental variables. They are very useful, as the community answered to the improvements of environmental quality through the increase of both the abundance of the organisms and the diversity of the species, and the shift of some species from tolerant to sensitive ones towards environmental pollution [Chang et al., 1992].

Recently, on the basis of Italian and European experience, the “Lesina” bioindex has been formulated [Breber and Strada, 1997], which is applied in the lagoon environments and proposes bivalves as important bioindicators for both their constant abundance and their benthic habitus, able to tolerate many environmental conditions as well as their unfavourable variations. This bioindex describes the environmental quality through a numerical value with a logarithmic scale: a quality increase corresponds to an increase of this value considering the zoning, the biomass and the species number of the benthic macrofauna represented by sessile, fossorial and sedentary invertebrates. It can be considered as a subset of a greater index named Biotic Integrity Benthic Index (B-IBI) [Weisberg et al., 1997], which is applied to the estuaries and was formulated after a twenty-year experimental campaign of monitoring and environmental evaluation of the U.S. EPA. The B-IBI allows to classify the status of health of the community, but both this bioindex and the “Lesina” one are applied to small lagoons at the mouth of a river, and to soft substrates. Therefore, a new bioindex has been recently introduced [Cima et al., 2006; 2007] for a complex coastal environment like the Lagoon of Venice and the study of the development of its macrofouling of hard substrates. This index allows to carry out quality comparisons among the different stations of the lagoon and follows in the time the seasonal variations even in relation to possible anthropic impact. It has been calculated with the following algorithm:

$$\mathbf{Log_{10}\,(\,R \cdot A \cdot I_{pH} \cdot I_T \cdot I_S\,)}$$

where:

R = species richness, i.e., number of species monthly recorded monthly on all panels of the same type

A = area of the surface monthly recorded monthly for each species (cm^2)

I_{pH} = pH quality index

I_T = temperature quality index

I_S = salinity quality index.

This bioindex is very useful to evaluate immediately with a numerical value in logarithmic scale, from 1 to 10, the status of health of a complex lagoon environment.

3. Summer 2007: application of the bioindex in four stations of the Lagoon of Venice

Station 1 was sited in the neighbourhood of Fusina (Lat. 45° 14' N, Long. 12° 15' E), near Porto Marghera. The panels were fastened to cement pillars of disused mussel rearing stations.

Station 2 was placed more to the North, near to Campalto island (Lat. 45° 29' N, Long. 12° 18' E) in an isolated zone characterised by a minor passage of crafts in comparison with the other stations.

Station 3 was settled in the neighbourhood of S. Servolo (Lat. 45° 24' N, Long. 12° 21' E), where the panels were placed along the perimeter of a shoal.

Station 4 was settled in front of Ca' Roman (Lat. 45° 15' N, Long. 12° 17' E), where docking woods were chosen to place the panels inside a disused mussel farm. Differently from the other stations, in which the seawater depth was of about 1.5 m, it was of about 3-4 m in this station since it was sited along a transit canal.

The panels – a pair of panel systems for station – were immersed in May 2007. Observations began in June 2007 and were concluded in October of the same year. Data sampling was carried out monthly by the acquisition of photos of the panels on both their sides with a Nikon Coolpix 995 digital camera. Specimens of organisms present on the panels were collected and immediately fixed in 4% formaldehyde in sea water for their subsequent recognition in laboratory. At the same time, water samples were collected together with data of the physico-chemical parameters – temperature, pH, electric conductivity, total dissolved solid – with a Cyber Scan PC300 multiparametric portable watertight probe (Eutech Instruments). Pictures of the panels were analysed with the Corel Photo Paint software in order to allow the recognition of the species. Then, the photos were rescaled and processed with the Casti Imaging software for calculating the covering area of each species on both the frontal and the back side of the panels in terms of percentage of the covered surface.

In summer months, the development of a succession comparable with those followed in annual campaigns of previous projects (March 2004 - April 2005, March 2006 - February 2007) in the basin of Chioggia (Southern Lagoon) [Cima and Ballarin, 2008] was observed. In this case, the development of the biocoenoses was much more rapid in comparison with the biocoenoses settled from spring and involved different but typical summer taxa. Initially, the pioneer organisms during June and July were chlorophyta and rhodophyta (*Ulva lactuca*, *Polysiphonia sertularioides*, *Ceramium ciliatum*), polychaetes (*Janua pagenstecheri*, *Hydroides dianthus*) and cirriped arthropods (*Balanus amphitrite* and *Balanus improvisus*). Chlorophyta were more abundant on the frontal side of the panels due to the direct exposure to the light (Fig. 1a). In the following months, the algae decreased, mainly on the back of the wood panels, and solitary (*Styela plicata*, *Ciona intestinalis*, *Molgula socialis*) and colonial (*Botrylloides leachi*, *Botrylloides violaceus*, *Botryllus schlosseri*) ascidians, increased together with cirripeds, bryozoans (*Bugula neritina*, *Bugula*

stolonifera) and serpulids (*Serpula vermicularis*), the latter covering large surfaces of the steel panels (Fig. 1b).

The ecological succession ended with the dominance of some taxa, represented not by mussels, as expected, but by serpulids and ascidians (Fig. 1c).

Fig 1. Colonisation of wood panels in June (A, B) and August (C). A. Frontal side with Ulva lactuca*. B. Back side with serpulids (*Hydroides dianthus*). C. Relative climax with serpulids and ascidians (*Styela plicata*).*

The highest values of the bioindex (Fig. 2) were recorded during August and September, in particular in the station 3 on the steel panels (9.34), when the species number was also high and the community reached the climax stage. As regards the substrate type, only in the station 1 a difference in both growth and covering higher on steel panels than on wood ones, was recorded. Stations 2 and 3 reached the highest values of the bioindex (Fig. 2), but station 3 was more homogeneous for both the number of the species and the covering. Station 4, although showing physico-chemical parameters similar to that of the other stations, maintained for a long time a biofilm covering, never reached a stable situation, biocoenosis was represented by a few species, and the bioindex assumed values similar to the initial values recorded in all the stations (Fig. 2).

Conclusions

Differences in the trend of the bioindex found in this study with the previous sampling campaigns can be due i) to the higher number – 4 instead of 2 – of sampling stations in various zones of the Lagoon basin, ii) to the minor duration of the sampling period, concentrated during the summer months and characterised by particular climatic and physico-chemical conditions for both the scarce precipitations and the high temperatures, but always in the seasonal averages without recording significant differences between the various stations. The species richness was never very high, probably depending on the short

duration of the sampling period. For the same reason, this period of time did not allow to reach a real climax stage characterised by bivalve dominance, but it was enough to identify the dominant organisms with a rapid growth, that are ascidians and serpulids on both the panel types with slight differences between the frontal and the back side.

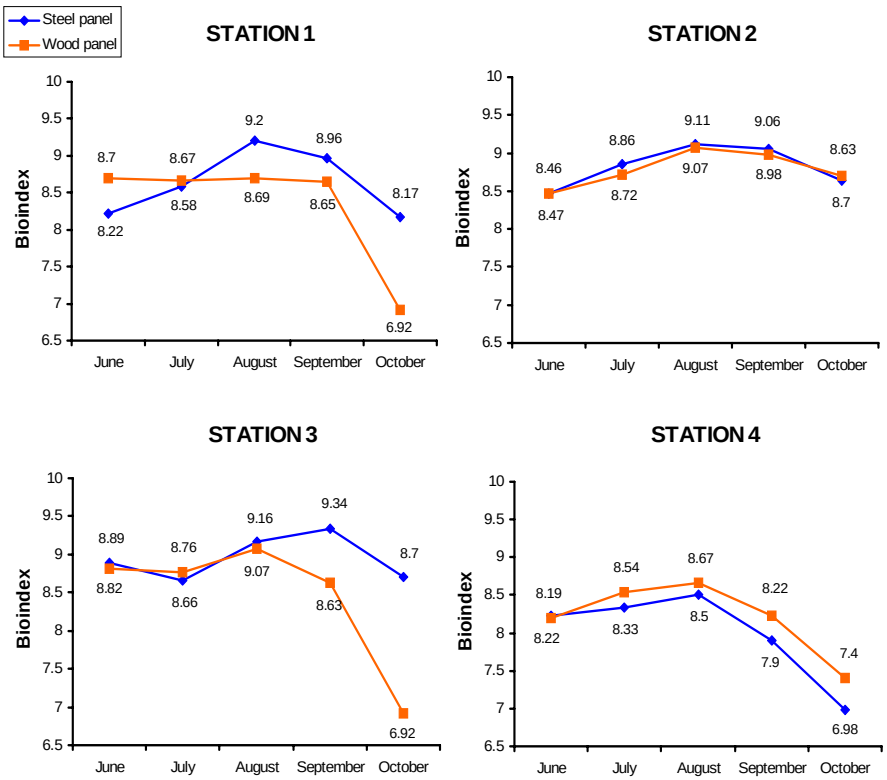

Fig 2. Trend of the bioindex in the four stations of the Lagoon from June to October 2007.

However, it must be remarked that, in the last few years, a lot of mussel farms of the lagoon was progressively removed, consequently the structure of the community previously considered typical of the Lagoon changed at least in the extent of the taxa constituting the dominant organisms of the climax.

Temperature, salinity, craft transit and substrate type represent the principal parameters which affect the final value of the environmental status of health. The lower bioindex values (6.92) were recorded during October, when the temperature decreased to 13.7 °C and the salinity reached the highest values (34.67‰).

Generally, the environmental status of health found in this study was good in all the stations, confirming the reliability of the bioindex since values similar to those observed – about 8-9 – were already found in the previous campaigns during the summer months. The organisms have shown an high adaptability also in high-risk environments, such as those near industries like station 1 in which, however, the absorption capacity of the xenobiotics by the substrate type appeared fundamental, or characterised by intense wave motion like station 4.

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PHYSIOGRAPHIC ZONING OF THE VENETIAN LAGOON

Tagliapietra D. [1], Zanon V. [12], Frangipane G. [12], Umgiesser G. [1], Sigovini M. [12]

[1] *Consiglio Nazionale delle Ricerche, Istituto di Scienze Marine (CNR-ISMAR), Venezia;*
[2] *Università Ca' Foscari di Venezia, Dipartimento di Scienze Ambientali*

Riassunto

Il presente lavoro ha lo scopo di questo lavoro era quello di delineare, sulla base di descrittori fisiografica e mesologici, un sistema gerarchico di ambiti lagunari sufficientemente omogenei in Laguna di Venezia. Si è partiti quindi da tre capisaldi, ossia l'esistenza e l'analisi del gradiente di transizione, la considerazione della natura gerarchica degli ecosistemi e i requisiti dettati dalla Direttiva quadro europea sulle acque (WFD, 2000/60/EC).

Abstract

This work was aimed to delineate, on physiographic and mesological basis, a hierarchical system of homogeneous environments within the Venetian Lagoon. Our tenets were the existence of a transitional gradient in the lagoon, the hierarchical nature of ecosystems and the requirement of the European Water Framework Directive (WFD, 2000/60/EC).

Keywords: Coastal Transitional Ecosystems, Zonation, Physiographyc zones, Water Framework Directive

1. Introduction

Conceptual framework

In coastal transitional ecosystems systems both landforms and biological processes are mainly physically controlled. The factors recognised as the most relevant ecological drivers for the lagoonal aquatic biota are salinity, seawater renewal and sediment type and condition. These factors are the main component of a composite poly-dimensional gradient ("transitional gradient"), the relative contribution of different factors depends on the main hydrodynamic energy source of the system (e.g. salinity in estuaries with high river energy, seawater renewal in microtidal lagoons) (Tagliapietra et al., 2009 and reference herein). Organisms react to the transitional gradient according to species and life stage; therefore, a given site can be occupied only by assemblages of species adapted to specific environmental conditions. Similar parts of a coastal transitional environment are, therefore, naturally characterised by similar combinations of important biological variables such as species, abundance, biomass, percentage of sensible species, trophic structure, energetic and biodiversity. These biological variables, usually combined in "quality indices", are widely used in environmental quality assessment of marine and transitional ecosystems. The inherent dependence of these biological variables on the

physical structure of the sites requires their “normalisation” to the range of variability these variables normally have in different lagoonal habitats. Not taking into account the dependence of biological variables, above all diversity, on the physical transitional gradient the impact of anthropogenic stress cannot be properly assessed.

The need of such a “normalisation” is perfectly in line with the philosophy of the WFD. The WFD strongly emphasise the importance of the biological quality elements for the assessment of the environmental quality status, on this basis, to avoid circular reasoning, the WFD expressly requires the identification of water types on the basis of physical features. The main drivers of ecological processes in coastal transitional ecosystems are included in the list of factors recommended by the WFD in order to identify water types. The WFD, as many other quality assessment procedures and environmental management practices, requires the resolution of the transitional gradient in discrete zones. A zonal approach was then adopted accepting, as a consequence, a considerable level of approximation due to the discretization of the continuum gradient. Water types were obtained analyzing the pattern emerging from the combination of the main component of the gradient. The identification of water bodies, as discrete patches belonging to the same water type, was the result of the transposition of water types into the spatial context.

2. Materials and Methods

The method was conceived to be simple, transparent ad reproducible, it consists in subdividing the Lagoon into discrete territorial units or “Operational Lagoonal Units” (OLUs), quantify basic hydrogeological parameter for every single unit, classify the units on the basis of the selected hydrogeological attributes. The subdivision of the lagoon in OLUs allowed the use of multivariate techniques to combine physical variables and achieve a hierarchical agglomerative classification. OLUs were delineated, at a suitable scale, using traditional topographic subdivisions (areas with consistent toponyms) and natural boundaries (canals, watersheds), a total of 226 OLUs were obtained. A similar system of land units was produced by MAV-CVN (MAV-CVN, 1999). A minimum set of physical variables were selected: salinity, percentage of sand/pelite and water transit time as a proxy for water renewal processes and confinement. Average salinity was calculated from data supplied by Consorzio Venezia Nuova on behalf of Magistrato All Acque di Venezia, sediment texture was obtained from a CNR-ISMAR dataset, the transit time was calculated from model (Cucco, and Umgiesser, 2006). Transit time was preferred to the residence time because its higher ability in identifying sub-basin watersheds. Before the application of multivariate methods values were transformed in percentage of their variation range to made all the factors lie between 0 and 1. Hydrogeological data were not available for all the main landforms of the lagoon, canals, salt-marshes and shallows, therefore we choose to conduct the analysis only on the more common depth stratum in the lagoon, the shallows between men sea level and -2 m, which represent the majority of the lagoon surface. OLUs were, hence, classified into Types (Hydrogeological Types or

"Water Types") on the basis of hydrogeological variables through a multivariate approach and mapped using GIS, adjacent OLUs belonging to the same type were regarded as consistent lagoonal "Water Bodies" or "Zones". The identified Water Bodies are bottoms zones sharing a common set of hydrological and sedimentological attributes relevant for the biota, particularly for benthic invertebrates.

The present paper is a synthetic report of the result achieved by WP1 ("Definition of environmental typologies") (Tagliapietra et al., 2006) of Research line 3.11 ("Indicators and Indices of environmental quality for the lagoon of Venice) included in the 2004-2006 CORILA Research Project and it has been the theme of a PhD Thesis (Zanon, 2006).

3. Results and Conclusions

At the higher level, there was a first subdivison into two major types that corresponded spatially to the classical subdivision into Open and Restricted Lagoon.

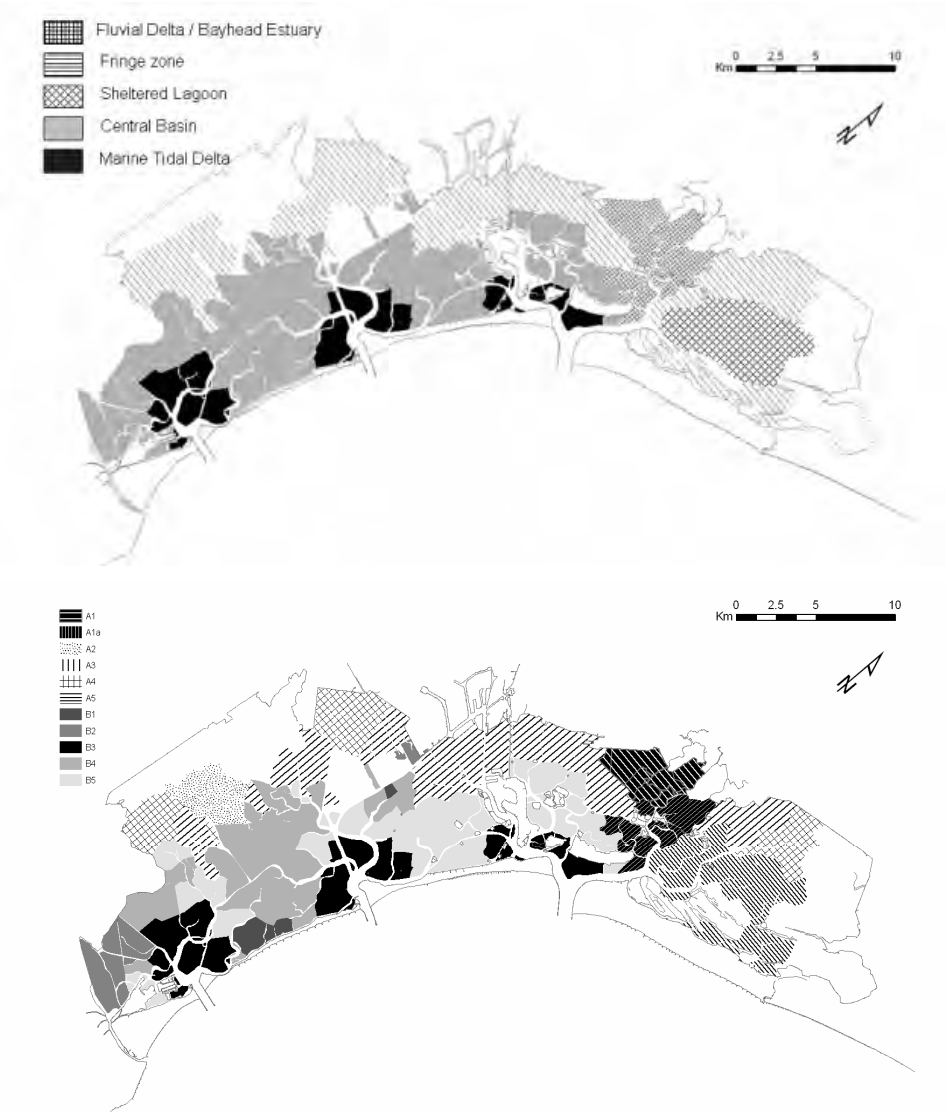

Fig 1. Hierarchical system of Water Bodies in the Venetian Lagoon. Above are reported the four middle-rank Water types, below are reported the 11 lower-rank types. The two higher-rank Water types are evidenced by different textures; Open Lagoon = filled, Restricted Lagoon = hatched. Water Bodies are discrete areas belonging to the same Water Type.

A second-rank subdivision was substantially coincident to the classic "Geomorphic zones" (Roy et al., 2001) of Wave Dominated Estuaries "Marine Tidal Delta" "Central Basin" and "Fluvial Delta" or "Bayhead Estuary". Typical of our classification is a landward type called "Fringe Zone" characterized by little freshwater inflow and a particular facies of the Central Basin that can be defined "Sheltered lagoon" due to its high residence time and salinity . A third-rank level classification gave 11 types, to be used in finer ecological analysis, used in the second phase of the project: "Upper Fluvial Delta" proximal, bay-head part of the Dese estuary (A1); "Lower Fluvial Delta" (A1a) distal part of the estuary; "Fringe Zone local Facies" (A2); "Marginal Fringe Zone" (A3); "Remote Fringe Zone" (A4); "Inner Fringe Zone" (A5); "Open L. Sheltered" (B1); "Open L. Exposed" (B2); "Marine Tidal Delta" (B3); "Central Mud Basin facies A" (B4); "Central Mud Basin facies B" (B5) (Figure 1). To these types should be added the oligohaline areas, and the highly modified or anthropogenic types of "Fishing Farms" and "Urban Estuaries" of the City of Venice, the Islands and the Industrial Zone, not included in this study for the small number of data.

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INTEGRATED QUALITY ASSESSMENT OF THE LAGOON OF VENICE

Christian Micheletti, Stefania Gottardo, Andrea Critto, Sara Chiarato, Jonathan Rizzi, Elena Semenzin, Antonio Marcomini

Dipartimento diScienze Ambientali, Università Cà Foscari di Venezia

Riassunto

Lo stato di qualità delle acque superficiali in Europa, inclusi gli ambenti di transizione come ad esempio le lagune costiere, è regolato dalla Direttiva quadro sulle acque [WFD, 2000/60/EU], che richiede la classificazione della qualità dei corpi idrici ed il raggiungimento di uno stato buono entro il 2015. Il raggiungimento di tale obiettivo in laguna di Venezia è condizionato dalla presenza simultanea di numerose pressioni di origine antropogenica (la contaminazione del sedimento) e di origine naturale (l'erosione del sedimento). Nel corso degli anni, diversi enti ed istituti hanno condotto monitoraggi e ricerche per individuare lo stato e gli impatti sull'ecosistema lagunare. Tuttavia, la valutazione integrata di tutte queste informazioni è diventata una priorità solo negli ultimi anni, sia per supportare l'implementazione della WFD, sia per fornire indicazioni agli enti locali preposti per una corretta gestione della laguna. Al fine di raggiungere questi obiettivi, è stata sviluppata una metodologia integrata di valutazione della qualità in laguna di Venezia basata sul metodo Weight of Evidence, che implementa strumenti proposti per l'applicazione della WFD. La metodologia integra 5 linee di evidenza (LOE) denominate Biologia, Fisico-chimica, Chimica, Ecotossicologia, e Idromorfologia, ognuna caratterizzata da indicatori specifici per la laguna di Venezia, e permette di classificare i corpi idrici lagunari su base probabilistica, utilizzando l'approccio ratio-to-reference. I corpi idrici lagunari sono stati identificati da Tagliapietra et al. (2006) sulla base delle tipologie di habitat lagunari. Nell'ambito del progetto CORILA, linea 3.11, la metodologia di valutazione integrata è stata testata su un set di dati di monitoraggio a disposizione in due tipologie lagunari, e con dati raccolti in 4 stazioni, due per tipologia, al fine di verificare l'applicabilità della metodologia sulla base di un set di informazioni omogeneo. In accordo alla metodologia di valutazione integrata proposta, gli indicatori selezionati sono stati assegnati alla LOE di pertinenza, ed il loro risultato espresso in classi di qualità (5 per la LOE Biologia, secondo le richieste della WFD, e 2 per le altre LOE) definite con l'aiuto del giudizio esperto. A questi risultati è poi stata applicata la procedura di aggregazione delle LOE per arrivare alla classificazione finale del corpo idrico, espressa come percentuale di occorrenza delle 5 classi di qualità. I risultati ottenuti indicano che l'applicazione della procedura basata sugli indicatori sviluppati nella linea 3.11 è utile per integrare i diversi aspetti della qualità lagunare, supportando inoltre l'identificazione delle principali pressioni responsabili degli impatti.

Abstract

The quality status of surface waters in Europe including transitional environments such as coastal lagoons is regulated by Water Framework Directive [WFD, 2000/60/EU]. WFD requires the quality classification of water bodies and the achievement of a Good ecological state within 2015. The attainment of Good ecological status in the lagoon of Venice is problematic because of the simultaneous presence of numerous anthropogenic (e.g. sediment contamination) and natural pressures (e.g. sediment erosion). During the last 15 years, institutes and regulatory bodies carried out monitoring programs and research works to identify state of, and impacts on lagoon ecosystem. However, the integrated assessment of this information became a priority only since the WFD was approved, both to support WFD implementation and to support a sound management of the lagoon by local public bodies. To reach these goals, an environmental quality integrated assessment methodology was developed, on the basis of Weight of Evidence approach and tools proposed for the implementation of the WFD. The methodology integrates five lies of evidence (LOE), namely Biology, Physico-Chemistry, Chemistry, Ecotoxicology, and Hydromorphology. Every LOE was characterized by indicators specifically developed for the lagoon of Venice. The integration of the LOE allows classifying water bodies obtaining a probabilistic result on the basis of the ratio-to-reference approach. The water bodies were identified by Tagliapietra et al. (2006) on the basis of habitat typologies. In the CORILA project framework (research line 3.11) the integrated assessment methodology was tested in two habitat typologies using a set of monitoring data. Subsequently, the methodology was validated using experimental data collected in 4 sampling stations, two per habitat typology, using homogeneous data to verify the applicability of the methodology. In the validation process, proposed site-specific indicators were assigned to proper LOE, and their results was expressed in quality classes (5 for LOE biology, and 2 for other LOE) defined by expert judgment. To these results was then applied the LOE aggregation procedure to classify the water bodies, which was expressed as the occurrence percentage of the 5 WFD quality classes. The results obtained so far indicates that the application of the procedure using the indices proposed in the research line 3.11 is helpful to integrate different aspects of the lagoon quality, supporting the identification of the key pressures.

1. Introduction

The implementation of the Water Framework Directive, WFD [European Community, 2000] requires the achievement of a good ecological status of European surface waters by 2015. The ecological status concept involves the evaluation of the impacts of multiple anthropogenic stressors on the structure of the biological communities and the overall ecosystem functions of water bodies [Heiskanen et al., 2004]. To reach this goal, the WFD focus on the integration of biological, chemical, physicochemical, and hydromorphological parameters (i.e. quality elements) by means of indicators and indices, thus defining quality classes (from high to bad) for the investigated water bodies. The ecological

quality of a water body type (river, coastal water, transitional water, lake, artificial water body) is defined according to a comparison with the ecological quality of the reference area (ratio-to-reference approach) for the same type, described in the annex V of WFD.

When applying the WFD to the lagoon of Venice, and especially the application of the ratio-to-reference approach, it has to be addressed the high diversity of the lagoon habitats, which is changing from the inlets to the confined areas. To correctly evaluate the quality of one water body, it is important to identify a comparable reference conditions, pertaining to the same habitat type.

To identify reference conditions, and to characterize the quality elements required by the WFD, there is the need to collect data on many parameters. The research undertaken up to now in the Venice lagoon provided data and information for a great variety of parameters (e.g. chemical, physical, hydromorphological, biological, ecotoxicological, and sedimentological parameters). However, all these data were not organized in a standardized structure, since they were obtained in different studies conducted with different goals and methodologies, as well as at different times and sampling stations.

Up to now, only few procedures and tools were developed, which can quickly identify the state and trends of the various lagoon's habitats, identify the stress agents of the ecosystem and estimate ecological integrity, as required by the WFD.

Within the framework of the CORILA research program we developed an integrated methodology to assess the environmental quality of the lagoon of Venice according to the WFD requirements. The objectives of the work were: i) to develop an environmental database organizing all available data into a standardized structure; ii) to identify indicators and indices suitable for the application in the lagoon of Venice; iii) to develop a methodology integrating environmental data into indices and thus classifying the quality of water bodies into the WFD 5 classes; iv) to test the methodology in two different habitat typologies.

The integrated assessment methodology was based on Ecological Risk Assessment paradigm [US EPA, 1998], applied by means of the Weight of Evidence (WOE) approach [Chapman, 2009] and supported by a GIS environment. WOE allows integrating heterogeneous data and information, organized in "lines of evidence" (LOE) such as chemistry and ecotoxicology, assessing the ecological status of a water body taking into account all the environmental components.

WOE approach reduces the uncertainty of the estimation, provides a traceable process from the raw data collection to the quality assessment thus reducing the loss of information, and it can be used to support the decision making by prioritizing critical areas according to users preferences and by supporting the identification of quality affecting factors.

2. Integrated assessment methodology: development and application

In this chapter the integrated assessment methodology developed within the project will be generally described, from the database definition to the applied data and indices. A brief description of the expected results type will be also reported, as well as future developments. The basis for the development of the methodology was the lagoon zonation carried out by Tagliapietra et al. (2006) within this project, identifying lagoon habitats and water bodies which are essential for a correct quality assessment according to the WFD. Data organization, quality assessment, and results presentation were based on this spatial organization of the lagoon.

2.1 Environmental database

To apply the integrated methodology an environmental database including data about different aspects (e.g. biodiversity, chemical contamination), and reporting the relevant information in a common format, was developed. The geodatabase included data collected from monitoring programs [Venice Water Authority, 1999; 2003; 2005; 2007]. The database easiness-to-use and exploration were supported by grouping data into five LOE (i.e. biology, physico-chemistry, chemistry, hydromorphology, and ecotoxicology) according to the WFD monitoring requirements for transitional environments [European Community, 2003a] and to the data availability. For each LOE (e.g. biology) parameters (e.g. fish) and subparameters (e.g. species abundance of *Tapes philippinarum*) were identified.

The main information collected in the database included the lagoon habitat typologies and water bodies, the sampling sites and the experimental parameters values, including metadata (e.g. sampling and analytical methodology) and the reference studies (e.g. year of the study, institution, aim of the study) supporting the data quality assessment.

A user-friendly interface has been implemented to easily search and report desired data, filtered by sampling site, individual parameter, and habitat typology. The database search results can be exported as report or as excel spreadsheet. Moreover, the selected data and sites can be visualized on a GIS map in order to verify their spatial distribution, to identify data gaps and to refine further searches.

2.2 Procedure and tools

The integrated assessment methodology implements the WFD monitoring and assessment requirements for transitional aquatic environments [European Community, 2003b]. In addition to the four LOE required by WFD for transitional environments, i.e. Biology, Physico-Chemistry, Chemistry, and Hydromorphology [European Community, 2003a], LOE Ecotoxicology was added to link chemical contamination to the ecological observations (i.e. biodiversity). The developed methodology integrates data at different spatial levels, from sampling site to water body scale.

Generally, data measured in different studies and for different purposes are measured in different sampling stations. To address this issue, data are assessed and integrated at different spatial levels, keeping in mind that the final analytical unit is the water body. The first step is to evaluate the category's parameters in sampling sites by using the ratio-to-reference approach. Reference conditions are parameters values measured in reference sites, or regulatory quality standards, depending on the LOE and on the available data. The parameters distance from the reference is classified in 5 classes (from High to Bad) for the LOE Biology, while for the others LOE a two-class classification (e.g. acceptable/not acceptable) is obtained. If regulatory thresholds are missing, experts' judgment is used to define the limits between quality classes. The second step is to aggregate the parameters classified in sampling sites at water body scale, obtaining a classification for each LOE. The LOE classification is reported as a frequency distribution, showing the percentage of parameters in each quality class.

The final step is to integrate the different LOE to obtain the water body quality assessment. This phase is carried out adapting the flow chart proposed by the CIS ECOSTAT working group [European Community, 2005], i.e. including the Ecotoxicology LOE. The flow chart input data is the classification of the LOE Biology, while the others LOE are used as supportive information, modifying the LOE Biology outcome. For the LOE Chemistry, Physico-Chemistry, and Hydromorphology, two level of compliance are used, one more conservative to confirm the Biology High quality class, and one less conservative, to confirm the Biology Good quality class. In this modified flow-chart, LOE Ecotoxicology is used to support or reject the Chemistry Good quality class.

2.3 Testing and validation

The integrated assessment methodology was tested in the water bodies of two habitat typologies, using the data extracted from the environmental database. The two habitat typologies were selected taking into account the highest gradient difference The results were reported as maps, with pie charts and a color coding, with the intention to avoid loss of information. At sampling site scale, the classification of categories was reported indicating the results of all applied indices. The LOE classification in water bodies, as well as the water body final quality classification (resulting from the application of the flow-chart) was represented using one pie chart per water body, with colored slices showing the percentage of each quality class.

The integrated assessment methodology, along with the proposed indices, was tested in four sampling stations, two for each habitat typology. The stations were selected on the basis of exiting data evaluated by experts, in order to have a set composed by one station with a relative low ecological status, and one station with a relative high ecological status, for each habitat typology.

The objective of this exercise was to test the effectiveness of the proposed indices, as well as of the methodology, to discriminate between different environmental qualities in different environmental conditions, by using

homogeneous experimental data (same location and same time) explicitly collected for the quality assessment.

The data collected by project partners (in round brackets) and used in this work are reported in the project final report [line 3.11 – extension; Final report, 2009]. In detail, for the validation were used the following data:

- LOE Biology: benthic biodiversity (Tagliapietra et al.), and hard substrate biotic community (Burighel et al.).
- LOE Ecotoxicology: Weighted Average Toxicity Index (Volpi-Ghirardini et al.), *Mytilus* cellular apoptosis (Tallandini et al.), DNA damage in *Mytilus* (Tallandini et al.), and gene expression in *Mytilus* (Venier et al.).
- LOE Chemistry: Vitellogenin in clams (Marin et al.).

For the LOE Chemistry, other two indices were calculated in the selected stations using existing data, namely the MSPI index [Shin and Lam, 2001], and the Food Web Index.

The testing and validation of the integrated assessment methodology showed that its application is effective to implement WFD in the lagoon of Venice, providing regulators with sound quality status and trend estimations. Moreover, the project validated some indices that can be already used by regulators and public authorities to characterize different quality elements.

3. Future development

The developed integrated assessment methodology represents a first step toward a more sophisticated and integrated methodology supporting the decision making and the implementation of the WFD in the lagoon of Venice. The next step will be to define appropriate reference conditions for chemical and physico-chemical parameters. Since regulatory standards are available only for priority substances, site-specific quality standards for water, sediment and biota need to be defined for chemicals that are relevant only at local level, following the WFD guidance on quality criteria definition.

Another further step will be the application of the methodology described in this paper to the whole lagoon, by using up-to-date data. From the collected information (e.g. data gaps, users requirements, applicability limitations), a GIS-based Decision Support System (DSS) will be developed, supporting the assessment and management of the Venice lagoon. The DSS will include MultiCriteria Decision Analysis (MCDA) methods, with the goal to define appropriate and flexible methods to aggregate the LOE and to increase the transparency in the inclusion of expert judgment. The DSS will be designed to be extendable to other transitional environments.

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PHYTOPLANKTON COMMUNITIES AS EVALUATION TOOLS OF THE WATER QUALITY OF THE LAGOON OF VENICE

Fabrizio Bernardi Aubry, Alessandra Pugnetti, Francesco Acri,
Franco Bianchi, Elisa Camatti

Consiglio Nazionale delle Ricerche, Istituto di Scienze Marine (CNR-ISMAR), Venezia

Riassunto

La principale domanda formulata durante l'attività di ricerca svolta nel 2007 dalla linea 3.12 era riposta nella considerazione se, ed in che modo, la comunità planctonica potesse essere accreditata come un efficiente indicatore della qualità delle acque lagunari.

Tuttavia, definire trend stagionali regolari per le comunità presenti negli ambienti di transizione risulta spesso un compito arduo: in questi ecosistemi, intrinsecamente variabili, l'uso del plancton come indicatore di qualità ambientale necessita della definizione ed individuazione di "condizioni di riferimento" che permettano di distinguere andamenti regolari e ricorrenti da eventi eccezionali o occasionali. Solo serie di dati pluriennali consentono ricostruzioni affidabili del ciclo stagionale del plancton presente in questi ambienti.

Per questo motivo, durante l'attività di ricerca svolta dalla linea 3.12 è stata analizzata una serie di dati decennale di conteggi fitoplanctonici e di rilevamenti idrologici in un'area centro-settentrionale della laguna di Venezia nel periodo 1997 – 2006.

Come risultato, sono stati individuati i cicli stagionali ricorrenti del plancton e sono state identificate le specie che periodicamente danno luogo a fioriture, valutando infine la presenza di specie indicatrici della qualità ambientale.

Abstract

The question if and how phytoplankton communities can be considered appropriate indicators of water quality in the transitional environments has been the core of the activity of the Research line 3.12 during 2007.

The definition of recurrent patterns and trends of phytoplankton communities represents a challenging task in the transitional environments. Indeed, some unique habitat attributes of these ecosystems markedly influence the phytoplankton seasonal pattern that, therefore, generally appears to be driven by more than a few climatic factors. The intrinsically high variability of these communities cannot be neglected and it must be taken into account, also for environmental management purpose. In this viewpoint, any effective use of the plankton communities as biological quality elements pose several constraints and it implies a strong necessity of individuation and definition of adequate baselines against which evaluate local vs. broad scale changes as well as

trends. To this respect, the existence of ecological pluriannual series, gathered with appropriate methods and at the appropriate scales of investigation, will prove invaluable.

For the above reasons, the activity of the Research Line 3.12 has been focused on the analysis of a ten-year series of data, concerning the plankton community and the main related abiotic factors, gathered at five stations in the northern and central area of this lagoon from 1997 to 2006. The main results of this analysis - i.e.: the identification of the recurrent plankton seasonal dynamics, the recognition of blooming species and of biomass thresholds and the evaluation of the existence of appropriate indicator species - are reported and discussed evidencing the role of the pluriannual series in bridging the gap between science and policy, by delivering scientifically sound information useful also to evaluate water quality, within the current environmental policy and management context.

Introduction

The definition of seasonal trends in transitional environments is often not easy due to their intrinsically high complexity and variability. In fact, some unique habitat attributes of these ecosystems (e.g. the shallowness, the strict benthic-pelagic coupling and the connectivity to both land and sea) markedly influence the phytoplankton seasonal cycle that, therefore, generally appears to be driven by more than a few climatic factors (Cloern & Jassby, 2008). Therefore the phytoplankton community of transitional environment is characterized by high spatial and temporal unpredictability; for this reason, the wide variability of environmental factors, together with their effects on phytoplankton, makes very difficult to define a typical seasonal cycle.

In this viewpoint, the use of phytoplankton community, considered in the European Water Framework Directive (EC, 2000) as the only planktonic element among the water quality indicator, need of individuation and definition of adequate baselines against which evaluate local vs. broad scale changes as well as trends. In this respect, the ecological pluriannual series represent a unique and invaluable tool for a reliable reconstruction of the phytoplankton seasonal cycle. The Venice Lagoon, the largest Italian lagoon, is one of the 20 sites presently included in the LTER-Italy network. The main goals of this research activity were focused on:

1. the identification of recurrent phytoplankton seasonal dynamics;
2. the recognition of blooming species;
3. the identification of biomass thresholds;
4. the evaluation of the existence of indicator species for the trophic environmental quality.

Methods

The investigation was carried out at five sampling stations, located in the northern and central basins of the Lagoon of Venice (Fig. 1), considered as representative of the main characteristics of these areas (Bianchi *et al.*, 1996; 1999; Socal *et al.*, 1999).

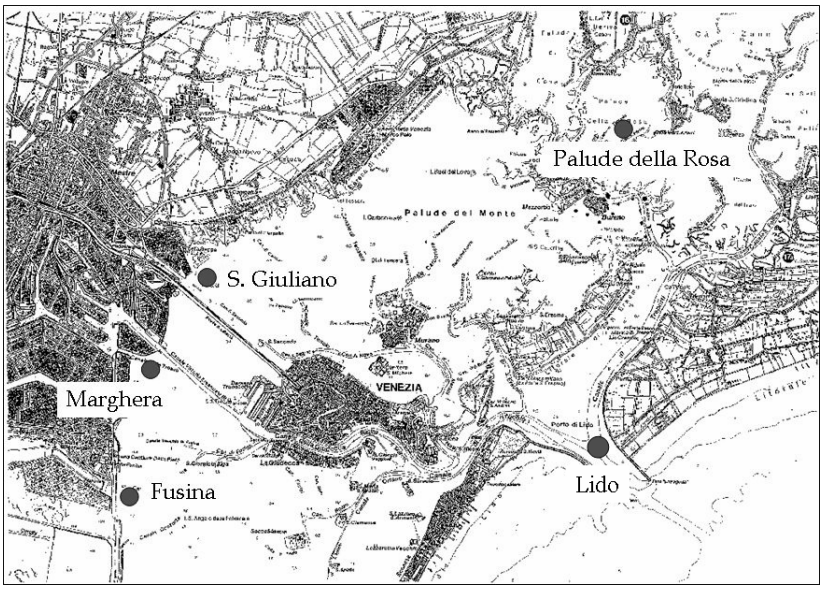


Fig. 1. The Lagoon of Venice: the five LTER sampling stations are indicated (dots).

At all stations, measurements and samplings were carried out at the near surface layer, monthly from 1997 to 2006. Water and phytoplankton samples were taken at surface, using 5 dm^3 Niskin bottles, at neap tide.

Transparency was measured by Secchi disk. Temperature, salinity, dissolved oxygen and pH were recorded by an Idronaut Ocean Seven 316 multiprobe and compared with the discrete measurements performed in the laboratory (Guildline Autosal 8400 B salinometer, Dosimat for Winkler titrations and pH meter). Chlorophyll *a* were analysed according to Holm Hansen *et al.*, (1965), dissolved macronutrients ($N\text{-}NH_3$, $N\text{-}NO_2$, $N\text{-}NO_3$, $Si\text{-}SiO_4$, $P\text{-}PO_4$) according to Grasshof *et al.*, (1999).

The samples of phytoplankton were examined according to Utermöhl, (1958) and Zingone *et al.*, (1990). Species composition was defined following Tomas (1997). Cell size, volume and biomass of phytoplankton were determined according to Strathmann (1967) and Smetacek, (1975). Statistical analyses (one-way ANOVA and linear correlation analysis) were performed using Statistica by Statsoft, after log-transformation of biological data (Cassie, 1962).

Results

1. Identification of recurrent phytoplankton seasonal dynamics

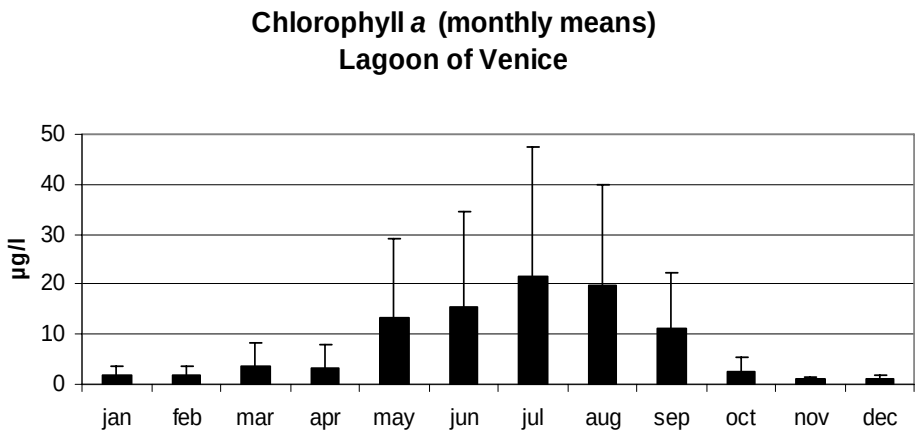
The seasonal variations of chlorophyll *a* concentrations (min = 0.3 µg l^{-1} – max = 124.6 µg l^{-1}) in the Lagoon of Venice (Fig. 2), as average of the ten years, show a prevalent unimodal pattern, with peaks occurring prevalently in summer. The seasonal phytoplankton growth appears mainly related with that of temperature and solar irradiance. A positive and statistically significant correlation was indeed found between phytoplankton chlorophyll *a* and temperature (Spearman Rank Correlation: $r = 0.61$; $p < 0.01$) and phytoplankton chlorophyll *a* and solar irradiance (Spearman Rank Correlation: $r = 0.65$; $p < 0.01$). On the contrary, the seasonal variation of phytoplankton is not correlated with that of dissolved macronutrients. The lagoon of Venice is a permanently nutrient-enriched ecosystem (Zonta *et al.*, 2005): nutrient enrichment seems to weaken the tight constraint of phytoplankton seasonal growth by nutrient limitation that is, on the contrary, found in the adjacent Northern Adriatic Sea (Degobbis *et al.,* 2000; Socal *et al.*, 2008).

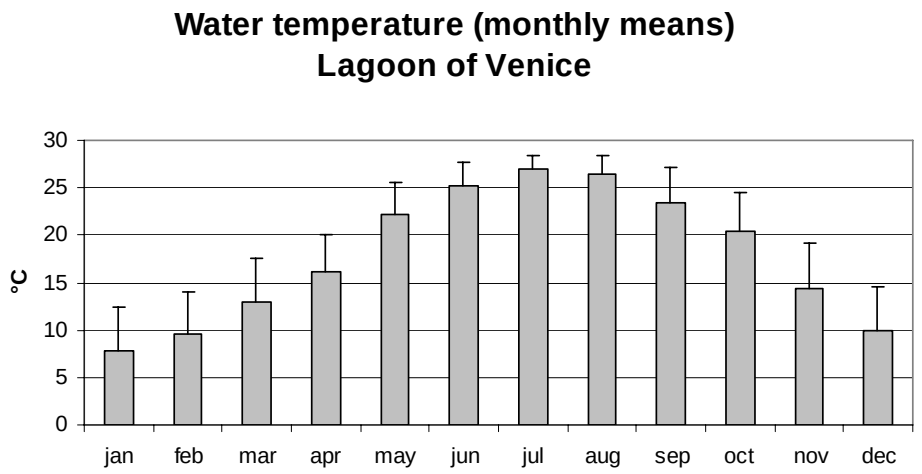
In the studied stations, interannual variability of the phytoplankton biomass is shown clearly from our time-series (Fig. 3). Overall, a decrease of phytoplankton chlorophyll *a* has been registered in the last five years (2002 – 2006); in particular, much lower biomass peaks were recorded throughout summer. This variation is not related to concomitant changes in nutrient concentrations. These data indicate, from one side, that the instantaneous values of nutrients concentration, as a proxy of resource availability, may explain only very partially the phytoplankton variability and trend; from the other, they suggest the key role of loss factors (e.g.: grazing, water residence time, etc.), not long-term assessed in our site, in the observed interannual variations.

2. Recognition of blooming species

The main bloom forming species in the lagoon of Venice belong to Diatoms: some of these are planktonic (*Chaetoceros compressus*, *Chaetoceros* spp., *Skeletonema marinoi*), some belong to microphytobenthos (*Nitzschia frustulum*, *Ceratoneis* (ex *Cylindrotheca*) *closterium*, *Thalassiosira* spp.

The analysis of the ten-year series allowed the definition of a “phytoplankton calendar” (Fig. 4), that identifies the prevalent seasonal succession of phytoplankton taxa in the lagoon waters. Benthic (such as *Amphora* spp. *Cocconeis* spp) as well as planktonic (*Cyclotella* spp) Diatoms characterize late autumn and winter, being however present also in other seasons; planktonic Diatoms, mainly *Skeletonema marinoi* (ex *costatum*) and *Thalassiosira* spp, and Cryptophyceans dominate in spring; a mixed assemblage, made up mainly by Diatoms (*Nitzschia frustulum, Ceratoneis (*ex *Cylindrotheca) closterium, Chaetoceros sp., Cerataulina pelagica, Proboscia alata*), but also by Dinoflagellates (*Gymnodinium* spp) and Euglenophyceans, typify the summer peaks.





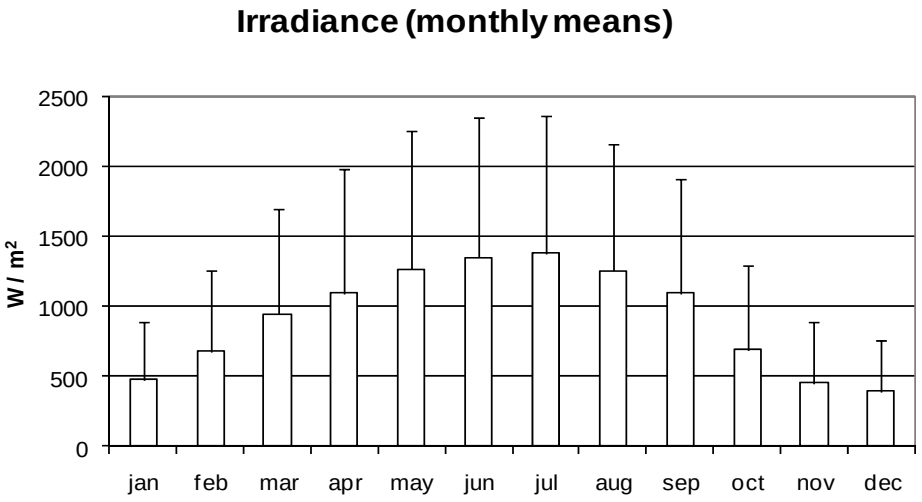


Fig. 2. Monthly averaged chlorophyll a concentrations (a), water temperature (b), irradiance (c). Means and standard deviations are calculated for the five LTER sampling stations.

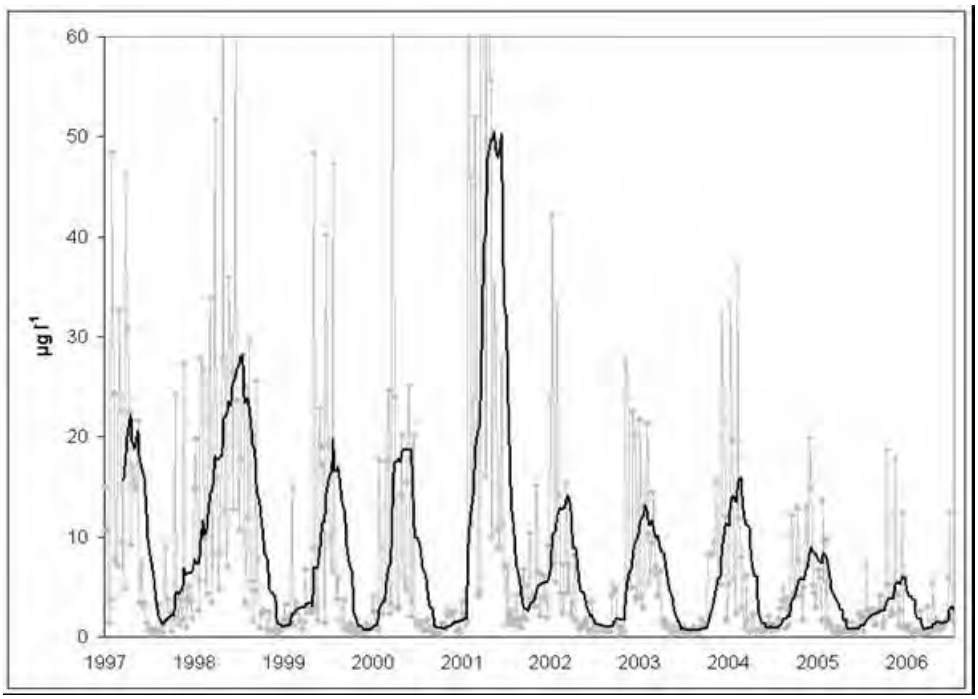


Fig. 3. Interannual chlorophyll a variations. Moving average, calculated for the five LTER sampling stations, is plotted yearly.

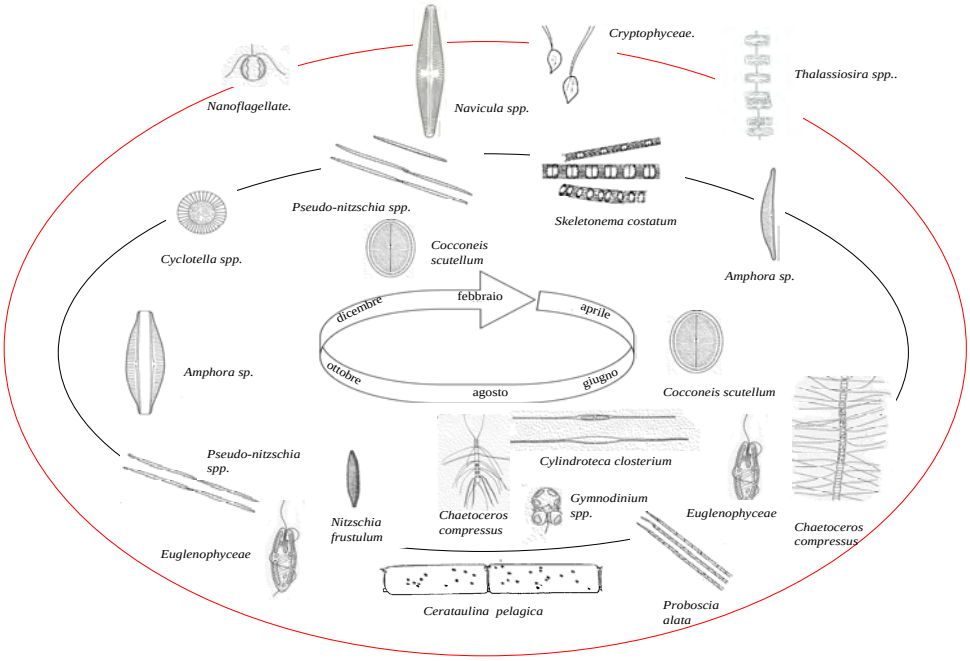


Fig. 4. Average seasonal pattern of the most abundant phytoplankton taxa.

3. Identification of biomass thresholds

The data analysed allow us to estimate the variations of phytoplankton biomass in the different seasons. This elaboration can be regarded as the way to obtain a sort of “reference conditions”, a useful tool for management purposes and environmental quality assessment. As an example (Table I), we have considered the medians, the third quartile and the 90 percentile of phytoplankton chlorophyll *a*, for each season, at only two of the five stations, as

representatives of the most different trophic conditions: S. Giuliano and Palude della Rosa. The values were obtained for the whole ten-year period and for the last five years, when the decrease of chlorophyll *a* took place (Fig. 3).

4. Evaluation of the existence of indicator species for the trophic environmental quality

Although the five stations are characterised by different trophic conditions, the most important taxa were common to all of them, independently from the trophic level. Diatoms, flagellates (Chlorophyceans, Euglenophyceans, Cryptophyceans, naked Primnesiophyceans), Dinoflagellates and the coexistence of pelagic and benthic forms, resuspended from the sediments, define the community. Forms belonging to different functional groups (colonial and single–cell Diatoms, small autotrophic flagellates, small and large Dinoflagellates) generally co-occur. Only some less abundant species (contributing to total biomass or abundance with values below 10%, defined as "rare species" ; Table II) could be identified as characterizing each station. Most of them belong to microphytobenthos, resuspended from the sediments, or are freshwater species.

San Giuliano		N	First Quartile	Median	Third Quartile	Percentile 90 th
1997-2006	Spring	29	3,97	9,26	23,60	51,96
	Summer	29	15,02	21,76	33,17	60,48
	Fall	29	0,98	1,37	2,65	6,52
	Winter	28	1,01	1,44	2,85	10,41
2002-2006	Spring	15	3,82	7,41	22,53	27,69
	Summer	13	7,27	18,74	21,76	33,17
	Fall	16	1,01	1,31	2,68	6,52
	Winter	14	0,96	1,27	1,68	2,27

Palude della Rosa		N	First Quartile	Median	Third Quartile	Percentile 90th
1997-2006	Spring	29	1,56	2,62	4,87	8,38
	Summer	29	2,62	5,27	9,90	27,54
	Fall	30	0,51	0,88	1,21	3,31
	Winter	29	0,65	0,96	2,29	5,19
2002-2006	Spring	15	1,19	2,04	4,14	5,22
	Summer	13	2,44	4,00	7,24	13,13
	Fall	16	0,43	0,68	1,01	1,30
	Winter	14	0,59	0,77	0,96	2,11

Tab. I. Seasonal chlorophyll a concentrations (µg l^{-1}) at two selected stations (S. Giuliano and Palude della Rosa), in two distinct periods (1997-2006 and 2002-2006). N = Number of observations.

Tab. II. "Common species" at two selected stations (S. Giuliano and Palude della Rosa) characterised by different trophic conditions. "Rare species" differentiating the two stations.

	San Giuliano	Palude
Common species	*Nanoflagellates*	
	Nitzschia frustulum	
	Und. Cryptophyceae	
	Thalassionema nitzschioides	
	Navicula spp.	
	Cylindrotheca closterium	
	Navicula cryptocephala	
	Chaetoceros spp.	
	Skeletonema marinoi	
Rare species	*Gomphonema olivaceum*	*Amphora hyalina*
	Gyrosigma fasciola	*Nitzschia longissima f. parva*
	Melosira nummuloides	*Nitzschia panduriformis*
	Rhoicosphenia curvata	*Pseudo-nitzschia delicatissima*
	Und. thecate dino <20 µm	*Ankistrodesmus spp.*
	Eutreptia lanowi	*Und. Chlorophyceae*
	Und. Euglenophyceae	*Und. Prasinophyceae*

Concluding remarks

The availability of pluriannual series of data allowed us to give a reliable representation of the phytoplankton community cycle in the Lagoon of Venice, an impossible task with information based only on one or few years of observations. Thanks to this activity, we are now able to define the main feature of this community. In particular, our studies assessed the order of magnitude and the timing of the phytoplankton biomass that, notwithstanding its year-to-year variability, can now be identified with a good degree of consistency. Moreover, regularities in the occurrence of the most important species throughout the seasonal cycle, together with the identification of those that may give rise to blooms, could be evidenced.

The identification of seasonal biomass thresholds, for the areas characterised by different trophic conditions, may give warning indications during ecological monitoring activity, as well as they may be considered as references against which evaluate possible future changes. On the contrary, on the base of the 10-year series here examined, it was not possible to identify any specific indicators in the phytoplankton assemblage: the same species were dominant and common to all the stations, independently from the trophic level. Only some less abundant species (or "rare species") could be identified as characterizing each station.

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MONITORING TURBIDITY DURING DREDGING ACTIVITIES

G. Di Silvio[1], C. Dall'Angelo[1], L. Zaggia[2], V.Defendi[2], M. Gacic[3] *

[1] *Dipartimento IMAGE, Università di Padova,*
[2] *Consiglio Nazionale delle Ricerche Istituto di Scienze Marine, Venezia ,*
[3] *OGS, Trieste*

Riassunto

L'articolo descrive le metodologie sviluppate per il programma di monitoraggio della torbidità creata dalle recenti operazioni alle 3 bocche di porto nella laguna di Venezia. L'articolo è organizzato in tre parti: (a) le procedure sperimentali (per mezzo di strumenti fissi e strumenti posizionati su imbarcazione) e la determinazione del valore di soglia della torbidità; (b) un modello matematico applicato per simulare il funzionamento di una draga idrorefluente a sfioro e la dinamica del pennacchio di torbidità; (c) misure in continuo della torbidità (3 anni) alle tre bocche e nelle vicinanze dei litorali, con qualche interpretazione dei dati riguardante i flussi netti a lungo termine scambiati tra laguna e mare.

Abstract

The article describes the methodology developed for the *monitoring program* of the turbidity created by the recent operations in the 3 inlets of the Lagoon of Venice. The article is organized in three parts: (a) the experimental procedures (by means of fixed and boat-mounted instruments) and the determination of the turbidity's threshold-value; (b) the mathematical model applied for simulating the functioning of a trailing suction hopper dredger and the dynamics of the turbidity plume; (c) the continuous data turbidity (3 years) in the three inlets and the nearby littorals, with some interpretation regarding the net long-term fluxes, from the lagoon.

1. Introduction

Monitoring of turbidity was mainly carried out during the dredging activities (with different types of dredgers), but also in subsequent periods in order to verify the effects due to disturbances others than dredging and to check "natural" values of turbidity with no disturbance.

Data of suspended sediment concentration (SPM) were collected with two different methodologies:

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* The group on turbidity monitoring was composed by: F. Arena, F. Costa, C. Dabalà, C. Dall'Angelo, V. Defendi, G. Di Silvio, S. Donà, R. Fiorin, M. Gacic, V.Kovacevic, G. Lorenzetti , G. Manfè, M. Meneghin, M. Morgantin, F. Riccato, F. Simionato, L. Zaggia.

- in proximity to the dredging zone, with a boat-mounted Acoustic Doppler Current Profiler (ADCP), during field surveys appropriately scheduled during the dredging activities (see Section0).
- continuous turbidity measurements by automated fixed station in the inlets and in open sea (fixed ADCP, Optical Backscatter Sensor (OBS)), that have worked continuously for over three years (see Section 0).

In addition to SPM, during the monitoring activity also current velocity data were collected both with the boat-mounted and the fixed ADCP.

Before starting with monitoring proper, the “admissible turbidity conditions” have been determined, i.e. the maximum concentration of SPM value that were to be respected for different situations (see Section 0).

To assess the extension of the turbidity plume and to check the compliance of the actual dredging activities with the above mentioned limitations, we developed a mathematical model of transport and dispersion of sediment. This model can calculate the spatial distribution of sediment concentration downstream of a dredger depending on dredging methodologies, manoeuvres required, tidal currents and size of the dredged sediment. The model was also used to establish some empirical rules to check at the appropriate distance during the monitoring itself (see Section 0).

Finally, in the absence of dredging activities or in period in which they gave rise to a lesser impact, continuous turbidity measurements were used to study the behaviour of the lagoon system undisturbed by the presence of the yards (see Section 0). Field measurements with a boat-mounted Acoustic Doppler Current Profiler (ADCP) have been used to extrapolate the spatial distribution of continuous turbidity measurements made by OBS installed in automated fixed station .

2. Measurement techniques and threshold values

2.1 Boat-mounted profilers

The instrument used was a 600 kHz RDI Workhorse Rio Grande [Teledyne RD Instruments, 2007a], mounted on a survey boat and operated with a 0.5 m vertical cell size. The boat typically moved along transects crossing the channel section, where the fixed ADCP is positioned. Velocity field (discharge) and acoustic backscatter data were simultaneously acquired. The instrumental setup was also used to make measurements along a wide series of paths: from closed circuits around the dredging zone to successive zig-zag transects across the turbidity plume at increasing distances from the source. The conversion of acoustic backscatter into SSC concentration values was performed by means of the Sediview method [Land *et al*., 2000; Land *et al*., 2001], an integrated model for the calculation of the acoustic signal attenuation during sound propagation along the water column. The calibration procedure, described in detail by [Defendi *et al*., 2009], uses temperature and salinity data, acquired by a multi-parameter probe [Ocean Seven 316 CTD; Idronaut S.r.l., 2002], as well as sample concentrations, as input for iterative computations. SSC transects were

then exported as numeric matrix into spreadsheets and used for calculations of solid flux by combining with discharge data.

2.2 Continuous measurements

SSC time series at fixed stations were obtained from two different types of fixed instrumental setups: eight stations near and within the inlets (Fig. 13) as well as in the open sea equipped with multi-parameter probe [Ocean Seven 316 CTD; Idronaut S.r.l., 2002] each mounting an OBS sensor and three bottom-mounted ADCPs, positioned in the middle of the inlet channel. Two 600 kHz RDI Workhorse Sentinels, [Teledyne RD Instruments, 2007b] were employed in the Lido and Malamocco Inlets, while a 600 kHz RDI Workhorse Monitor [Teledyne RD Instruments, 2007b] was used in the Chioggia Inlet. The three bottom-mounted instruments, whose depth cell size was set to 1.0 meter, recorded current velocity and acoustic backscatter for over three years.

Turbidity measurements from OBS sensors (in formazine turbidity units, FTU) were converted to SSC values with respect to sample concentrations, measured in water samples collected during the maintenance of the instruments (cleaning operations and data recovery). The frequency of these operations was weekly or biweekly, depending on water temperature, which controls the formation of fouling on the sensors. A complex filtration procedure, described in detail by [Magistrato alle Acque, 2006], removed from time series spurious peaks, due to occasional blocking of the light path of the sensor, low-frequency oscillations and long-term drifts, caused by fouling. A linear regression was established between turbidity and SSC data pairs. The regression equation was then used to compute the SSC time series from the instrument records.

The procedure for the calibration of the acoustic backscatter data from the bottom-deployed ADCPs was similar to that described for the boat-mounted ADCP in Section 2.1. However, in this case, the calibration is indirect, using estimated SSC profiles as input data. These profiles were extracted from the boat-mounted ADCP calibrated transects, as the average of the 20 ensembles, centred on the position of the bottom-mounted ADCP.

2.3 Admissible turbidity within the inlets

Threshold values were established by identifying an “acceptable range of variability” with respect to the natural conditions for hydrodynamic, sedimentological and biological characteristics. A “threshold value” for turbidity [Magistrato alle Acque di Venezia, 2005] not to be exceeded in any case outside the “Total Impact Zone”, has been defined as the value exceeded only 10% of time in natural conditions (90% percentile).

According to a statistical analysis of “natural turbidity” (namely in the absence of dredging activities) in terms of both maximum value and persistence, one finds:

C_{F90}=16.7 mg/l=Value exceeded 10% of time at a given point (90% percentile at Lido fixed station)

In order to extend the threshold value to any other point of the inlet, by taking

into account the spatial variability, C_{F90} has been multiplied by a coefficient of spatial variation:

$$C_{\text{var}} = \frac{C_{M50}}{C_{F50}} \tag{1}$$

Where :

C_{M50}=7.6 mg/l=median value at the mobile station from a series of measurements made on a large number of samples collected in different places inside the inlets

C_{F50}=4.2 mg/l=median value of all measurements at the fixed station

C_{*10}= C_{F90}x C_{Var}=30 mg/l

This value in fact is considered to be tolerable by the coenosis of the inlets, as it is exceeded with not negligible frequency during the most intense bora events, with a permanency of at least six hours, half tidal period, or more (slack tide).

It should be accepted, however, that this value will be exceeded inside the « Total Impact Zone » (T.I.Z.), the extent of which is limited both in terms of surface and in term of width (Fig. 1), in comparison to the inlet:

Maximum surface (< 1/10 of the inlet total surface) = 50000 m^2

Maximum width (< 1/3 of the inlet total with) = 150 m

The shape of the sediment plume, produced by dredging activities, and then the shape of « TIZ » depends on tidal current, resulting to be long and narrow for high velocities.

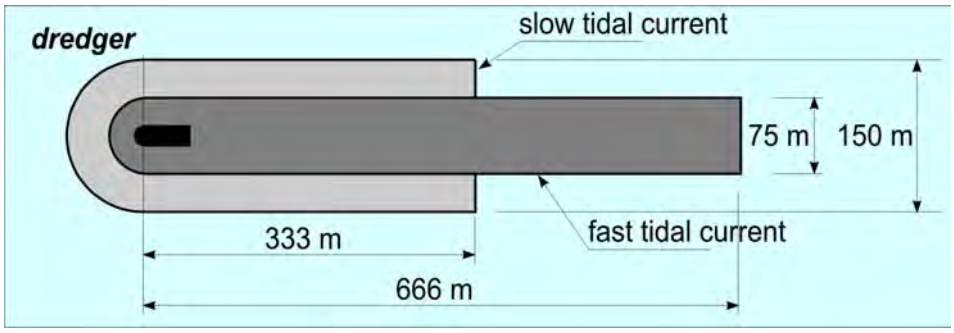

Fig 1. "TIZ" in case of two different flow pattern.

3. A model of dredger plume

3.1 Basic hypothesis

The analytical model presented here has been realized to describe the turbidity plume produced by dredging activities in the inlets of the lagoon of Venice and to simulate the dispersion and deposition of sediments introduced by the dredger into the water column.

Before describing in detail the model we list the simplifying hypothesis that allow

an analytical solution:

- Constant water depth;
- Uniform and stationary water velocity;
- Continuous sediment input;
- Definite and limited dredging zone;
- Negligible re-suspension by currents and waves;

Input parameters which should be known (in principle), but often are not:

g_0 =sediment input (inaccurate data, irregular in time and space) (kg/s);

R_0 =extent of the dredging zone (variable and irregular) (m);

t_f =prior duration of dredging (missing data, intermittency) (s).

Parameters intrinsically approximate (non-uniform and non-stationary):

U=water flow velocity (m/s);

h =water depth (m).

Process parameters:

w_s=equivalent falling velocity of the grain mixture (depends on grainsize distribution, probably decreases with distance X) (m/s);

k_R=lateral dispersion coefficient (depends on turbulence scales, probably increases with distance X and stream velocity U) (m^2/s)

γ=overall decay parameter (better to be evaluated by calibration).

$$\gamma = \frac{w_s}{h} + \frac{6k_r}{R_0^2} \qquad (2)$$

This coefficient γ (inverse of a time) has two components: the first one, sedimentation component, is due to the weight of the particles and the second one, dispersion component, is due to the dispersion of suspended sediments scaled to the initial size of the cloud.

3.2 Evolution of an isolated cloud

Let us consider first a cloud of suspended sediments in still water (Fig. 2) and estimate its evolution.

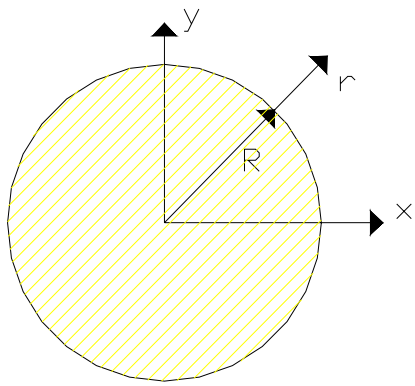

Fig 2. Circular cloud of suspended sediments of radius R(t).

We consider a triangular distribution, at any time, of the depth-averaged concentration:

$$c(r,t) = C(t) * (1 - \frac{r}{R(t)}) \tag{3}$$

where:

C(t) = depth-averaged concentration in the centre of cloud at time t

c(r,t) = depth-averaged concentration in any point at a distance r, at time t

R(t) = radius of cloud at time t

The depth-averaged concentration in the centre of cloud tends to decrease owing to dispersion and sedimentation; simultaneously the cloud tends to expand itself (Fig. 3).

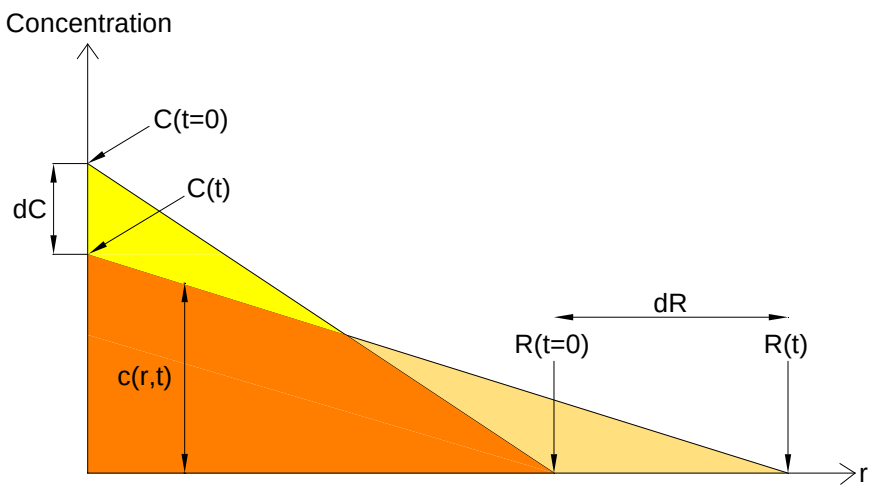

Fig 3. Turbidity cloud. Uniform vertical distribution in still water.

We calculate the mass of sediment in the cloud of radius R(t):

$$M(t) = \int_0^R ch2\pi rdr = \frac{C(t) * h * \pi * R^2(t)}{3} \tag{4}$$

We obtain this equation by substituting the expression (3) in the variable c (t, r) inside the integral.

From this equation is it possible to deduce the initial input of a mass M_0 in a given circular cell of radius R_0:

$$M_0 = \frac{1}{3} * C_0 * h * \pi * R_0^2 \tag{5}$$

where C_0 is the initial concentration in the centre of the cloud.

The next step is to examine the evolution of the mass of sediment in time and to analyze how fast the process evolves.

To this purpose we will set the balance equations considering two different kinds of volumes: “material volume” and “control volume”:

The “material volume” (Fig. 4) changes shape and dimension over time, because it follows the sediment mass in its expansion. For a conservative material (no flux trough the bottom), the mass will always be contained within the material volume and the “principle of mass conservation” is written as it follows:

$$\frac{dM}{dt} = 0 \tag{6}$$

However, as we are in the presence of a flux of sediments trough the bottom (sedimentation) we should write (6) as it follows:

$$\frac{dM}{dt} = \int_{\text{bottom}} ws * c(r,t) * dS_{bottom} \tag{7}$$

where the second term expresses the amount of particles that settles on the bottom in the unit of time.

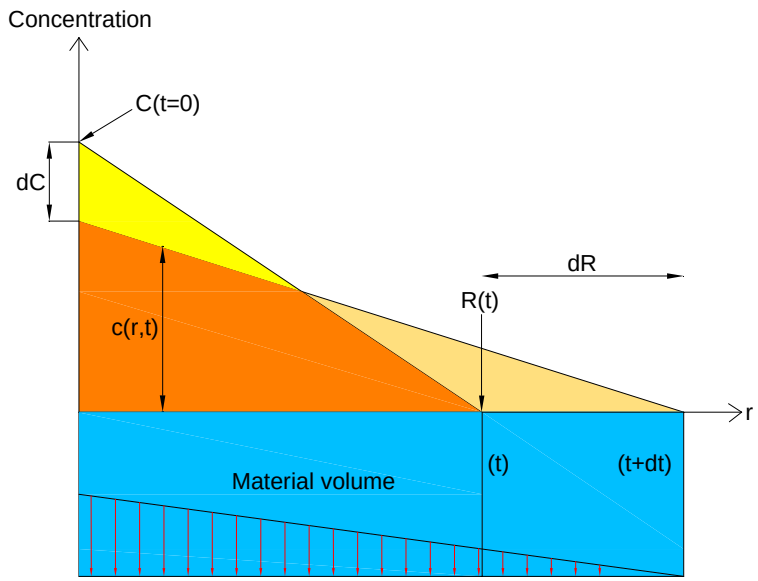

Fig 4. In light blue the “material volume. Red arrows represent sedimentation.

Substituting (3) in the integral and changing the integration limits we can rewrite (7) as:

$$\frac{dM}{dt} = \int_0^{R(t)} w_s * C(t) * \frac{R(t) - r}{R(t)} * 2\pi r * dr \tag{8}$$

The following equation expresses the variation of mass $\frac{dM}{dt}$ within a "material volume"

$$\frac{dM}{dt} = -\frac{1}{3} ws * C(t) * \pi * R^2(t) = \frac{\pi h}{3}\left(R^2(t)\frac{dC}{dt} + 2C(t)\frac{dR}{dt}R(t) \right) \tag{9}$$

where the first term represents the flux by sedimentation obtained from (8), the second is the derivative of mass with respect to time obtained from (4). Note that the variation of mass is influenced, in opposite way, both by the decrease of concentration within the "material volume" and by the enlargement of the cloud size.

We express the variation of mass as the total derivative of (4) because we consider the balance within the material volume that takes, at any time, the shape of the cloud of sediments. The control volume, by contrast, even though following the current in its direction, maintains fixed its shape and size. (Fig. 5). Clearly, by definition, the two volumes are coincident only at t = 0.

In order to express the principle of mass conservation for the control volume, we use the Reynold's theorem or "transport theorem": the variation of mass in the material volume $\frac{dM}{dt}$ equals the variation of mass within the control volume minus the outgoing flux of sediment due to transport (in this case only dispersive) namely:

$$\frac{dM}{dt} = \int_v \frac{\partial \rho}{\partial t} * dV - \Phi \tag{10}$$

The variation of mass within the control volume is simply the punctual variation of the sediment concentration integrated with respect to a generic radius r, given that the depth is constant. The outgoing flux, due to dispersion, on the other hannd, can be written as the concentration gradient with respect to the distance r, multiplied by lateral dispersion coefficient and integrated over the lateral surface.

It follows that:

$$\frac{dM}{dt} = \int_0^R \frac{\partial c}{\partial t} 2\pi r h * dr - \int_0^R Kr \frac{\partial c}{\partial r} 2\pi h * dr \tag{11}$$

where:

Kr = lateral dispersion coefficient (m^2/s)

R = radius of the cloud, at a fixed time (given that is a control volume) (m)

Taking into account the hypothesis of triangular distribution of concentration given from (3) and considering that the concentration gradient is expressed by C/R, the integral (11) provides the following relation which expresses the variation of mass within the control volume.

$$\frac{dM}{dt} = \frac{\pi h}{3}\left(R^2 \frac{dC}{dt}\right) + 2\pi h k_R \frac{C}{R} R \qquad (12)$$

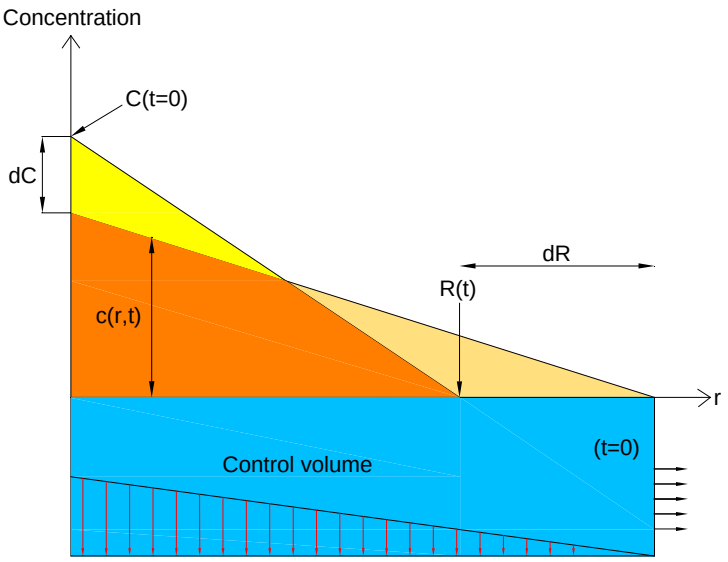

Fig 5. In light blue the "material volume. Red arrows represent mass fluxes. Vertical arrows represent sedimentation, horizontal arrows represent sediment flux that goes out from the boundary, carried by current.

Since both formulas (9) and (12) express the principle of mass conservation, although with regard to different kind of volumes, we can now set the system.

$$\frac{\pi h}{3}\left(R^2 \frac{dC}{dt}\right) + 2\pi h K_R \frac{C}{R} R = \frac{\pi h}{3}\left(R^2 \frac{dC}{dt} + 2C \frac{dR}{dt} R\right) = -\frac{1}{3} ws * C(t) * \pi * R^2(t) \qquad (13)$$

From the equality of the first two terms, we obtain an important information on the evolution of radius over time.

$$\frac{dR}{dt} = 3\frac{K_R}{R} \qquad (14)$$

Eq. (14) demonstrates the close relationship between the expansion of the cloud of sediment and the lateral dispersion coefficient and shows how the growth is progressively slowed down by the presence of R(t) in the denominator.

By substituting (14) in (9) and making the variation of concentration C over time

explicit, we obtain:

$$\frac{dC}{dt} = -6k_R \frac{C}{R^2} - \frac{ws}{h} C \tag{15}$$

The (15) expresses the time decrease of the maximum concentration in the cloud, provided by two negative terms: the first one interprets the dispersive phenomenon, whereas the second one represents the deposition on the bottom.

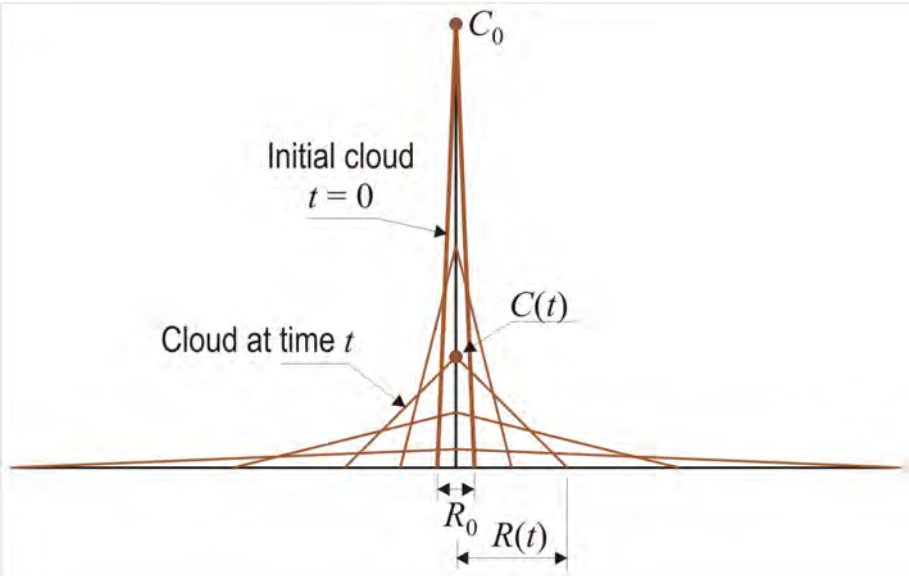

Fig 6. Evolution process of initial cloud in still water.

Fig. 6 describes the change over time of size and concentration of a cloud in still water.

At the initial time t=0 we find a concentration C_0 and the cloud appears narrow and compact with a radius of R_0. At the generic time t the cloud is larger and concentration has decreased, while keeping a triangular distribution.

Eventually when t tends to infinity, the concentration will be returned to the undisturbed value and the boundaries of cloud will not be visible anymore.

It is good to remember that the symbol C indicates the maximum concentration of sediment in the centre of cloud, time-dependent, whereas the symbol c refers to punctual concentration, function of time and space.

By integrating (14) we obtain the evolution of the size of the cloud over time:

$$R(t) = \sqrt{R_0^2 + 6k_r t} \tag{16}$$

where:

t = elapsed time from the beginning of diffusion phenomenon (s)

R_0 = initial radius of cloud (m).

By integrating (15) we obtain the evolution of the concentration over time:

$$C(t)=C_0 \exp(-\gamma t) \tag{17}$$

where:

t = elapsed time from the beginning of diffusion phenomenon (s)

C_0 = initial concentration (mg/l).

3.3 Evolution of a continuous plume

By a substitution of variables it is possible to transform the time relations above into a dependence on space, that is the distance from dredger (indeed X=U*t), on condition that the current velocity U is assumed constant.

Let us consider now not an isolated cloud of sediments, but a continuous dredging activity that introduces into the water column a continuous quantity of sediment g_0 (kg/s). We can represent the turbidity plume generated by the dredger as a sum of the elementary clouds created with successive instantaneous input of infinitesimal mass.

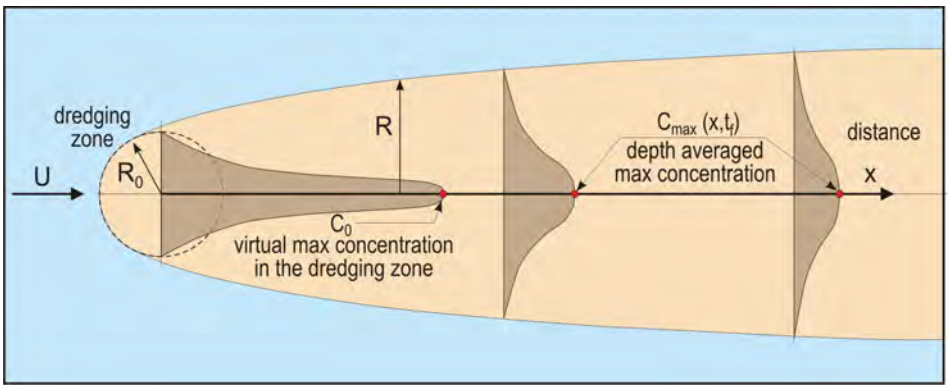

Fig 7. Turbidity plume produced by a dredger releasing a, continuous, constant amount of sediment g_0.

Let us determine from (17) the elementary concentration, ΔC, at time t, corresponding to the initial elementary concentration, ΔC_0, generated at time t=0 by an instantaneous elementary release:

$$\Delta C = \Delta C_0 \exp(-\gamma t) \tag{18}$$

In the same way let us determine from (5) the elementary release of sediments of initial mass ΔM_0 that provides the elementary concentration ΔC_0 in the initial cloud:

$$\Delta M_0 = \frac{1}{3}\Delta C_0 * R_0^2 * \pi * h \tag{19}$$

From (18) and (19) we can eliminate ΔC_0 and find:

$$\Delta C = \frac{3\Delta M_0}{\pi R_0^2 h}\exp(-\gamma t) \tag{20}$$

representing the elementary increase of concentration in the cloud due to the

elementary input ΔM_0.

The amount of sediments g_0, introduced continuously into the water column (input rate) can be written as the ratio between the elementary mass ΔM_0 and the elementary interval of time Δt:

$$g_0 = \frac{\Delta M_0}{\Delta t} \tag{21}$$

By substituting in (20) we find

$$\frac{\Delta C}{\Delta t} = \frac{3g_0}{\pi R_0^2 h}\exp(-\gamma t) \tag{22}$$

Where the input g_0 does not need to be constant in time. In fact, from the measurements made on board of the dredger " Astra", it results that the amount of sediments overflowed in the sea, $g_0(t)$, tends to increase almost linearly during dredging activities. In fact, as g_0 is given by the product between liquid flow Q (almost constant) and the concentration of overflowed sediments Cs, which tends to increase linearly in time, g_0 assumes its maximum value at the end of excavation.

If we consider any time (t) after the start, it is possible to reconstruct what it has happened before, imposing that at the beginning of overflow ($t=t_s$) g_0 is zero and increases linearly in time. Namely:

$$g_0(t) = \alpha_t (t - t_f) \tag{23}$$

where the coefficient α_t was calibrated against the measured data of $g_0(t)=C_sQ$.

We obtained a value:

α_t=1.4 g/s^2

Specific quantities Q and Cs however may be also calculated by using a sub-model described in detail in Section 0.

3.4 Sorted sediments

Let us assume moreover, that the input of sediments g_0 is composed by n granulometric fractions each of which (i=1,2,....n) is characterized by a representative diameter (d_i), and the corresponding overall decay parameter function of the falling velocity $w_{si.}$ To each diameter is associated the percentage βi, obtained from the grading curve of discharged material.

The granulometric composition β_i of the material introduced in water column is determined as described in the Section 0.

Considering the expression of C (22) for each grainsize class i and the relevant composition β_i we may set

$$g_{0i}=g_0\beta_i \tag{24}$$

with (23) and therefore obtain

$$\frac{dC_i}{dt} = \frac{3\beta_i \alpha(\mathrm{t - t_f})}{\pi R_0^2 h} \exp(-\gamma t) \tag{25}$$

Following the integration from t_f (start of discharge) to t_e (measuring time) we found the concentration $C_i(t_e)$ of grain-size fraction i, at time t_e, in the released cloud

$$C_i(t_e) = \frac{3\alpha_t \beta_i}{\pi R_0^2 h} \int_{tf}^{te} (t - t_f) \exp(-\gamma t) dt \tag{26}$$

$$C_i(t_e) = \frac{3\alpha_t}{\pi R_0{}^2 h} \frac{1}{\gamma_i} \left[\beta_i e^{(-\gamma_i t_e)} \left(t_f - t_e - \frac{1}{\gamma} \right) + \beta_i \frac{1}{\gamma} e^{(-\gamma_i t_f)} \right] \tag{27}$$

The total concentration of the discharged material is the sum of the concentrations of the 5 grain-size fractions, considered here:

$$C(t_e) = \sum_{i=0}^{5} Ci(t_e) \tag{28}$$

As, at time t_e, the cloud has moved to a distance from the dredger $X=U(t_e-t_f)$, (27) expresses the concentration $C_i(t_e)$ measured at this distance. Note that, with the same initial time t_f, we may consider different measuring times t_e and therefore different positions X along the plume.

The relation (27) represents the final expressions that describe the evolution in space and time of the plume determined by the input $g_{0i}=\beta_i g_0=\beta_i \alpha_t(t-t_s)$ at the dredger.

It follows from this expression that the parameters that control plume configuration (spatial and temporal distribution of the concentration and composition of sediments) are of two different kinds: the ones that depend on the physical characteristics of system (current velocity U, water depth h, lateral dispersion coefficient Kr) and the ones that depend on the characteristics of dredging operations (dredging zone R_0, quantity of sediment introduced into the water column, distinguished by grainsize, g_{0i}). In particular the size of dredging area (constant) R_0, conglobe all effects of dredge's course, as a matter of fact widely changeable over space and time.

We observe that, as the overflow of material from the dredger increases over time, the concentration along the plume (27) may even present increasing values as we move away from the dredger, up to a certain distance downstream. The increase or decrease depends in fact on the relative importance of the initial overflow (increasing over time) and the subsequent dispersion and sedimentation of sediments (also increasing over time, as the cloud moves away).

In order to reproduce correctly the plume dynamics, is then necessary to know exactly the sediment release in the water column, $g_{0i}(t)$, both as quantity g_0 and composition β_i.

3.5 Sub- Model of particle size selection in the hold of the dredger

The composition β_i of the discharged material overflowing from the dredger is much thinner than the dredged (bottom) material, although it tends to became a little coarser during the overflow operations.

In order to quantify this phenomenon, we have prepared a sub-model that describes the behaviour of the dredged mixture inside the hold and predicts the grainsize composition of the discharged material.

During the loading of sediments most of the coarsest particles settle in the hold, whereas most of the thinnest ones remain in suspension (because of turbulence) and eventually overflow in the sea via an opening on the sides of the hold.

The input data to the sub-model are the quantity of the dredged material

$\sum_{i=0}^{5} Q \cdot C_{ti}$ and its composition $\alpha_i = C_{ti} / \sum_{i=0}^{5} C_{ti}$

When the dredger starts to dig and to introduce the mixture in the hold, the

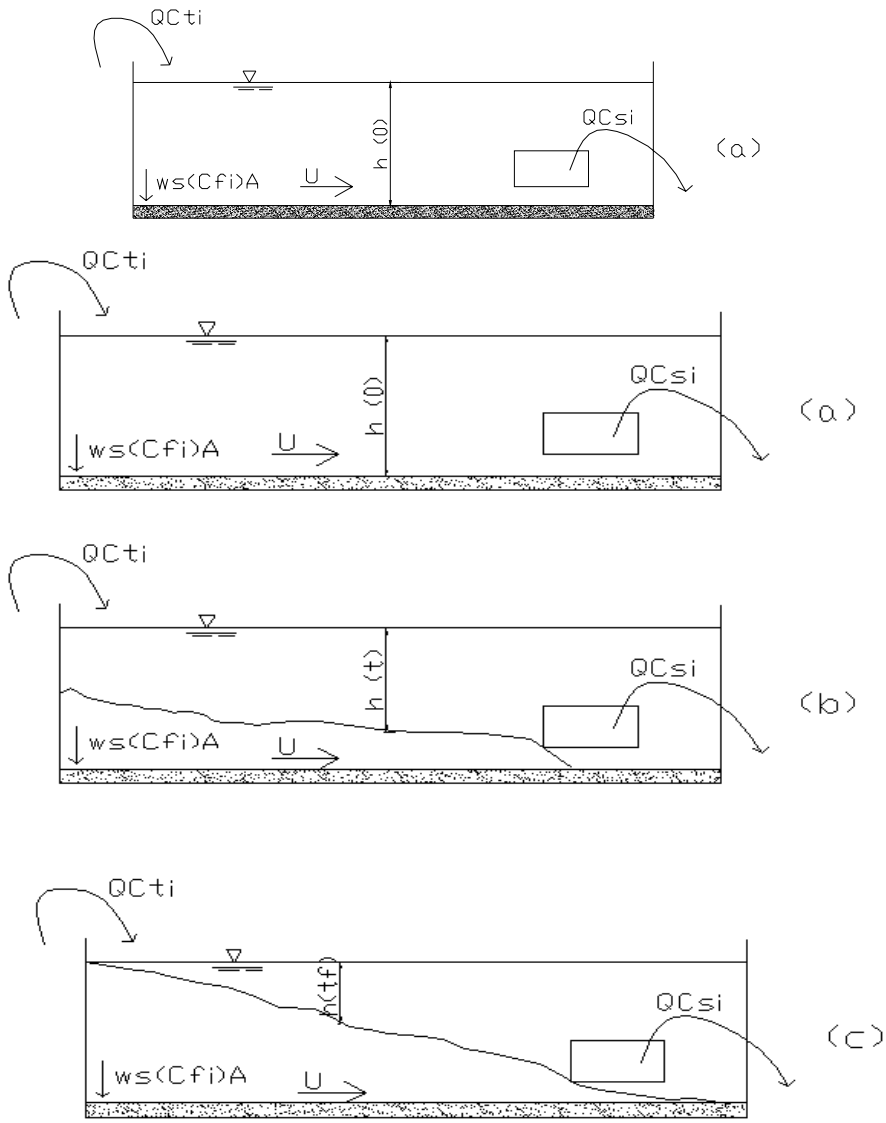

Fig 8. Schematization deformed scale of the process of loading and overflow into the hold. Initial Situation at t=0. (b) intermediate situation at time t. (c) final situation at time tf.

As the sand volume increases, the flow velocity also increases and, consequently, the concentration of the suspended material that overflow into the water column.

At the beginning only water and the thinnest particles overflow, while most of the coarsest material continues to settle. But as the sand bed volume increases longitudinal water velocity also increases, while even the coarsest particles come out in larger and larger quantity.

The operation terminates when the amount of the released materiel is so high that dredging is no more convenient.

The balance between the dredged sediments, the sediments settled in the hold and the sediments discharged in the sea is written below for each granulometric fraction “i” (i=0,1,2,3,4,5).

For each granulometric fraction the characteristic median diameter and the falling velocity of particles, is shown in the Tab. 1 following.

CLASS	INTERVAL	MEDIAN DIAMETER D(µm)	VELOCITY OF SEDIMENTATION (m/s)
0	1 µm <D<3µm	D1=1.73	0.000002
1	3 µm <D<10µm	D1=5.47	0.000015
2	10 µm <D<30 µm	D2=17.32	0.0002
3	30 µm <D<100 µm	D3=54.77	0.0018
4	100 µm <D<300 µm	D4=173.20	0.016
5	300 µm <D<1000 µm	D5=547.72	0.08

Tab. 1. For each granulometric class is indicated averaged diameter and falling velocity.

Indicating with:

Q= water discharge (m^3/s);

Ct_i= concentration of the dredged material (kg/m^3);

Csi= concentration of the overflowed material (kg/m^3);

Cf_i= concentration of the settled material (near bottom) (kg/m^3);

A= horizontal surface of the hold (m^2).

We can distinguish, for each granulometric function, the following fluxes:

QCt_i= incoming material in unit time (kg/s);

QCs_i= outcoming material in unit time (kg/s);

$wsCf_iA$ = settling material in unit time (kg/s).

Assuming that the settled material is a fraction (to be determined) of the outgoing material, we introduce the coefficient ψ_i which depends on the material grainsize

$$Cf_i = \psi_i \, Cs_i \tag{29}$$

Writing the balance:

$$QCt_i = QCs_i + wsCf_iA \tag{30}$$

$$QCt_i = QCs_i + ws \, \psi_i \, Cs_iA \tag{31}$$

The following expression of the overflow material is obtained:

$$Cs_i = \frac{Ct \cdot \alpha_i}{1 + \frac{ws_i A \psi_i}{Q}} \tag{32}$$

By substituting

$$Ct_i = Ct \, \alpha_i \tag{33}$$

where the ratio αi represents the percentage of the granulometric fraction “i” in the bottom (dredged material).

Indicating with:

$$Cs = \sum_{i=0}^{5} Cs_i \tag{34}$$

The total concentration of the discharged material, by substituting in (32) gives:

$$Cs = \sum_{i=0}^{5} \frac{Ct \, \alpha_i}{1 + \frac{ws_i A \psi_i}{Q}} \tag{35}$$

The (35) gives the expression of granulometric composition of discharged material:

$$\beta_i = Cs_i / Cs = \frac{Ct \cdot \alpha_i}{C_s \left(1 + \frac{ws_i A \psi_i}{Q}\right)} \tag{36}$$

The ratio ψ_i of each fraction basically represents the ratio between the concentration in the hold near to the bottom and the concentration near the outlet; it depends on diameter of the considered fraction and, above all, on the characteristics of turbulent flow in the hold, namely depends on ratio between falling velocity, w_{si}, and velocity friction along the bottom of the hold, u*. The theoretical determination of ψ_i, for each fraction, as a function of hydrodynamic characteristics of the hold, was not even attempted due to lack of all the necessary information. It was observed however that ψ decreases with the flow velocity, namely with the filling of the dredger hold and therefore with time.

Under the assumption of ψ constant for all the grainsize classes, the expression

(32) gives:

$$Cs_i = \frac{Ct \cdot \alpha_i}{1 + \frac{ws_i A\psi}{Q}} \tag{37}$$

Whereas the expression (35) gives

$$Cs = \sum_{i=0}^{5} \frac{Ct\,\alpha_i}{1 + \frac{ws_i A\psi}{Q}} \tag{38}$$

Once the value of ψ is known , the equation (38) gives the composition βi of the mixture released in the water column.

$$\beta_i = Cs_i / Cs \tag{39}$$

The constant value of ψ was obtained, by trial and error, from the measured values of Cs (concentration of discharge), Ct (total concentration of dredged sediments), and α_i (fraction concentration of dredged material).

As it was observed before, during the filling of the hold, the velocity and turbulence of the current increases and the value of the ratio ψ tends to become smaller and smaller. By comparison with the data collected in five days (14-15-16-17-18 September 2005) and 9 cycles of excavation the value of ψ has been found to vary between 7000 (at the beginning of the overflow) and 100 (at the end of the overflow). Even if the measured variations of ψ are quite strong, the time-averaged value of ψ varies for the 9 cycles between 3000 and 800. But even a constant value of ψ=2000 appears to give acceptable results.

The figures below (Fig. 9 and Fig. 10) report two granulometric curves of the measured dredged material and the corresponding granulometric curves of the overflowed material determined using a ψ=2000.

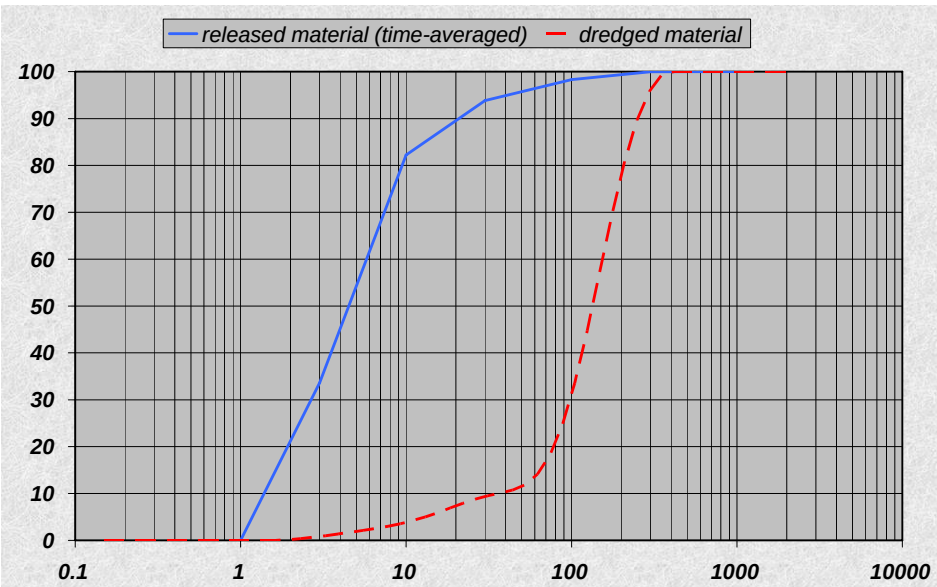

Fig 9. Granulometric curve of the dredged bottom material αi and material introduced into the water column βi, in Lido San Nicolò channel.

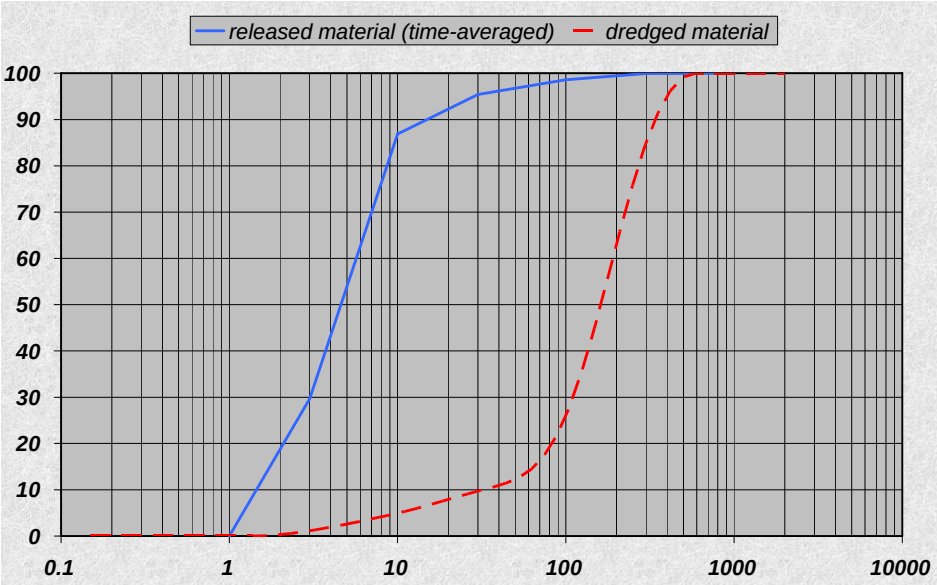

Fig 10. Granulometric curve of the dredged bottom αi material and material introduced into the water column βi, in Lido Treporti channel.

3.6 Plume model calibration

The plume model has been calibrated and verified using the data collected during the operations by the trailing suction hopper dredger "Astra" [Magistrato alle Acque di Venezia, 2006].

The measured value of R(x) (plume width) has been compared with the values provided by (16) where the elapsed time has been transformed in distance from the dredger t=X/U.

The measured value of C(x) (total axial concentration in the plume) has been compared with the value provided by (27) and (28) where the input composition β_i was calculated by assuming an averaged constant value of ψ=2000.

Assuming a constant value for the input coefficient α_t=1.4 g/s^2 and for the lateral dispersion coefficient Kr=1 m^2/s and comparing the concentrations thus calculated with those measured we find, depending on measuring campaign, the corresponding values of the dredging area size R_0 (not measured); this values vary between R_0= 65 -130m, with the exception of only one case in which we find higher values.

The comparison between calculated and measured values is shown in Fig. 11 and Fig. 12 respectively for the width R of the plume and the maximum concentration C on this axis.

The dispersion of results is likely to be attributed to uncertainties in the assessment of R_0 and g_0 in different measurement campaigns.

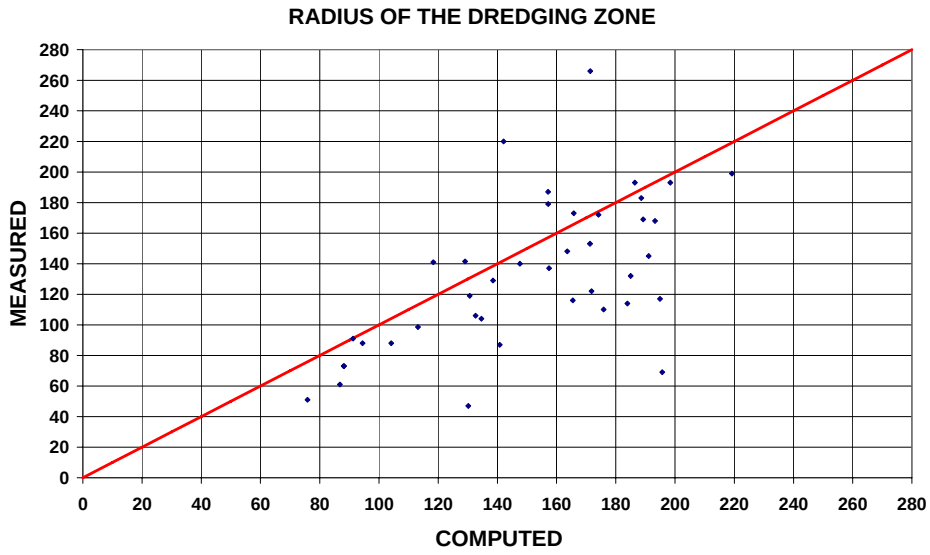

Fig 11. Comparison between R measured and R calculated (with of the plume).

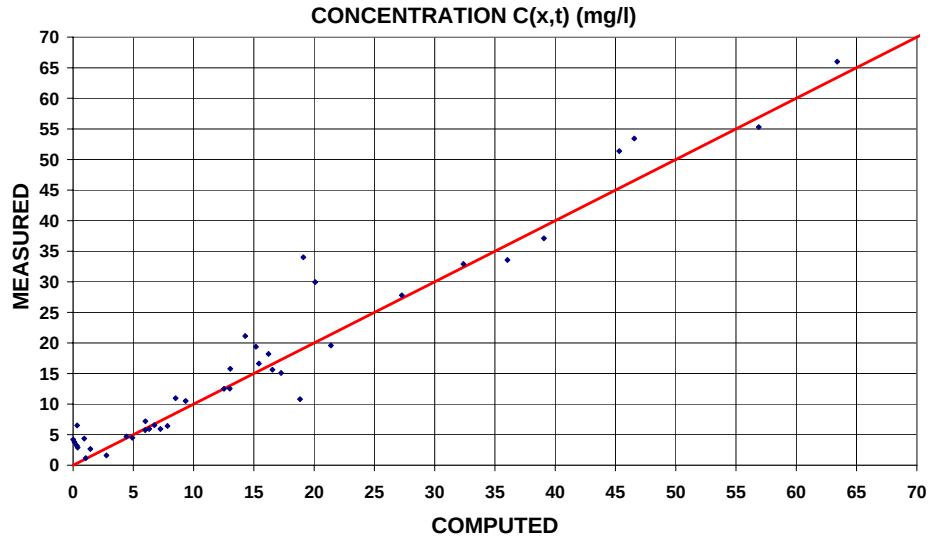

Fig 12. Comparison between C measured and C calculated.

4. Estimating net natural fluxes through the inlets

Besides the monitoring campaigns by boat-mounted ADCP, turbidity measurements have also been carried out in continuous (both during dredging operations and in other periods) by fixed instruments (Fig. 13) placed in the three inlets, inside the lagoon and in the sea [Magistrato alle Acque di Venezia, 2006, Magistrato alle Acque di Venezia, 2007, Magistrato alle Acque di Venezia, 2008].

Fig 13. The network of fixed stations; in blue the stations used only during the first year.

These instruments, equipped with an OBS sensor, provide the raw data of turbidity, which, once filtered and corrected are converted to mg/l through a relationship of site-specific and season-specific correlation.

The new correlation curve is drawn by collecting water samples at each station, during the numerous maintenance interventions.

These surveys, carried on during three years, have been used for a first evaluation of the net flux trough the inlets: Lido (station LMR e LMR-2); Malamocco (station MAP); Chioggia (station CHP); through the main channels of access to the northern lagoon (station LTP) and central lagoon (stations LSN e LSA).

This evaluation [Magistrato alle Acque di Venezia, 2009], was made by calculating the time-averaged values of concentration, respectively during ebb (Ce) and flood (Cf) flow, for quite long periods of time characterized by specific weather conditions:

- no wind (v < 5 m/s)
- bora wind(45°<α<90° e v>10 m/s)
- other winds
- all weather conditions

In the table below (Tab. 2) are shown the averaged values of the difference (Ce - Cf) and of the tidally averaged concentration $\overline{C} = (\frac{Ce + Cf}{2})$ calculated over the three years considered (2005-2006, 2006-2007, 2007-2008).

April 2005-May 2006

		NO WIND			BORA WIND(45<direz.<90) Vv>10 m/s			OTHER WINDS			ALL WEATHER		
		Ce-Cf	C	Duration	Ce-Cf	C	Duration	Ce-Cf	C	Duration	Ce-Cf	C	Duration
•	LMR	1.480	6.180	63.53%	-10.570	26.815	7.83%	0.794	8.710	28.64%	0.340	8.520	100%
•	LMR-2	\	\	\	\	\	\	\	\	\	\	\	\
	LIM	-1.080	8.330	60.76%	-1.150	58.415	9.53%	-5.468	14.423	29.70%	-2.390	14.915	100%
•	LTP	0.980	14.850	63.38%	-13.350	35.515	10.07%	-3.942	19.345	26.55%	-1.770	18.125	100%
•	LSN	1.820	14.800	65.49%	-1.730	33.095	6.49%	0.001	18.878	28.02%	1.080	17.130	100%
•	LSA	\	\	\	\	\	\	\	\	\	\	\	\
	MAM	-0.080	8.110	61.05%	3.580	59.120	8.72%	-2.327	14.897	30.23%	-0.440	14.610	100%
•	MAP	0.250	7.355	64.64%	5.080	19.990	8.59%	0.867	9.615	26.77%	0.830	9.045	100%
•	CHP	0.050	7.805	64.92%	4.920	33.550	9.19%	0.524	10.817	25.89%	0.620	10.950	100%
	CHM	124.00%	17.800	0.645	-0.590	149.605	7.98%	-2.585	34.190	27.56%	0.040	32.830	100%

June 2006-May 2007

		NO WIND			BORA WIND(45<direz.<90) Vv>10 m/s			OTHER WINDS			ALL WEATHER		
		Ce-Cf	C	Duration	Ce-Cf	C	Duration	Ce-Cf	C	Duration	Ce-Cf	C	Duration
•	LMR	1.250	5.895	69.78%	-2.520	18.620	4.34%	0.104	7.704	25.88%	0.790	6.915	100%
•	LMR-2	2.470	7.815	70.56%	-7.930	19.245	4.18%	0.392	10.594	25.25%	1.510	8.995	100%
	LIM	-0.030	9.265	68.91%	-47.740	109.380	5.09%	-7.729	38.377	26.00%	-4.460	21.930	100%
•	LTP	1.520	12.510	70.09%	-6.470	21.785	4.27%	-1.049	14.943	25.63%	0.520	13.530	100%
•	LSN	\	\	\	\	\	\	\	\	\	\	\	\
•	LSA	1.140	16.060	70.06%	-5.180	35.170	4.70%	0.337	18.600	25.24%	0.640	17.600	100%
	MAM	\	\	\	\	\	\	\	\	\	\	\	\
•	MAP	0.210	6.125	69.61%	4.100	17.610	4.45%	0.275	8.338	25.94%	0.400	7.205	100%
•	CHP	-0.470	4.725	70.57%	2.610	27.585	4.33%	1.190	8.136	25.10%	0.080	6.570	100%
	CHM	\	\	\	\	\	\	\	\	\	\	\	\

June 2007-April 2008

		NO WIND			BORA WIND(45<direz.<90) Vv>10 m/s			OTHER WINDS			ALL WEATHER		
		Ce-Cf	C	Duration	Ce-Cf	C	Duration	Ce-Cf	C	Duration	Ce-Cf	C	Duration
•	LMR	0.780	6.150	57.75%	-5.350	17.905	6.43%	-0.241	8.367	35.82%	0.020	7.700	100%
•	LMR-2	1.940	6.380	55.91%	-6.560	18.220	7.51%	0.049	8.719	36.57%	0.610	8.125	100%
	LIM	-0.840	9.060	56.77%	-1.650	33.005	6.58%	-4.105	15.990	36.65%	-2.090	13.175	100%
•	LTP	1.200	12.610	58.44%	-7.470	19.755	6.01%	-2.173	15.453	35.54%	-0.520	14.050	100%
•	LSN	\	\	\	\	\	\	\	\	\	\	\	\
•	LSA	0.830	8.805	56.92%	-2.570	13.665	6.07%	-0.450	10.196	37.00%	0.150	9.615	100%
	MAM	-0.180	4.650	58.29%	-2.460	17.020	8.23%	-0.815	7.106	33.48%	-0.580	6.490	100%
•	MAP	-0.200	8.930	59.48%	5.290	24.245	5.62%	0.864	12.107	34.90%	0.480	10.900	100%
•	CHP	-0.160	4.910	56.78%	6.810	17.995	7.18%	1.088	7.063	36.04%	0.790	6.625	100%
	CHM	\	\	\	\	\	\	\	\	\	\	\	\

Tab. 2. Tidally averaged concentration and difference between averaged values during ebb and flood conditions

As shown in Tab. 2 the values of the tidal differences (Ce - Cf), for each of the different meteorological conditions considered, present the same sign in all three years of measurement. The few exceptions correspond to extremely low values of the difference itself, smaller than measurement error.

Considering the strong symmetry between the tidal flow during ebb and flood conditions, at least for the stations in the tidal channels (marked by dots) , the sign of difference (Ce - Cf) gives an idea of the net flux of sediments: outgoing (positive) or ingoing (negative). The absolute value of the net fluxes may be roughly estimate as the product of these differences by the corresponding annual tidal prisms.

For the stations located in tidal channels, we observe that:

- With no wind (duration 56 - 70%) we find a fluctuating sign of the exiguous net flux, for the years 2006-2007-2008 in the inlets of Malamocco and Chioggia. In the three stations of the Lido inlet, the values of the net flux are more significant and invariably outward.
- With bora wind (duration 4 - 10%) the net flux is invariably inward in all stations of the Lido inlet, whereas is invariably stronger and with a decidedly outward direction in the two stations of Malamocco and Chioggia. This means that in the Southern lagoon, the bora wind re-suspends the sediments mainly inside the lagoon, therefore increasing the outgoing net flux. On the contrary, in correspondence of the Lido inlet, bora wind promotes sediments re-suspension mostly in the sea, with a consequent larger incoming net flux for all channels, Treporti, S. Nicolò and S. Erasmo
- With other winds (duration 25 - 37%) the net fluxes presents an intermediate configuration between the two mentioned above.
- Considering the whole year, net fluxes are all outward, with only one exception in Treporti station (LTP) in (2005 – 06) and (2007-08), but with quite limited values.

It should be noted that, although quite strong in absolute terms, the net fluxes under conditions of bora have a limited duration (less than 10%) so that become relatively important the net fluxes with other winds (duration 30%) and those without wind (duration 60%).

As there is a certain compensation between the net fluxes in the presence and absence of wind it is confirmed at an annual scale, a tendential loss to the sea in all three inlets [Arena *et al*, 2009]. As for the two channels converging into the mouth of the Lido, it seems confirmed the difference in behaviour between the Central lagoon (stations and LSA LSN) which indicates every year an annual net flux outwards and the Northern lagoon (station LTP) which shows a net flow both incoming (in 2005-2006 and in 2007-2008) and outgoing in (2006-2007).

Different comments should be made for the turbidimetric stations at sea (marked by no dots) (LIM, MAM and CHM).

In the Western side of the Adriatic sea, in fact, the tidal propagation moves from North to South. The sediment transport in the sea, however, is controlled by the “convective” littoral current, more than by the small alternate (“dispersive”) tidal currents.

For these stations, then, the difference (Ce-Cf) for all the 3 years indicates the presence of a negative concentration gradient toward South in front of the Lido inlet, a negative gradient still toward South, but to a lesser extent, in front of the Malamocco inlet and an even weaker negative gradient, this time toward North, in front of Chioggia inlet. The sign of these gradients is probably related to the presence of river mouths in the North (Piave) and South (Brenta and Adige) of the lagoon.

The results discussed above are physically reasonable but for a quantitative

assessment of net fluxes a more precise and detailed knowledge of the time-averaged values of concentration, respectively during ebb and flow tide, is necessary.

The data on net fluxes, combined with data that provide the spatial gradients of tidally averaged concentration, are also crucial for the verification of a two-dimensional morphodynamic model of the lagoon of Venice [Di Silvio *et al*., 2009].

Conclusions

The dredging operations carried on over more than 3 years in the inlets of the Venice Lagoon, as a part of the project for the construction of the movable barriers, have been carefully monitored by a group of researchers of different disciplinary backgrounds. The design, execution and evaluation of this complex monitoring program has endowed the group with frequent opportunities of extremely fruitful exchanges of ideas about the behaviour of the sediments (basically sand and silt) present in the inlets, not only when re-suspended by the dredgers, but also when naturally moved by tidal currents and waves, inside and outside of the lagoon. The monitoring has been conducted by a combined application of fixed stations and several measuring campaigns with boat-mounted ADCP. The measured data (water flow, turbidity and grain size composition of the suspended material) have been discussed and interpreted, also by means of an especially developer model which simulates the functioning of a trailing suction hopper dredger and the formation of its turbidity plume, with special regards to the grainsize selection of the excavated sediments, first within the dredger hold and subsequently along the turbidity plume itself.

The data collected during the monitoring program and the methodologies developed for their interpolation, have been reported in detail in the CORILA documentation for the Venice Water Authorities (Magistrato alle Acque di Venezia). This information may be useful for the design of similar monitoring program and for the dredging industry, as well as for the interpretation of the selective transport of suspended sediments in the lagoons, under natural conditions.

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MONITORING OF THE ENVIRONMENTAL EFFECTS OF MOBILE GATES CONSTRUCTION AT THE VENICE LAGOON INLETS (MOSE)

Belosi F.[1], Contini D.[2], Gambaro A.[3], Venier G.[4]

[1] *Istituto Scienze dell'Atmosfera e del Clima (ISAC) – CNR, Bologna*
[2] *Istituto Scienze dell'Atmosfera e del Clima (ISAC) – CNR, Lecce*
[3] *Istituto Dinamica dei Processi Ambientali (IDPA)- CNR, Venezia*
[4] *CORILA, Venezia*

Riassunto

La realizzazione degli interventi alle bocche lagunari per la regolazione dei flussi di marea (MOSE) implica lo svolgimento di attività potenzialmente foriere di pressioni ambientali che si aggiungerebbero a quelle già presenti nell'area lagunare. La presenza di numerosi mezzi di cantiere e marittimi, il transito di mezzi pesanti diretti ai cantieri, la movimentazione di pietrame e sabbia, etc. rappresentano infatti delle potenziali sorgenti di inquinanti che possono alterare lo stato della qualità dell'aria nelle aree circostanti le lavorazioni.

La scelta degli inquinanti da monitorare è stata effettuata considerando sia le specifiche tipologie di sorgenti, potenzialmente dovute alle lavorazioni inerenti il MOSE, sia la normativa ambientale vigente (ed i relativi aggiornamenti).

Le strategie di monitoraggio adottate hanno tenuto conto sia della esigenza di caratterizzare le eventuali emissioni provenienti dalle aree cantieristiche sia delle caratteristiche ambientali generali che risentono delle condizioni climatiche che frequentemente non favoriscono la diluizione degli inquinanti rilasciati nella Pianura Padana.

Abstract

The construction activities of the mobile gates at the Venice Lagoon entrances might impact over several environmental matrixes; among them there are the atmospheric emissions due to off-road and marine vehicles, heavy duty trucks, stones movement, et. Therefore the monitored pollutants are those considered by the European and national legislations and those potentially emitted from combustion sources (engines) and dust resuspension. The monitoring activity has considered both the specific sources due the construction activities as well as the general pollutants present in the Lagoon and coming from the Po Valley and from the industrial district of Porto Marghera and Mestre.

1. Introduction

The construction activities of the mobile gates at the Venice Lagoon entrances might impact over several environmental matrixes; among them there are the atmospheric emissions due to off-road and maritime vehicles, heavy duty

trucks, stones movement, etc.

The monitored pollutants are the following: PM_{10} on an hourly frequency at Punta Sabbioni, PM_{10} elemental composition at the three lagoon inlets, PAHs both in the gas and in the aerosol at Malamocco and Punta Sabbioni, and gases (NOx, NO_2 and CO) at hourly frequency at Punta Sabbioni and Malamocco gates. The monitoring strategy is completed by the collection of the atmospheric fall out (bulk deposition fluxes) at the three lagoon inlets and by performing short campaigns (each 2 days long) with two simultaneously PM_{10} sampling stations.

The sampled data elaboration is based on the comparison of each pollutant averaged concentration with its specific threshold (in some cases legal ones, in other cases obtained through statistical elaboration of data obtained in absence of working activities) and on the correlation with the meteorological parameters (a meteorological mast has been positioned in Punta Sabbioni, while in Malamocco the MAV meteorological station of Molo Ceppe is considered). The comparison of the monitored data with the meteorological conditions is very important in case of critical episodes, because it allows the discerning of them as if they were due to the MOSE activities or if they were a consequence of a regional bad air quality condition. In the following the strategy followed and some results from the monitoring studies will be shown.

2. Instruments and methods

Sampling protocols for each pollutant and the relative elaboration strategy will be described. As a common rule data elaboration procedure, as pointed out in the previous paragraph, is based on two criteria:

the comparison of the pollutants average concentration between courty yard activity/non-activity periods;

the correlation between pollutants concentration and wind direction in order to investigate the relative sources.

The monitored pollutants are the following: PM_{10} on an hourly frequency at Punta Sabbioni, PM_{10} elemental composition through two/three fortnight campaigns at the three lagoon inlets, PAHs both in the gas and in the aerosol phase at Malamocco and Punta Sabbioni (two campaigns each year) and gases (NOx, NO_2 and CO) at hourly frequency (one week campaign at month) at Punta Sabbioni and Malamocco gates. The monitoring strategy is completed by the collection of the atmospheric fall out (bulk deposition fluxes) at the three lagoon inlets and by performing short campaigns (generally 2/3 days long) with two simultaneously running PM_{10} sampling stations. The mobile samplers are positioned one inside the courty yard and the other one nearby a receptor (i.e. residential houses) in order to evaluate any dust transport from the yard towards the receptor.

2.1 PM_{10} monitoring

PM_{10} aerosol fraction is continuously monitored at Punta Sabbioni by means of a light-scattering type sampler, widley used in air quality network cabs (LSPM10, Unitec, Ferrara-Italy). It is based on a 90 degrees scattered light measured from a photomultiplier. The sampling flow rate is 38.3 l/min (2.3 m^3/h) according to the European standard for the PM_{10} sampling (EN 12341) and the Italian legislation requirements [DM 60, 2002]. The scattered light is converted into aerosol concentration through a manufacturer calibration factor; the sampler can be equipped with a gravimetric unit, and the gravimetric filter weighing can be compared with the analyzer's readings to check their accuracy. A meteorological mast is positioned nearby the aerosol sampler, equipped with standard meteorological sensors (MET 3000R). Hourly PM_{10} average concentration and meteorological parameters are stored for further analisys. The sampler has been certified on 25/01/2005 (prot.068/2005), from the Atmospheric Institut for Environmental Pollution (IIA-CNR).

Three thresholds are considered: the legally daily average concentration of 50 µg/m^3; an hourly threshold based on the average of the PM_{10} concentrations measured during no-working activities (holidays, 8 am-8 pm) plus one standard deviation (different thresholds for winter and summer periods are considered); a threshold from dust resospension due to high wind velocity (it is based on dust concentrations measured before the starting work activity, ante operam, in conditions of wind velocity > 4 m/s).

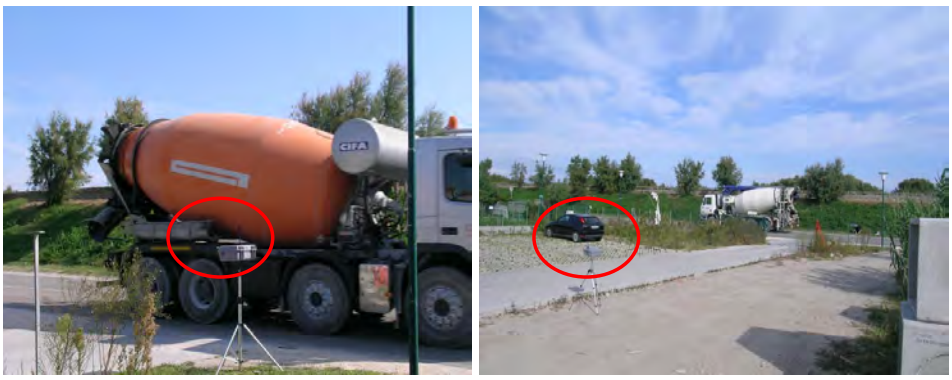

Fig 1.PM_{10} monitoring stations near Murazzi road (at the kerbside on the left)

Every month a 2/3 day sampling monitoring is performed with two parallel running DUSTTRAK™ (TSI, Inc.), which uses light scattering measurement to determine PM_{10} aerosol mass concentration in real-time. Usually one sampler is positioned inside the courty yard (at Malamocco or Punta Sabbioni) while the second one is positioned near a sensitive receptor ("Al Bacaro" restaurant at Punta Sabbioni or S. Maria del Mare Hospital at Malamocco). The aim of the survey is to find out if dust is transported from the courty yards towards the receptors (wind directions and intensities are correlated with the dust concentrations). Fig. 1 shows a special monitoring session at the kerbside along the Murazzi road (Pellestrina island) to determine the contribution, to the aerosol background, of the emissions coming from high duty veichles employed in the working activities.

2.2 PM_{10} Elemental composition

Samples of PM_{10} have been periodically taken at the three lagoon inlets: Chioggia, Malamocco and Punta Sabbioni (usually on September/October and on January/February of each year). A third measuring campaign is performed in July where the working activities are more critical (at the present state in Malamocco). Collected particles have been chemically analysed for the determination of the following metal concentrations: V, Cr, Fe, Co, Ni, Cu, Zn, As, Mo, Cd, Sb, Pb and Tl. Each sample has been collected using a low-volume sampler operating at 2.3 m^3/h for 24 hours (Skypost PM, TCR Tecora, Italy). Analysis are performed by the Institute for the Study of the Dynamics and Environmental Processes (IDPA-CNR). The analitycal methodology is described elsewhere [CORILA, 2004 and CORILA, 2007].

DM 60 and DL.vo n. 152 [DL.vo 152, 2007] give annual average concentration value for Ni, As, Cd and Pb (objective values); even if the survey is not performed every day (as required from the air quality legislation) nevertheless such thresholds are considered as reference values. Furthermore, in order to put in evidence a possible contribution from the emissions of the construction work, measurements have been divided into working days and holydays, and from wind sectors (meteorological data have been taken from the weather station of Punta Sabbioni, the MAV stations of Ceppe and San Felice for Malamocco and Chioggia).

2.3 PAHs

PAHs have been monitored by means of a High Volume sampler (Tisch Environment) at 0.4 m^3/min sampling flow rate. A quartz fiber filter followed by a polyurethane foam (puf) allows the measurement of both aerosol and gas phase. Two sampling campaigns are usually conducted each year at Malamocco (September and Juanuary/February), and at Punta Sabbioni (November and February). National legislation set an annual averaged limit of 1 ng/m^3 for Benzo(a)Pyrene in the PM_{10} fraction [DL.vo 152, 2007]. Because of historical reasons the Benzo(a)Pyrene content is still considered in the PM fraction (instead of the PM_{10} fraction). Because of the PAHs concentration dependency from the air temperature, a further comparison is based on the monthly averaged Benzo(a)Pyrene concentration measured from the Regional Protection Agency (ARPA Veneto) near Mestre (Circonvallazione and Bissuola stations): the average concentration of Benzo(a)Pyrene, measured during MOSE survey, is compared with the average concentration of Benzo(a)Pyrene (plus one standard deviation) of the same month measured from ARPAV [ARPAV, 2009]. The analysys on the sampled filters and pufs are accomplished by the MAV laboratory of Voltabarozzo.

2.4 Gaseous pollutants

Measurements of gaseous pollutant concentrations (CO, NOx, NO_2) have been performed on hourly basis using thick film sensors (ETL2000, Unitech srl, Italy). Data are collected at two sites: Punta Sabbioni and Malamocco for 1 or 2 weeks each month. Sampled data are validated considering the minimum threshold of the detector used (0.1 mg/m^3 for CO, 10 µg/m^3 for NOx and 5 µg/m^3 for NO_2). The measured gas concentrations are compared with the legislation limits

[DM 60, 2002]. Furthermore, in order to put in evidence a possible contribution from the construction works of MOSE, the data have been analysed separating the period of construction activity (between 8 am to 8 pm during working days) and in the period of inactivity (between 9 pm and 7 am during working days and all the day during holydays).

2.5 Atmospheric deposition fluxes

Atmospheric deposition fluxes of organic and inorganic compounds are measured by means of bulk deposimeters positioned at the three lagoon entrances and in a site far distant from the courty yard (elementary school S. Pertini, Punta Sabbioni). The last one is considered not influenced from the construction activities and therefore it gives the deposition reference flux. Two yearly sampling campaigns (June-October and December-March), each made of three samples (one month length) have been performed. Organic compounds (PAH's) are extracted and analized by the MAV laboratory of Voltabarozzo, while the inorganic compounds (elemental composition) are measured by IDPA-CNR [see Gambaro et al., 2009 for the detailed methodology]. Since there are no legislation limits for the atmospheric deposition, the comparison is made with international reference limits, adopted in some european countries, [EC, 2001] and with literature data from research study performed in the Venice lagoon [Rossini *et al*., 2005a, Rossini *et al*., 2005b, MAV, 2009].

Since the last yearly survey, depositions have been monitoring only at Punta Sabbioni (near the courty yard and at the elementary school).

3. Results and discussion

In the following, examples of results from the survey activity will be shown for each monitored pollutant, with a short discussion.

1.1 PM_{10} monitoring

Fig. 2 shows the average PM_{10} hourly concentrations obtained during last monitoring year (from May 2008 to April 2009) for the summer (April-September) and winter (October-March) seasons for working hours and no-working hours One standard deviation is also reported.

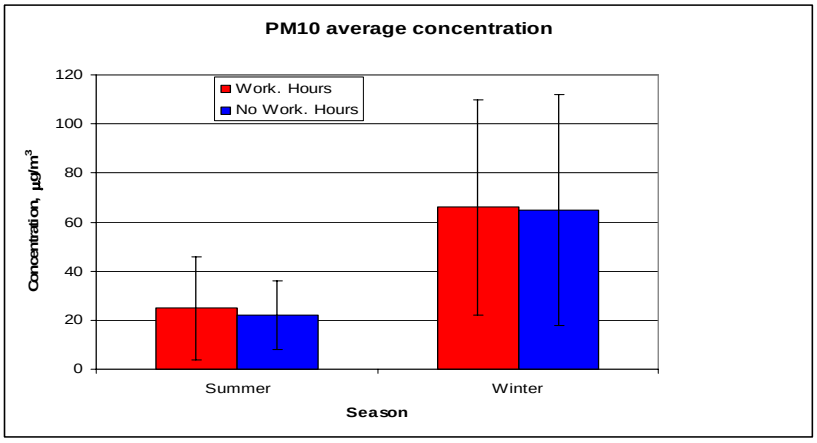

Fig 2. Hourly PM_{10} concentrations at Punta Sabbioni

3.2 PM_{10} Elemental composition

Table 1 gives the average concentrations of the elements under legislation control. Reference values are the following: As 6 ng/m^3, Cd 5 ng/m^3, Ni 20 ng/m^3 and Pb 500 ng/m^3.

To further investigate the possibility of a contribution from the construction work, the meteorological data have been used in an elaboration in which samples taken in working days have been divided into two groups for each measurement site. The first group includes samples in which the prevalent wind direction is in the sector compatible with the position of the construction work. The second group includes samples in which the prevalent wind direction is from a sector non compatible with the position of the construction work. Results show that in the Punta Sabbioni site all the metals show average concentrations larger for wind directions associated to the position of the construction work (which is also the direction of the industrial district of Porto Marghera). In the other two sites some metal concentrations are larger for wind directions not compatible with the position of the courty yards.

Element (ng/m^3)	**Malamocco (80 samples working days 13 samples holydays)**		**Chioggia (68 samples working days 14 samples holydays)**		**Punta Sabbioni (64 samples working days 12 samples holydays)**	
	Working days	**Holydays**	**Working days**	**Holydays**	**Working days**	**Holydays**
Ni	**4.2** (3.4)	**5.4** (4.4)	**3.6** (2.5)	**5.5** (7.0)	**4.9** (4.6)	**2.3** (1.6)
As	**3.0** (3.1)	**4.9** (6.3)	**1.6** (1.3)	**1.5** (1.3)	**3.3** (4.0)	**1.4** (1.9)
Cd	**1.9** (2.3)	**6.1** (8.0)	**1.5** (1.9)	**1.8** (1.7)	**3.6** (6.1)	**0.5** (0.5)
Pb	**15.8** (11.1)	**18.2** (15.4)	**12.3** (9.1)	**14.0** (12.8)	**22.1** (20.7)	**18.5** (11.1)

Tab. 1. Concentrations of metal in PM10 obtained separating working days from holydays. Data are taken from 2006 to 2009. Standard deviation in brackets.

3.3 PAH's

Fig. 3 shows and example of the Benzo(a)Pyrene concentrations measured during the two campaigns performed last year. For comparison the reference values, obtained from ARPAV, are also indicated, as well as the data variability (one standard deviation).

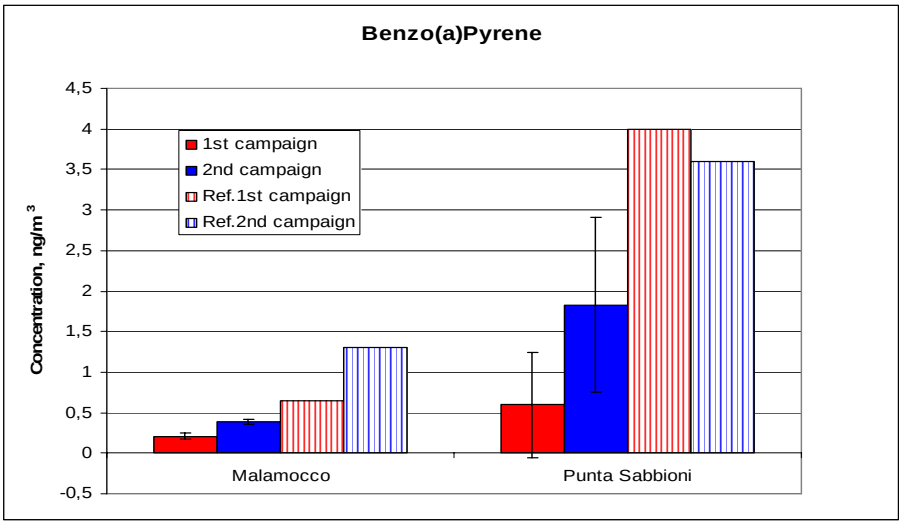

Fig 3. Benzo(a)Pyrene concentrations

3.4 Gaseous pollutants

A Summary of all the data collected between July 2006 and August 2009 has been reported in Table 2; in the table it is also reported the number of samples available for each case. Results indicate that average concentrations of all analysed gases (All period) are larger in the Punta Sabbioni site; however the two sites show a different behaviour in the selection of working and non-working hours. In the site of Punta Sabbioni the average concentrations of all gases are slightly larger during non-working hours, instead in the Malamocco site the concentration of CO and NOx are lower during non-working hours, and concentration of NO_2 is basically the same (in average terms).

A second analysis has been performed correlating hourly measured concentrations in the two sites with wind direction excluding low wind speed cases (wind speed lower than 1 m/s) because at low wind speed the direction is often not well defined presenting high fluctuations. Results indicate that the largest hourly concentrations in the different wind direction are similar for working and non-working hours. A further analysis has been performed evaluating average concentrations, limited to working hours, for winds associated to the sector compatible with the emissions and for the other sector. Results show a different behaviour for the two sites. In Malamocco site the average concentration of CO and NOx are slightly smaller for wind directions compatible with the position of the construction work and the average concentration of NO_2 are basically the same in the two sector of wind directions. Instead in the Punta Sabbioni site the average concentrations for all the analysed gases are larger when associated to wind directions compatible with the position of the

construction work and the industrial district of Porto Marghera.

Site	Period	CO (µg/m^3)	NOx (µg/m^3)	NO_2 (µg/m^3)
Malamocco	Activity (Samples: 2683)	Mean: 946 St. Dev: 840	Mean: 53 St. Dev: 46	Mean: 16 St. Dev: 16
Malamocco	Inactivity (Samples 3322)	Mean: 881 St. Dev: 844	Mean: 46 St. Dev: 43	Mean: 16 St. Dev: 16
Malamocco	**All period (Samples: 6005)**	**Mean: 911 St. Dev: 843**	**Mean: 49 St. Dev: 45**	**Mean: 16 St. Dev: 16**
Punta Sabbioni	Activity (Samples: 2755)	Mean: 922 St. Dev: 844	Mean: 57 St. Dev: 58	Mean: 19 St. Dev: 18
Punta Sabbioni	Inactivity (Samples 3250)	Mean: 1004 St. Dev: 870	Mean: 67 St. Dev: 62	Mean: 24 St. Dev: 22
Punta Sabbioni	**All period (Samples: 6005)**	**Mean: 966 St. Dev: 859**	**Mean: 62 St. Dev: 60**	**Mean: 22 St. Dev: 20**

Tab. 2. Summary of observed gaseous pollutant concentrations in the period between July 2006 and August 2009.

3.5 Atmospheric deposition fluxes

Fig. 4 shows the deposition fluxes of the inorganic compounds obtained during 4 years of survey activity.

It can be seen a large variability in the deposition fluxes among the different lagoon locations; nevertheless the deposition flux near the courty yard at Punta Sabbioni is comparable with the flux at the reference bulk deposimeter (Sabbioni Ref.). The same occurs for the organic compounds (results non shown here). Cd deposition fluxes are always lower then 2 µgm^{-2}die^{-1}, which is considered a reference value in Austria and in Switzerland.

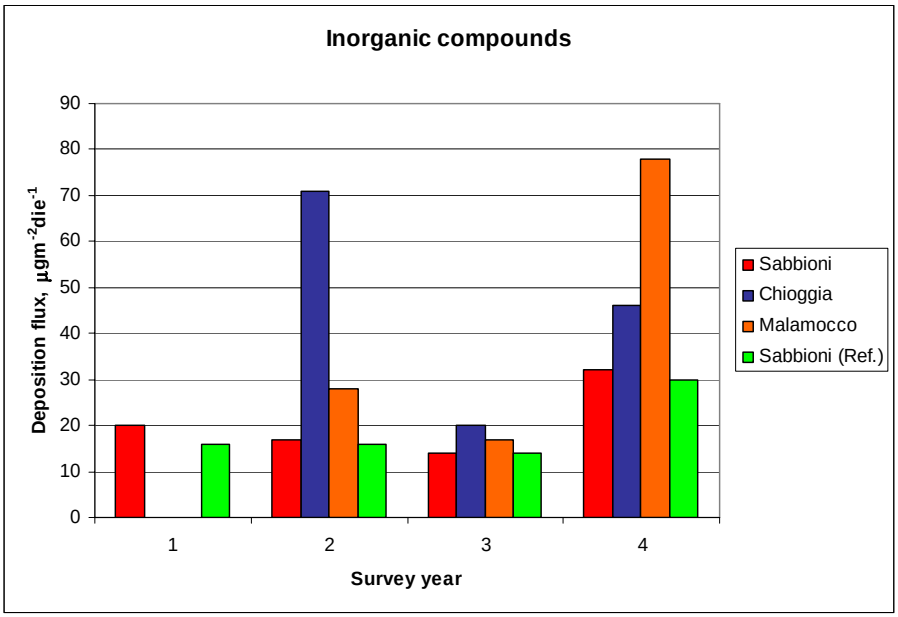

Fig 4. Inorganic deposition fluxes.(V, Cr, Co, Ni, As, Mo, Cd, Sb, Pb, Tl).

Conclusions

The survey strategy followed to verify possible environmental impacts, due to the construction activities of the mobile gates at the Venice Lagoon entrances, have been described. Some typical results have been also given. So far no rilevant impacts, due to the construction activities, have been registered for all the monitored compounds. Some single events have occurred, linked to high duty trucks movements from and in the courty yard at Punta Sabbioni. Local interventions have been suggested in order to mitigate dust resospension from the road in front of the courty yard.

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MONITORING PLAN OF MOSE BUILDING SITES (VENEZIA): THE HYDROGEOLOGIC SITUATION AROUND THE BUILDING SITES

Alessandro Casasso, Rajandrea Sethi, Antonio Di Molfetta

DITAG – Dipartimento del Territorio, dell'Ambiente e delle Geotecnologie, Politecnico di Torino

Riassunto

Nell'ambito del progetto Mo.S.E. per la protezione di Venezia dalle acque alte, la realizzazione dei porti rifugio di Treporti e di Ca' Roman ha richiesto la costruzione di due bacini (ture) al fine di rendere agibili altrettante aree di cantiere poste ad una quota inferiore al livello del mare. L'attivazione di una serie di idrovore e di un sistema di *dewatering* perimetrale ha permesso, a partire dal 2006 per il cantiere di Punta Sabbioni e dal 2008 per il cantiere di Ca' Roman, di prosciugare le ture foranee per permettere la costruzione dei cassoni delle barriere.

Al fine di monitorare gli effetti derivanti dalle attività di cantiere sulle aree circostanti, sono stati installati due sistemi di monitoraggio dei livelli piezometrici in corrispondenza dei primi due livelli acquiferi nei due siti. La rete di monitoraggio a Punta Sabbioni è costituita da oltre una decina di postazioni doppie, mentre quella di Ca' Roman è costituita da un'unica postazione doppia.

I sistemi di monitoraggio installati in entrambi i siti hanno permesso di separare efficacemente l'influenza delle forzanti naturali (precipitazioni, pressione atmosferica, effetto mareale) da quelle antropiche (costruzione e *dewatering* della tura). Gli effetti derivanti dalle operazioni di cantiere sono state identificati dai piezometri superficiali, che hanno evidenziato un parziale isolamento dell'area peninsulare dal mare con un conseguente aumento di livello idrico e diminuzione del tenore salino. I piezometri profondi, più prossimi alla tura, evidenziano, al contrario, un decremento dei livelli a seguito delle operazioni di *dewatering*.

Abstract

In the framework of Mo.S.E. project for the protection of Venice against exceptional high tides, the development of Treporti (Lido's inlet) and Ca' Roman (Chioggia's inlet) harbours in the Venice Lagoon required the realization of two provisional sea basins (cofferdams) which have been drained to provide access to the building sites, positioned below the sea level. The dewatering systems installed on the perimeter of the basins, which have been active since 2006 in Punta Sabbioni and since 2008 in Ca' Roman, permitted to dry up the cofferdams, where the concrete lodging caissons of mobile barriers are to be built.

Two groundwater monitoring systems have been emplaced to measure

hydraulic heads in the first and second aquifer levels, in order to monitor the effects of the dewatering systems in the proximity of the constructions sites. The monitoring network is composed of more than twenty piezometers intercepting both aquifer layers in Punta Sabbioni and two in Ca' Roman.

The monitoring systems were emplaced in order to discriminate between the effects of natural driving forces (rainfall, atmospheric pressure, tidal oscillations) from the anthropogenic ones (construction and dewatering of the cofferdam). The effects of construction works on the first phreatic aquifer have been highlighted by shallow piezometers. The measurements indicate a partial isolation of this groundwater body from the sea with a consequent increase in the hydraulic head and a decrease in the groundwater salinity. The deep piezometers next to the cofferdam showed instead a decrease of hydraulic head due to dewatering operations.

1. Introduction

The historical centre of Venice is affected by seawater flooding due to exceptional high tides, whose magnitude and frequency is increasing because of sea level rise and land subsidence, resulting in a relative sea level rise of 23 cm in the last century [Cecconi, 2005]. The countermeasure adopted by Italian Government to protect Venice against these phenomena is the so called "Mo.S.E. project", consisting in a system of four rows of mobile flap-gate barriers at the Venice Lagoon's inlets, that will isolate the Lagoon from the sea during high tides (more than 1.10 m); other operations such as the raising of embankments and streets, have also been put in action [Cecconi, 1997].

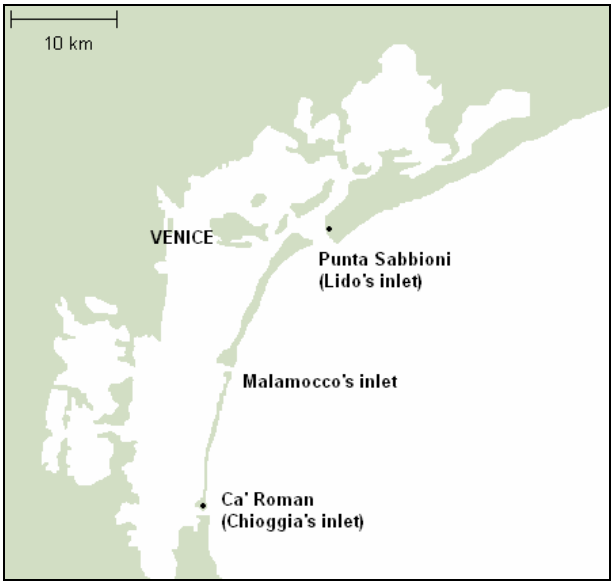

Fig 1. The Venice Lagoon and its inlets.

Three harbours at the inlets of Lido, Malamocco and Chioggia (Figure 1) will assure the operational continuity of the seaports while mobile barriers are lift, permitting the boats to overtake the level gradient between the Lagoon and the

sea by a navigation lock. Two of these three basins (Lido – Punta Sabbioni and Chioggia – Ca' Roman) are used as building sites for the concrete lodging caissons of mobile barriers: in order to assure their accessibility and safety, they are bounded by cofferdams and dried up by wells around their boundary to keep the groundwater level inside the basin under its bottom (about 9 m under the mean sea level) [Magistrato alle acque di Venezia, 2004].

The impact of the dewatering system is continuously monitored with two networks of piezometers, and monthly measures of electric conductivity profiles are carried out to study the evolution of saltwater intrusion.

In this study, after a discussion on the driving forces of the system, the results of groundwater monitoring in the building sites of Punta Sabbioni and Ca' Roman are discussed, identifying the impacts of the constructions works.

2. Monitored aquifers: driving forces and measured parameters

The temporal evolution of hydraulic heads and groundwater salinity in the monitored aquifers is influenced by both natural and anthropic driving forces [CO.RI.LA. – Politecnico di Torino, 2005b], which are (Figure 2):

- tidal oscillations, inducing forced oscillations of the phreatic aquifer levels (and, to a lesser extent, on the second aquifer layer) over a belt of a tens of meters from the coastline;
- rainfall events, causing abrupt water table rise in the phreatic aquifer;
- evapotranspiration, causing a progressive decline of the water table in the phreatic aquifer specially during the hot months;
- atmospheric pressure, used to compensate pressure logging in the piezometers.

Anthropogenic driving forces are, instead:

- the dewatering inside the cofferdams;
- the impermeable barriers dredged between the coastline and the basin, in order to reduce the inland impact of the dewatering pumping.

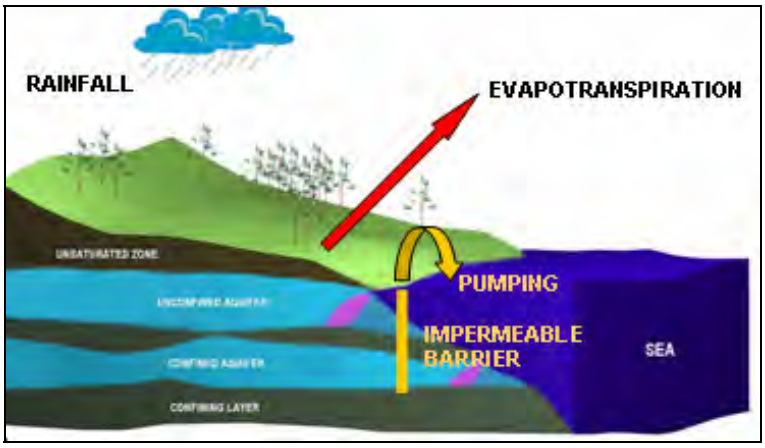

Fig 2. Driving forces influencing the monitored aquifers.

The objective of the groundwater monitoring carried out by DITAG – Politecnico di Torino and coordinated by CO.RI.LA. is to assess the impact of the construction works on both aquifers by measuring and comparing the hydraulic heads and the groundwater conductivity before ("A Phase") and after ("B Phase") the construction of the harbours. The monitoring activity started on October 2005 in Punta Sabbioni and in February 2007 in Ca' Roman.

The monitoring network in Punta Sabbioni (Figure 3) is composed by 11 shallow piezometers, intercepting the first phreatic aquifer (depth: 0 ÷ 15 m from ground surface), and 14 deep piezometers, intercepting the second confined aquifer (about 20 ÷ 25 m from ground surface). The aquifers are separated by an impervious 5m-thick clayed silt layer [CO.RI.LA. – Politecnico di Torino, 2005a].

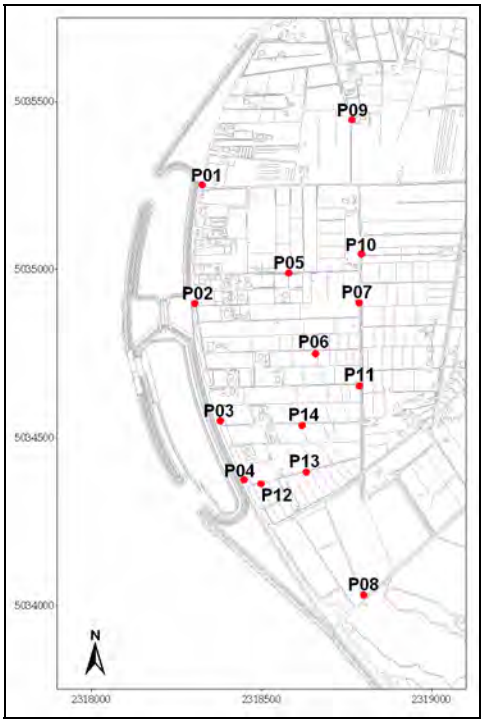

Fig 3. Monitoring network in Punta Sabbioni

The vertical profiles of electric specific conductivity are measured every month in both shallow and deep piezometers and increase with depth to water table, generally showing an abrupt increment at the salt wedge.

Other data are acquired to explain levels variations in the aquifer:

- rainfall data are acquired from meteorological stations in the proximity of the building sites;
- tidal levels are acquired from the measurement stations of Diga Sud Lido and Diga Sud Chioggia (Istituzione Centro Previsione e Segnalazione Maree, Comune di Venezia).

Tidal levels are used also to calculate "low level thresholds" for groundwater levels [CO.RI.LA. – Politecnico di Torino, 2005b]. If the hydraulic head in a

piezometer is more than 1 m under the sea level, this threshold has been overcome, due to level depression induced by dewatering pumping or simply to a high tide. If the hydraulic head is higher than the well top, the “high level threshold” has been overcome: this happens in the shallow piezometers during intense rainfall events.

3. Monitoring results in Punta Sabbioni (Lido’s inlet)

After the completion of Mo.S.E. system, the harbour of Punta Sabbioni will be used as a navigation lock to permit the boat to cross the Lido’s inlet while mobile barriers are lift; now it is dried up and used as a provisional building site (the so-called “tura”) for the concrete lodging caissons of the flap-gate barriers. The surface area of the building site is about 50000 m^2, and the bottom elevation of the basin is of 8.70 m below the mean sea level: a dewatering well system is continuously pumping water from the second aquifer layer to keep the groundwater level under the bottom of the basin. The basin is delimited by cofferdams and, on the inland side, also by an impermeable barrier to mitigate the impact on the groundwater bodies [Magistrato alle acque di Venezia, 2004].

The phreatic aquifer shows distinct behaviours:

- over a narrow belt of some tens of meters from the coastline, the levels are influenced only by tidal oscillations (“coastal piezometers” PS01 and PS02), as shown in Figure 4. The amplitude varies mainly with distance from the coastline and local hydraulic conductivity;
- in the inland area (piezometers: PS05÷11), the levels are influenced by rainfall events, which cause abrupt level increments, and evapotranspiration, which cause slow level declines (Figure 5). The effect of these driving forces is very strong and recognizable due to the reduced depth to water table, ranging from about 0.6 to 2 m;
- levels in piezometers PS03 and PS04 initially showed a trend similar to the coastal piezometers but, after the completion of the impermeable barrier of the *tura* (Summer 2006) they changed dynamics and now exhibit a behaviour similar to the inland piezometers (Figure 6).

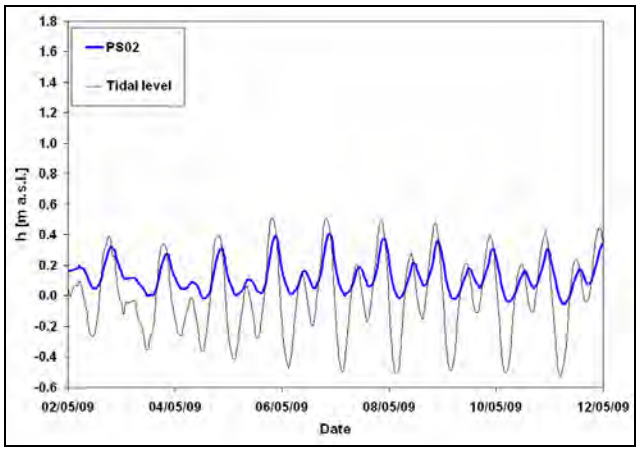

Fig 4. Comparison between levels in coastal piezometer PS02 and tidal oscillations.

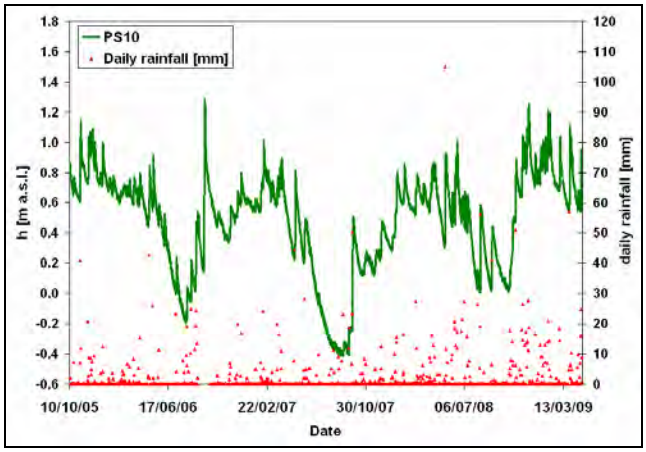

Fig 5. Level time series in an inland piezometer (PS10).

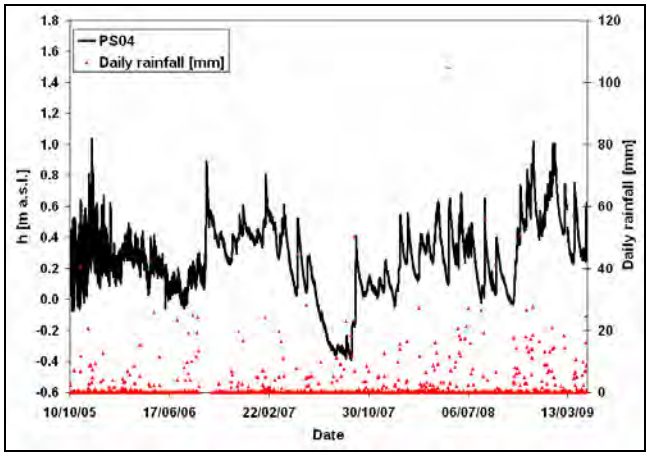

Fig 6. Level time series in coastal piezometer PS04.

The influence of construction works on piezometric surface of the shallow aquifer appears to be very limited. A slight water table rise has been recognized in PS03 and PS04, due to the isolation of this portion of the phreatic aquifer from the sea caused by the impermeable barrier.

The deep aquifer is influenced by the dewatering pumping of the *tura*, which has induced decrements of hydraulic heads ranging from about 1 to 5 meters, as shown in Figure 7. The drawdowns in the second aquifer layer vary logarithmically with the distance from the *tura*

The groundwater electric conductivity profiles show a seasonal variability due to evapotranspiration, rainfall and variations in the direction of groundwater flow: generally the conductivity increases in the summer and decreases in the winter [CO.RI.LA.. – Politecnico di Torino, 2009]. This behaviour is mostly recognizable in the shallow aquifer. In the piezometers PS03 and PS04, the profiles show another effect of the isolation of this part of the phreatic aquifer from the sea: a downtrend of conductivity, and hence of salinity, is observed, due to the interruption of the flow of saltwater from the sea.

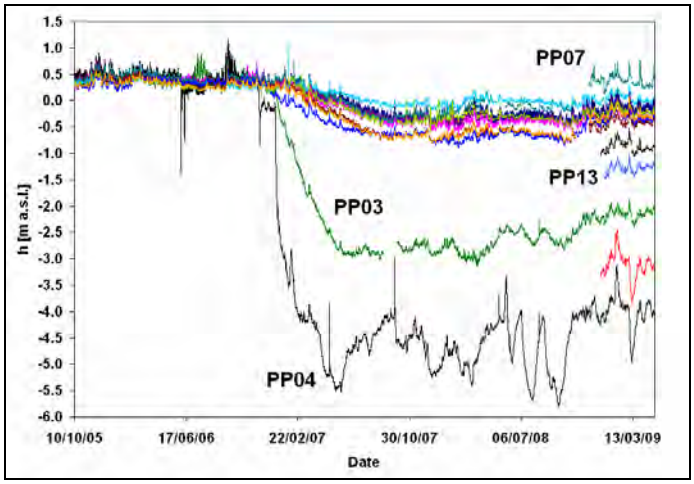

Fig 7. Hydraulic heads in deep piezometers.

4. Monitoring results in Ca' Roman (Chioggia's inlet)

The harbour at Chioggia's inlet is similar to the one in Punta Sabbioni. These navigation locks are going to be used by smallest boats, while the biggest cargo-ships will cross the Malamocco inlet to enter into the lagoon.

The monitoring network in Ca' Roman is composed by a shallow piezometer (0÷15.2 m from ground surface) and a deep piezometer, which intercepts the confined aquifer layer (21.2 – 37.3 m from ground surface) [CO.RI.LA. – Politecnico di Torino, 2007].

The monitoring activity started in February 2007. The effects of the construction works are recognizable since January 2008, as the impermeable barrier isolated a portion of both aquifers from the sea. The dewatering pumping started on April 2008, causing a level decline in the deep aquifer of about 5-6 m (Figure 8). The shallow phreatic aquifer, instead, showed a level increment of about 1m due to the isolation from the sea.

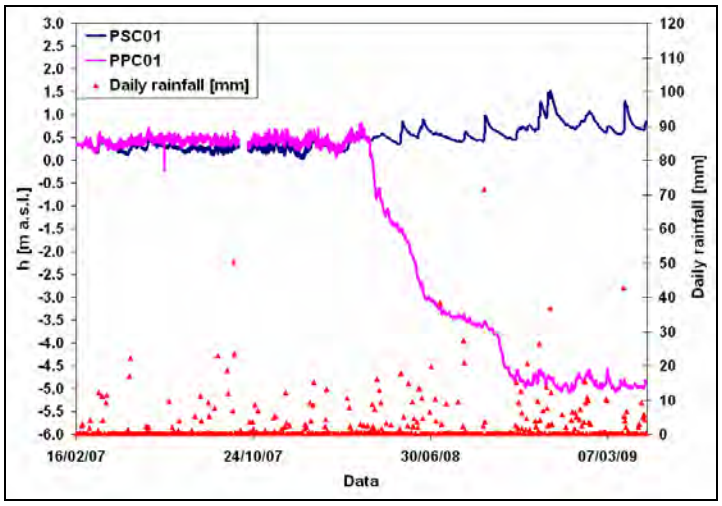

Fig 8. Groundwater levels measured in Ca' Roman.

Conclusions

Two harbour of Mo.S.E. project are now used as provisional building sites for the construction of concrete lodging caissons of mobile barriers. To assure their accessibility and safety, these basins have been bounded by cofferdams and impermeable clay barriers and dried up with dewatering wells systems. The impact of the pumping on the two shallowest aquifers has to be monitored.

Two monitoring networks have been implemented next to the building sites of Punta Sabbioni (October 2005) and Ca' Roman (February 2007). Groundwater levels are acquired with automatic pressure transducers in every piezometer and vertical profiles of water specific electric conductivity are measured monthly. Other data, as rainfall and tidal levels, are acquired in order to explain the hydraulic head variation in observation wells.

The impact of construction works, both in Punta Sabbioni and Ca' Roman, are:

- the isolation of a portion of the shallow phreatic aquifer from the sea, due to the impermeable barrier of the provisional building site. Two effects have been recognized: a water table rise and an electric conductivity (and hence, salinity) decrease;
- a depression cone around the dewatered basin in the deep confined aquifer. Level drawdowns vary logarithmically with the distance from the construction sites, with a maximum of 5-6 m next to the impermeable barrier.

The monitoring network proved to be efficient in assessing the effects of both anthropogenic and natural driving forces on the monitored aquifers. A better comprehension of the behaviour of the phreatic aquifer in Punta Sabbioni could be achieved by monitoring the level in the land reclamation channels delimiting the monitored area.

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EVALUATING SEDIMENT INPUT OF RIVERS FLOWING IN THE LAGOON OF VENICE

Giampaolo Di Silvio[1], Mariateresa Franzoia[1], Michael Nones[1], Davide Bonaldo[1], Luca Zaggia[2], Giuliano Lorenzetti[2], Chiara Dall'Angelo[3]

[1] *Dipartimento di Ingegneria Idraulica Marittima Ambientale e Geotecnica, Università di Padova*
[2] *Consiglio Nazionale delle Ricerche, Istituto di Scienze Marine (CNR-ISMAR), Venezia*
[3] *CORILA, Venezia*

Riassunto

Nell'ambito di un futuro piano di gestione regionale dei sedimenti fluvio-marittimi, si vogliono ricercare metodologie alternative di misura e previsione della quantità dei sedimenti provenienti dai fiumi del bacino scolante che sboccano direttamente in Laguna di Venezia. Inoltre si vuole capire quali tipi di misurazioni dovranno essere previste per uno sviluppo ottimale di studi futuri.

Partendo dalla formulazione del trasporto solido dei fiumi nelle condizioni di equilibrio, l'Università di Padova ha sviluppato un modello che riesce a riprodurre e prevedere il trasporto solido in un fiume anche in condizioni di non equilibrio (Di Silvio *et al.*, 2010).

Tale modello, inizialmente sviluppato per fiumi di medie e grandi dimensioni con bacini d'afferenza molto vari, vuole essere applicato in questo più limitato contesto di pianura, peraltro potenzialmente più ricco di dati sperimentali.

Abstract

As a part of a future plan for regional management of river and sea sediments, we want to search alternative methods for measuring and predicting the quantity of sediments conveyed by the rivers flowing directly in the Lagoon of Venice and also to understand what types of measurements may be useful in the future study.

Starting from a formulation of the sediment transport of rivers in equilibrium conditions, the University of Padua has developed a model that, after appropriate calibration, is able to reproduce and reasonably predict the instantaneous sediment transport of a river even in non-equilibrium (Di Silvio *et al.*, *2010*).

This model, initially developed for large rivers with different upperland watersheds, is meant to be applied in this more limited lowland contest, however potentially richer in terms of experimental data.

1. Introduction

In order to assess the long-term sediment balance between the total river transport and the sediment fluxes (controlled by tidal currents and waves) in the Venice Lagoon and the Adriatic coast, it is of primary importance to evaluate the quantity of the sediments transported by the rivers flowing directly in the lagoon

and eventually conveyed trough its inlets to the Adriatic sea. Even though this river input is presently a very small term of the balance, it used to be a dominant term before the large rivers Brenta and Piave were diverted out of the Lagoon.

A proper monitoring plan would be very costly and, in any case, quite untimely. We have then decided to address the research towards alternative methods of evaluation and prediction by utilizing only existing data, wanting also to understand what types of measurements may be useful in the future analysis.

A natural river reach is affected by a lot of variability in time and space along its course and across each cross-section. Variability concerns not only hydrology (time-depending water flow), but also sediment inputs (solid transport rate and grainsize composition) and geometry (bottom profile and river width).

If we assume that all these quantities, except water and sediment inputs, remain stationary in time, the relationship between instantaneous water flow and instantaneous sediment transport will be provided by a unique curve (corresponding to the “equilibrium” transport formula) while the transport composition will remain constant in space and time. These are in fact the “equilibrium conditions” which can be easily observed in a laboratory.

In nature, however, the relationship between water and sediment inputs is far from being unique. Conversely there are significant unrelated oscillation of water and solid inflows, especially in the farthest portions of watersheds, where exceptional rainfall events tend to change the local morphology and change the ordinary transport.

These phenomena indeed cause deviations from the equilibrium conditions, in terms of total transport, bottom elevation and grainsize composition, which propagate slowly and progressively damped over long distances from their sources down to the lowland course of the river, where they are still responsible for the persisting deviations in the water flow vs sediment transport curve. Difficulty arises especially for the sediment transport curve at instantaneous or even daily scale, while a better assessment of sediment transport is often possible if we consider averaged values over longer periods.

According to Fasolato *et al.*, 2009, these deviations can be reproduced deterministically once the boundary conditions of the system (namely the forcing terms that cause fluctuations in sediment input) are known. Referring to a natural system, however, it is impossible to know in detail all these conditions. Di Silvio *et al.*, 2010, have proposed a general mathematical framework that is able to reproduce these conditions at basin (or sub-basin) scale on the basis of a few available direct measurements of sediments transport and river discharge.

Obviously the model requires a calibration, which will be of course "site-specific" but achievable with a limited amount of observations, even non-systematic.

In the case of small lowland watercourses with relatively uniform (cropland) basin, the transported material is finer and the concentration of sediments does

not have a large temporal variability as in the mountain basins, dominated by the presence of landslides and debris flows. Sporadic exceptional storms, however, can also produce important deviations from equilibrium, also related to the vegetation (crop) development. For both upper-and low-land basins, a statistically significant historical series of measured data are necessary to calibrate the model. We may expect, however, that the propagation times of perturbations in lowland rivers will be generally shorter, as the material is generally finer.

2. Site of study

The direct watershed of the Venice Lagoon is composed by two parts: the first one includes the rivers that are exclusively fed by rainfall, the second one includes also draining rivers fed by resurgence water.

The entire basin is nearly 2040 km^2 and covers about 1/9 of the Veneto region area. The watershed is limited southernly by the Gorzone Channel, westernly by the Colli Euganei and Roncajette Channel, northernly by the Brenta River and the Alps and easternly by the Sile River (Fig. 1).

In our study we analyze the interactions between hydrology and sediment transport in four gauging stations (circled in yellow in the Fig. 2) controlling the following water courses: the Zero River and the Marzenego River, the Serraglio Channel and the Tergolino Channel (Fig. 2).

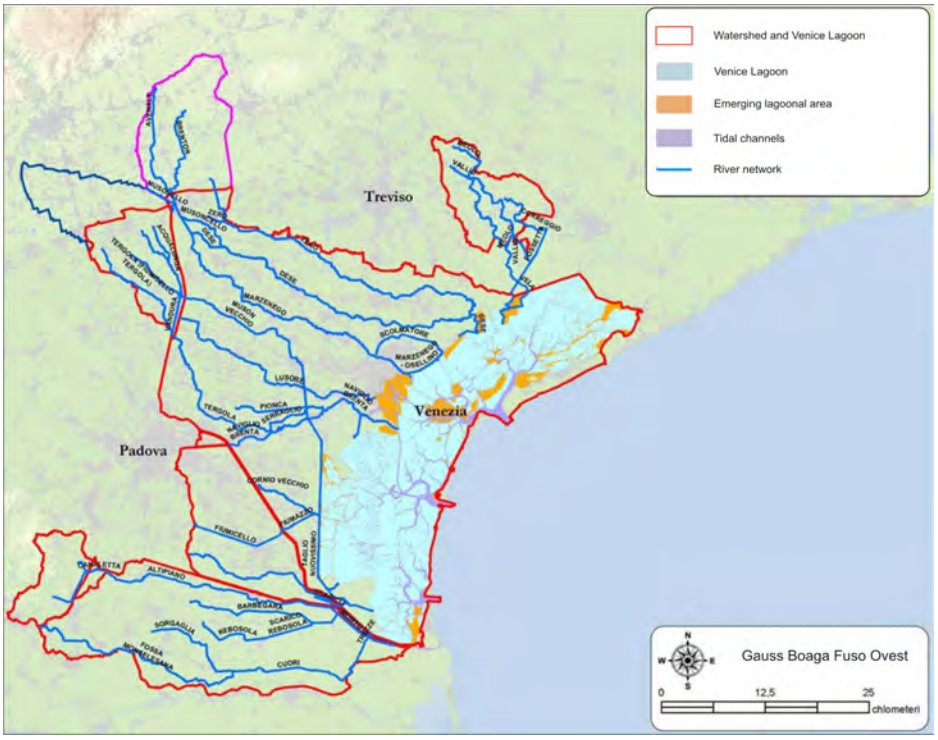

Fig 1. River network of the basin.

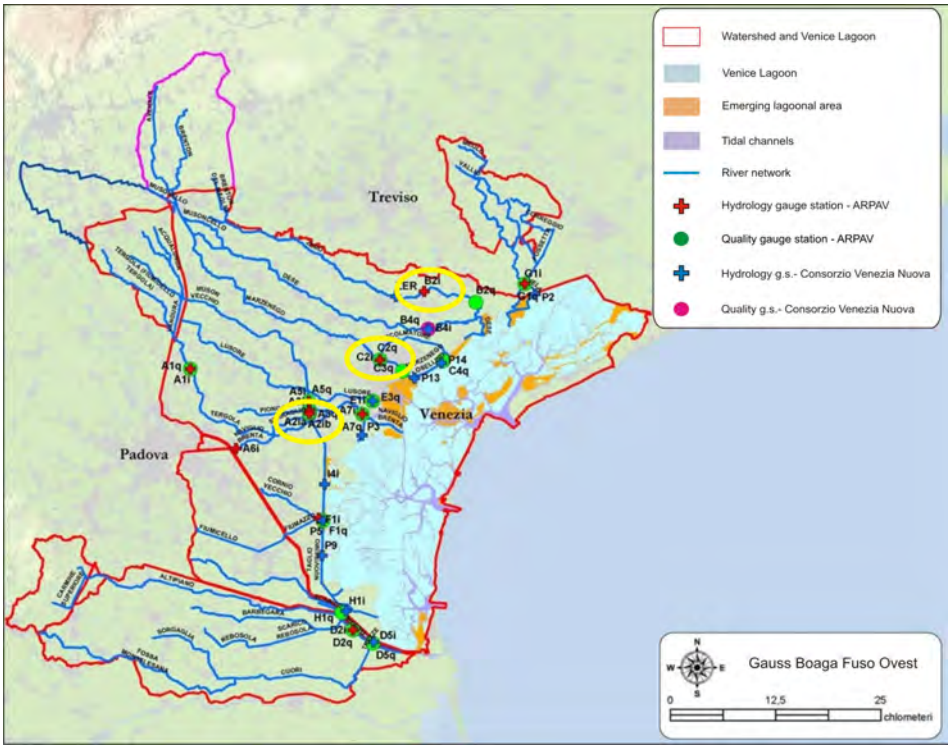

Fig 2. Gauging stations: station A2a on the Serraglio Channel, station A2b on the Tergolino Channel, station B2 on the Zero River and station C2 on the Marzenego River.

2.1 Available data

The four gauging stations are managed by ARPAV (*Agenzia Regionale per la Prevenzione e la Protezione Ambientale del Veneto*, namely the Regional Environmental Agency) and can measure both the hydrology and the quality parameters of the river water. In the next table (Tab. 1) we have summarized the available data for the period from 2006 to 2010.

Water course	*Gauging station*	*Hydrology*		*Quality*		
Serraglio	A2a	water depth	discharge	turbidity	air temperature	rainfall
Tergolino	A2b	water depth	discharge	turbidity	air temperature	rainfall
Zero	B2	water depth		turbidity	air temperature	rainfall
Marzenego	C2	water depth	discharge	turbidity	air temperature	rainfall

Tab1. Available data.

These data are sampled at time intervals of one hour. The discharge is measured along each river, except for the Zero River, where it is not available. For each station we have also some samples of the suspended sediment, that can be daily average or instantaneous.

With the values of the suspended sediment concentration, it is possible to compute a regression relationship between them and the turbidity measured at each gauging stations. If we analyze this relationship, it is possible to check some abnormal behaviours (excessive peaks, sudden falls or rises), maybe due to cleaning or maintenance operations performed by the stations manager.

2.2 Suspended sediment transport

Suspended sediment concentrations (SSC) were obtained from time series of turbidity recorded from automated stations (Table 1). The first step of the conversion procedure was based on a linear regression between the SSC measured in water samples regularly collected at the intake of the automated station and the corresponding instantaneous values of turbidity recorded by the instruments. An example of the regression is presented in Fig 3.

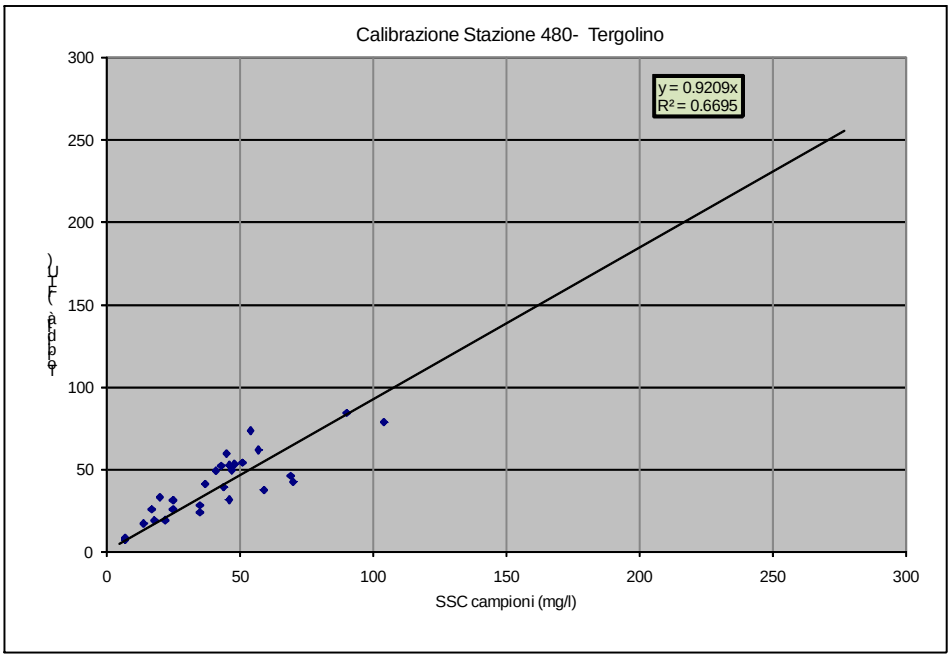

Fig. 3. Example of the linear regression between SSC and turbidity for the automated station on the Tergolino Channel (station A2b).

Data outside the 95% confidence interval were excluded from the initial population of samples and regression was recalculated only considering reliable data. The linear regression relationship was then used to convert time series of turbidity in time series of SSC.

A filtering procedure to remove short term fluctuations and a quality check was then performed on the obtained time series of concentration. The procedure essentially correspond to that used in similar monitoring programs within the Lagoon of Venice and coastal areas. [MAG. ACQUE - CORILA, 2010].

An example of the time series of SSC for the automated station on the Tergolino Channel is given in Figure 4.

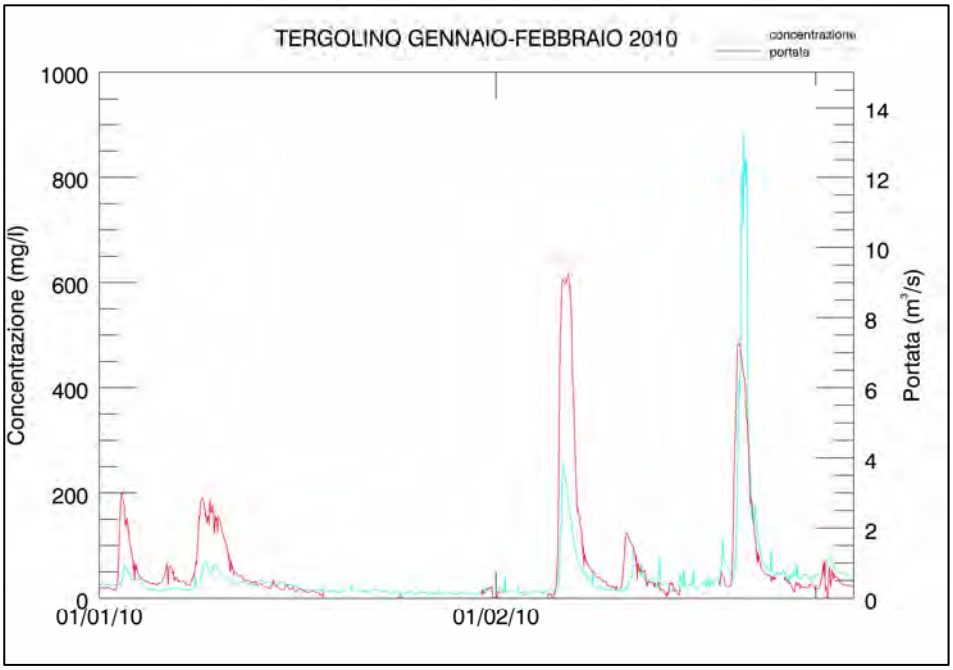

Fig. 4. Time series of the SSC and discharge for the automated station on the Tergolino Channel.

3. Mathematical modeling of the sediment transport

The model proposed here follows a general approach based on the deterministic analytical solution for the "harmonic river" (Fasolato *et al.*, 2009), combined with a recursive model of the ArMa type (Di Silvio *et al.*, 2010) and it is used to predict the deviations of the sediment rating curve from the equilibrium conditions. The recursive empirical model for a certain river (calibrated against a relatively small dataset of regular measurements) will provide the "instantaneous" sediment discharge as a function of the "instantaneous" water flow (equilibrium component) and of the water flow measured at one or more previous time steps (non-equilibrium components).

3.1 1-D hydro-morphodynamic model

The complete 1-D mathematical model (namely the deterministic model) of the evolution of a river is formed by two partial differential equations describing the water flow, plus the following two equations (for each grain size class), respectively describing the sediment exchange between stream and river bottom and the mass balance of sediment in the active layer. In order to obtain an *analytical harmonic solution*, these equations have been linearized around a reference stationary configuration, considering only two representative grain size classes of sediments (Fasolato *et al.*, 2011).

Given the boundary conditions of the system, the harmonic solution is composed of an homogeneous part and a particular solution. The particular

solution is represented by the “equilibrium conditions”, while the homogeneous part can be expressed as the sum of three basic damped harmonic waves. These waves propagate in the downstream direction (waves n. 1 and 2) and in the upstream direction (wave n. 3)

All three morphological waves have celerities many orders of magnitude slower than the water flow. Moreover the first wave is much faster than the other two, so all the perturbations created at the boundaries with respect to the equilibrium conditions propagate relatively slowly, but only the first wave has a relatively long attenuation distance. This means that at a very short distance from the upper end and from the lower end of the reach, we may respectively neglect the second and third wave with respect to the first one.

For a simplified description of the liquid phase, the hypothesis of quasi-uniform flow (LUF hypothesis) (Fasolato *et al.*, 2011) is assumed. This hypothesis is generally accepted when averaging on the cross-section is performed over a sufficiently long reach, which depends on the Froude number.

3.2 Solid Transport Analysis

In order to combine the structure of the ArMa model with some results of the deterministic model (Sec. 3.1), note that the latter considers linearized equations distinguishing between the equilibrium conditions (unique relationship of sediment transport curve vs water flow curve) and the non-equilibrium perturbations (propagating from the river boundary upstream).

We can assume that the relative deviations of the instantaneous sediment transport from the equilibrium can be described by a first-order linear model of ArMa type.

For the deterministic model these deviations are described by the damped wave formed at the center of the basin by two major perturbations of the boundary conditions: the alteration of the amount of sediment transport and the alteration of the grain size composition. Proposing an analytical formulation of these forcing terms, each of them will have a different weight which will be calibrated by recursively solving the ArMa model (Di Silvio *et al.*, 2010). The first disturbance is mainly due to the increased transport of sediments already present in the farthest branches of the hydrographic network. We assumed that it is determined by a corresponding disturbance of the flow transport capacity with respect to the long-term average water discharge.

The second disturbance, instead, is mainly due to the finer grain size composition of the sediment input from the cropland compared to the river bed composition. We assumed that it is essentially determined by storms produced by exceptionally high rainfall intensity, which in their turn correspond to very strong values of the erosivity factor R the U.S.L.E. formula (Wischmeier *et al.*, 1978).

This case study is about short lowland channels with relatively uniform basins: the cross-section is almost constant, the material involved is fine and there is not a mountainous watershed where a massive production of sediment input

with great temporal variance can take place. At most there can be somewhere sporadic landslides of the banks. Moreover these channels are not greatly influenced by the seasonal fluctuations, but they convey almost a constant discharge all over the year. By contrast, in this case an important role is played by the time variation of vegetation cover (namely the crop factor *C* in the U.S.L.E. formula)

Therefore the historical series described in the Sec. 2.1 can be used for the model described in the Sec. 3 that can be applied on daily averaged values.

If the few available daily data and instantaneous samples of sediment transport may be sufficient to apply our model on this case of study, other data are missing: we need in fact at least an estimate of the grain size curve of the bed material.

Conclusions

The model has been already tested and applied to some large rivers, as the Adige River (Di Silvio *et al.*, 2010; Nones *et al.*, 2010) and the Po River.

The aim of this paper is evaluating the applicability of the model to the case of small rivers in small, flat (cropland) watershed, characterized by different processes of formation and transport of the fluvial sediments.

At this moment, the lack of some data (mainly the grain size of the bottom river and some occasional measurements of sediment transport) can not allow the direct application of the model.

On the other hand, it is possible to make some qualitative considerations: i) the most important phenomena are due to extreme hydrological events (namely for large values of the erosivity factor *R*), combined with thin and sparse vegetation (namely for large values of the crop factor *C*); ii) this pattern creates the transport of fine sediment, characterized by a very large adaptation length and able to be carried by the river with a faster response than for the coarser sediment coming from mountainous watersheds.

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GEOSPECIATION IN THE SEDIMENTS OF THE VENICE LAGOON

Fabiana Corami, Warren R. L. Cairns, Chiara Rigo

Istituto per la Dinamica dei Processi Ambientali, CNR-IDPA, Venezia

Riassunto

Nell'ambito del progetto "Linea 6 Biodisponibilità e Biotossicità dei Contaminanti Lagunari ed Evoluzione della Normativa" è stata studiata la geospeciazione (o geofrazionamento) di elementi in tracce nei sedimenti di due siti della Laguna di Venezia: San Giuliano – Campalto e Sacca Sessola. Nei sedimenti dei medesimi siti sono stati studiati sia il TC (carbonio totale) sia il TOC (carbonio organico totale). Nei sedimenti di San Giuliano – Campalto e di Sacca Sessola la concentrazione totale degli elementi in traccia analizzati presenta valori confrontabili per Cu e Pb, ma molto diversi per Zn. Tali diversità possono essere correlate al trend della piovosità e della portata dei corsi d'acqua. La distribuzione degli elementi in traccia analizzati nelle diverse fasi del geofrazionamento varia in relazione all'elemento considerato e al sito studiato. Per entrambi i siti e per tutti gli elementi in traccia studiati sono stati calcolati l'Indice di Geoaccumulo (Geoaccumulation index, Igeo), il fattore di concentrazione (Concentration Factor, CF) e l'Indice di Carico Inquinante (Pollution Load Index, PLI). La qualità delle acque è grandemente influenzata dalla qualità dei sedimenti. Dai dati emersi nello studio della geospeciazione e considerato l'Igeo degli elementi studiati, si evince che elementi in tracce quali il Cd ed il Hg rappresentino un rischio per il biota.

Abstract

Geospeciation (geofractionation) of trace elements has been studied in the sediments of two site of the Venice Lagoon: Sacca Sessola and San Giuliano – Campalto. TC and TOC in the sediments of the very same sites have been assessed. In the sediments of San Giuliano – Campalto and Sacca Sessola the total concentrations of trace elements assayed showed similar values for Cu and Pb and very different values for Zn. This dissimilarity may be related to the rain fall regime and to the rivers flow. The distribution of trace elements assayed in the different phases of the geofractionation varied according to the trace element studied and to the site investigated. In both the sites and for all the trace elements studied geoaccumulation index (Igeo), concentration factor (CF) and Pollution Load Index (PLI) have been evaluated. Water quality is largely affected by the sediments quality. From data come out in the geofractionation study, considered the Igeo of the trace elements studied as well, a risk for biota by trace elements such as Cd and Hg was inferred.

1. Introduction

Programming an accurate environmental management goes hand in hand with a considered and specific legislation, which has to contain a thorough and rigorous environmental risk assessment. Thus, methodologies to trace guide lines, which have to be conveniently applied in the environmental risk assessment and in the environmental quality, are of prime importance. These studies may not be only technical or legal, but they have to necessarily merge with the most up to date scientific knowledge.

The Venice Lagoon, a many sided environment and a natural laboratory as well, needs new control tools, able to evaluate the environmental quality and to follow its evolution. In the Venice Lagoon diverse studies have been carried out and some are still under way. Among these it is worth remembering: Mappatura dell'inquinamento dei fondali lagunari (MAG.ACQUE - SGS-SELC, 1999); Progetto 2023 (MAG.ACQUE, 2001); MELa1 (MAG.ACQUE - Thetis, 2004); MELa2 (MAG.ACQUE - SELC, 2005); MELa3 (MAG.ACQUE - SELC, 2006; MAG.ACQUE - OGS, UNIVE, 2006); ICSEL (MAG.ACQUE – CNR-ICIS, 2005; MAG.ACQUE – Thetis, 2006); DPSIR (MAG.ACQUE – Thetis, 2006); SIOSED (MAG.ACQUE – Thetis, 2007). This research project develops within this context.

According to the Gantt chart, six sampling campaigns have been carried out in Sacca Sessola and San Giuliano – Campalto bi-monthly during 2009-2010. Sediments were sampled in each campaign at each study site. During each campaign pH, Redox, Dissolved Oxygen, Temperature, Conductivity, etc. were recorded as well. All the sediments aliquots were then preserved at -20°C before being analyzed.

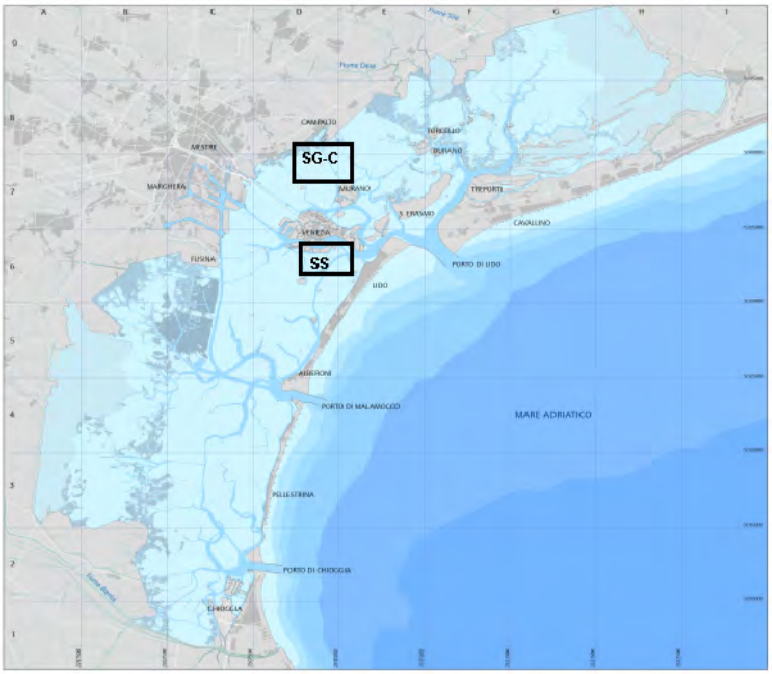

Fig. 1. The sampling sites: Sacca Sessola (SS) and San Giuliano – Campalto (SG-C).

Cleaning of vials and vessels for preserving, pretreatment and/or analyzing samples were done in order to minimize any contamination (in clean room class 100, by using Suprapur grade reagents). Aliquot parts of sediments from the two studied sites were analyzed to determine the total concentration of trace elements, such as cadmium (Cd), copper (Cu), mercury (Hg), lead (Pb) and zinc (Zn). On other aliquot parts of the very same sediments geospeciation (geofractionation) was studied by a sequential extraction procedure (SEP, Tessier's procedure (Tessier *et al*., 1979) modified and optimized at the labs of CNR-IDPA, Venezia).

2. Sequential extraction procedure (SEP) to study geospeciation in sediments of the Venice Lagoon

The sequential extraction procedure (SEP) applied to study the geospeciation or geofractionation in the sediments, sampled in the campaigns of this project, is a modification and an optimization of the Tessier's SEP; it was modified and optimized by the research group at CNR-IDPA within a previous project (Corami *et al*. 2009 a, b, c, d)

In literature, in numerous studies of geospeciation sediments were assessed by different sequential extraction procedures. The most used SEP was the Tessier's scheme (Tessier *et al*., 1979), by which five different fractions are distinguished:

- I fraction – readily exchangeable;
- II fraction – bound to carbonates;
- III fraction – bound to oxides/hydroxides of iron and manganese;
- IV fraction – bound to organic matter and sulfides;
- V fraction - residual, relative to the crystal lattice.

In particular, in several sites of the Venice Lagoon geospeciation in sediments was studied by Argese (Argese et al., 2001), according to a slightly modified Tessier's SEP (fig. 2). The first fraction, that is the readily exchangeable fraction, which usually represents a very low percentage of the total concentration, is immediately available or bio-accessible to organisms. In literature, I fraction and II fraction are often defined as *labile* fraction, since the fraction bound to carbonates may be solubilized by the gastric acid. As reported by Tessier (Tessier *et al*. 1979, 1987, 1988), benthic organisms may accindentaly or intentionally swallow particulate matter present in the sediments. Thus, in their digestive guts the fraction bound to carbonate, and to a lesser extent other fractions such as that bound to organic matter, may be dissolved, then trace elements may be available for the biota and they may consequently go back in the trophic web. Turner, in a recent study (Turner *et al*. 2006) highlighted the importance of re-mobilization of some trace elements in the sediments at the hands of digestive enzymes, which are present in the guts

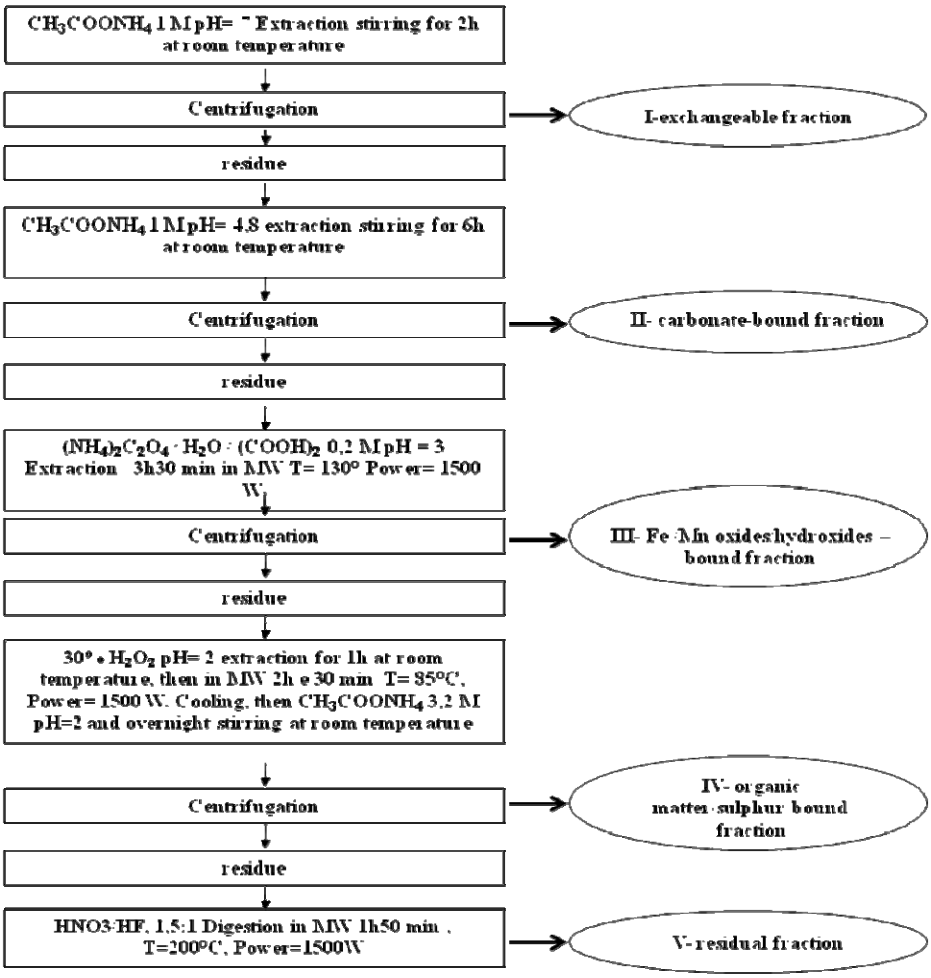

Fig. 2. Tessier's SEP scheme (Argese et al. 2001)

of benthic organisms. In fact, some amino acidic residues, able to complex trace elements, may efficiently compete for the binding sites of the fraction bound to carbonate and, to a lesser extent, for the binding sites of the fraction bound to oxides/hydroxides of iron and manganese. Thus, a re-mobilization of trace elements may occur.

However, the conclusions by Tessier supported the hypothesis that water is the vector in trace elements' uptake by benthic organisms. Therefore, not only was the content of trace elements in the sediments important, but the content of trace elements in the pore water and in the water column were important as well.

In several species of filter feeder benthic mollusks, high concentration of trace elements were observed in gills and in mantles, organs that have a wide surface and are exposed to a great water flow. These organs in the mollusk represent a wide portion of the body.

The percentage of the third fraction is often high, since trace elements may easily form complexes with iron and manganese (via co precipitation, oxides and hydroxides). These complexes may be released in the environment in

strong anoxic conditions. In the channels and in the rii of Venice Lagoon, due to the organic load and to the intense degradative microbial activity, anoxic conditions may be present in the water very close to the surface sediments. In these conditions it might happen that trace elements may be released from the third fraction and may be complexed in unavailable forms for biota, due to the presence of sulfides (because of the intense activity of sulfur reducing bacteria) and to the high amount of organic matter.

Furthermore, a relevant percentage (generally around 30% or higher) of trace elements may be found in the fifth fraction; thus the release from this fraction is unlikely to happen. Few elements, such as Cu, Hg or Zn show the highest percentage in the fourth fraction, bound to the sulfides and the organic matter. The release of these elements from the fourth fraction may happen in more oxidative environmental conditions.

It is important to highlight that in the surface sediments bioturbation and wave motion, due to the heavy nautical traffic and the fishing, may promote sediments resuspension and then a release of trace elements in the water column.

Samples of sediments collected were divided in aliquot parts by quartering. On some of them SEP (Tessier SEP modified and optimized, Corami *et al*. RISED project) was applied to study geospeciation, while some other aliquot parts were acid digested via microwave (Ethos, Milestone) to assess the total concentration of trace elements. Trace elements concentrations in all the aliquot parts were assessed by an ICP-MS Quadrupole (collision cell technology, with shield plate (Agilent).

Results and Discussion

Geospeciation by SEP and total concentration of trace elements such as Cd, Cu, Hg, Pb and Zn were studied in the sediments collected in the period May 2009 – March 2010. For each sample of the sediments collected at least 3 aliquot parts were analyzed. The results of total concentration and the five fractions of geospeciation are expressed as mg/kg (wet weight). In a previous study of geospeciation in the sediments of the Venice Lagoon (Tessier SEP modified and optimized, Corami *et al*. RISED project), where total concentrations of trace elements were assessed as well, the results of wet weight were reported to dry weight by means of the relative humidity; these results were perfectly comparable to the results of dry weight (within the error expressed as RSD%, percentage relative deviation standard). In this study we proceeded in the same way.

Every single aliquot part was analyzed four times by ICP-MS. The precision of measurement was ≤ 5% (RSD %). The data of total concentration and of the five fractions of the geospeciation showed a RSD% ≤ 10%.

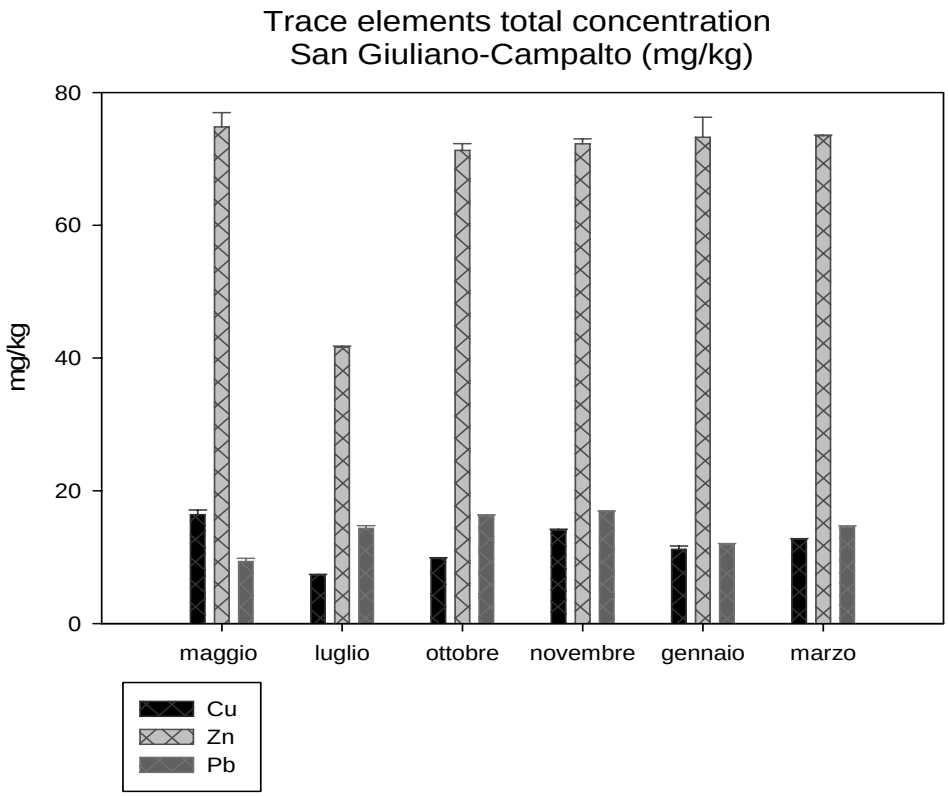

Fig. 3. Trace elements total concentration – San Giuliano Campalto (2009-2010).

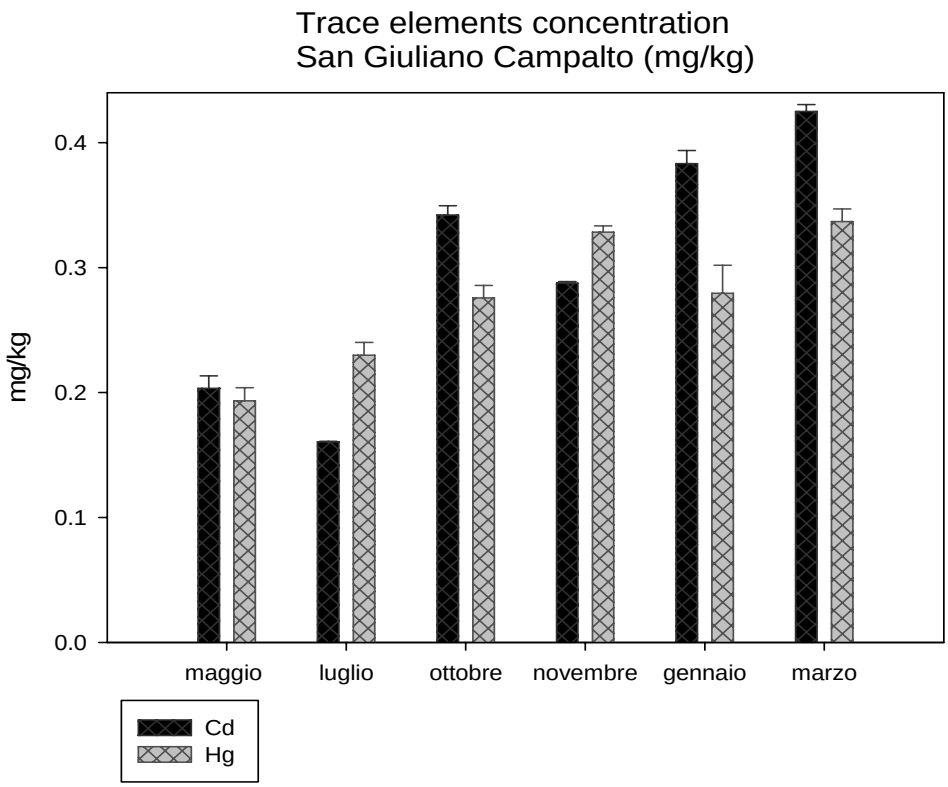

Fig. 4. Trace elements total concentration – San Giuliano Campalto (2009-2010).

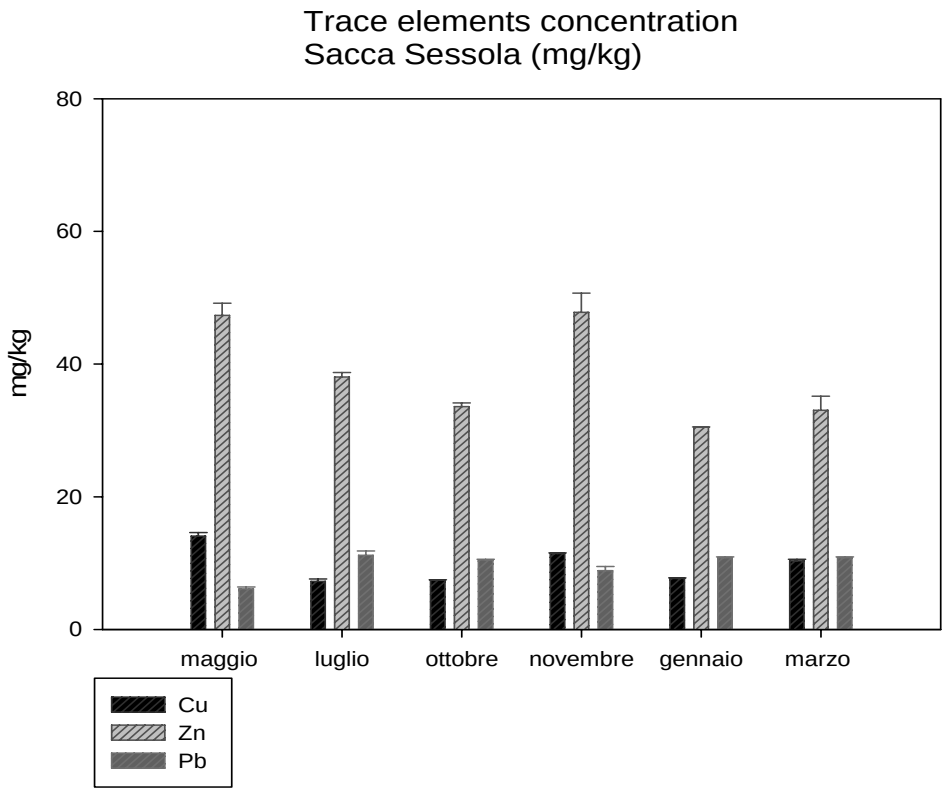

Fig. 5. Trace elements total concentration – Sacca Sessola (2009-2010).

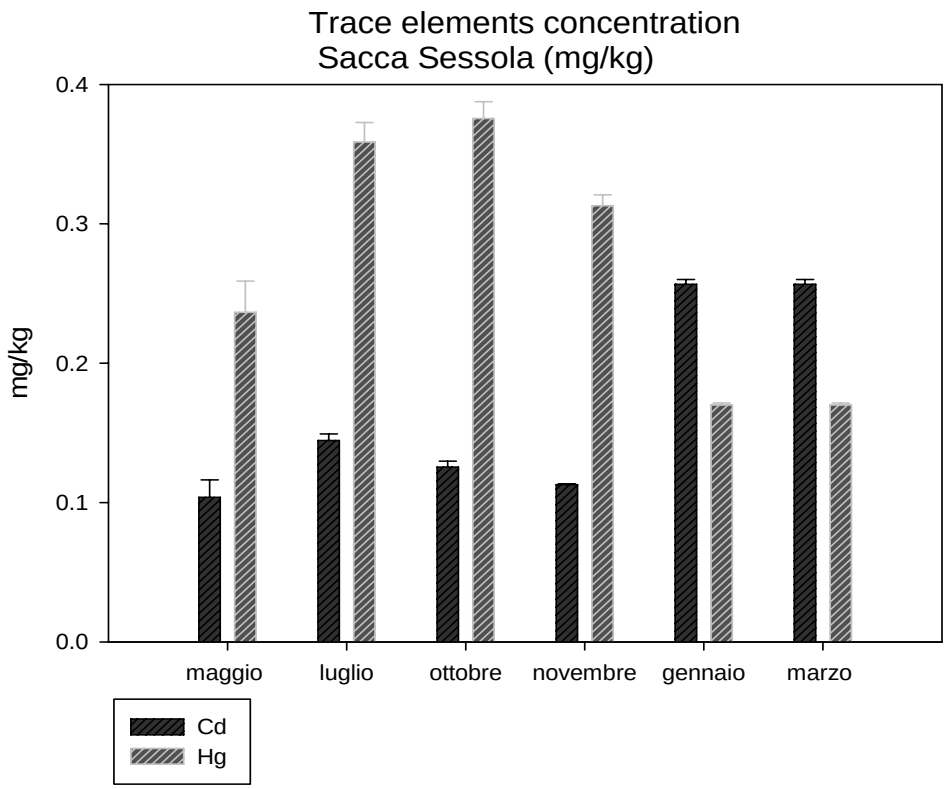

Fig. 6 Trace elements total concentration – Sacca Sessola (2009-2010).

For some trace elements in some of the fractions analyzed the instrumental signal of the sample was ≤ LOQ (the instrumental signal of the procedural blank ± 10 times the standard deviation of the procedural blank).

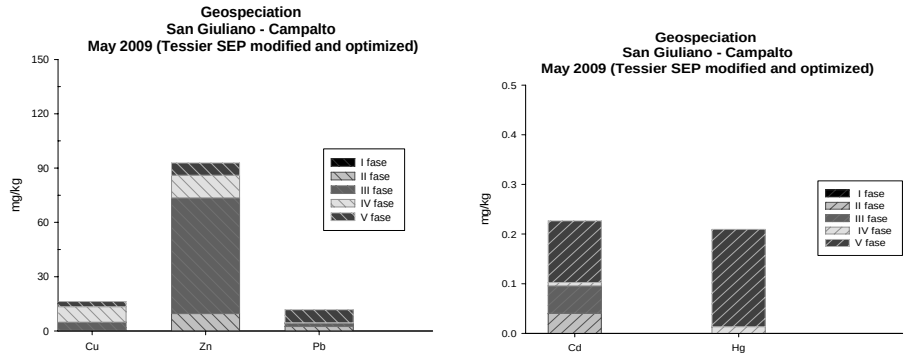

Fig. 7. Geospeciation May 2009 San Giuliano Campalto.

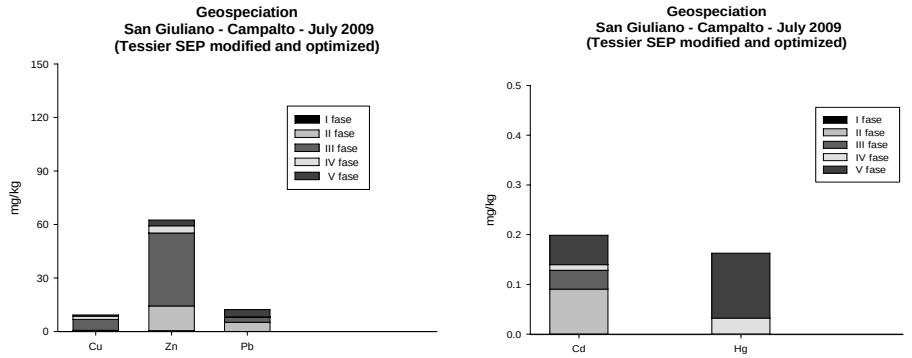

Fig. 8. Geospeciation July 2009 San Giuliano Campalto.

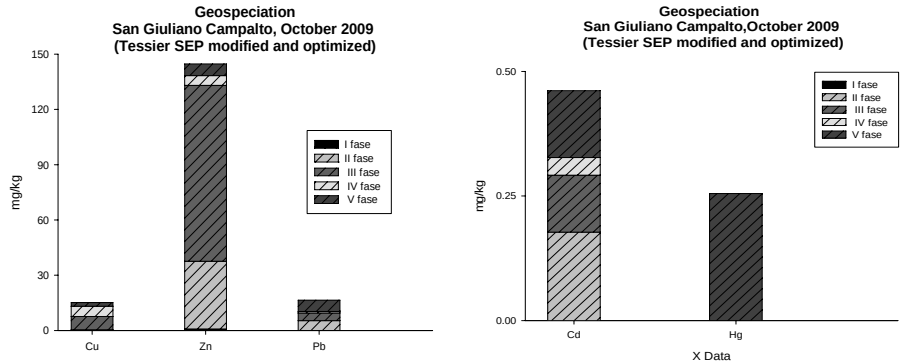

Fig. 9. Geospeciation October 2009 San Giuliano Campalto.

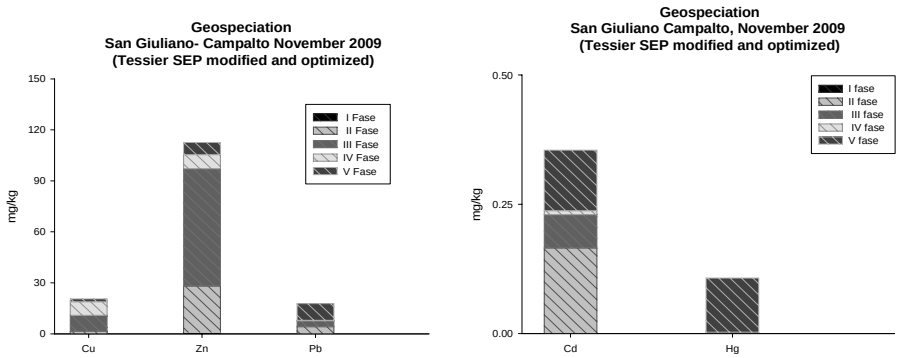

Fig. 10. Geospeciation November 2009 San Giuliano Campalto.

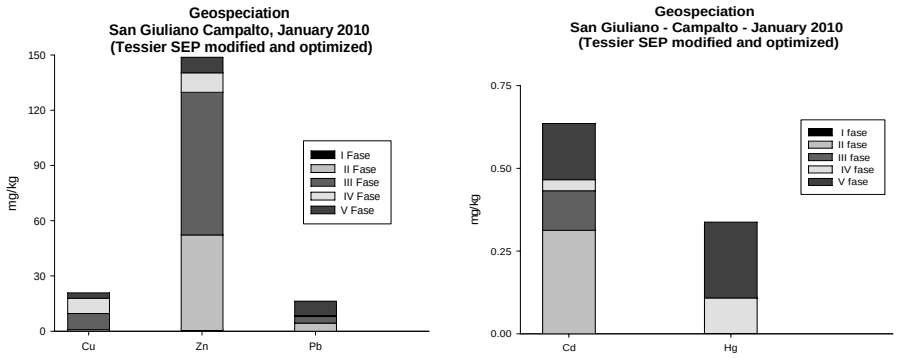

Fig. 11. Geospeciation January 2010 San Giuliano Campalto.

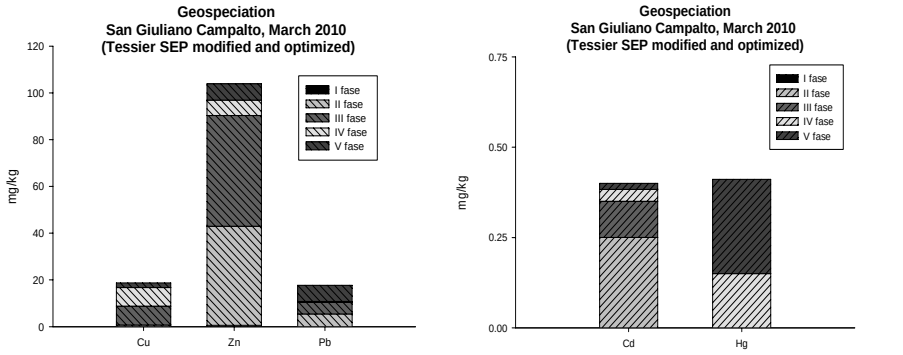

Fig. 12. Geospeciation March 2010 San Giuliano Campalto.

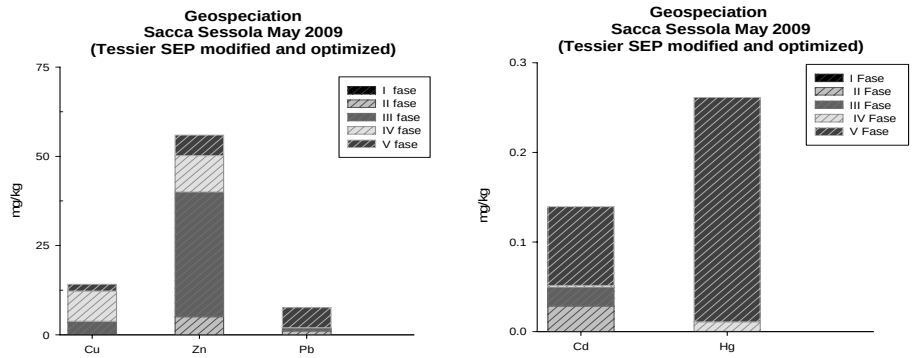

Fig. 13. Geospeciation May 2009 Sacca Sessola.

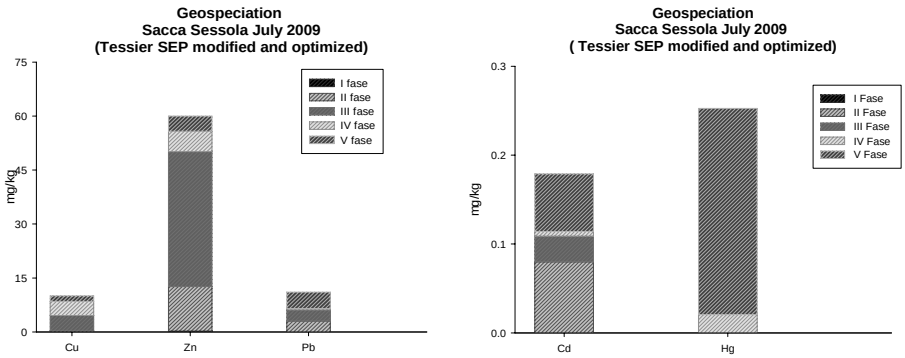

Fig. 14. Geospeciation July 2009 Sacca Sessola.

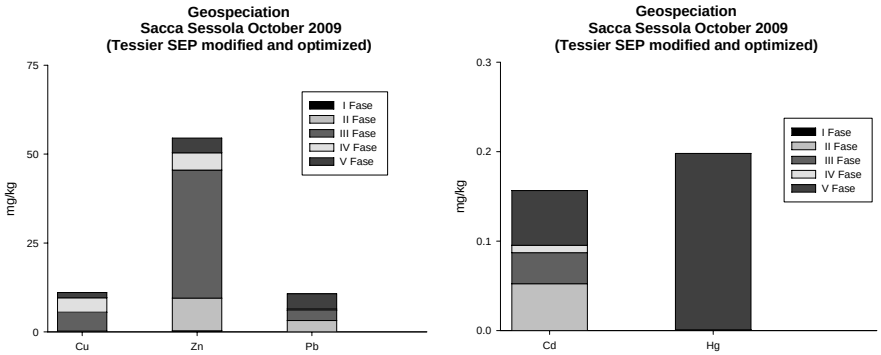

Fig. 15. Geospeciation October 2009 Sacca Sessola.

Differences between the two sites studied were observed. In the geospeciation study, according to the five fractions obtained, diverse trace elements showed different trends.

The total concentration of Zn in the surface sediments of San Giuliano – Campalto is 40% higher than the total concentration observed in the surface sediments of Sacca Sessola. Furthermore, in the surface sediments of San Giuliano – Campalto the total concentration of Zn was almost even, except for the concentration observed in July 2009. In the surface sediments of Sacca Sessola, on the contrary, the trend of the total concentration of Zn was decreasing, from the summer season to the winter season, although the maximum value observed was in November 2009.

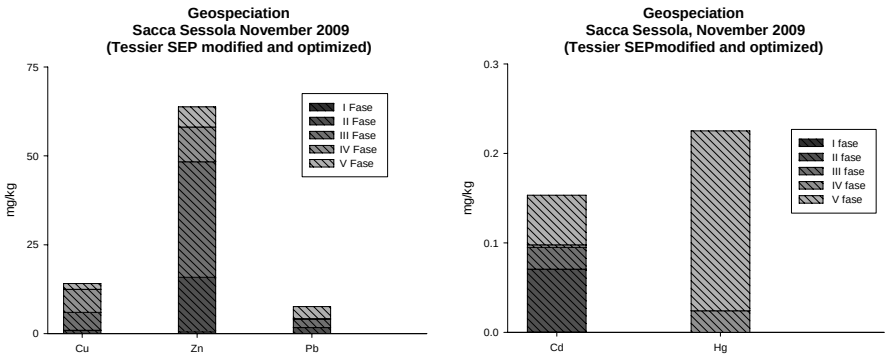

Fig. 16. Geospeciation November 2009 Sacca Sessola.

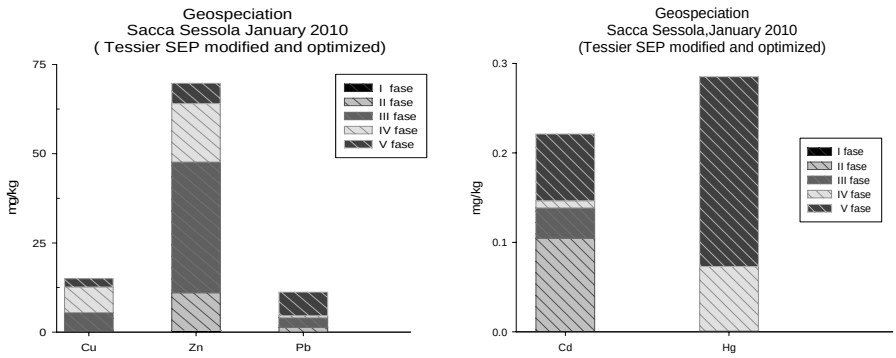

Fig. 17. Geospeciation January 2010 Sacca Sessola.

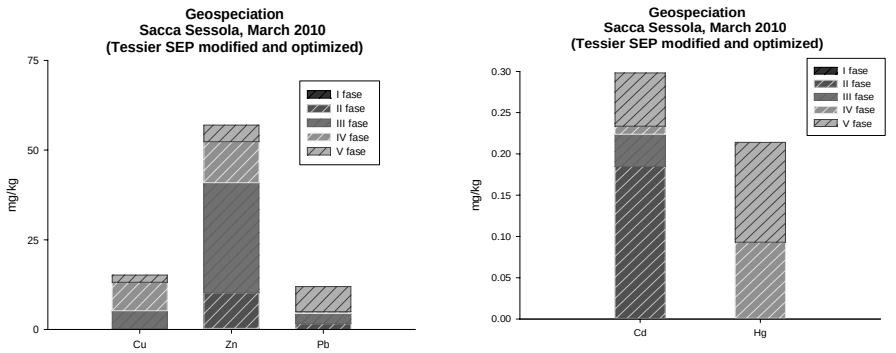

Fig. 18. Geospeciation March 2010 Sacca Sessola.

In the sediments of transitional environments a correlation between maximum values of total concentration of trace elements, such as Zn, and rainy seasons was observed (Essien *et al*., 2009). Thus, the total concentration of Zn was higher in rainy months, with an increase of rivers flow, than in dry months, with a decrease of rivers flow. In Veneto, the rivers flows were rising in the late spring (May 2009), due to the thawing of snow deposits and in relation with the rainfalls in the previous months, as well (data 2009 Arpav, *http://www.arpa.veneto.it/bollettini/htm/risorsa_idrica.asp*), and they started decreasing during the last decade of June; this decreasing trend was partially slowed in July 2009. In the following months a partial inversion of the trend was observed with leopard spots phenomena, that is an alternation of heavy rainfalls and dry periods within the very same month.

The trend of raininess and of the rivers flow might affect the trend of total concentration of Zn in San Giuliano – Campalto more than in Sacca Sessola, since the first site may be more influenced by the catchment area than Sacca Sessola.

Variations in the concentrations of the five fractions obtained by SEP were observed as the seasons changed. Even though the concentration of the first fraction, which is the readily exchangeable one, was always very low, changes in the concentrations of the fraction bound to carbonates and of the fraction bound to sulfides and organic matter were observed; the concentrations of these fractions seemed to increase during the cold seasons.

Probably the different velocities of the metabolic activities affected the trends of the five fractions. The fraction bound to carbonates, together with the readily exchangeable fractions, is defined as labile fraction, since trace elements may be accessible to biota when arriving in the guts (acidic environment). Thus, due to the coming of the new summer season and to the increase of the metabolic activities by in-fauna and bacteria, trace elements might be metabolized.

The geospeciation of Pb highlighted that this element was not present in the first fraction (readily exchangeable) and in the fraction bound to sulfides and organic matter in both the sites studied. As the seasons changed, the concentration of the second fraction (bound to carbonates) changed and then Pb may be accessible to biota. The total concentrations of Pb in both the sites studied were of the same order of magnitude.

The total concentrations of Cu in the two sites studied were similar. In the geospeciation, especially the fourth fraction (bound to sulfides and organic matter) changed as the seasons changed. The so called labile fraction (I and II fraction) was scarcely present.

In both the sites studied, the total concentrations of Cd were comparable and showed an increase in the winter season. From the geospeciation study it could infer that the fractions which this element was mostly bound were the second one (bound to carbonates) and the residual fraction. In particular in San Giuliano – Campalto the fraction bound to carbonates, which may make Cd accessible once in the guts of biota, showed a decrease during the summer season, probably due to the metabolic activities of the organisms inside the sediments (in-fauna, benthos and bacteria); this fraction showed an increase during the winter season, when the metabolic activities slowed down. A similar trend was observed in Sacca Sessola, as well.

Even though Cd did not show high affinity for the fourth fraction (bound to sulfides and organic matter), in the winter months this fraction showed an increase, probably due to the degradation of the algal and phytoplanktonic biomass, which was present during the summer season in large amount.

The total concentrations of Hg were similar in both the sites studied and the trend showed an increase in the cold season (January 2010 in San Giuliano – Campalto October 2009 in Sacca Sessola). The value of October 2009 in Sacca Sessola might be influenced by disturbing events in that area. The geospeciation study highlighted that Hg showed high affinity only with the fourth fraction (bound to sulfides and organic matter) and with the residual fraction (the fifth fraction). As observed for Cd, in both the sites studied an increase in the fourth fraction was observed during the winter season. The microbial degradation of the biomass, which was stored during the summer season (even at the end of summer when the latest blooms occur), might affect the geofractionation of Hg.

On the basis of Protocollo Fanghi (aka Protocollo Venezia), in relation with the total concentrations of the trace elements analyzed, the surface sediments of the two sites studied may be classified as type A.

For both the sites studied the Geoaccumulation Index (Igeo), the Concentration Factor (CF) and the Pollution Load Index (PLI) were evaluated.

The first definition of Igeo was from Müller (1979). This index allows evaluating the contamination of sediments by comparing the current total concentration of a trace element and its pre-industrial levels (Loska K. et al., 1997, Rubio et al., 2000, JI Yaqin et al. 2008, Praveena S. et al. 2008, 2007, Essien et al. 2009, Nobi et al. 2010), although reaching the pre-industrial sedimentary layers may be rather difficult. Furthermore, this index is used to comprehend the litogenic effects.

$$Igeo = \log_2 C_n/1.5\ B_n$$

C_n is the total concentration measured and B_n is the background concentration 1.5 is a matrix factor of correction for litogenic effects. Rubio and coworkers (2000) strongly advise to consider the regional concentrations as B_n, while in diverse studies the background concentrations used were the crustal concentrations as showed by Turekian and Wedepohl (1961) (Loska K. et al., 1997, Praveena S. et al. 2008, 2007, Essien et al. 2009, Nobi et al. 2010). In this study the crustal concentrations by Wedepohl (1995) were used as background concentrations. According to Müller (1979) six different classes of Igeo correspond to six different degrees of pollution/contamination.

In San Giuliano – Campalto the Igeo for Zn, Cu and Pb was of class 1; this indicated that these elements are not a source of contamination/pollution in the environment. On the contrary, the Igeo for Cd was of class 2, a state of moderate pollution/contamination.

The Igeo of Hg was always of class 3, from moderately polluted to polluted. In Sacca Sessola the Igeo for Zn, Cu and Pb was of class 0 (background values). The Igeo of Cd was of class 2 in the late winter –early spring, in agreement with the highest values of the total concentration observed. The Igeo of Hg in Sacca Sessola was similar to that observed in San Giuliano – Campalto.

The concentration factor (CF, Hakanson 1980) allows evaluating the environmental pollution caused by a single pollutant.

$$CF= C_{metal}/C_{background\ value}$$

C_{metal} is the concentration of the trace element measured in the sample, while $C_{background\ value}$ is the background concentration of the same trace element. If CF is <1 the trace element does not show an enrichment and the sediments are not polluted. On the contrary, if the CF is >1, the trace element shows an enrichment and is a potential pollutant for the environment.

The CF trend for the trace elements studied in San Giuliano – Campalto and in Sacca Sessola was quite in agreement with the Igeo trend observed in both the two sites studied. In the first site, both Zn and Cu showed a CF >1 and the Igeo

for these two elements was in class 1 (not polluted sediments); then the enrichment observed may be natural.

The values of CF for Cd and Hg in San Giuliano – Campalto and in Sacca Sessola, together with the Igeo for these trace elements, showed that these elements were pollutants and posed a risk for the health of the environment.

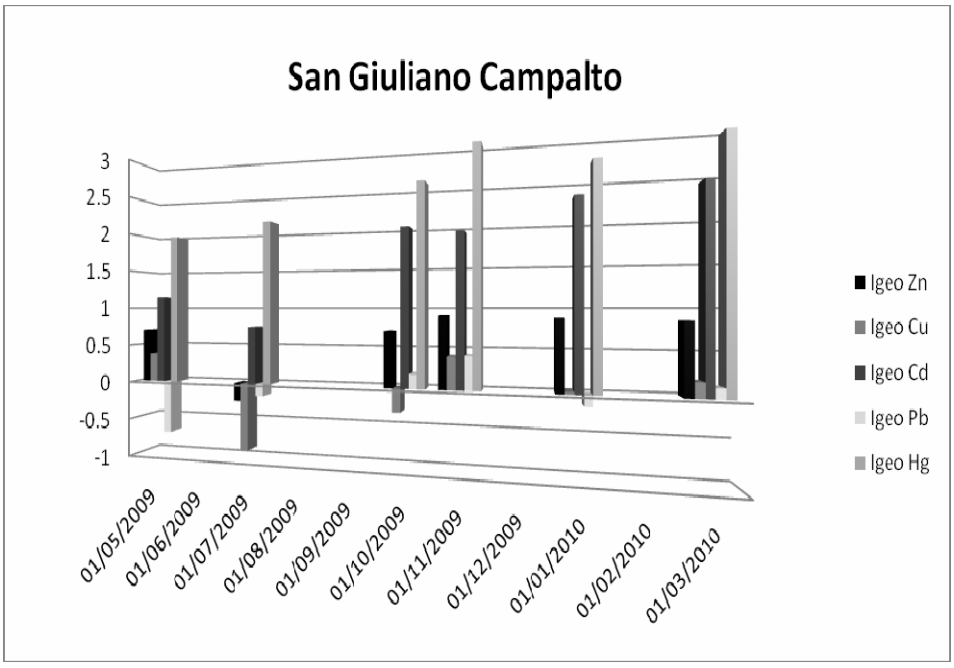

Fig. 19. Igeo San Giuliano Campalto.

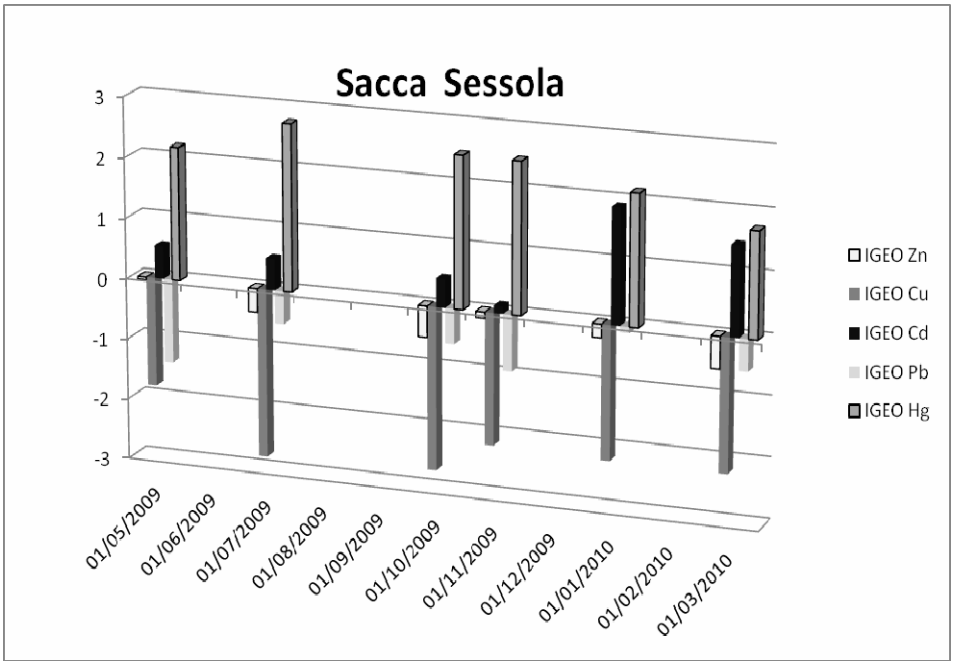

Fig. 20. Igeo Sacca Sessola.

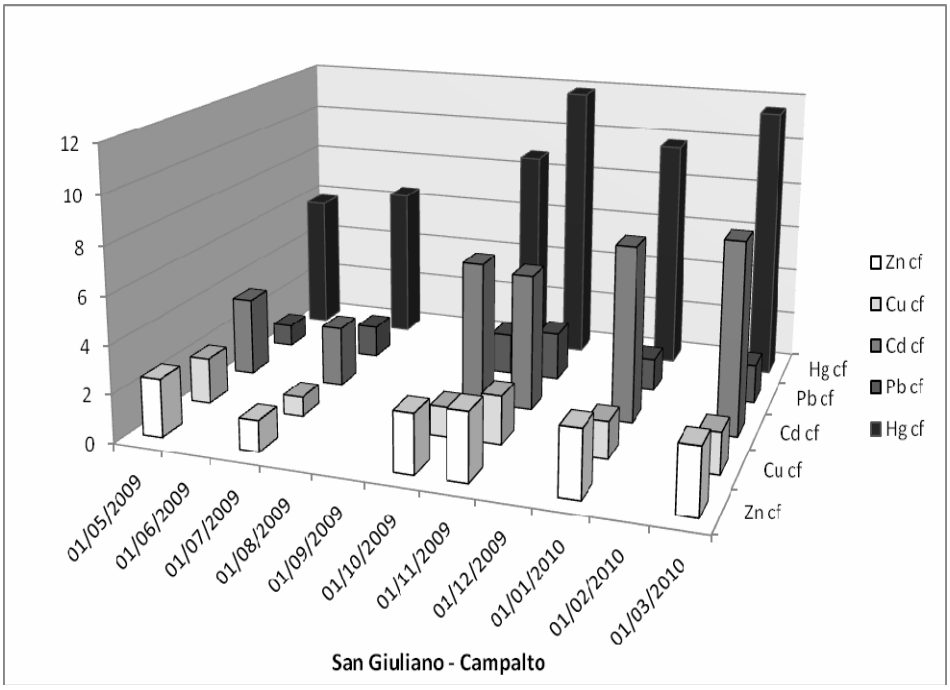

Fig. 21. CF San Giuliano Campalto

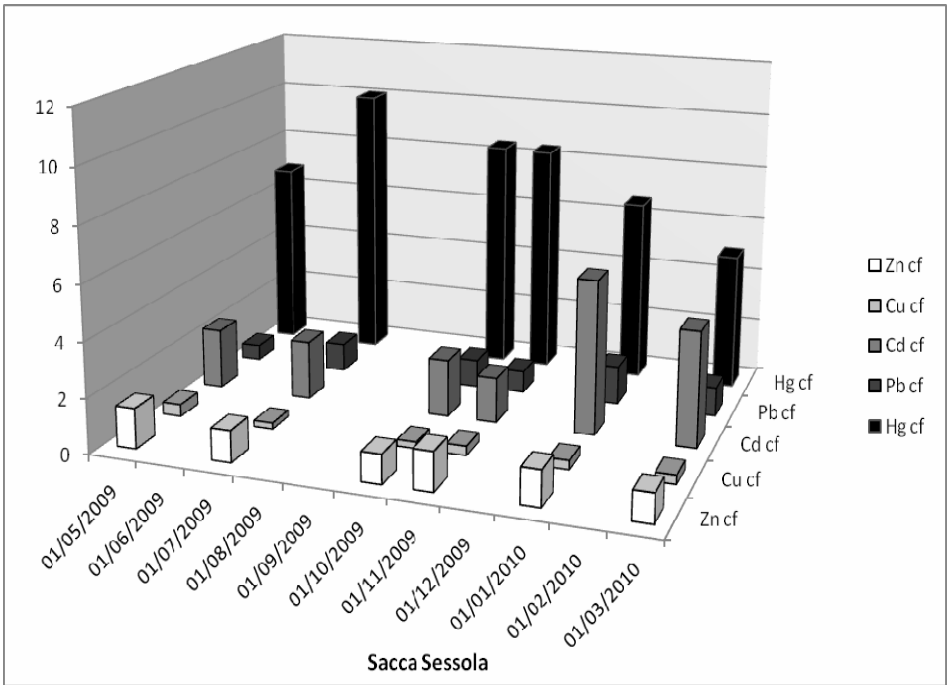

Fig. 22. CF Sacca Sessola

The Pollution Load Index (PLI) was developed by Tomlinson (1980) and allows evaluating the environmental contamination by trace elements.

$$PLI = \sqrt[n]{CF_1 * CF_2 * CF_3 * \ldots * CF_n}$$

CF is the concentration factor and the index “n” is the number of trace elements considered.

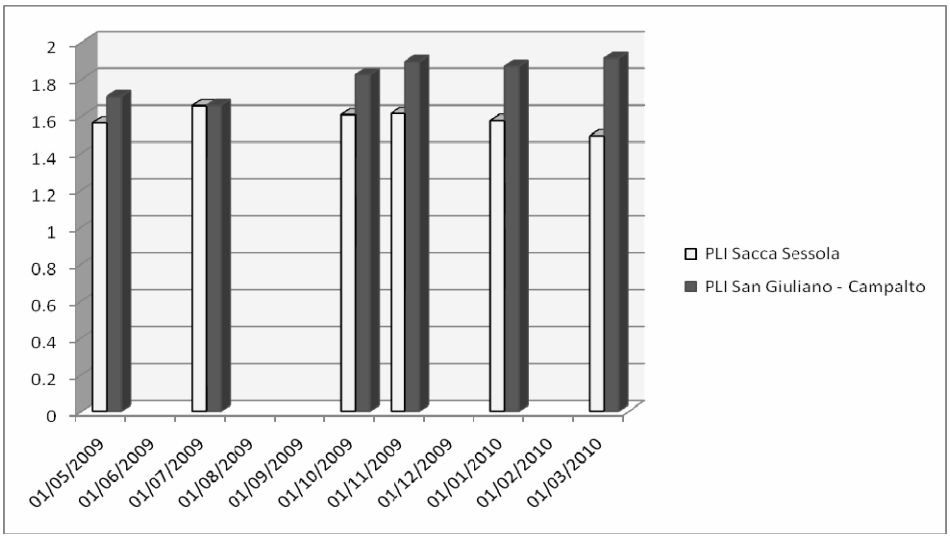

Fig. 23. Pollution Load Index in the two sites studied

It is important to underline that PLI (Praveena 2007) is affected by the number of trace elements analyzed, but it allows comparing levels of pollution, which were estimated in different times and different places, provided that the same number of trace elements was studied.

According to the PLI both the sites studied were moderately polluted, even though the PLI in the first site is higher than in Sacca Sessola. If only this index was considered, in the two sites studied trace metals might not pose a risk for the environment. This was not in good agreement with the trends of CF and Igeo observed in the two sites.

Conclusions

In the sediments of San Giuliano Campalto and Sacca Sessola the values of total concentration of Cu and Pb were comparable, but the values of total concentration of Zn were not. These differences may be related to trend of raininess and of rivers flow.

The distribution of trace elements analyzed in the five fractions of geospeciation varied in relation with the trace element considered and of the site studied. Futhermore, seasonal variations were observed.

On the basis of Protocollo Fanghi (aka Protocollo Venezia) and according to the total concentrations of the trace elements analyzed, the surface sediments of the two sites studied may be classified as type A. For both the sites studied the Geoaccumulation Index (Igeo), the Concentration Factor (CF) and the Pollution Load Index (PLI) were evaluated. According to the Igeo and the CF, Cd and Hg were pollutants and posed a risk for the health of the environment. This was not in agreement with the PLI. This index tends to mediate and thus some risks

may be underestimated, such as the risk posed by Cd and Hg in the two sites studied. Therefore evaluating and comparing all the indices of environmental quality of sediments is fundamental.

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BEHAVIOURAL AND PHYSIOLOGICAL EFFECTS OF TEMPERATURE INCREASE ON EUROPEAN SEA BASS (*Dicentratchus labrax L.)* AND GILTHEAD SEABREAM (*Sparus aurata L.*)

Carla Cioni[1], Stefano Malavasi[2], Arianna Manciocco [3], Mattia Toni[1], Donatella Crosetti[4], Giacomo Cipolato[2], Vyron Georgalas [2], Amanda Tedesco[5], Enrico Alleva[5]

[1] *Dipartimento di Biologia e Biotecnologia "Charles Darwin", Università La Sapienza, Roma*
[2] *Dipartimento di Scienze Ambientali, Informatica e Statistica, Università Ca' Foscari Venezia*
[3] *Dipartimento Progettazione Molecolare, Consiglio Nazionale delle Ricerche, Roma*
[4] *Istituto Superiore per la Protezione e la Ricerca Ambientale;*
[5] *Sezione di Neuroscienze Comportamentali, Dipartimento di Biologia Cellulare e Neuroscienze, Istituto Superiore di Sanità, Roma*

Riassunto

Nell'ambito del progetto "Analisi neurochimica e comportamentale degli effetti del cambiamento climatico e conseguente aumento della temperatura sull'attività del sistema nervoso centrale nelle specie ittiche di interesse alieutica quali spigola *(Dicentratchus labrax*) e orata (*Sparus aurata*)", sono stati svolti esperimenti condotti in condizioni di laboratorio controllate su esemplari giovanili e post-larvali di spigola. In questo lavoro vengono presentati alcuni dei risultati finora ottenti riguardanti l'attività di nuoto, il comportamento affiliativo e quello alimentare. Vengono inoltre riportati i risultati di esperimenti di western blot e di immunofluorescenza effettuati per indagare l'effetto della temperatura sui sistemi colinergici e nitrergici di esemplari giovanili.

L'attività di nuoto e il comportamento affiliativo sono stati studiati in giovanili (10-15 cm di lunghezza standard) esposti per un periodo di 21 giorni a due differenti temperature (18 °C e 22 °C) quando posti in presenza di prede (*Chironomus salinarius)*, di uno stimolo olfattivo e di uno avverso. Inoltre, gli effetti della temperatura (tre trattamenti a 19, 22, e 26 °C) e della densità di prede (nauplii di *Artemia*, due trattamenti, bassa vs alta densità) sono stati testati sul comportamento alimentare di fasi post-larvali di spigola (13-20 mm di lunghezza standard). I risultati mostrano che dopo 21 giorni di alta temperatura gli animali modificano la loro attività di nuoto, passando da una locomozione esibita prevalentmente sul fondo della vasca a un utilizzo più omogeneo dell'ambiente. Inoltre, gli individui giovanili mantenuti a 22 °C, quando posti in presenza di uno stimolo olfattivo di tipo alimentare, mostrano un'attività esplorativa di gruppo maggiore di quelli mantenuti alla temperatura più bassa. Diversamente, la temperatura non risulta avere effetto nell'esibizione del comportamento affiliativo in risposta a uno stimolo avverso. Per quanto riguarda le fasi post-larvali, i risultati mostrano che gli animali aggiustano le loro tattiche alimentari tanto in relazione alla temperatura quanto alla densità di prede, riducendo l'attività predatoria alle

basse temperature e alte densità, e aumentando l'attività predatoria alle alte temperature, a scapito dell'attività di nuoto.

Le analisi di western blot effettuate sugli omogenati del cervello degli stessi giovanili osservati nei test comportamentali, dimostrano che gli enzimi colina acetiltransferasi (ChAT) e ossido nitrico sintasi neuronale (nNOS/NOS1) sono espressi con un pattern simile a 18°C e a 22°C. Ad entrambe le temperature ne la proteina da shock termico HSP70 ne l'isoforma inducibile dell'ossido nitrico sintasi (iNOS/NOS2) sono espresse. Questi risultati suggeriscono che l'aumento della temperatura testato non determina effetti da stress individuabili a livello cellulare.

Abstract

In regard to the research project "Analisi neurochimica e comportamentale degli effetti del cambiamento climatico e conseguente aumento della temperatura sull'attività del sistema nervoso centrale nelle specie ittiche di interesse alieutica quali spigola *(Dicentratchus labrax*) e orata (*Sparus aurata*)", experiments under laboratory conditions on juveniles (10-15 cm, Standard Length) and post-larval stages (13-20 mm, Standard Length) of European sea bass were carried out. We present preliminary results on swimming activity, affiliative and feeding behaviours. Moreover, results of western blot and immunofluorescence analysis on the effects of the increased temperature on cholinergic and nitrergic systems of juveniles are reported.

Behavioural tests such as prey presence, olfactive cue and object introduction were proposed to juveniles maintained at 18 and 22 °C over a period of 21 days to investigate the effects of temperature on swimming activity and affiliative behavior. Furthermore, effects of increased temperatures (19, 22, 26 °C) and prey density (*Artemia* nauplii) were tested on feeding behaviour of post-larval stages. Results showed that juveniles changed their swimming activity with a reduction of the time spent on bottom after 21 days at the upper temperature and the presence of peer groups in the area with olfactive cue resulted to be higher at 22 than 18 °C. Conversely, affiliative behaviour did not affect from temperature in response to object presence. Post-larval stages adjusted their feeding tactics in relation to both temperature and density, reducing predatory attacks at low temperatures and high density, and increasing predatory attacks at higher temperatures, at the expense of swimming activity.

Western blot analysis performed on the brain homogenates of the juveniles observed in behaviour tests, demonstrated that both the enzymes choline acetyltransferase (ChAT) and neuronal nitric oxide synthase (nNOS/NOS1) are expressed with a similar pattern at both 18°C and 22°C. Neither the heat-shock protein HSP70 nor the inducible isoform of nitric oxide synthase (iNOS/NOS2) were expressed at both temperatures. These results suggested that the tested increased temperature does not induce detectable stressor effects at the cellular level.

1. Introduction

The increase of temperature is thought to be one of the main effects of climate change (IPCC, 2007) and highly unpredictable environments such as lagoons and coastal wetlands are recognized to be particularly affected by these changes (Eisenreich, 2005). One of effects of the projected increase of temperature is the influence on physical, chemical and biological properties of aquatic ecosystems, with predominantly adverse impacts on many animal and plant species, community composition and water quality (IPCC, 2007). Based on this evidence, the research project "Analisi neurochimica e comportamentale degli effetti del cambiamento climatico e conseguente aumento della temperatura sull'attività del sistema nervoso centrale nelle specie ittiche di interesse alieutica spigola *(Dicentratchus labrax* L.) e orata (*Sparus aurata* L.)" (Progetto Corila-Regione Veneto) provides an experimental approach to the analysis of effects that the raising temperature may have on behavior and physiology of commercially important fish species. In particular, the European sea bass was selected as study model species, to extend then the results and conclusions also to the gilthead sea bream . The European sea bass is slightly more sensitive to higher temperatures than the gilthead sea bream, constituting a more conservative model to test the effects of increased temperature. The juvenile stages of the European sea bass are a valuable biological resource in the Northern Adriatic lagoons, including the Venice lagoon, where they are subjected to specialized forms of aquaculture and fisheries.

The combination of behavioral studies with neurochemical and neuromorphological investigations allows to correlate the sub-cellular and cellular responses to temperature increase and to their possible ecological consequences due to potential alterations of behaviors significantly affecting the individual fitness. The experimental control of temperature allows to simulate the potential warming of some degrees, as it is thought to occur in shallow sea basins and wetlands, such as the Venice lagoon.

In this extended abstract we present preliminary results of some experiments carried out in the framework of the project, regarding i) the effect of temperature and prey density on feeding behaviour of post-larval stages of *D. labrax, ii)* the effects of temperature on swimming activity and affiliative behaviour of juveniles *D. labrax* iii) the effects of the increased temperature on cholinergic and nitrergic systems.

2. Materials and Methods

2.1 Effects of increased temperature on feeding behaviour of post-larval stages of the European sea bass D. labrax (L.) *in relation to prey density*

The effects of increasing temperature, in relation to prey density, was tested on the feeding behaviour of post-larval stages of the European sea bass *Dicentrarchus labrax* L. under controlled laboratory conditions. Feeding behaviour was analysed in relation to three temperature treatments (19, 22 and

26 ° C) and two prey density treatment (high vs low density treatment). *Artemia* nauplii at 4 days from hatching were used as living prey. Post-larval stages of European sea bass from hatchery origin (13-20 mm of Standard Length) were assigned to three thermal treatments, allocating them into three different communal tanks (50 specimens for each tank) of 200 L capacity, where the acclimatization process was started. Room temperature was maintained at 19 ° C and all fish were initially maintained at this base-line temperature. In two of the tanks, temperature was then gradually raised of 1 °C/day to reach 22 and 26 °C in each tank respectively, whereas in the reaming tank the base-line temperature of 19 °C was not further changed. Once treatment temperatures were reached, fish were subjected to an acclimatization period of 21 days, before the beginning of experiments. Experiments were conducted in small glass tanks of about 3 l capacity, illumined by a suspended 60 W lamp and filled with the same water of the acclimatization tanks. Before the beginning of the experiments, larvae were subjected to a starvation period of 12 h, to standardise the motivational hungry level. Fish were randomly captured from the acclimatization tanks and transferred singly into the small experimental tank. After a period of 10 minutes of acclimatization, the experiment trials could start by releasing Artemia nauplii into the tank by means of a pipette. Depending on the prey density treatment assigned (low: d1 and high: d2), a solution of nauplii was introduced into the tank to reach a prey density of 400 nauplii/L (d1) and 1400 nauplii/L (d2), respectively. By means of a digital video-camera focused on the fish, the behaviour of the experimental specimens was recorded for about 10 minutes, starting from the release of the nauplii into the tank. The video-recording of behaviours allowed then to measure the main MAPs (Modal action Patterns, according with Brown 1986, and Georgalas et al. 2007) characterising the larval behaviour. In the present work, the results related to two behavioural variables are reported: “normal swimming”, that is the “ordinary” swimming activity performed with apparently constant speed and sustained by rapid movements of the caudal fin (expressed as percent time on the total recording time, %), and the feeding attacks, that is the lunge associated to prey ingestion and mastication (expressed as frequency, n/min). Results were analysed by non-parametric statistics.

2.2 Effects of increased temperature on swimming activity of juveniles of the European sea bass **Dicentrarchus labrax (L.)** *in relation to prey presence*

The effects of increasing temperature, in relation to prey presence, was tested on the swimming activity of juveniles of the European sea bass under controlled laboratory conditions. Swimming activity was analysed in relation to two temperature treatments (18 and 22°C) in presence of living prey *Chironomus salinarius.* Sixty juveniles of European sea bass (10-15 cm of Standard Lenght, hatched and reared at the farm facility of Panittica Pugliese, BR Italy) were assigned to 2 thermal treatments, allocating them into six different communal tanks (10 specimens for each tank, with 3 replicates for each temperature treatments) of 180 l capacity. All fish where initially maintained at the temperature present in the farm facility, equal to 20°C. In six experimental

tanks, temperature was then gradually raised or decreased of 1°C/day to reach 18 and 22 °C, respectively. The temperature of 18 °C represented the base-line condition. Fish were subjected to an acclimatization period of 21 days. After 24 hours that the treatment temperatures were reached, a solution of *Chironomus salinarus* was introduced into each tank by means of a pipette, to reach a prey density of 30 *C. salinarus*/180l. This procedure was replicated at the day 7, 14 and 21. Before the beginning of the experiments, juveniles were subjected to a starvation period of 24 h, to standardise the motivational hungry level. By means of digital video-camera focused on the tank, the behaviour of the specimens was recorded for about 5 min., starting from the release of the *C. salinarus* into the tank. The video-recording and the use of specific software package (Observer 3.0, NOLDUS 1991) allowed then to measure the swimming behaviour, as well as the feeding attacks. In the present abstract, the results related to two swimming variables on day 1 and 21 are reported: "swimming on the bottom", that is, the presence of 3 or more individuals on the bottom of tank (expressed as time spent on the bottom, s) and "swimming on the top" performed with presence of 3 or more individuals on the top of tank (expressed as time spent on the top, s). Results were analysed by non-parametric statistics.

2.3 Effects of increased temperature on affilliative behaviour of juveniles of D. labrax (L.) *in relation to olfactive and aversive stimulus*

Fish maintained in the experimental conditions described above were subjected to olfactive cue and aversive stimulus challenges to investigate the effects of the increasing of temperature on affiliative behaviour. After 24 hours from the reaching of treatments temperatures, and then at 7, 14 and 21 day, the two challenges were proposed to individuals.

The olfactive cue test was performed using five larvae of *Sarcophaga carnaria* inserted into a holed steel tin can and dipped in a side of tank. By means of digital video-camera focused on the tank, the behaviour of the specimens was recorded for about 10 min, starting from the dipping of larvae into the tank. The video-recording and the use of specific software package (Observer 3.0, NOLDUS 1991) allowed then to measure behaviours such as "cohesiveness around cue", "contact with cue", "excitatory events". In the present work, the results related to "cohesiveness around cue" in the day 1 and 21 are reported. This behaviour is defined as the presence of three or more fish in proximity of olfactive cue and expressed as frequency (events/min).

With regard to aversive stimulus challenge, a black ball (4 cm diameter) was thrown into the tank. Few seconds before the ball dropping, a video recording started and went on 10 min. By video recording, behaviours such as "flight response", "contact with object", "cohesiveness around object", "excitatory events" were measured. In the present abstract, the results related to "cohesiveness around object" in the day 1 and 21 are reported. This behaviour is defined as the presence of 3 or more fish in proximity of object and expressed as frequency (events/min). All results were analysed by non-parametric statistics.

2.4 Samples collection for western blot and immunofluorescence analysis

In western blot and immunofluorescence experiments were analyzed the same juveniles studied in the behaviour tests described above. At the end of the observations, samples were anesthetized with 2-phenoxyethanol (0,3 ml/L) and decapitated for western blot analysis or transcardially perfused for immunofluorescence experiments.

2.4.1 Western blot experiments

Brains (N=4) were homogenized in lysis buffer (50 mM Tris-HCl, pH 7.5, 2 mM EDTA, 100 mM NaCl, 1 % Triton X100, 5 mM NaF, 1 mM Na3VO4, 10 mM *β*-glycerolphosphate, 1 mM PMSF) containing protease inhibitors (Roche, Germany) and the particulate matter was removed by centrifugation at 10.000g for 20 min. Rat brain was used as positive control. The protein concentration was determined by the Lowry method (1951). For electrophoresis analysis, the samples were boiled in a Sample Buffer for 5 min to denature the proteins. Then, 100 µg of proteins was loaded in each lane and separated in 8 % SDS-polyacrylamide gels (SDS-PAGE) according to Laemmli (1970). After electrophoresis, gels were immunoblotted on nitrocellulose paper (Hybond C+ Extra, GE Healthcare, UK). Membranes were stained with Ponceau S to confirm transfer of proteins and succesively immunolabelled with the following antibodies raised against mammalian proteins: anti NOS 1 C-terminus (Santa Cruz Biotechnology, U.S.A.) diluted 1:500, anti NOS 2 (Santa Cruz Biotechnology, U.S.A.) diluted 1:500, anti ChAT (Millipore, USA) diluted 1:1000, anti HSP 70 (Santa Cruz Biotechnology, U.S.A.) diluted 1:200 and anti actin diluted 1:600 (Santa Cruz Biotechnology, U.S.A.).

Detection was performed using the ECL Plus system (GE Healthcare, UK). In electrophoresis experiments, the molecular weight marker ‘‘Wide range (6.5–205 kDa)’’ (Sigma-Aldrich, U.S.A.) was used.

2.4.2 Immunofluorescence analysis

Fish were transcardially perfused with 4% paraformaldehyde (PFA), the brain was dissected out, post-fixed in PFA for 24 hours, and cryoprotected in PBS containing 30% sucrose for 48 hours. Thereafter, samples were embedded in O.C.T. compound (Tissue-Tek II, Quiagen, Italy), frozen and cut in a cryostat into 10-20 µm transverse sections. Consecutive serial sections were collected on microscope slides coated with chromalum gelatin and processed for immunofluorescence. Briefly, sections were permeabilized with PBS plus 0.5% Triton-X-100 (PBST), blocked with 3% Bovin serum albumine in PBST for 30 min. and succesively incubated with a goat anti ChAT antibody (diluted 1:50) overnight at 4°C. The sections were then incubated for 1 h at room temperature with a CY3-conjugated anti-goat antibody (diluted 1:50). After several washes with PBS, the sections were mounted on slides coverslipped and observed with a fluorescence microscope.

3. Results and discussion

3.1 Effects of increased temperature on feeding behaviour of post-larval stages of D. labrax (L.) *in relation to prey density*

Within the low density treatment (d1), no statistically significant effect of temperature was detected (Kruskal-Wallis test, p>0.05). By contrast, within the high density treatment (d2), there were statistically significantly differences across temperatures in terms of both percent swimming activity and attack frequency (Figure 1, a and b).

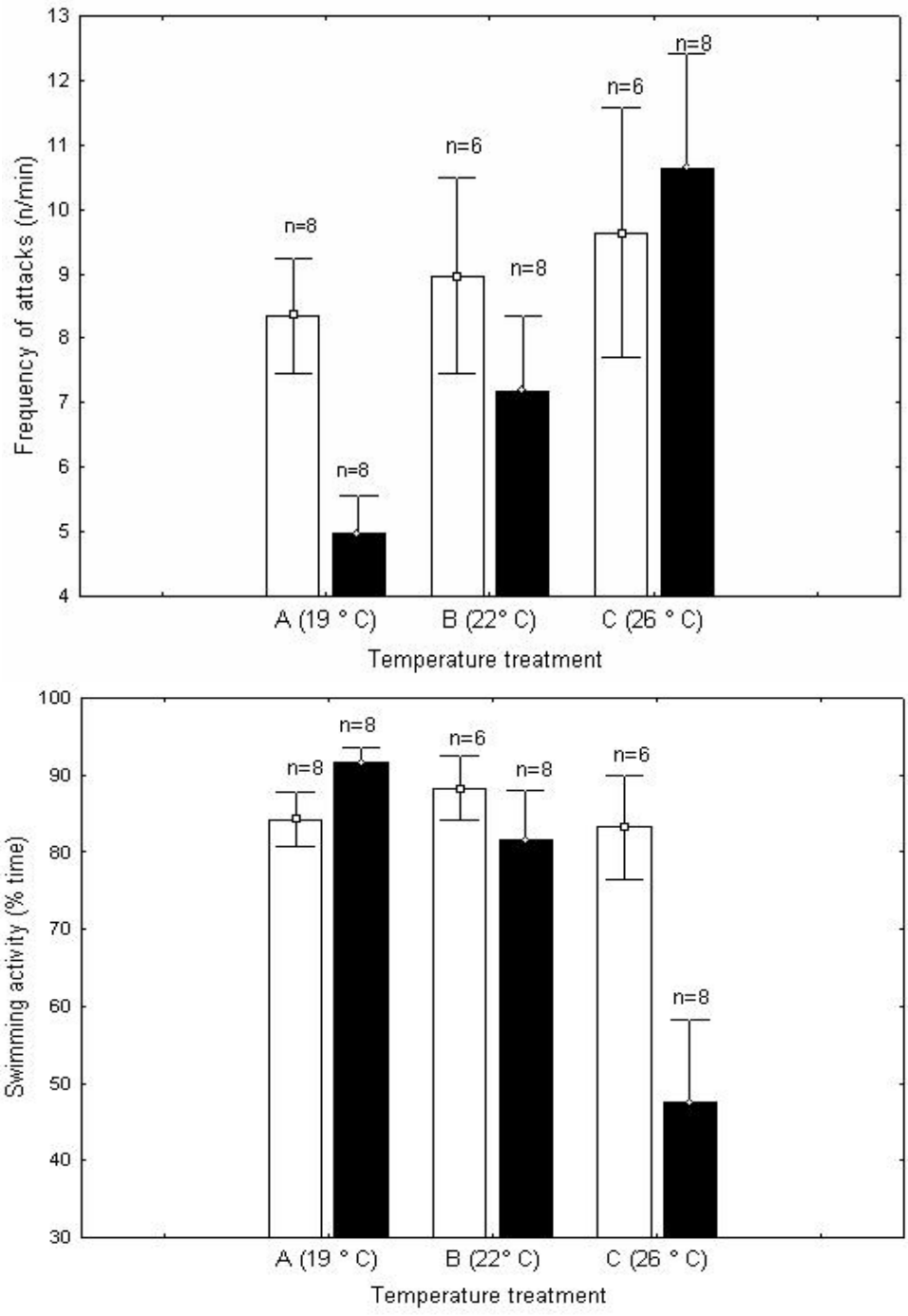


Fig. 1. Frequency of feeding attacks (a) and percent time of swimming activity (b) in the post-larval European sea bass as regards three temperature treatments and two density treatments (white bars= low density, d1=400 Artemia nauplii/l; black bars= high density, 1400 Artemia nauplii/l). Numbers on the bars refer to the number of replicates conducted for each treatment.

Percent of swimming activity decreased significantly with increasing temperature, whereas frequency of attacks showed an opposite pattern, with the number of attacks increasing at higher temperatures. Within the base-line temperature of 19 °C, the frequency of attacks was higher in the high-density treatment than in the low density treatment (Mann-Whitney Test, $p< 0.05$), whereas within the highest temperature treatment (26 °C), the swimming activity was significantly lower in the low-density treatment than in the high-density treatment.

Body size of fish was not significantly different between density treatments whereas experimental fish were significantly larger in the highest temperature treatment (26 °C) with respect to intermediate and low temperatures (Kruskal-Wallis test, $p< 0.05$), and this was likely to be the consequence of a higher growth rate in the warmer tank.

These results suggest that the feeding strategy is modulated as a response to the combined effect of temperature and prey density with fish changing their behaviour especially at the extremes of the temperature range, and at higher prey density. The reduction of feeding rate at the base-line temperature of 19°C seems to suggest that the so called confusion effect is acting: fish attack less frequently the prey, to probably be more vigilant in terms of anti-predator responses. On the other hand, higher densities were able to induce higher feeding rate as temperature increased, at the expense of swimming activity at 26 ° C. This higher tendency to perform more attacks with increasing prey density could enhance growth at the expense of antipredator response, with potentially negative consequence on individual fitness.

3.2 Effects of increased temperature on swimming activity of juveniles of the European sea bass in relation to prey presence

With regard to “swimming on the bottom” and “swimming on the top”, no statistically significant effect of temperature was detected between 18 and 22 °C on day 1 (Mann-Whitney Test, MWT, $p>0.05$, respectively). By contrast, there was statistically significantly difference across temperatures in terms of time spent on the bottom of tank during the day 21 (MWT, $p<0.05$). In particular, initially all fish mainly used the bottom of tanks, probably as response to an anti-predator strategy (Pickett and Pawson, 1994). Then, fish maintained at higher temperature shifted their swimming activity, balancing through the whole tank and including the top (Figure 2, a and b). This result can be likely the consequence of a higher metabolic demand and feeding rate at 22°C as response to the faster growing of animals (Barnabé, 1991), that drives fish to swim across the whole tank to search prey, with potentially negative consequences on individual fitness, being more easily vulnerable by aerial predator. Nevertheless, it should also noted that high temperature influences the oxygen availability (Taylor et al., 1997) could finally affect the swimming pattern of animals.

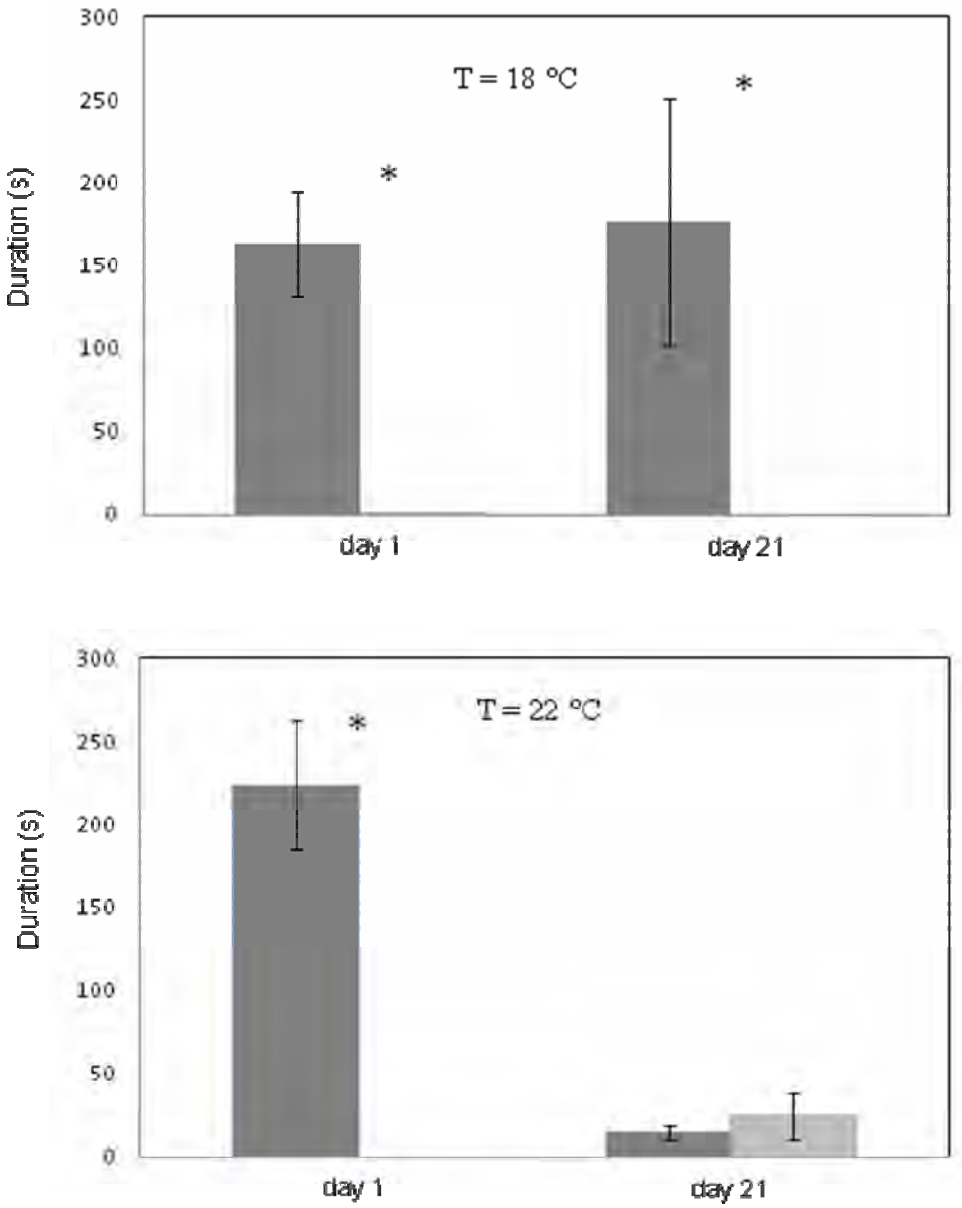
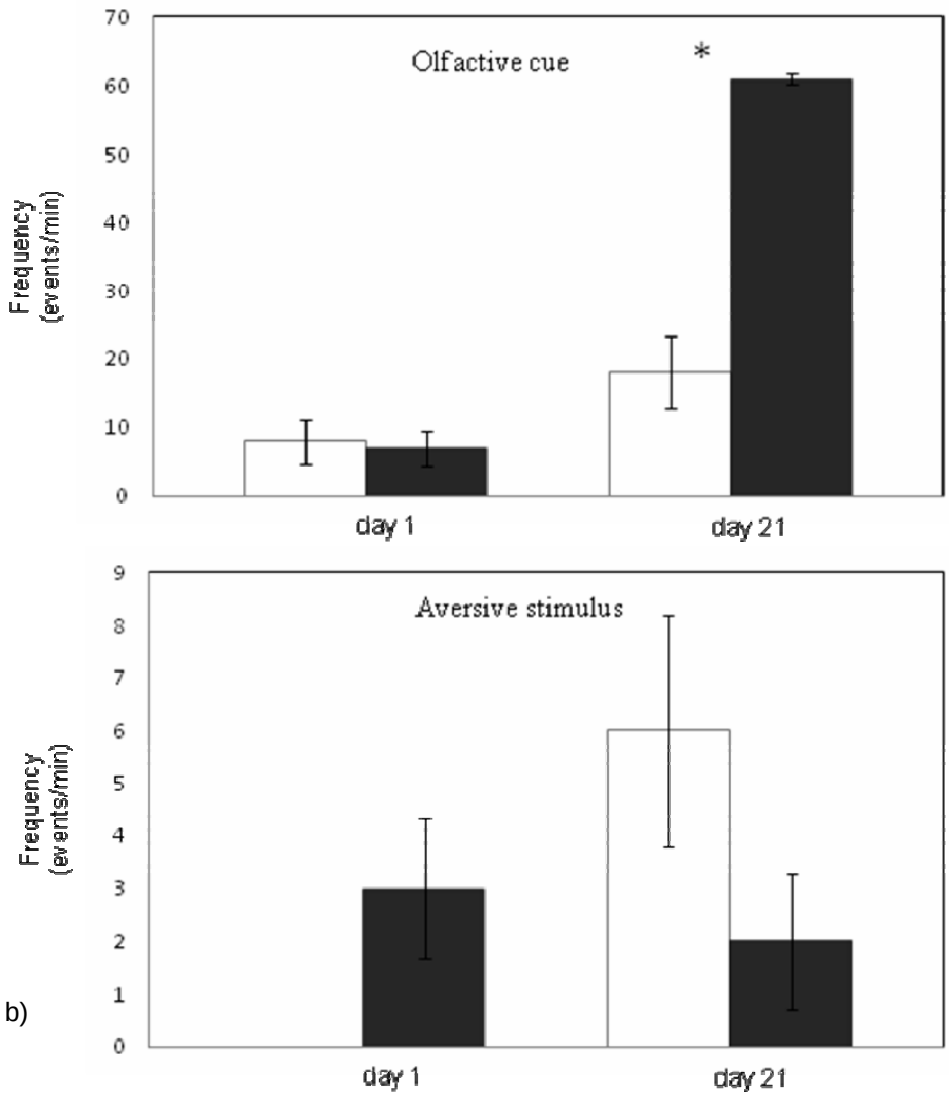


Fig. 2. Time spent (± S.E.) on the bottom or top of tanks (black grey bars= bottom; light grey bars= top) from three or more individuals at 18 °C (a) and 22 °C (b) during the acclimatization period. Three replicates were conducted for each temperature.

3.3 Effects of increased temperature on affilliative behaviour of juveniles of D. labrax (L.) *in relation to olfactive and aversive stimulus*

Statistically significant effect of temperature for behaviour "cohesiveness around cue" during the day 21 was found (MWT, $p<0.05$). Fish maintained at 22 °C over 21 days established shoal to approach olfactive cue more frequently than those at 18 °C (Figure 3a). By contrast, in presence of aversive stimulus no statistically significant effect of temperature was found (MWT, $p>0.05$), even if after 21 day of temperature treatments a trend with fish maintained at 18 °C more interested in shoaling to explore object was present (Fig. 3b). These results seem to suggest an influence of temperature on affiliative behaviour of juveniles of *D. labrax* in response to feeding stimulus. In accordance with results described above, higher explorative activity seems to be present to

satisfy higher feeding rate associated with a warmer temperature. Instead, prolonged periods of upper temperature did not influence the response to negative stimulus. Higher frequency of shoaling from fish at 18 °C in correspondence of object during 21th day may be due to higher presence of individuals on bottom of tank where object is located. In conclusions these preliminary results show an effect of high temperature on changes in the feeding strategy, whereas no significant impact of temperature seems to be as respect to anti-predatory response.



b)

Fig. 3. Frequency (± S.E.) of visits in the area with olfactive cue (a) and object (b) of three or more individuals as regards two temperature treatments (white bars= 18 °C; black bars= 22 °C) during the acclimatization period. Three replicates were conducted for each temperature.

3.4 Effects of increased temperature on the expression of ChAT and NOS1

To investigate the cholinergic system, we have used antibodies against the enzyme ChAT, which catalyzes the one-step synthesis of the neurotransmitter acetylcholine (ACh) in the cytoplasm of cholinergic neurons. The effects of thermal acclimation on nitrergic system were investigated by antibodies against

the NO- producing neuronal nitric oxide synthase (nNOS/NOS1), that is expressed in the brain of most vertebrates, including fish. ACh is co-localized with NO in the fish brain (Giraldez-Perez et al., 2009) and a cross-talk between the two enzymatic pathways was suggested since the activation of ACh muscarinic receptor may influence the endogenous NO production in mammals (Marquez-Ruiz et al., 2007). However, NO production must be finely regulated since NO may be responsible for oxidative and nitrosative damages at the cellular level (Stamler, 1994).

The expression of ChAT and NOS1 were compared in brain homogenates from fish acclimed to 18° and 22°C by Western blot. Immunoblots performed with a polyclonal anti-ChAT antiserum revealed the presence of two bands with a slightly higher and lower molecular weight than the rat brain ChAT (68-70 kDa) used as control (Fig.4 C).

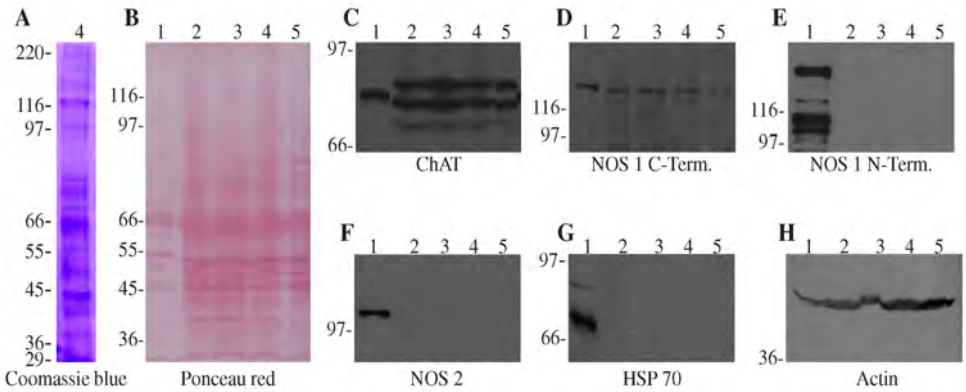


Fig. 4. Western blot analysis of protein homogenates of rat brain (lane 1, as a positive control) and of the brain of European sea bass specimen acclimated at 18°C (lanes 2 and 3) and at 22°C (lanes 4 and 5). Coomassie blue (A) and Ponceau red (B) staining of brain proteins. Immunoblotting cross-reactivity with different antibodies raised against mammalian proteins (C-H). Polyclonal anti ChAT antibody (C), polyclonal antibodies against the C-terminus (D) and N-terminus (E) of nNOS, polyclonal anti NOS2 antibody (F), monoclonal anti HSP 70 antibody (G) and monoclonal anti actin antibody (H). Polyacrylammide gel concentration: 8%.

The immunoreaction product increased as a function of the amount of protein (not shown) and these results indicated that the antibodies specifically recognized fish ChAT proteins. The two bands were detected at both T0 and T1. Thus, ChAT expression in the sea bass brain showed a temperature-insensitive pattern at the temperatures tested. The two protein bands could represent two different ChAT isoforms that are specifically expressed in this species. Indeed, a similar Western blot analysis revealed a single band around 68-72 KDa in the goldfish (Giraldez-Perez et al., 2009). The expression of NOS1 was analyzed by two different polyclonal antibodies raised against the C-terminus or the N-terminus of this enzyme (Fig. 4 D and E). A single band around 155 kDa was detected by the antibody against the C-terminus (Fig. 4 D) at both T0 and T1, whereas no bands were detected by the antibody against the N-terminus (Fig. 4 E). A similar positive band was found in the rat brain homogenates used as control. These results demonstrated that sea bass NOS1 molecules are expressed in the brain at both temperatures. They also suggested that the C-terminus of sea bass NOS1 is evolutionary conserved more than the N-terminus, which was not recognized by heterologous antibodies.

The distribution of cholinergic neurons was analyzed by ChAT immunofluorescence in the brain of a specimen acclimed to 22°C. ChAT

positive cells were widely distributed in the brain vesicles, with the exception of the telencephalon, where they were only detected in the paired olfactory bulbs (Fig 5 A). ChAT immunoreactive (ChAT-ir) cells were localized in the preoptic region of the diencephalon, the optic tectum (Fig 5 B, C), the tegmentum of the mesencephalon (Fig 5 D), the cerebellum (Fig 5 E), the rostral (Fig 5 F) and caudal (Fig 5 G, H) medulla oblongata. Within the optic tectum, the only ChAT-ir neurons appeared in the periventricular layer (Fig. 5 B).

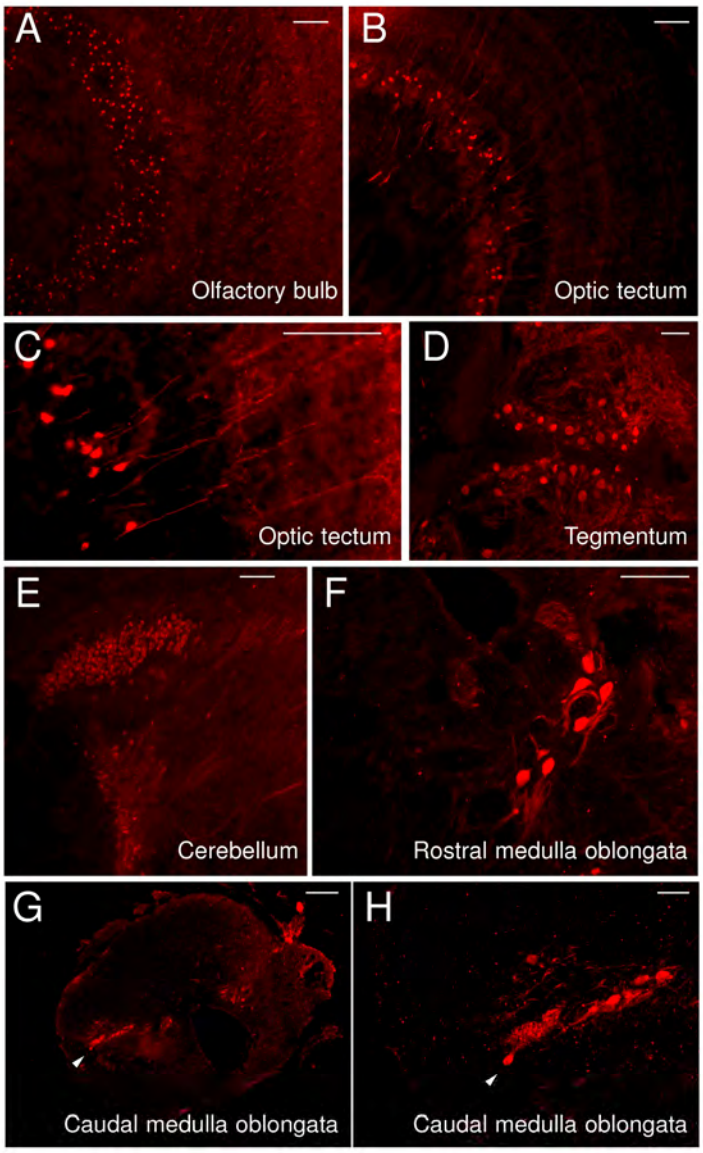


Fig. 5. Distribution of ChAT immunoreactivity in the brain of European sea bass acclimated at 22°C. A: ChAT positive cells in the olfactory bulb. B and C: photomicrographs of the optic tectum showing ChAT positive cells in the periventricular stratum; D: immunolabelled cells in the the tegmentum of the mesencephalon; E: ChAT positive cells can be observed in the valvula cerebelli; F-H: distribution of ChAT positive cells in the rostral (F) and caudal (G, H) part of medulla oblongata. The white arrowheads in G and H indicate the same cell at different magnification. Scale bar= 50 um expet for G (200 um).

Positive cells showed pyriform somata and one apical dendrite oriented perpendicular to the lamination. This thick dendrite ramified in the superficial fibrous layer which was also positive (Fig. 5 C). This type of cholinergic neurons were identified in the optic tectum of different species and considered a well-conserved feature among all groups of teleosts (Clemente et al., 2004). ChAT immunoreactivity is widely distributed in the sea bass tegmentum, in the oculomotor (III) and trochlear (IV) nuclei (Fig. 5 D) as well as in the rostral

medulla oblongata, where motoneurons of the trigeminal (V), abducens (VI) and facial motor nuclei are cholinergic (Fig. 5 F). In the caudal medulla oblongata, motoneurons of the glossopharyngeal (IX) and vagal (X) motor nuclei also appeared ChAT immunoreactive (Fig. 5 G,H). In the sea bass cerebellum, ChAT-ir cells were only observed in the valvula cerebelli (Fig. 5 E).

3.5 Effects of increased temperature on the expression of HSP and NOS2

We have also examined the expression of the heat shock protein HSP70 and the inducible NOS2 by Western blot to evaluate the effects of the increased temperature on molecular markers of the cellular stress response. Western blotting experiments performed by polyclonal NOS2 or HSP 70 antibodies did not reveal the expression of the iNOS isoform or the heat shock protein in the brain homogenates of fish acclimed to both temperatures (Fig. 4 F). These results suggested that the increased temperature did not cause a cellular stress sufficient to induce the expression of HSP 70, a molecular marker of thermal stress, and of the inducible isoform of NOS in the brain of European sea bass.

Conclusions

Although the present results are still preliminary, they suggest that different aspects of the behavioural repertoire of the study species, the European sea bass *Dicentrarchus labrax* L., could be significantly changed by increased temperatures, with potential consequences on individual fitness. Further experiments will allow to better understand the behavioural impairment determined by temperature increases and the relationships between the neurochemical and the behavioural level.

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