QUADERNI CA'VENDRAMIN

LABORATORIO INTERNAZIONALE DELTA E LAGUNE JOURNAL

RECENT MORPHOLOGICAL EVOLUTION OF THE SACCA DEGLI SCARDOVARI

NATURALITY VALUE AND INTERVENTION MANAGEMENT IN THE LAGOONS OF THE PO DELTA

0

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THE VENETO REGION AND THE MANAGEMENT OF ITS LAGOONS

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In the early 1990s, the Veneto Region first took up the important task of revitalizing the lagoons of the Po delta and Caorle, in the framewok of Integrated *Mediterranean Programs (IMP)* contained in *Community Directive 2088/85*, entrusting it to the *Consorzio di Bonifica Delta Po Adige* of Taglio di Po and *Pianura Veneta* of Portogruaro.

These operations, primarily aimed at improving the lagoon's hydrodynamic system and restoring its morphology, led to a general environmental reclamation of the lagoon areas, the recovery of its productive resources and the development of related economic activities, mainly concerning shellfish farming, fishing and tourism.

However, it was evident that in order to maintain environmental quality and adequately support economic activities in these areas, any completed work would have to be maintained, in the long term, through sustained action coordinated by interventions carried out on the inter-connecting hydraulic lagoon network, followed by the constant monitoring and management of its bodies of water and regulative systems.

With Article 29 of the Regional Law 22 February 1999 n. 7, The Veneto Region specifically entrusted the management and carrying out of interventions in the lagoons of the Po delta and Caorle to the reclamation consortiums and authorized the Regional Executive to finance specific maintenance projects by the aforementioned reclamation consortiums.

The management began in earnest in 2001, and led to the launching of systematic scientific investigations on the Po delta's lagoons carried out by the *Consorzio di Bonifica Delta Po Adige* in collaboration with the leading experts in the field in order to integrate the project results in the most appropriate way, adapting the needs of the fishing world to those of the environment and of hydraulic safety.

The findings of these investigations, projects and interventions were then evaluated by an Interdisciplinary Commission appointed by the Regional Council with the

objective of finding solutions in order to guarantee the most effective use of the available financial resources.

The aforementioned Commission's meetings with representatives of the cooperative world of the Po fishermen and fishery activities to discuss their needs, resulted in the confirmation of the institutional model of the *Consorzio di Bonifica* which, in addition to assuming an agency role, would carry out the necessary monitoring and maintenance of small lagoons and the management of interventions.

A healthy relationship between the institutions and economic & socio-economic forces involved in the lagoon's productive activities has made the carrying out of interventions more effective.

The Veneto Region's strong desire to develop and enhance the museum system of the Po delta, its historical artifacts and rural hydraulic archeology in order to render them useful to tourism in the Delta, a growing area with innate potential value in this sector, resulted in the establishing of the *Fondazione Ca' Vendramin*.

The *Fondazione Ca' Vendramin*, in collaboration with the *Università del Veneto* and the *Centro Universitario di Rovigo (CUR)*, promotes, manages and coordinates advanced research, primarily on the Po delta but also on other territories, through a similar scientific research center called the "*Laboratorio internazionale delta e lagune Ca' Vendramin*".

As a scientific tool the "Laboratory", through interdisciplinary research, should be able to "export" a methodological approach developed in the Po delta to other areas of Italy and the world.

The Veneto Region's involvement in the concrete realization of a research center to promote and disseminate knowledge and opportunities offered by the Delta's communities and territories represents a fundamental contribution to innovation and the development of our territory's economic system.

THE LAGOONS OF THE VENETO TERRITORY AND MANAGEMENTS TOOLS

RICCARDO DE GOBBI
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The current configuration of the Po delta region, with its lagoon-valley areas intermingled with intensely cultivated land, areas in which it is not always possible to differentiate between "water and land", that is, areas made up of salt marshes, lagoons, canals, sandbanks, tidal flats, embankments and solid land represents, as it might have done at the beginning of the 1900s, about a third of the entire territory of the Veneto Region.

Let us not forget that at the beginning of the last century, large parts of the territory we now know as the Verona, Padua, Venice and Rovigo provinces, underwent a major hydraulic reclamation, turning wetlands and marshes (and therefore eliminating the problems of malaria and agricultural neglect) into today's hundreds of thousands of hectares of cultivated agricultural land and urbanized territories. When looking at our region on old maps and charts, it's enlightening to think that not too long ago, in place of the cities, villages, hamlets and cultivated countryside, there were ponds, marshes, lagoons and uncultivated areas. Take for example the entire *Valli Grandi Veronesi* area, many of the same now cultivated areas in the Po delta, and all the districts south of present-day Venice-Trieste motorway.

Nowadays, mainly due to the fact that we have overcome sanitary and socio-economic problems, but also as a result of the rediscovery of irreplaceable environmental functions of the natural and recreational resources of the "wetlands", the conservation and preservation of the current lagoon environment including the fauna and flora that characterize them, as well as human activities that have developed in them, has become a priority shared by the whole community.

The Veneto Region, along with only a few others worldwide, is distinguished by large lagoon areas and valleys making it a "*unicum*" in the Mediterranean. Starting in the north, there is the Caorle lagoon, a community interest site where one can still admire the "*Casoni*", traditional lagoon fishing shelters built of wood and cane from the marshes, using a technique thats origins are lost forever. Ernest Hemingway described this lagoon in winter in his famous novel " Across the River and into the Trees". In the towns of Jesolo and Eraclea we have the *Laguna del Mort*, which together with the maritime pine forest *Eraclea Mare*, has also been defined as a community interest site. The lagoon covers an area of approximately 125 ha having formed very recently, in 1935, when the Piave burst its left bank just at the point where it curved north east and overflowed into the sea abandoning its original bed thereby closing the connection between the original bed and the river itself through the deposition of sand and mud.

The Venice Lagoon, covering an area of 550 km^2, does not need any introduction. About a sixth of its surface (equal to 92 km^2) is occupied by "fish farms", large areas separated from the open lagoon by a fence consisting of fixed poles or embankments, in which fish are bred. Just over 18% of the lagoon's surface is occupied by nume-rous islands, "*motte*" (artificial islands in fishing areas) and islets, like those making up the "suburbs" of Venice and the many smaller islands, each with its own history and memories of an illustrious past. Finally there is the Po delta, rightly declared a UNESCO World Heritage Site, with its lagoon-valley wetlands consisting

primarily of two "*Sacche*" (shallow water coves into which river branches flow) the *Sacca del Canarin* and the *Sacca degli Scardovari*, seven separate lagoons (*Caleri, Vallona, Barbamarco, Batteria, Burcio, Basson* and *Bonelli Levante*) and 24 *valli da pesca* (embanked fishing lagoons), the latter covering an area of about 8 600 ha.

As is well known, the main characteristic of all the lagoon-valley systems is their changeability, instability and the constant risk of progressive silting due to fluvial deposition or on the contrary, the partial or complete disappearance of the sandbanks and coastal defenses due to tidal erosion risking transformation of the lagoon into a part of the sea. As early as the *Serenissima Repubblica di Venezia*, major divertive works were carried out in the Brenta, Sile, Piave, Muson and Marzanego rivers to counter the gradual silting of its lagoon. The European Union, aware of the need to intervene in order to improve the hydrodynamic system and to restore the lagoon's morphology has, under the *Integrated Mediterranean Programs (IMP)*, funded major structural and infrastructural interventions for the regeneration of the Po delta and Caorle lagoons, entrusting the work in concession to the reclamation consortiums.

Lastly, the Veneto Regional Council, in order to carry out work and ensure the maintenance of the lagoon basin system's hydrological structure, in passing two le-gislative measures (Regional Law no. 7, 22 Feb. 1999 and Regional Law no. 14, Jan. 2003), provided funding for specific maintenance projects presented by the reclamation consortiums as well as offered widespread regional support for management interventions in the lagoon-valley basins.

Given the complexity and the particular nature of the interventions affecting the lagoon-valley areas, the Regional Council of Veneto, with deliberation no. 6005, 28 December 1993, established an interdisciplinary Commission with the task of verifying the compatibility of hydraulic-environmental work in order to regenerate the lagoons and to verify the results thereof. The Commission encompasses all of the necessary and appropriate technical and administrative skills in order to apply an integrated and multidisciplinary approach to the complex problems of lagoon and fishing areas. The Commission was founded in relation to the actions initiated under the *Integrated Mediterranean Programs*, with subsequent deliberations no. 6890/1994, 3392/2003 and 1598/2004. The Commission has been improved and enlarged all the while maintaining its objectives and expanding its powers to all interventions carried out by the regional financial partnerships in the Delta and Caorle lagoons.

With the involvement of scholars and researchers on issues of biodiversity, sustainable development and the balanced hydraulic regulation of the deltas, wetlands and coastal areas, the planned establishing of the "*International lagoons & deltas laboratory*", with its headquarters at Ca' Vendramin, could certainly provide the Interdisciplinary Commission with useful suggestions, information and design solutions, in this way contributing to the further enhancement and protection of the Po delta, which we are obligated to pass on to future generations in an "improved" state.

THE RECLAMATION CONSORTIUM (CONSORZIO DI BONIFICA) AND HYDRAULIC MANAGEMENT OF THE DELTA WATER SYSTEM

FABRIZIO FERRO
President of the *Consorzio di Bonifica Delta Po Adige*

The Po delta in the Veneto Region[1] covers a surface area of 60 000 ha[2] and is bordered to the west by the Po di Goro, Po di Venezia & Po Brondolo, to the north by the Adige, and to the east and south by the Adriatic Sea. It's a morphologically and hydrographically complex area made up of 42 000 ha of agricultural land and settlements, largely originating from reclamation work carried out over the past centuries, and 18 000 ha of wetlands containing fishing areas and lagoons.

Almost completely below sea level, and that of its bordering and intersecting rivers, from which it is protected by over 400 km of embankments, it is hydraulically controlled by a dense network of canals consisting of several land drainage pumping stations with a capacity of about 200 m^3/s, for the disposal of zenith water.

In the closing decades of last the century, the **reclaimed land's** hydraulic works, which had been damaged by subsidence mainly caused by the extraction of methane water from the subsoil between **1950 and 1960**, underwent incisive renewal interventions and important moderation works carried out on the reclamation and irrigation structures, in this way improving the balance and efficiency of the territory. In the late 1980s the situation in the river **lagoon-valleys** was so sensitive that urgent interventions were required in order to address degradation in the most environmentally fragile parts of the delta territory. In the early 1990s, thanks to the *Integrated Mediterranean Programs (IMP)* contained in Community Directive 2088/85, renewal works were carried out in the lagoons that resulted in a significant environmental improvement, and from which both mussel farming and fishing activities benefited significantly.

With L.R. no. 7, 22/02/1999 (Articles 25÷29), the Veneto Region entrusted the **management** of the delta lagoons (in addition to that of Caorle[3]) to the *Consorzio di Bonifica Delta Po Adige* with the aim of taking advantage of the positive results of the *IMP*'s work and to maximize the efficiency of the lagoon hydrodynamics. In 2001 the *Consorzio* officially initiated its management phase by making use of a *Commissione di Sovrintendenza* appointed by the Veneto Region in order to verify and monitor project maintenance from the planning stages through to their completion.

As of 2006, the *Consorzio* deemed it necessary to accompany the technical department with a Scientific Commission made up of experts from nearby universities in order to identify techniques and methodologies suitable for the carrying out of work and the setting up of research activities on the delta lagoons with the aim of identifying a *modus operandi* attuned to the territorial politics of the local governing bodies and to initiate an overall strategy for the planning of hydraulic and environmental interventions.

The evolution of the Scientific Committee's activities into a "delta and lagoon research center" appears to be the logical conclusion of a path that has seen the use of the *Consorzio di Bonifica Delta Po Adige* to develop plans and projects for the Po delta and collaborate with other delta and wetland areas throughout the world in order to identify methodologies and solutions in the management of wetland areas with the aim of proposing and submitting projects to the governing bodies (Town councils, Provinces, Regions, States, European Union, Ministry of Foreign Affairs, FAO etc.)

In this regard, *Consorzio di Bonifica Delta Po Adige* along with the Veneto Region, the Province of Rovigo, and the *Ente Parco Regionale Veneto del Delta del Po* has promoted the establishment of the *Fondazione Ca' Vendramin* not only for the enhancement and management of the Ca' Vendramin museum system and other historical hydraulic structures found in the territory, but also to set up a "Laboratory" capable of involving the scientific world, intellectuals in the field and institutions in order to establish a balanced hydraulic, environmental and urban regulation of the Delta.

The "*International delta and lagoon laboratory*" with its headquarters in Ca' Vendramin, will develop interdisciplinary research with the aim of promoting co-existence and harmonization in the resolving of the varied and diverse issues pertaining to deltas, lagoons and coastal wetlands areas throughout the world. It will be a veritable and unique wealth of not just technical and scientific, but more importantly, socio-economic knowledge, and it is our desire to make it available in order to improve the quality of life and maximize the potential of this extraordinary territory that we know as the Po delta.

[1] The area falling in the Province of Ferrara makes up what is the "historic" part of the river formed in the centuries prior to 1200 when the great river burst its banks at Ficarolo (*Rotta di Ficarolo*), moving the river's course towards the north.

[2] The reclamation district containing the *Isola di S.Anna di Chioggia* between the rivers Adige and Brenta, has a total area of 62 780 ha.

[3] Entrusted to the *Consorzio di Bonifica Pianura Veneta di Portogruaro*.

LABORATORIO INTERNAZIONALE DELTA E LAGUNE CA' VENDRAMIN: ITS HISTORY, OBJECTIVES AND ACTIVITIES

LINO TOSINI
Director of the *Consorzio di Bonifica Delta Po Adige*

The Po delta is a complex system in constant evolution. It is a mosaic of more or less natural ecosystems interspersed with anthropogenic structures, in which human intervention, although necessary, should be balanced and should respond to a variety of needs.

Hydraulic and environmental management of the Po delta and its lagoon systems is the main problem of the territory: the Veneto Region makes use of the *Consorzio di Bonifica Delta Po Adige* as the institution responsible for ensuring the proper maintenance of the water, fishing activities and aquaculture as well as enhancing the environmental resources. Along with traditional activities of reclamation and irrigation, for the last 20 years, the *Consorzio* has been entrusted with the safeguarding of the lagoon valley environments that fall in this area, considering a unified strategy in the planning and management of hydraulic and environmental interventions throughout the Delta fundamental.

The *Consorzio* has therefore initiated research activities in the Delta and its lagoons in harmony with the territorial policies of local institutions: The Region, Provinces, Municipalities, Park Authority, using a Scientific Committee[1] composed of experts from universities close to the territory. The need for an interdisciplinary scientific approach to the problems of the Po delta and the lagoons is the result of the complexity of the measures put in place by the *Consorzio* in order to achieve effective environmental restoration through morphological adaptation and improvement of hydrodynamics of the lagoon environments also for productive purposes.

The scale of operations, across the whole area of the Delta, the necessary and varied connections with the activities of the fishing areas and the land reclaimed in the internal areas, bordered by coastal dunes and therefore the sea on the outside, required more precise and accurate methods of intervention that take into account not only their effectiveness in production but also their impact on an extremely fragile territorial structure. It must be added that there is a need to comply with European and national environmental directives, since the areas under consideration are completely subject to SIC and Z.P.S.[2] regulations as well as those of the *Ente Parco Regionale Veneto del Delta del Po*.

At a special meeting held by Chancellors of the Universities of Venice, Ferrara,

Padova and the representative of the *Consorzio Universitario di Rovigo (CUR)* in October 2008, conclusions were reached about the approach taken in identifying the interdisciplinary scientific model to be applied not only to the lagoons and deltas of the Po, but also to those throughout the world in order to combine and make compatible apparently contrasting environmental needs and the development of economic and social activities.

This scientific approach was shared by many representatives of institutions present at the meeting, including the Region of Veneto, the Province of Rovigo, the *Ente Parco Regionale Veneto del Delta del Po* and the *Consorzio di Bonifica Delta Po Adige*. A work group, coordinated by the *CUR*, was then set up, consisting of professors of nearby universities with the task of preparing a project of "scientific model to be applied to the Po delta concerning its management and the resolution of hydraulic and environmental issues to be applied to deltas and humid areas of the Mediterranean and other parts of the world ". The most appropriate instrument for achieving the objectives was identified as the *Laboratorio internazionale delta e lagune Ca' Vendramin*, able to further interdisciplinary research and to "export" its scientific approach, thus far developed in the Po delta to the Mediterranean area and other parts of the world.

Other than the Italian universities, the *Universidad de Zaragoza* will be represented by Prof. Antonio Embid, the *Instituto Superior de Urbanismo, Territorio y Ambiente de Buenos Aires* by Arch. Andrea Behar, *Universidad Politècnica de Catalunya* of Barcelona by Prof. Luis Berga, and *Huè University of Agriculture and Forestry* (Vietnam) together with professors and experts from institutes and universities of various parts of the world.

In order to concretize the realization of such a research center the *Fondazione Ca' Vendramin* was founded, that in addition to the task of managing and enhancing the museum system of the land housing the former Ca' Vendramin scooping plant and other historical hydraulic artifacts of the territory, has an objective of promoting, managing, and coordinating advanced research on the deltas, lagoons and their coastal wetlands also with respect to local connecting territorial systems and, in particular, the establishing of the *Laboratorio internazionale delta e lagune Ca' Vendramin*[3].

[1] Consisting of: prof. Luigi D'Alpaos, Università di Padova; prof. Francesco Donati, Università di Udine; ing. Fabio Galiazzo, director Distretto Idrografico Adige-Po-Canalbianco; prof. Pippo Gianoni, IUAV di Venezia; prof. Remigio Rossi, Università di Ferrara; prof. Pietro Traverso, Università Ca' Foscari di Venezia; ing. Lino Tosini, director of the Consorzio di Bonifica Delta Po Adige, ing. Giancarlo Mantovani, vice director of the Consorzio di Bonifica Delta Po Adige

[2] SIC (SCI - Site of community interest) and ZPS (SPAs - Special Protected Areas).

[3] According to the *Statuto della Fondazione Ca' Vendramin*, Art 4, comma 2.

THE QUADERNI CÀ VENDRAMIN

Scientific Committee

The *Laboratorio internazionale delta e lagune Cà Vendramin* inaugurated the ***Quaderni Ca' Vendramin*** with the publication of issue 0, the first trial publication on a scientific-cultural path that will in time be built up and progressively consolidated.

The Scientific commission, having supported the *Consorzio di Bonifica Delta Po Adige* in this first phase in its proposed initiative relating to the Po delta lagoons, favored the idea, publishing the *Quaderni* for flexibility and continuity reasons. This will be a series that collects and disseminates practical experiences and scientific studies sponsored by the *Laboratorio internazionale delta e lagune Ca' Vendramin*, its scientific partners and academic institutions active in lagoon management both in Italy and internationally.

The idea of publishing a journal indicates the will to promote the ongoing growth, expansion, experimentation and networking of experiences and applications within the highly complex and dynamic field of lagoon and delta management.

We hope that the *Quaderni* will serve as a basis for the exchange of experiences and the most effective practices in order to develop the knowledge about and the management of these extraordinary environments.

The journal will be published regularly and will cover specific areas be it in the form of monographs, or different scientific articles. The journal itself, will be accompanied by a web page containing computer data, a Web-GIS of the Po delta, and information regarding the *Laboratorio internazionale delta e lagune Ca' Vendramin*.

An editorial committee will coordinate the publication of the *Quaderni* while a scientific reading committee will be appointed by the editor to ensure quality of its contents. Edition 1, scheduled for spring 2010, will bring together and present reports on the *1° Convegno internazionale sulle Lagune* in Ca' Vendramin from the 1st to the 3rd of October 2009.

VENETO PO DELTA
TOPONYMIC MAP

Po Adige Delta district:
surface area: about 62 780 ha

Po delta:
surface area: about 60 000 ha

Agricultural and settlement areas:
surface area: 42 000 ha

Wetlands:
surface area: 18 000 ha

7 *sacche* and lagoons:
surface area: 8 150 ha
Laguna di Caleri
Laguna Vallona
Laguna Barbamarco
Laguna del Burcio
Laguna del Basson
Sacca del Canarin
Sacca degli Scardovari

Other wetlands:
surface area: 1 250 ha
Batteria
Bonelli Levante

24 *valli da pesca* (embanked fishing lagoons):
surface area: 8 600 ha

Branches of the Po River:
surface area: 4 000 ha
Po di Venezia
Po di Goro
Po di Gnocca
Po di Maistra
Po di Tolle
Po di Pila

River banks and sea defensive embankements:
400 Km


Brenta
Ca' Lino
S. Anna
Adige
Rosolina Mare
Valle Boccavecchia
Canal d'Valle
Valle Cannelle
Valle Morosina
Valle Passarella
Valle Spolverina
Valle Segà
Laguna di Caleri
Isola di Albarella
Rosolina
Valle Capitania
Valle Vallesina
Valle Veniera
Valle Sagreda
Valle Pozzatini
Porto Levante
Po di Levante
MARE ADRIATICO
Valle Bagliona
Collettore Padano Polesano
Porto Viro
Valle Sacchetta
Laguna Vallona
Valle Chiusa
Valle Baglioncina
Valle Canocchione
Valle San Leonardo
Valle Scanarello
Valle Ripiego
Valle Moraro
Boccasette
Taglio di Po
Valle Ca' Pisani
Valle San Carlo
Laguna Barbamarco
Laguna del Burcio
Busa di Tramontana
Batteria
Piano
Po di Venezia
Valle Ca' Pasta
Po di Maistra
Valle Ca' Zuliani
Pila
Busa Dritta
Ca' Zuliani
Po della Pila
Ca' Venier
Laguna del Basson
Busa di Scirocco
Tolle
Ca' Tiepolo (Porto Tolle)
Polesine Camerini
Rivà
Pisana
Donzella
Sacca del Canarin
Ca' Mello
Po di Tolle
Scardovari
Oasi Ca' Mello
Oca
Bonelli Levante
Sacca degli Scardovari
Po di Gnocca
Santa Giulia
Gorino Sullam
Po di Goro
N

The southern inlet (*Bocca Sud*) of the *Sacca degli Scardovari*.

_PREFACE

RECENT MORPHOLOGICAL EVOLUTION OF THE SACCA DEGLI SCARDOVARI

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Università di Padova

As part of investigations promoted by the Scientific Committee on behalf of the *Consorzio di Bonifica Delta Po Adige* a geographical database of physical, biological and ecological information available on the physical characteristics of the Delta's lagoons was set up. In this context, the knowledge of cartographic and topographic characteristics was very important, allowing for the reconstruction of the most recent morphological changes undergone by the *Sacca degli Scardovari*.

The analysis of these data, supplemented by an extensive series of photographs starting with the GAI flight in 1955, is the subject of the contribution of Eng. B. Matticchio, which is part of the first edition in a series of books that the *Consorzio* intends to issue illustrating technical and scientific studies promoted in recent years.

Of the problems the Sacca has recently undergone concerning the preservation of the lagoon system, our attention is drawn to two aspects in particular. The first is the stability of the coastal barrier separating the Sacca from the sea. Over the last sixty years, this coastal barrier has been affected by intense dynamism capable of changing its location and elevation over relatively short periods, as is clearly evident when comparing geo-referenced aerial photographs.

The coast underwent major regression and changes in its configuration from which it has yet to recover, in the years following the First World War. This is a complex phenomenon, fueled by not yet fully understood natural processes and heavily influenced by the work of man, in particular in the 1950s with the extraction of methane water and the subsequent years' interventions on the branches of the Delta closest to the Sacca in order to increase their flow capacity in case of flooding. These measures contributed in changing the interaction of coastal currents induced by storm waves, and sediments of fluvial origin. The intensity of these processes is particularly evident when examining the evolution of the seabed closest to the shoreline in front of the Sacca as documented, at times in great detail, in available bathymetric surveys.

Of the problems concerning the Sacca, the stabilization of the shoreline is an absolute priority in order to prevent the risk, as in the 1960s, of the Sacca losing its original characteristics and becoming a part of the sea. The second interesting aspect is the evolution of Sacca's lagoon beds, which condition the tidal current circulation and ultimately, the exchange of water in the hydraulically more distant ends of the basin as well as the stability of the inlets.

When looking at bathymetric survey results, the lagoon beds' tendency to deepen

and to a certain extent, become more uniform is clearly evident. The main cause of this phenomenon is undoubtedly subsidence following the afore-mentioned extraction of methane water throughout the Delta.

This resulted in important general morphological changes, although did not change what has always been a feature of the Sacca, i.e. the presence of a hydraulically more active area closer to the sea and separated from the far side by a shallow zone where the intensity of tidal currents abates, reducing the importance of the role of tidal currents on water exchange, which is primarily caused by wind-induced secondary circulation phenomena.

The availability of bathymetric surveys on the Sacca referring to different periods presented some very interesting investigative scenarios, and offer the possibility of comparing the results of the mathematic modeling of changes in its hydrodynamic behavior, morpho-dynamics and sea-lagoon exchanges in particular.

This analysis, carried out on both fixed and moving lagoon beds in order to take into account, above all, transport phenomena induced by waves upon which the contribution of Delta branch's solid transport is superimposed, could help clarify evolutionary processes recorded in recent years, while addressing possible solutions to current problems.

Looking ahead, another point of interest could be the evaluation, again using mathematic models, of the consequences of stratification between the sea's salt water and fresh water of the Delta's secondary branches in the Sacca that lead to the limits of the shoreline boundary.

This is an aspect to be further explored with a specific series of measurement surveys, as bodies of freshwater are driven by tides and wind inside the Sacca and tend to stagnate in the part furthest from the inlet, creating a more pronounced horizontal stratification, and at times causing problems in marginal areas and the environmental quality of these areas.

As is quite evident from this brief account, that apart from the undoubted value of the analysis itself, as conducted by B. Matticchio on the collected morphological data, the potential development of the knowledge acquired could be used in the streamlining of increasingly sophisticated morphological numerical models that scientific progress has made available in the past, and will continue to do so in the future.

_STUDY

RECENT MORPHOLOGICAL EVOLUTION OF THE SACCA DEGLI SCARDOVARI

BRUNO MATTICCHIO
Ipros Ingegneria Ambientale Srl

The periodic undertaking of aerophotographic flights and topographic bathymetric surveys has allowed for the morphological analysis of changes to the lagoons, their beds and the shoreline separating them from the sea, while noting the effects of excavations and observing its evolution over time. The possibility of archiving and analyzing data within a geographic information system (GIS) enables us to monitor and quantify morphological variations of the coastal systems in an evermore-precise way, providing useful support in the planning of interventions.

In this work we expound certain results of surveys conducted in order to evaluate the *Sacca degli Scardovari*'s morphological changes since 1950, distinguishing the lagoon from the sandbar that defines its boundary using available aerial photographs and bathymetric surveys. The lagoon was subdivided into homogenous areas including internal stretches water, salt marsh areas and sandbars. It also considers the recent evolution of inlets and the seabeds in the stretch of sea in front of the lagoon. The purpose of the evaluations is to provide support in the planning of defensive and regenerative interventions, and the establishment of programs to monitor and control evolutionary trends.

Brief historical background: the *Sacca degli Scardovari* prior to 1950

It's a known fact that the formation of the *Sacca degli Scardovari* was mainly due to Venetian interventions carried out in the early 1600's in order to prevent river sedimentation, originating from the Po River and deposited in the sea, being driven north by coastal currents and interfering with the Veneta lagoon.

The interventions, of which the most famous is the *Taglio di Porto Viro*, where intended to divert the Po River's flow eastward and southward leading to the rapid expansion of the Po delta over the following two centuries and resulting in the formation of most of the lagoons that are currently distributed along the coast, including the *Sacca degli Scardovari*.

The Sacca, landlocked in the peninsulas of the branches of the *Po di Goro*, and the *Po di Gnocca* to the southwest and the *Po di Tolle* peninsula to the northeast, began its formation in 1800. Its northern side currently corresponds with what would have been the coastline in the early nineteenth century, while the eastern side and western sides correspond with the shores of the aforementioned peninsulas. In the 1800s the *Po di Tolle* underwent rapid development.

The morphological evolution of the Sacca during the nineteenth century can be seen in detail by looking at a series of land surveys carried out in 1811, 1860, 1886, 1896 and 1905 (*Magistrato alle Acque* 1950). In particular, in the second half of the 1800s, the channels of the *Po di Gnocca* and *Po di Tolle* were shorter.

They flowed into the sea at *Canestro* and *Busa di Garbin* respectively, thereby forming the borders of delta formations in the inner part of the lagoon and what is now known as the *Sacca degli Scardovari*.

Later, at the beginning of the twentieth century the rapid southward movement of the mouths of the *Po di Tolle* and *Po di Gnocca* resulted in the formation of a second outer basin (the *Sacca di Bottonera*) connected hydraulically with the *Sacca degli Scardovari* forming a single lagoon.

The growth of the mouths of the branches of the *Po di Goro*, *Po di Gnocca* and *Po di Tolle* stopped in the first decades of the 1900s mainly because of subsidence and a reduction in the Po River's sedimentation.

In recent years the lagoon has been characterized by a planimetric configuration (Figure 1), corresponding only in part with what we can see today. If the perimeter of the basin, with the exception of some areas on the western side, is practically the same at present, the internal morphology is appreciably different, having been characterized by vast emerged areas along the perimeter, which have now disappeared entirely. Besides this, the conformation of the sandbars separating the lagoon from the sea, is profoundly different and has over the years, continued to undergo considerable changes.

During the first half of the 1900s, the lagoon suffered only slight morphological changes as highlighted when comparing the map as seen in Figure 1 and the aerial views of 1949 and 1955 as seen in Figure 2. Note in particular the recovery and agricultural use of the salt marsh areas

Figure 1 : current perimeter of the *Sacca degli Scardovari* superimposed on the *Istituto Geografico Militare* map, Sheet No 77, Comacchio, 1:100 000 scale, completed in 1938.

positioned in the west between the *Sacca degli Scardovari* and the *Sacca di Bottonera* in the *Canestro* area thanks to the creation of a small defensive embankment (absent in Figure 1 and the IGM flight aerial photos of 1931-33, but already visible in the aerial photos from the 1949 IGM flight).

The reclamation was short-lived mainly due to storms caused by the Sirocco that, over a short period damaged and destroyed weak defensive embankments protecting the land (*Magistrato alle Acque*, 1950). A second attempt to recover salt marsh areas for agricultural use in the same period can be found near the mouth of the *Po di Gnocca* (*punta del Polesine*). This can in fact be seen in the 1955 aerial photo (Figure 2) while not in the 1949 IGM flight aerial photo.

Please note that, in this period some minor branches of the *Po di Gnocca* and *Po di Tolle* still flowed into the lagoon basin determining low-salinity water conditions as seen in the remarkable development of fragmites along the area between the lagoon and the mainland. (*Magistrato alle Acque*, 1950).

The major morphological changes that occurred in the first fifty years of the twentieth century can be found on

the beaches separating the lagoon from the sea.

The more recent evolution of these morphological structures, as documented by detailed topo-bathymetric surveys, is the subject of current work and is illustrated later; here we can only note that between 1931 and 1949 (IGM Flights) the southern sandbar moved back some 500 m, at the same time stretching southwards (Figure 3).

This retraction changed the shape of the mouth of the *Po di Tolle* and in particular, caused the secondary branch supplying the *Sacca degli Scardovari* (visible in Figure 3 on the IGM Map in Figure 1) to disappear.

For a more extensive and detailed description of the historical evolution of the *Sacca degli Scardovari* prior to the 1950s, please refer to the work of Masters (1981), Bondesan (1985, 1990), Veggiani (1985) and especially that of the *Magistrato alle Acque* (1950 and the citations within).

The following is an illustration of activities undertaken in the analysis of the Sacca as of 1950. The survey is based on the elaboration of much more accurate topographical data than that previously available.

From this date on, in addition to the availability of aerial photos, there are detailed bathymetric surveys of the whole of the bottom of the lagoon basin that allow for the analysis of the morphological evolution of the lagoon and accurate estimates regarding its evolutionary trends.

Figure 2: aerial photo of the *Sacca degli Scardovari*, 1955 (GAI flight). The dotted red line represents the perimeter of the Sacca as we know it today.

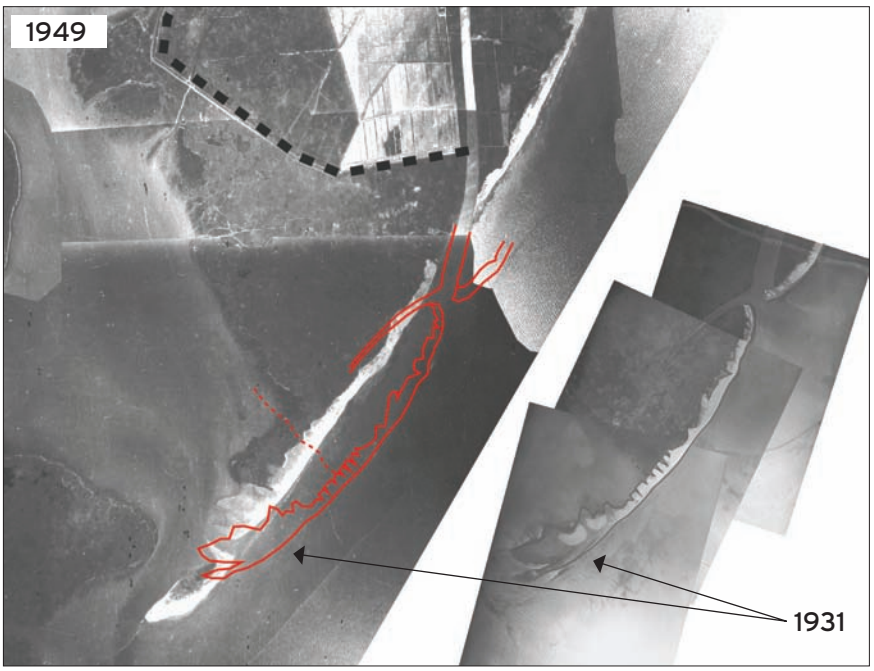


Figure 3: aerial photographs taken in 1931 and 1949 (IGM Flights) of the sandbar of the *Sacca degli Scardovari*. The solid line on the 1949 photo shows the contour of the bank as seen in the 1931 photo and dotted line represents the perimeter of the Sacca today.

Survey methods

The *Archivio Geografico delle Lagune del Delta del Po*, recently created by the *Consorzio di Bonifica Delta Po Adige*, is the information database from which data were drawn and processed. Its objectives are as follows:

- to collect and compile various existing data relating to not only the physical structure of the lagoons and their evolution, but also to their socio-economic aspects. An archive is then created and organized according to the level of information useful in the management of the lagoon system.

- to provide a tool for the analysis and comparison and cross referencing of different information and results of monitoring programs and studies, thus enabling communication with the Delta's technical services personnel and supporting project development.

- to build a structured and up-gradable archive that facilitates the implementation of new data and the sharing and dissemination of information and results of studies.

The archive has been built, based on a GIS in relation to the specific functional requirements related to the various ways in which data will be used, not only by the *Consorzio di Bonifica Delta Po Adige* but by all of the Delta's technical services personnel. Parallel to the data implementation we have provided a *metadata* catalogue in accordance with current requirements and specifications in force, relating to the storage of geographical data.

The documentation of data is an essential element in the sharing of information, particularly with reference to scientific studies and monitoring programs, and is therefore an important part of the planned network-sharing of the *Archivio Geografico delle Lagune del Delta del Po* (WEBGIS).

When referring to the *Sacca degli Scardovari*'s recent morphological evolution mainly two types of information contained in the GIS were used: Aerial photographs and topo-bathymetric surveys.

Aerial photo analysis

When analyzing the evolution of the *Sacca degli Scardovari* and the sandbars delimiting it from the sea, geo-referenced aerial imagery has proved to be a very effective tool and in many cases and has also enabled the obtaining of geometric quantative assessments. The *Archivio Geografico delle Lagune* contains details of the main flights covering the delta coast from 1949 to date. In particular, the following flights have been taken into consideration: IGM 1949; GAI 1955; IGM 1977; ReVen 1983; ReVen 1990; ReVen 1999; orthophoto IT2003; orthophoto 2006; flight CDBPA 2008.

All aerial photographs were available in digital format except those frames

taken on flights IGM 1977 and IGM 1949, which were scanned from prints of the original photographs.

In some instances photos were available already geo-referenced in the Gauss Boaga reference system (GAI flight in 1955, orthophoto IT 2003 and orthophoto 2006). In all of the other cases however, geo-referencing was carried out using a *checkpoint method* on the *Carta Tecnica Regionale* (Regional technical map) at a scale of 1:5 000 (orthophotos IT 2000 and IT 2003). In other particular situations, comparing the *DEM* derived from the LiDAR survey carried out by the *Genio Civile* of Rovigo in April 2006 proved to be very useful.

The difficulty in geo-referencing Flight IGM 1949's images was not only due to its poor quality black and white photographs, but also the considerable changes that the territory has undergone from the period in which the photograph was taken and the map was published, affecting data retrieval and identification of checkpoints especially along the sandbars. It is therefore possible that the 1949 photos of the aforementioned areas have been subject to some distortion thus limiting their accuracy.

The images taken on each flight were put together like mosaics; they were assembled in a way that allows them to overlap in order to create an image with homogenous geometric resolution, color, brightness and contrast.

For every mosaic, a composite of the frames was created, which was then archived in the GIS. The composite contained the original identification code of each frame, the date and time of each shot and the height of the tide as attributes.

Regarding this, and in gene-ral when referring to the digitization of all the morphological elements considered, research was carried out in order to establish the tidal level corresponding to the different photographic series. The date and time of shot of every frame were pin pointed and are readable on the photos themselves.

Having identified each moment in this way, the height of the tide was established using available records, complete as of 1983 and limited to extreme values for years before, in part relating to the marigraph of the *Diga Sud Chioggia*, and in part to the *Punta della Salute* in Venice, now managed by *ISPRA* of Venice.

In the first case the data were also considered valid for the Po delta because the delay of the astrological component of the tide in propagation between the coast of Chioggia and the Delta is only a few minutes.

In the second case, the tide level time series was brought forward by one hour, thus accounting for the delay that is observed between the Adriatic tides and those of the *Punta della Salute*.

It was then necessary to correct the older tidal data taking into account that the zero sea level at the *Punta della Salute*, against which the data are referenced has over time, progressively dropped due to a combined effect of eustacy and subsidence, to the current level of approximately 25 cm below the average sea level generally used as a point of reference (Genoa, 1942). Therefore, tidal levels before 1980 have been corrected using the previously mentioned reconstruction proposed by Gatto and Carbognin (1981).

The following Table 1 shows values obtained using the above method, representing an average of those values relating to the single frames that make up each mosaic. Unfortunately the data are incomplete in some cases (flights GAI 1955, IT2003 and 2006) because the instant in which the photo was taken could not be established. One sees that tidal

Flight	Date	Time	Level (m.a.s.l.)	Sea conditions
IGM 1949	10/07/1949	10:55÷11:24	0.14	*medium-high*
GAI 1955	n/a	n/a	n/a	*n/a*
IGM 1977	10/08/1977	12:18÷12:26	-0.05	*medium*
ReVen PD-RO 1983	10/05/1983	12:17÷13:52	-0.21	*low*
ReVen 1990	05/05/1990	11:56÷12:29	-0.57	*low*
ReVen 1999	05/07/1999	9:34÷10:50	-0.15	*low*
orthophoto IT2003	n/a	n/a	n/a	*n/a*
orthophoto Agea 2006	n/a	n/a	n/a	*n/a*
CDBPA 2008	09/02/2008	14:55÷15:01	-0.64	*low*

Table 1: sea conditions as per each individual aero-photographic flight.

conditions from one flight to another may vary considerably, with differences of up to 0.5 m. In particular the 1990 and 2008 flights show more accentuated lower tides with sea levels of -57 and -64 cm respectively. In other cases, medium to low tide conditions prevail and the sea levels range from 0 cm to about 20 cm.

These indicative values therefore, are not devoid of practical meaning in that they provide useful support to the analysis and interpretation of aerial photos especially in identifying shorelines and partially submerged forms.

It must be pointed out that because of the criteria adopted in digitization and the macroscopic size of the movements of the analyzed morphological elements (around sand bars in particular), for the most part, the influence of tidal conditions on the obtained results is minimal.

Bathymetric data analysis

The basis for evaluating morphological variations that the beds of the *Sacca degli Scardovari* have been subject to is based on bathymetric surveys describing the geometric structure of the submerged areas and lagoon canals in different periods. All available bathymetric data supplying a representation of either the Sacca or at least some parts of it, is stored in the *Archivio Geografico delle Lagune*. These data refer to surveys conducted by different entities from 1950 onwards, while data recorded prior to 1950 was not considered detailed or extensive enough to be of significant use to the surveys.

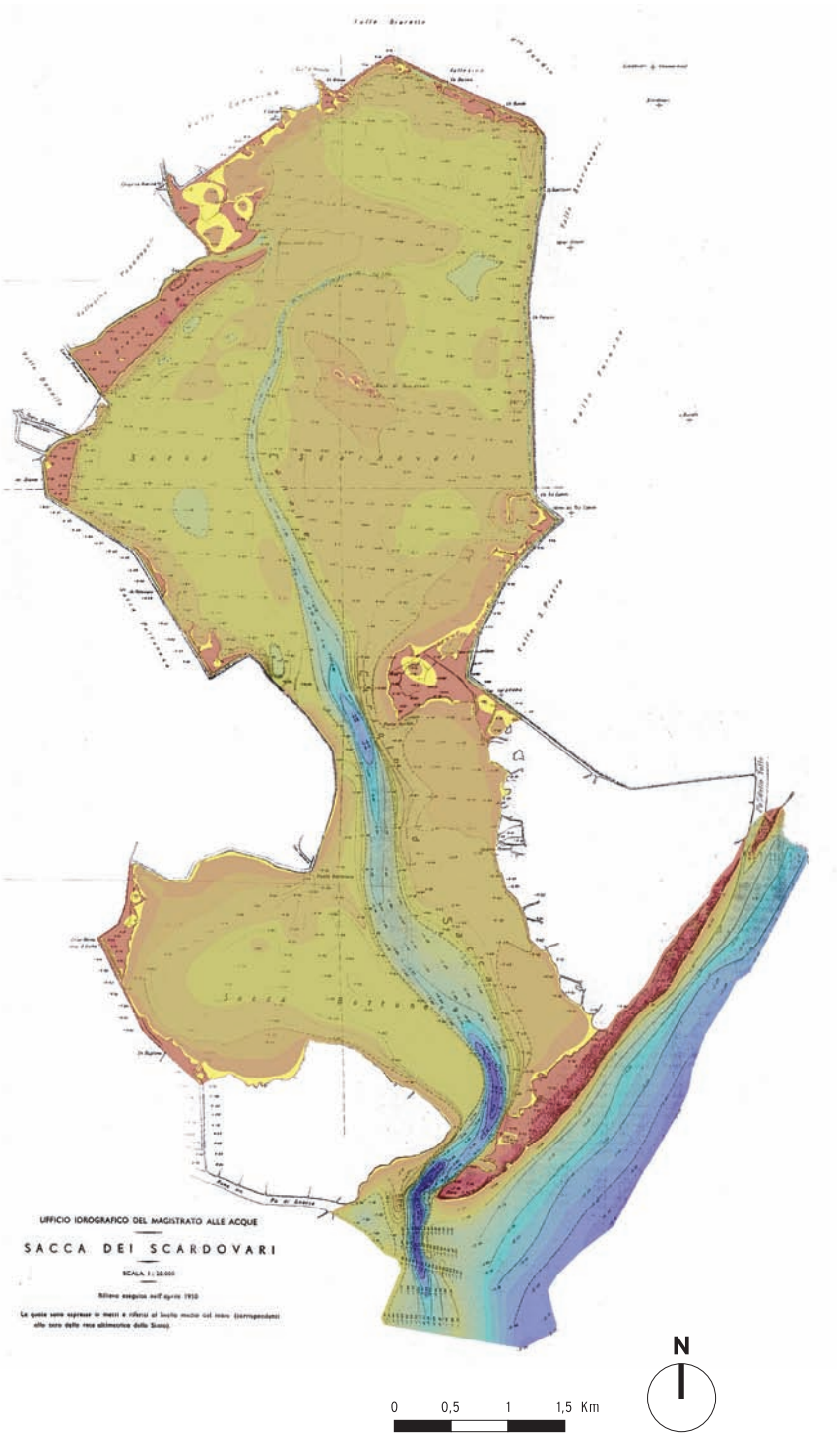


Figure 4: elaboration of the 1950 bathymetric map using the superimposed digital model.

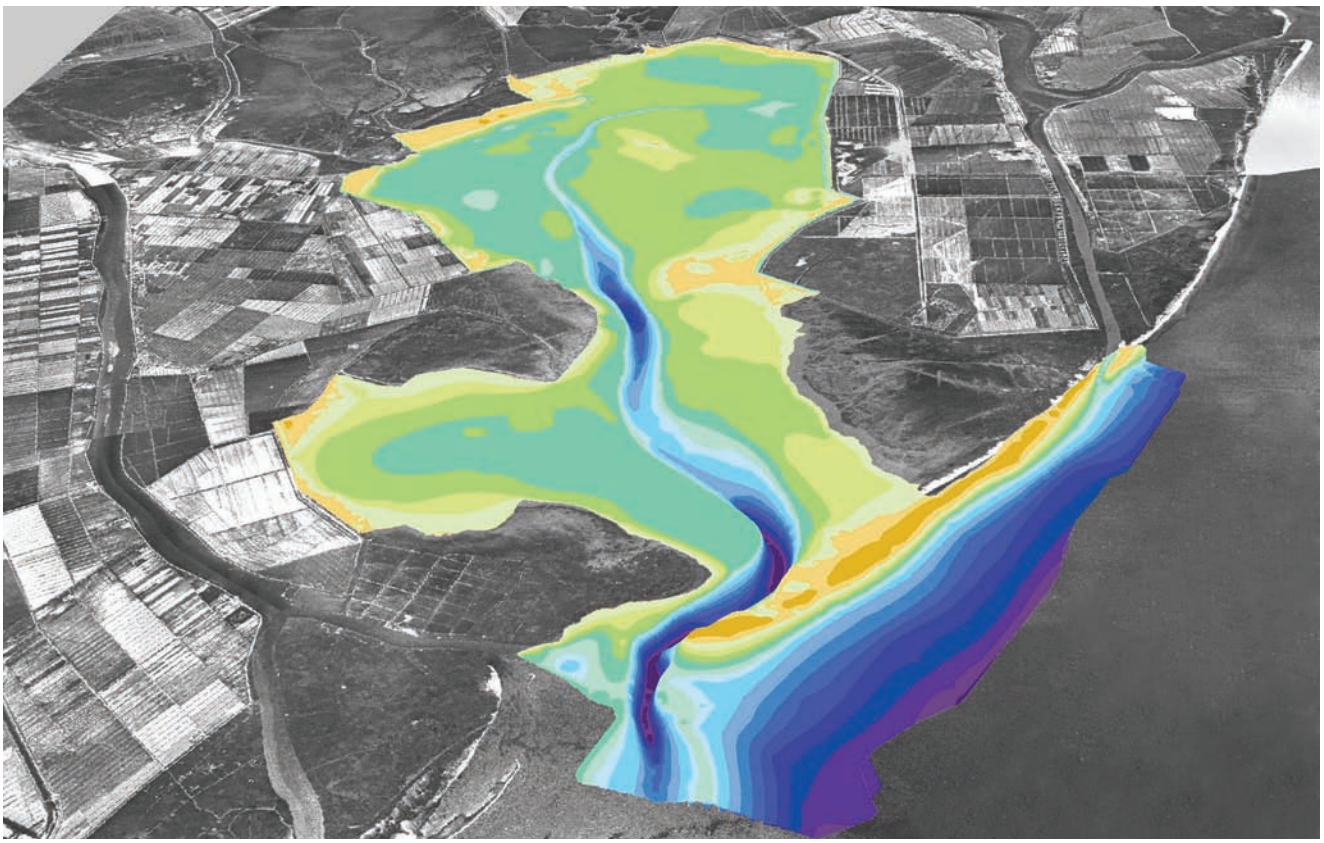


Figure 5: perspective view of the aerial photograph (GAI 1955) with the superimposed digital model of the 1950 bathymetric map.

The 1950 bathymetric survey

The first detailed bathymetric survey of the entire *Sacca degli Scardovari* was conducted by the *Ufficio Idrografico del Magistrato alle Acque* in April/May 1950. The 1:20 000 (*Magistrato alle Acque*, 1950) paper map was accompanied by an extensive report that in addition to providing precious data on the morphology of the Sacca prior to 1950, also describes the methods used in taking measurements and the landmarks used as points of reference.

The measurements are expressed in meters and refer to the average sea level corresponding to the zero tide level of the altimetric grid of the State (1898). From this report, we see the problems in correctly classifying altimetric plains of the survey in an area subject to such strong variations are well acknowledged by the authors of the study. A series of assessments were made based mainly on comparisons between mareographic measurements taken specifically in the Sacca, and tidal trends of the *Punta della Salute* in Venice Lagoon.

Based on these assessments one arrives at, on one hand, the quantification of the lowering of local altimetric landmarks, and on the other, an estimate of the rising of the average sea level in the Sacca in respect to the zero tide level of the altimetric grid of the State.

In particular, the increase was said to be about 12 cm, i.e. the same amount recorded in Venice. Strictly speaking, the bathymetric data shown on the map

would have to be corrected in order to be compared with other surveys. However, given the relatively small difference and above all, the notable uncertainties of the above evaluations, as highlighted by the authors themselves, the data were kept in their original format in order to facilitate testing and analysis.

The bathymetric map shows all the affected points, generally laid out in strips of about 250÷300 m across the whole of the Sacca, moving closer in the most significant areas like around the mouths of the sea and along the wide canal that crosses the whole lagoon longitudinally (*Canale Curiolo*). It also shows the isobaric curves, with equidistances of 10 cm in areas with deeper beds and 1 m along the *Canale Curiolo*.

Unfortunately, the survey doesn't cover the emerged areas, and in particular the large areas of salt marsh areas that span the two sides of the southern part of the *Sacca di Bottonera*. However, the map is rich in details allowing one to reconstruct, at least quantitatively, the morphology of these areas, especially those along the margins of the Sacca.

The map was scanned and geo-referenced using the Gauss Boaga reference system. The necessary reference points were identified using the *Archivio Geografico delle Lagune*'s previous maps and in particular, the IGM maps and aerial photos taken on the 1949 IGM flight.

The bathymetric data were digitalized and converted into "*shape files*" in order to prepare a digital elevation model (*DEM*) necessary for data processing. Given the morphological complexity of the lagoon beds compared with the density of the available data, the digitization of additional points and polygons as to those present on the paper map was considered appropriate in order to 'bind' the *DEM*, in this way making it conform to the map.

Ultimately the shape files were grouped into the following 3 types:

- those containing only isobaric values indicated on the bathymetric map: points and isobaric lines.

- those containing data derived from information reported on the map (channels, emerged areas and banks), to which conventional values were applied e.g. on the edges of the canals the value of the nearest point was assigned and on the edges of the emerged areas and banks, representing the limits of the domain, a value 0.05 m.a.s.l. was assigned.

- those containing "fictitious" points, that is, bathymetric data included in order to complete the mesh in areas where the data obtained by digitalization doesn't allow for a faithful reproduction of the morphology represented on the paper map: for example the points on the edges and bottom of the canals were given intermediate values between the two nearest points based on the length of the canal, and points around the limits of emerged areas and on the inside of the sandbar, were given an intermediate value between the two nearest points.

The *DEM* was made using GIS elaborations. A *raster-grid* with a 2.5 m mesh was constructed using shape files to which a specified interpolation procedure following precise values of the points of contact (Natural Neighbor) was applied.

The superimposition of the *DEM* with the original map (Figure 4) enriches it, highlighting the most significant morphological details hereby documenting the profound differences with the Sacca in its current state.

The perspective view of the digital bathymetric overlap model of the aerial photograph (Flight GAI 1950) represented in Figure 5 is also of interest.

The 1967 bathymetric survey

In April 1967 the *Ente Delta Padano*, a body created with the aim of providing support for agricultural development in the provinces of Venice, Rovigo, Ferrara and Ravenna, conducted a new bathymetric survey of the entire *Sacca degli Scardovari*. The survey is represented in the form of a 1.25 000 planimetric paper map which can be found in the *Consorzio di Bonifica Delta Po Adige*'s archive.

As shown on the map, the survey was conducted under the "*Progetto di massima per la chiusura della Sacca dei Scardovari*" and values are expressed in meters with respect to the average sea level using the Entities' local landmark system as references.

The map shows recorded values that are spread over the entirety of the Sacca in transverse strips positioned about 300 to 350 m from each other, as well as isobaric curves with equidistances equal to 0.25 m.

All emerged areas separating the Sacca from the sea (*Scanno del Palo* and *Punta del Polesine*), the edges of the Sacca and areas surrounding the embankments are mapped in detail. Lastly, the map also shows a comparison between the outline of the *Canale Curiolo* inferred by the survey, and that derived from the 1950 bathymetric map highlighting planimetric movements.

As with the previous map, the Gauss Boaga system was used in the scanning and geo-referencing. The map was referenced using the metric grid on the map itself that refers to the aforementioned system. The result was then verified using a series of checkpoints found on the aerial photographs and maps found in

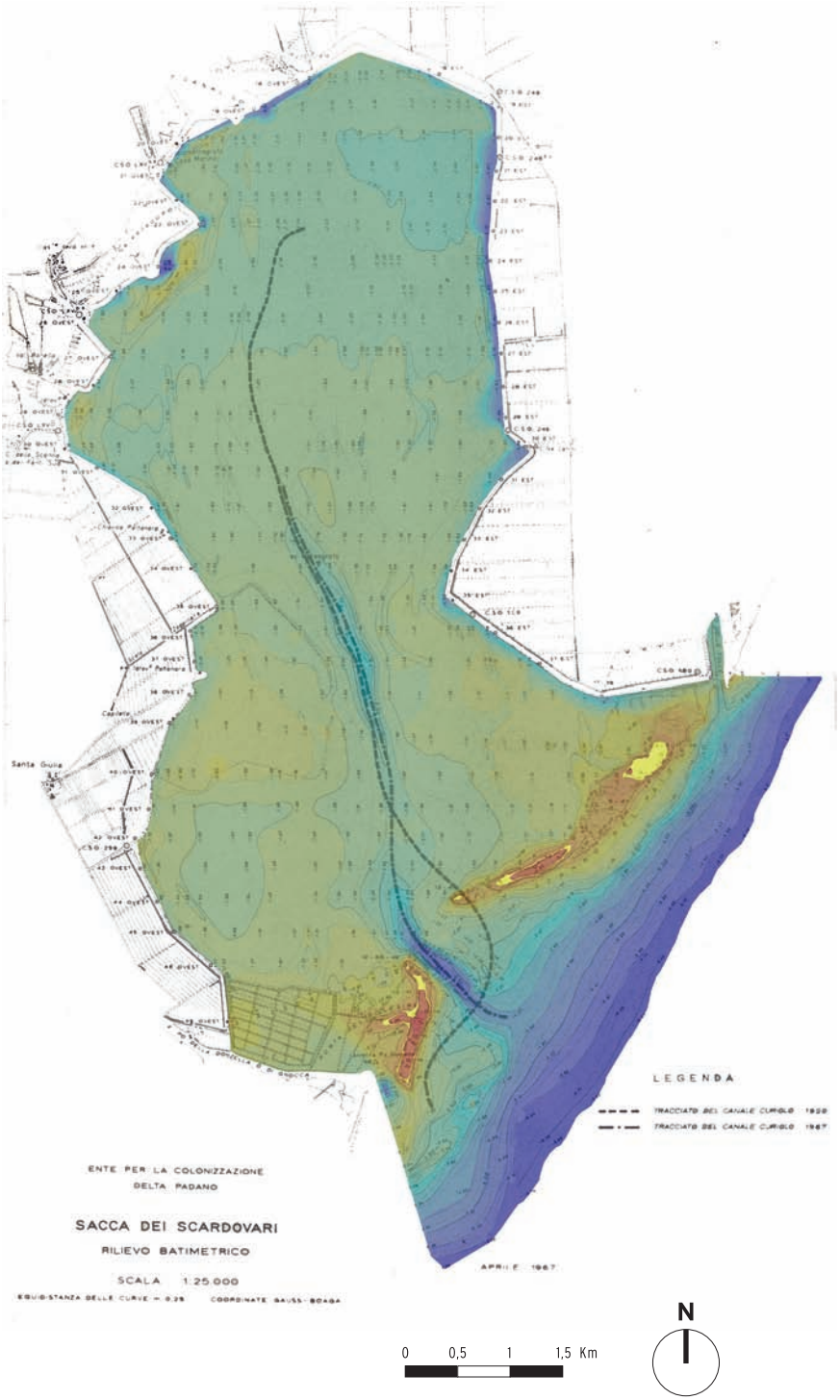


Figure 6: elaboration of the 1967 bathymetric map through the superimposition of the digital model.

the Archive.

All bathymetric data (survey points and isobaric curves) were converted into shape files. In this case, the density and distribution of the data with respect to the morphological complexity of the lagoon beds was deemed sufficient for construction of the digital model, therefore the construction of additional points and "fictitious" polygons was not required. Only one polygon delimiting the domain (Clip Buffer), necessary to exclude areas with no bathymetric data from the elaborations, was digitized. Figure 6 shows the superimposition of the *DEM* and the original map.

1991-1994 bathymetric survey

The following bathymetric survey of the *Sacca degli Scardovari* dates from the period 1991-1994. In those years projects were prepared for the hydraulic systemization of the Sacca, and in order to carry out these projects, the need for an updated bathymetric survey of the beds was recognized.

In 1991, the first full-scale bathymetric survey of the whole of the Sacca was realized and followed by, in 1994, a series of checkpoint strips at the southern basin (*Sacca di Bottonera*) and at the mouth of the sea.

Unfortunately the original data from the first survey was unable to be retrieved. The analysis was therefore carried out using digital format maps found in the *Consorzio di Bonifica Delta Po Adige Archive* showing the Sacca's planimetry and 0.5 m equidistant bathymetric curves. Only in the central and northern parts of the basin was the 20m-step digital grid used to construct the bathymetric survey's curves able to be used.

Therefore, even if the data can probably be considered more accurate due to the fact that more modern and efficient methods were used in the survey, it is in fact less detailed than those conducted in 1950 and 1967, at least in the *Sacca di Bottonera* and in the areas around the mouth to the sea and sandbars.

The *DEM* was reconstructed without the insertion of new points or additional polygons, but with the use of an outline polygon in order to delimit the domain of the digital model covered by the data in addition to the afore mentioned data, and was used for the elaborations described afterwards.

2008-2009 bathymetric surveys

In the years following 1994, the *Consorzio Delta Po Adige* conducted several different surveys mainly aimed at planning and monitoring the dredging of canals and the construction of artificial salt marshes in order to revive lagoon waters. The findings were incomplete and do not allow the construction of a real and complete "model" of the Sacca.

A detailed investigation covering the whole basin was only carried out in March 2008. The whole of the Sacca was surveyed using a regular 250 m-step bathymetric grid and densified with ulterior intermediate strips and detailed bathymetric surveys in canals and significantly important points.

Later in January 2009, a detailed survey including the lagoon bed was conducted at the mouth of the sea and at the *Scanno del Palo* using a grid with a step of about 50 m.

This data was then integrated with strips acquired in further bathymetric surveys conducted by the *Consorzio Delta Po Adige* in January 2008 aimed at detecting and detailing the geometry of the new canal that penetrates from the *Bocca Nord* across the north of the lagoon.

All of this data was assembled creating an ulterior altimetric digital model of the Sacca (*DEM*) using the same procedure used in previous cases.

The Sacca's evolution: 1950 to today

The description of the morphological evolution of the *Sacca degli Scardovari* from 1950-2008, and the debate surrounding the phenomena and results determined by this evolution is divided into three parts in the following paragraphs. In order to have a clearer picture, distinctions have been made between descriptions of the evolution of the lagoon basin, around those relative to the salt marsh areas, sandbars and stretches of coastline facing the lagoon.

The lagoon

As reported previously, the *DEM* (Figure 7) was reconstructed using primarily data relative to the four bathymetric surveys of the Sacca available in the 1950-2008 period, with which it was possible to develop both quantitative and qualitative analysis of the evolution of the lagoon.

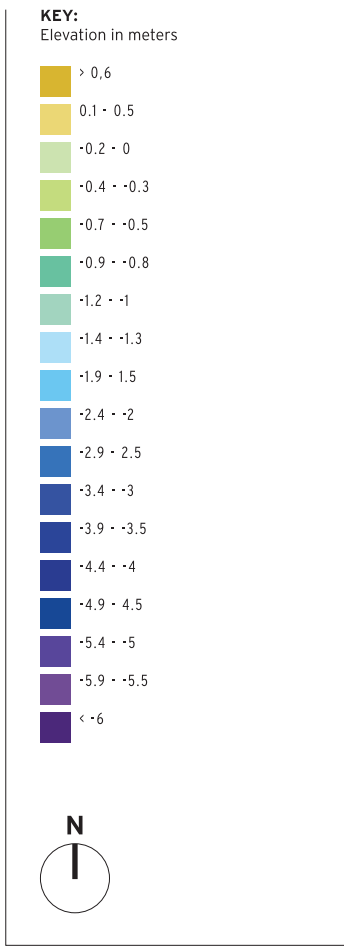
In 1950, as we have seen, the geometry and depths of the *Sacca degli Scardovari* were highly articulate due to the old internal deltas made up of the *Po di Gnocca* and the *Po di Tolle*'s secondary branches.

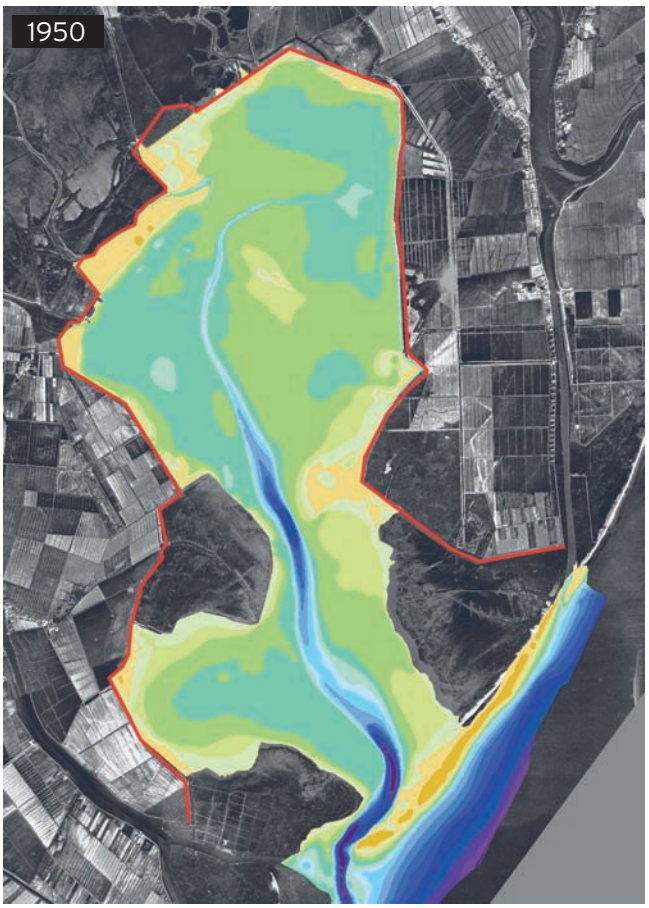
In the northern part along the whole margin there are groups of salt marshes and partially emerged areas where canal waters are deposited (by means of water scooping systems) or where there are sluice gates connecting with the *valli da pesca* (embanked fishing lagoons).

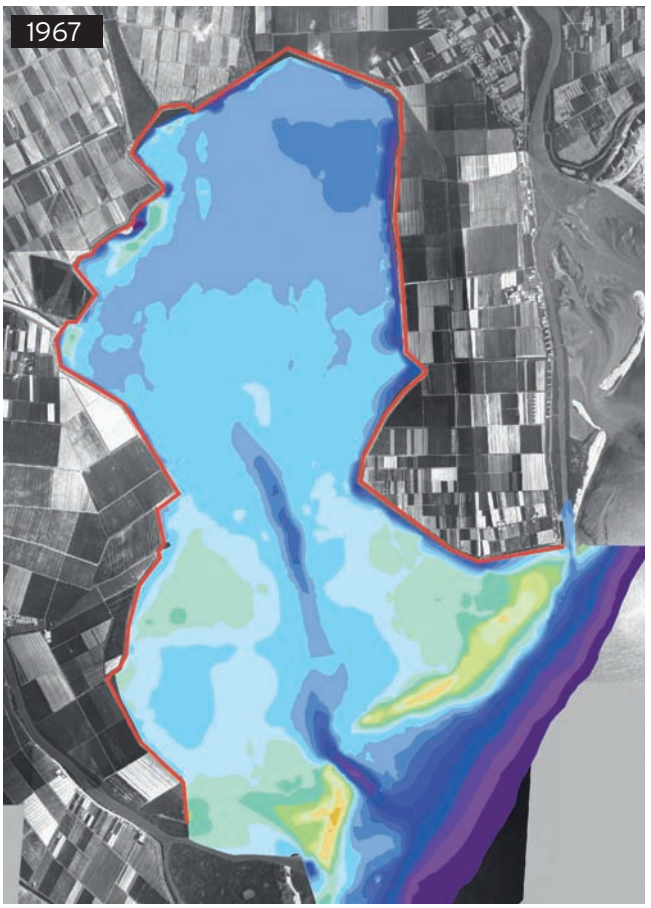
The lagoon's water surface area is characterized by the presence of a single large canal (*Canale Curiolo*) that from the mouth to the sea, runs towards the innermost edge, in the process developing almost rectilinearly across a wide section of the *Sacca di Bottonera*, then slowly weakening into a series of less-defined oxbows in the *Sacca degli Scardovari*.

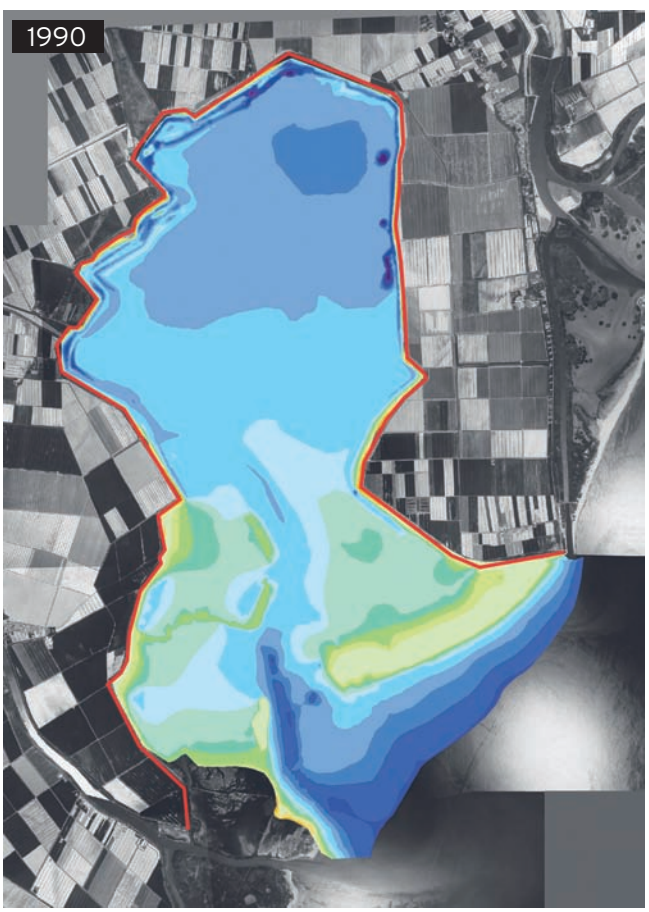
Across the whole lagoon, on the perimeters, there are large areas of salt marshes and stretches of shallow water, which the authors of the survey define as being "in a process of decay ", when compared with data from a previous survey performed in 1933-1935 (*Magistrato alle Aque*, 1950). In particular, these areas regard a cordon of shallow lagoon beds extending to the centre of the

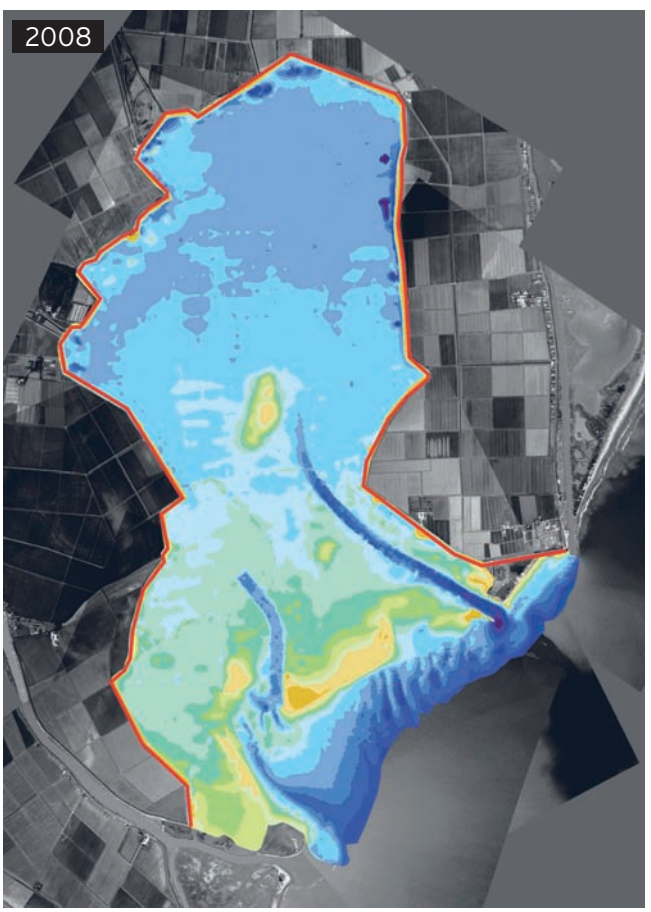
Figure 7: altimetric models of the *Sacca degli Scardovari* constructed from bathymetric surveys superimposed over the available aerial photos closest corresponding to the time frame of the former: bathymetry 1950 - GAI flight 1955; 1967 bathymetric survey - IGM flight 1977; 1991-1994 bathymetric survey - ReVen flight 1990; 2008 bathymetric survey - *Consorzio di Bonifica Delta Po Adige*; February 2008.




1950


1967


1990


2008

Sacca degli Scardovari (*Bari di Scardovari*) and the salt marsh areas along the eastern embankment towards the strait closing the *Sacca di Bottonera* (*Punta Garbin*).

In phases of erosion, as defined by the authors of the survey, the salt marsh areas extending along the western perimeter are seriously damaged, principally by the action of the sea Sirocco, as is the bordering embankment on that same side that excludes the vast *Canestro* area from the lagoon.

The same authors define the salt marsh areas, be it those along the eastern edge or along the western edge of the *Sacca di Bottonera*, taking into account the evolutionary process to which the sandbar is subjected that seems to progressively limit the sea mouth area, as stable in their conformation and size.

Compared to other maps represented in Figure 7, the depths of the sea beds in 1950 are somewhat more limited and, in the northern part, reach a maximum of about 0.9 m.a.s.l. This bathymetric situation probably favors mixing processes and therefore allows for a good hydraulic exchange determined by the combined action of the tides and the process of dispersion due to the heterogeneity of the kinetic fields, which is in turn linked closely to the variety of sea bed depths.

Compared to the situation illustrated in Figure 1, which represents the conformation of the lagoon in the first part of the 20th century, the 1950 map shows an expansion of the salt marsh areas reclaimed and protected by man made embankments on the western side of the Sacca (*Sacca Paltanara* and *Canestro* area). The embankments' construction represents an important aspect of morphology in that it is found in the transitional zone between the land and lagoon. It also represents a clear separation between these two environments and determines evolutionary trends independent of the lagoon bed and mainland.

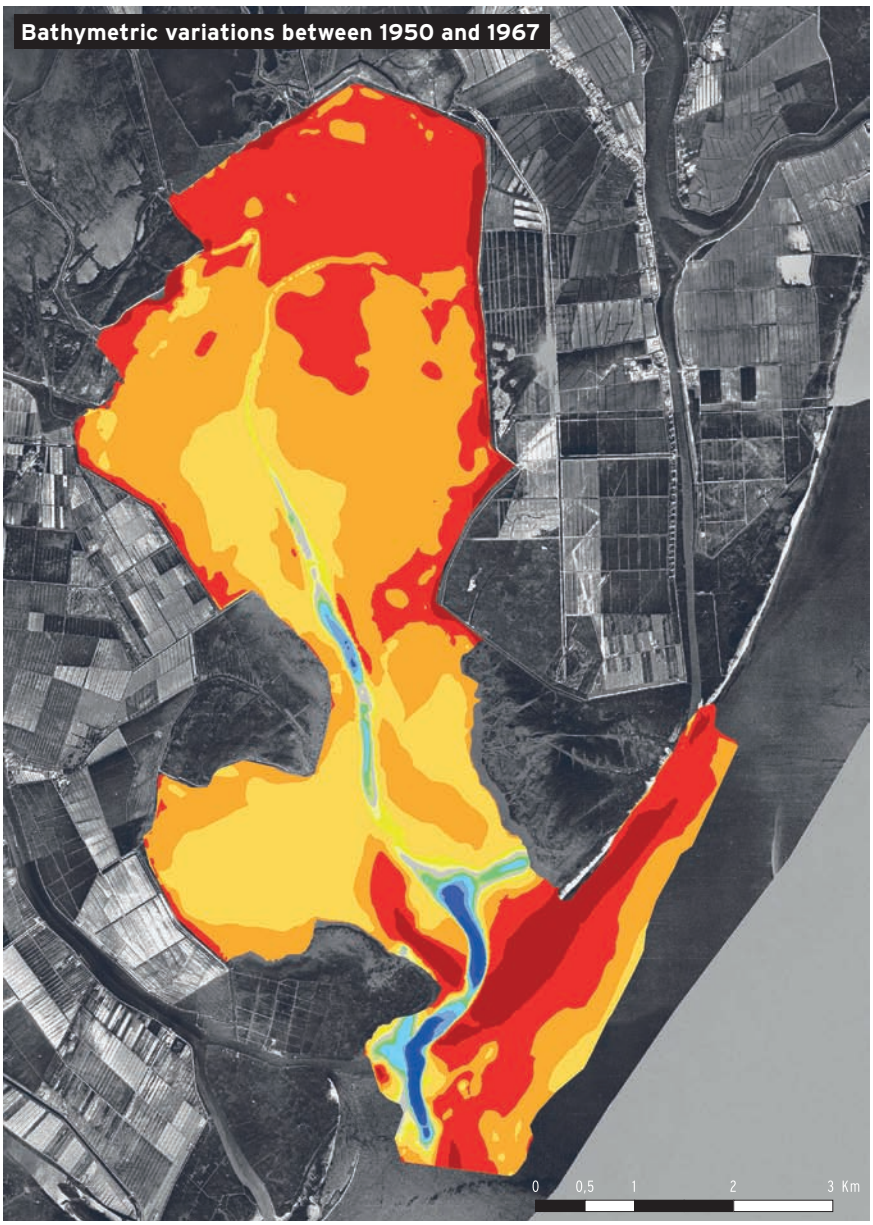
If you compare the 1950 bathymetric survey with that of 1967 (see Figure 7) considerable differences can be noted. In fact in the brief period between the two surveys, the lagoon underwent profound changes from a morphological point of view. In short, in the northern most part there is a general deepening of the seabed, accompanied by a loss of morphological heterogeneity and the almost complete disappearance of the *Canale Curiolo*.

In the central part we see the disappearance of marginal salt marsh areas, both on the western side (*Canestro* area) and on the eastern side (*Punta Garbin*). In the southern part, the emerged areas that in 1950 closed both sides of the *Sacca di Bottonera*, by 1967, had disappeared completely. Finally one sees the considerable retreat of the sandbar separating the lagoon from the sea.

These profound changes were mainly caused by two factors. The first being the phenomenon of subsidence, which, from 1945-1960 was significantly accelerated due to the extraction of methane from wells distributed over the whole *Polesine* delta area.

In this regard, despite not having precise figures, it is said that the lowering of the land in the northern part of the Sacca is in the order of meters (Gambardella *et al.*, 1991). Smaller drops have affected the southern most part of the lagoon

Figure 8: differential model of the Sacca's bed variations in 1967 compared to the 1950 Bathymetric Survey's values. Background: IT2000 orthophoto.



KEY:

- decrease of more than 3 m
- decrease of between 3 and 1.5 m
- decrease of between 1.5 and 1 m
- decrease of between 1 and 0.5 m
- decrease of between 0.5 and 0.25 m
- decrease of between 0.25 and 0.1 m
- stable
- elevation of between 0.1 and 0.25 m
- elevation of between 0.25 and 0.5 m
- elevation of between 0.5 and 1 m
- elevation of between 1 and 1.5 m
- elevation of between 1.5 and 3 m
- elevation of more than 3 m

N

presumably provoking a reduction in dimensions of the sandbars thereby resulting in a weakening of said sandbars.

In regard to this, it is to be observed that the land to left of the *Po di Tolle* was permanently emerged and used for agricultural purposes in 1955 (Figure 2 and Figure 7). In 1967, this terrain was completely flooded, forming the *Bonelli* Lagoon, bordered in the west and the north by two branches of the *Po di Tolle* (the mouth of the *Tolle* and *Busa del Bastimento*).

During the same period (1950-1967) some particularly strong sea storms caused by the Sirocco wind were noted, of which the most serious was that of November 1966 which further north, at the *Lido di Venezia*, caused extensive damage to the *Murazzi*, the dyke defense made of blocks of Istria stone built to protect the lagoon from the sea.

In particular in November 1966 these storms, when coming into contact with the weakened natural defenses, caused the sandbars to be covered and large portions of the *Isola della Donzella*, that is the territory between the *Po di Tolle* and the *Po di Gnocca*, to be flooded.

The strong storms, spread over seabeds significantly deepened by subsidence, caused intense erosive processes also in the more internal part of the lagoon, which in all probability helped to further deepen this part of the Sacca.

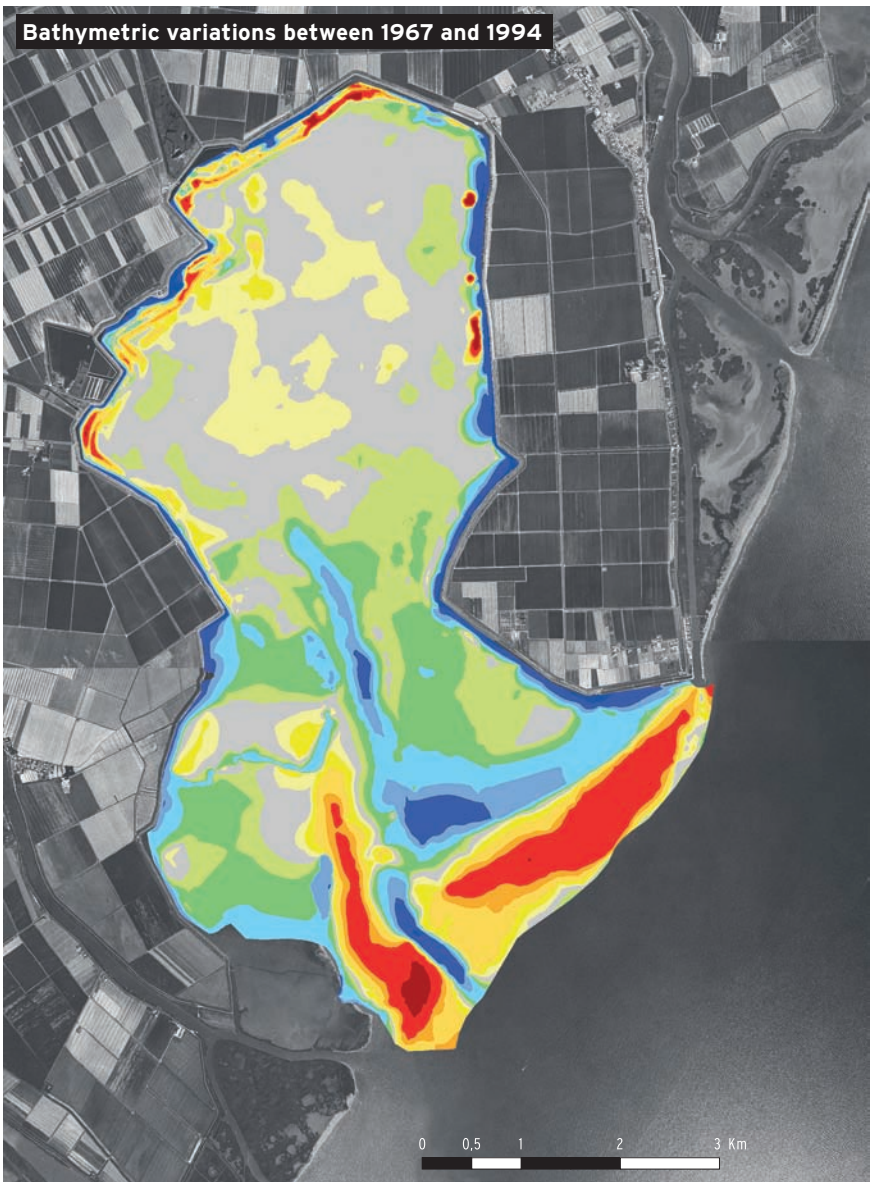
The homogeneity of the values of the lagoon bed, as it remains to this day, can presumably be attributed to the wave motion phenomena, specifically that which is generated within lagoons affected by the Sirocco. In fact, with a depth of 2.0÷2.5 m, wind speed often

exceeding 10 m/s and a fetch of 3÷4 km, lagoon waves as big as 1 m may develop in the northern part of the lagoon producing effects capable of moving lagoon bed sediment. It is also to be noted that immediately after the events of 1966, the Sacca's dyke, damaged by the sea storm was rebuilt and raised to its current size, resulting in an even bigger separation between the mainland and the lagoon.

The differentials between the two bathymetric surveys, constructed using the GIS process, and illustrated in Figure 8 provide an immediate and quantitative picture of the morphological changes the lagoon underwent between 1950 and 1967. One observes in particular, the way in which most of the lagoon beds have suffered a drop of between 0.5 and 3.0 m. Generally, one sees from the map that the area most affected by the dropping of the lagoon bed is found in the northern part of the Sacca, including the sandbar area and the strip of sea just in front of them.

The wide, dark, elongated red band running in a NE-SW direction that represents the erosion of the *Scanno del Palo*, with drops of more than 3 m in total, is particularly evident. The few areas where the beds have risen are limited to those taken from the outline of the *Canale Curiolo* (canal bed increases of greater than 3 m) and two small areas adjacent to it (in pale blue) corresponding to the new location of the sandbars (which have migrated northward) as seen in the 1967 data.

In the southernmost part of the lagoon, two strips can be seen: one red (marked "decrease") and the other blue (marked "elevation") adjacent to these and stretching in a roughly N-S direc-



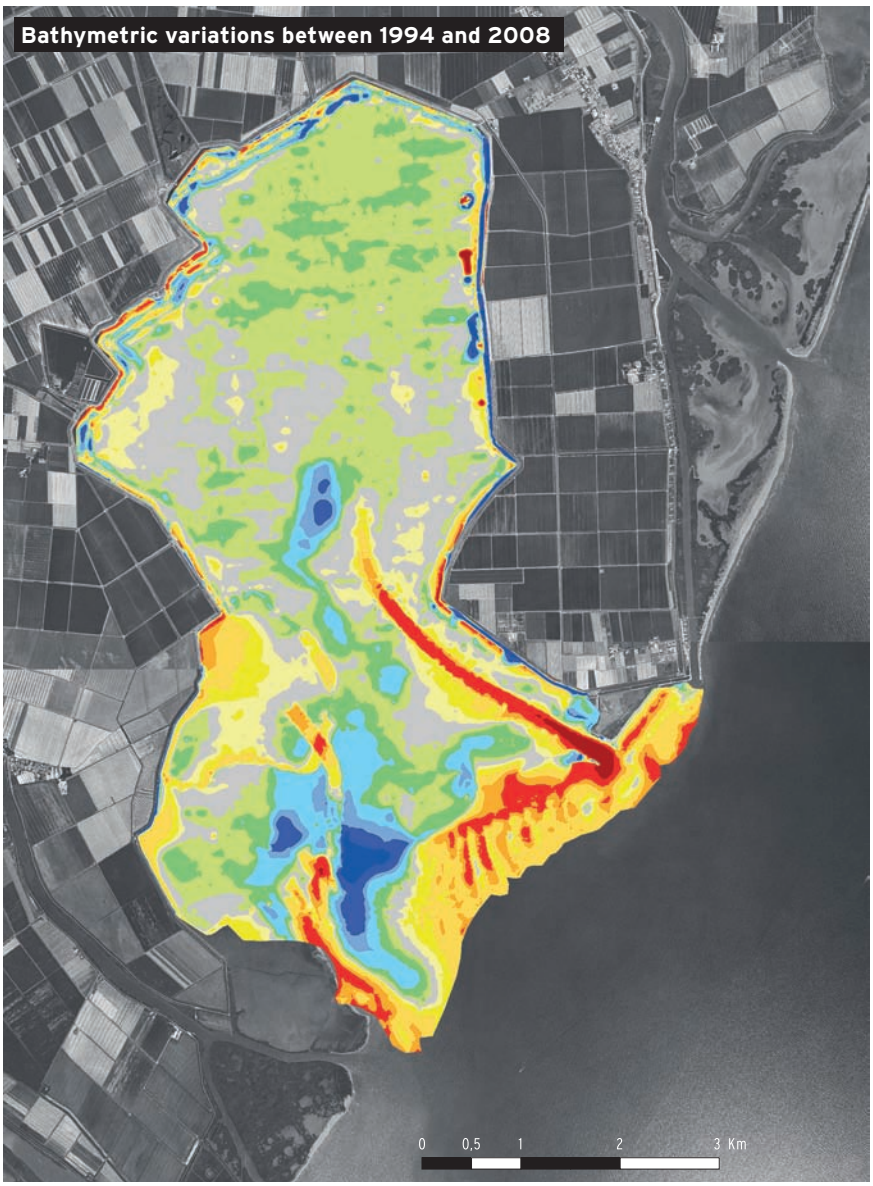


Figure 9: differential models of bed variations in the *Sacca degli Scardovari* between 1967 and 1994 and between 1994 and 2008. (The chromatic scale being the same as Figure 8).

tion. It's indicated that the axis of the *Canale Curiolo* underwent a significant shift of about 500 m towards the southwest in the section of its mouth between 1950 and 1967. This circumstance confirms the indication already present on the original 1967 bathymetric map in which the movement of the outline of the *Canale Curiolo* is schematically represented by two dotted lines (Figure 6).

There were modest changes to the internal part of the lagoon in the following years, as seen in the 1994 and 2008 bathymetric surveys (see Figure 7) and the differentials illustrated in Figure 9. From this we deduce that the deeper parts allow for swells to develop internally especially when the Sirocco blows, which tends to flatten the beds. With regard to this one can find an analogy to what is happening in the Venice Lagoon.

For more than a century the *Palude dei Sette morti* has been gradually and uniformly expanding, maintaining a depth of approx 2.0÷2.5 m. This phenomenon is interpretable as the result of the morphological dynamic set off by the wave motion, created by winds produced inside the lagoon basin (Faghe-razzi, Defina, Carniello, D'Alpaos, 2005, 2006, 2007).

Using the *DEM* as a base, an elaboration was constructed highlighting the Sacca's storage capabilities and the average depth of the lagoon bed as of 1950. The lagoon scope (intended as the part of the basin in which the beds are at an altitude of less than 0.0 m.a.s.l.) closed at the lagoon mouths , was taken into consideration for each year.

The results compared in Figure 10, highlight the considerable differences between 1950 and 1967.

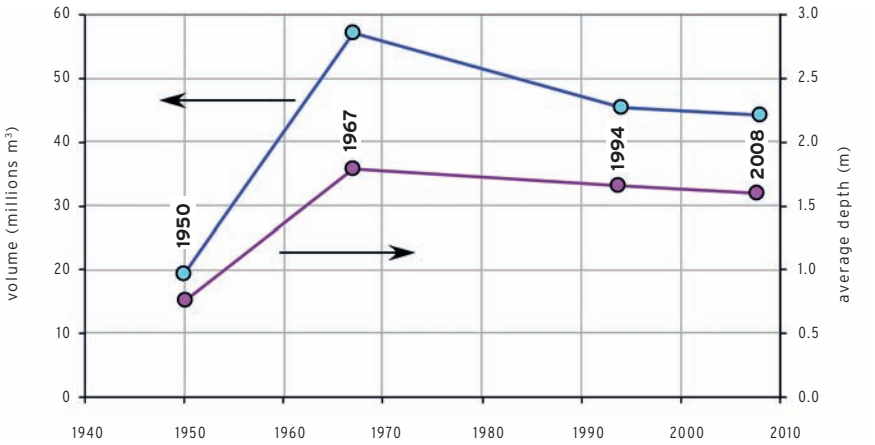


Figure 10: variations in volume of water of the *Sacca degli Scardovari* over the years together with the variation of the average depth of the basin.

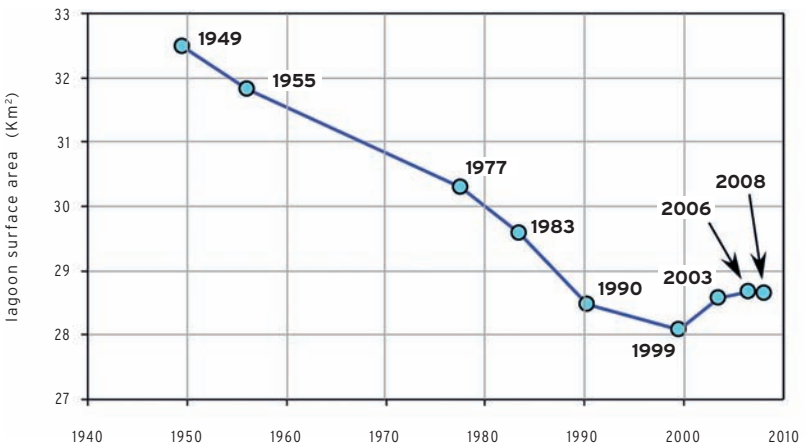


Figure 11: reduction in surface area of the *Sacca degli Scardovari* between 1949 and 2008.

The volume of water in 1967 is triple that of 1950. Part of this increase in volume can be attributed to the enlargement of the lagoon surface area due to the disappearance of the emerged areas, but it is for the most part due to a lowering of the lagoon bed, of which the average depth increased by two thirds between 1950 and 1967.

The 1994 data shows a significant decrease in volume while the average depth of the bed shows only a modest drop that, in this case, depends on the diminishment of the lagoon surface given that only a modest reduction of the average depth of the bottoms is verified. Finally in 2008, the average volume and depth are basically unchanged when compared to those of 1994.

The variation of the total area of the *Sacca degli Scardovari* as defined by a hypothetical "borderline" from 1949 to 2008 was evaluated using available aerial photos.

On the inside of the basin, this borderline was identified following the dyke defense along the shore, while on the waterside it was materialized as the inner edge of the sandbars and the hypo-

thetical line joining the internal edges of the sandbars across the inlets.

The results of the elaboration are summarized in Figure 11; a graph showing a gradual reduction in size of the lagoon from 1949 to 1999 at an average speed, it is estimated, of about 9ha/year. Over the last 10 years, there has been modest growth. The reduction shown on the graph for the period 1949-1955 mainly refers to the retraction of the *Scanno del Palo*, already evident at that point.

In subsequent years, the limit of the lagoon border grew significantly to include the vast area of the *Sacca del Canestro* (more than 2 km^2) along the western margin of the Sacca. As already mentioned, these areas are once again starting to be permanently invaded by lagoon waters due to subsidence and the demolition of the dyke defense due to the effects of sea storms.

The graph in Figure 11 shows, however, that the total area the lagoon covers is lower than that recorded in 1977 and is significantly lower than that recorded in 1955. This is due to a strong retraction of the *Scanno del Palo* in that period. Following 1977 the Sacca's surface area was further reduced due to an additional retraction of the lines of sandbars.

Overall, the Sacca's surface area has ranged between approximately 32.5 km^2, as estimated from the digitization of photos taken in 1949, and 28 km^2 according to aerial surveys carried out in 1999. The images for the years subsequent to 1999 show a substantial stability of the area in question or more precisely, a modest increase of between 28 and 28.5 km^2.

The salt marsh area

The salt marsh areas positioned just above the average sea level, yet occasionally affected by high tides and generally colonized by halophytic vegetation, are a morphological characteristic of the lagoons. In the *Sacca degli Scardovari*, these salt marsh areas were quite large up to 1955, especially in the southern part of the lagoon (the *Sacca di Bottonera*) as seen on the maps in Figure 1 and in Figure 12.

The size of the salt marsh areas visible on the map in Figure 1 coincides with that of the aerial photo taken in 1949 (see Figure 12). Some differences can be observed when comparing it with detectable salt marsh surface areas on aerial photos taken in 1955 (Figure 2 and Figure 12). In the central and northern parts of the Sacca the growth of the salt marsh areas along the margins is notably reduced, similarly there is a lowering of the land due to subsidence.

In the following years the more notable differences relate to the loss of vast western areas (*bacino Canestro*). In the 1949 photo one is able to observe in particular, that these areas that close the *Sacca di Bottonera* in the northwest were separated from the lagoon by a small embankment and the land was cultivated. As early as 1955 the same areas were abandoned and we can see clear traces of lagoon water influx. As of 1977, these areas were regarded as a part of the waters making up the lagoon.

An attempt to reclaim the internal terrain, at the *Punta del Polesine* (found at the south-western extremes of the Sacca close to the mouths of the *Po di Gnocca*), for agricultural use that was subsequently abandoned due to sink-

ing can also be noted on the 1995 aerial photo (Figure 2). In the photos that followed, this land also appears to have been abandoned.

The images following that of 1955 give evidence of the extent to which a large part of the salt marsh areas had been completely submerged within the Sacca leaving only a small area to the south as seen in the 1977 image (Figure 12).

In subsequent years even this area gradually disappeared and at present consists of only a few long thin limbs demarcating the southern part of the Sacca. The loss in the internal part of the Sacca is almost exclusively due to the process of subsidence, whereas in the southern part (*Sacca Bottonera*), to a combination of subsidence and sea storms.

The graph shown in Figure 13 quantitatively summarizes the changes in the lagoon area and areas occupied by the salt marshes. The graph distinguishes the lagoon surface, corresponding to that falling within the borders, from that of the liquid surface considered as an extension of the surfaces characterized by bed values lower than the average sea level. The difference between these two surfaces essentially corresponds to the salt marsh area.

It is interesting to note that the curve representing the water surface area (in orange) grew progressively between 1949 and 1977, eventually almost coinciding with the curve of the bordered surface. Conversely, the surface of the salt marsh areas underwent a progressive reduction, a drastic decrease leading up to up 1977, and more modest changes in subsequent years.

It is evident, that from 1949 onwards the Sacca almost entirely lost its system of emerged and semi-emerged areas that characterized its morphology, and that these areas were replaced with water.

Figure 12: size of the salt marsh areas in the internal part of the *Sacca degli Scardovari* between 1949 and 2008. The shaded area corresponds with the *Canestro* basin, excluded from the borders of the lagoon prior 1955.

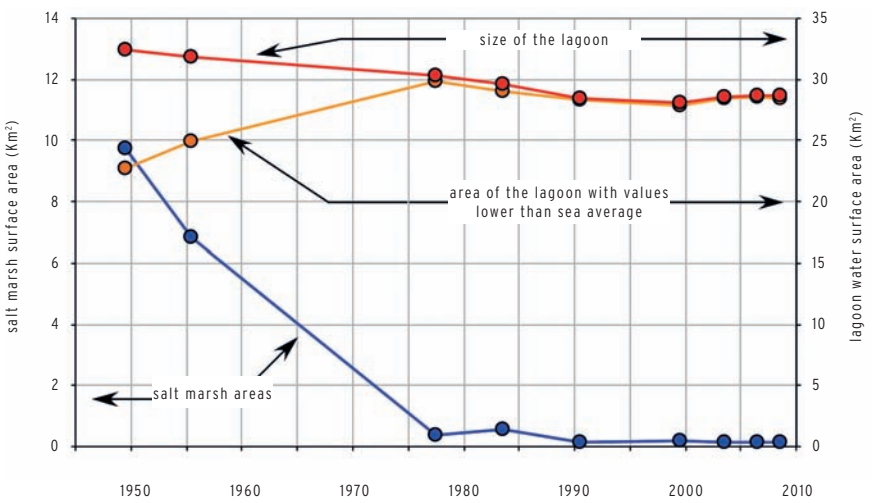
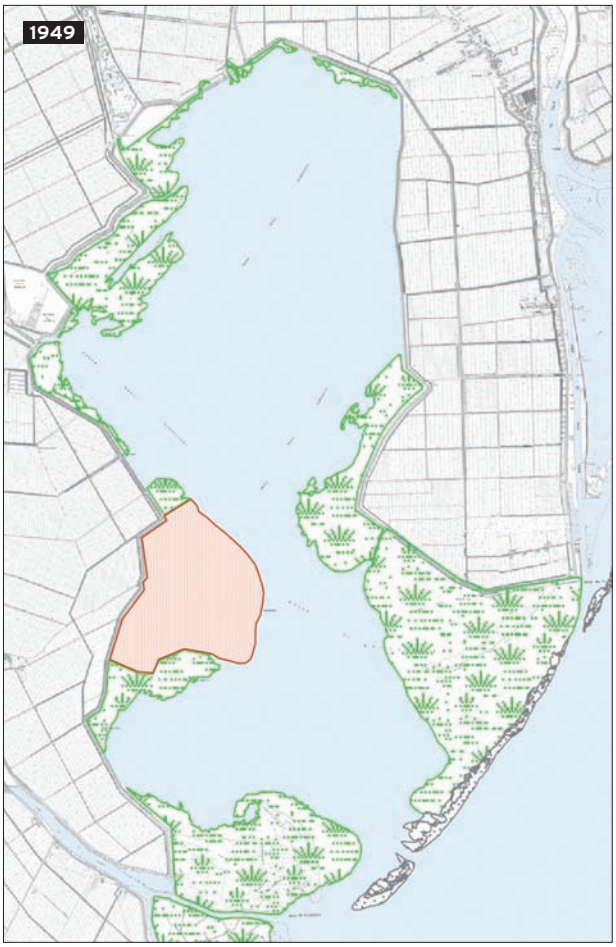
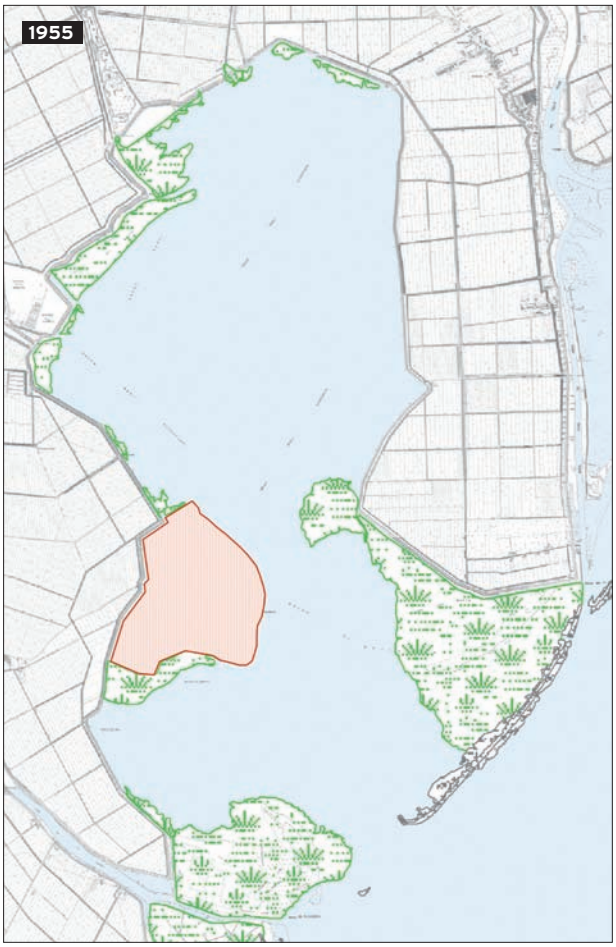
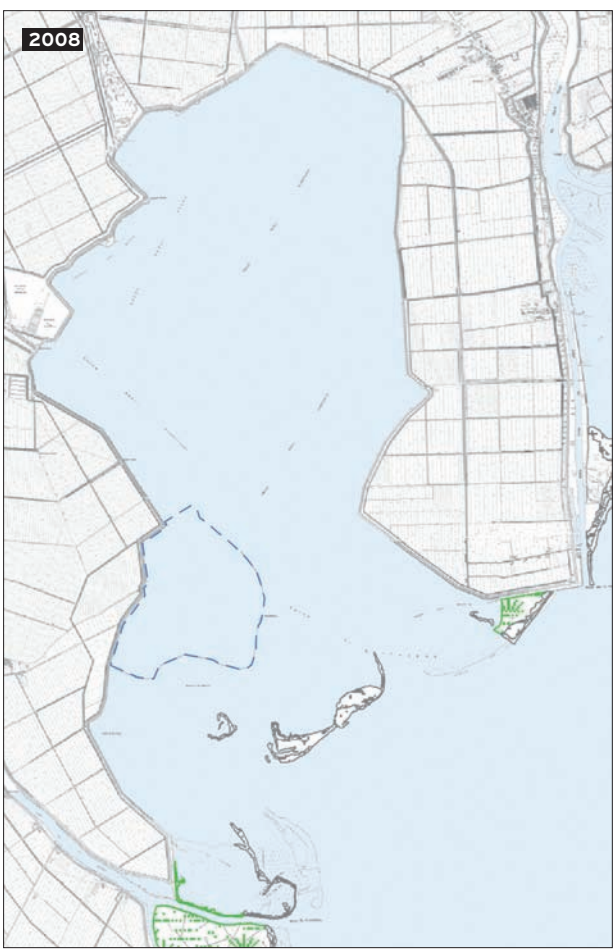


Figure 13: variations of the lagoon water surface areas and the salt marsh areas of the *Sacca degli Scardovari*. For better readability the axis scale of the ordinates has been changed.


1949


1955


1977


2008

The sandbars

As seen from the examination of certain IGM topographic maps and from the historical data found, (*Magistrato delle Aque*, 1950) during the first 50 years of the twentieth century, the position, shape and size of the sandbar closing the lagoon on the sea side (*Scanno del Palo*), due to a precarious balance subject to seasonal & annual maritime variations and the intensity of river and coastal transport, underwent changes that cannot be overlooked.

Figure 3 shows the evolution of the sandbar from 1931 to 1949. Based on aerial photos, in this period the sandbar retracted notably, but above all, extended in a south-west direction, forcing the canal mouth to bend in the same direction and to be compressed between the bank of the *Punta del Polesine* (on the left side of the mouth of the *Po di Gnocca*) and the southern part of the *Scanno del Palo*. In the 1949 aerial photo (Figure 3), one can already see the sinking of the sandbar and the opening of a new lagoon mouth to the north that appears to be completely formed in the 1955 image (Figure 2).

Figure 15 shows the sequence of maps obtained through the digitization of the salt marsh areas and of sandbars identified on available aerial photographs as of 1949. These morphological elements contained in the GIS were superimposed over the Regional Technical Map (compiled using the 1983 aero-photographic survey) used as a base of reference in order to facilitate the comparison of the two different situations.

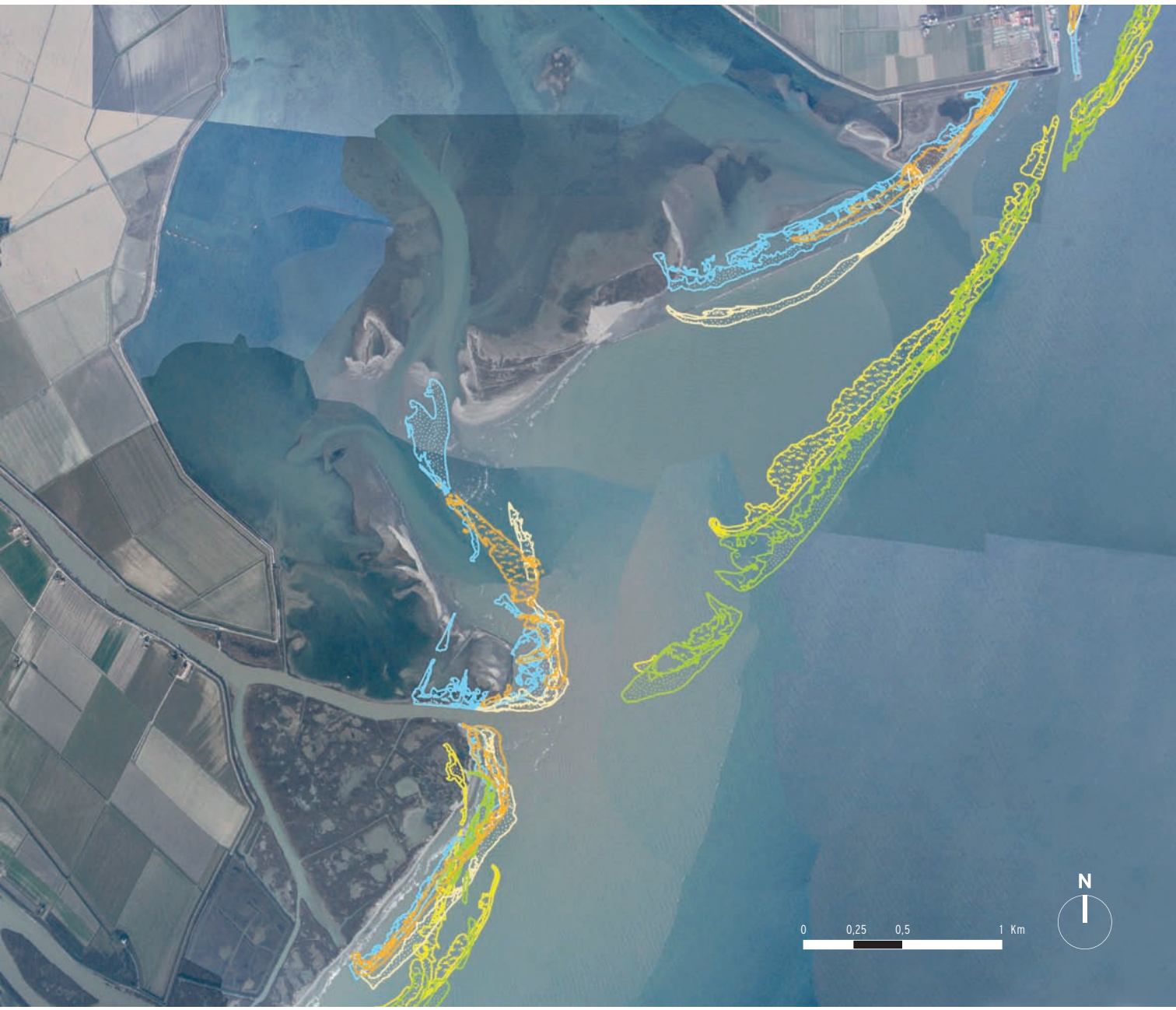
The figure shows that between 1949 and 1955, the southern tip of the sandbar disappeared, augmenting the size of the new mouth, as mentioned before, in a slightly retracted position.

From 1955-1970 the combined action of subsidence and the intensity of the sea that characterized this period of time produced profound morphological changes not only to the lagoon, but to the sandbars in particular. The magnitude of these changes is demonstrated in Figure 14 showing a comparison between the position and importance of the sandbars before 1955 and after 1977. It is noted, in particular, a sharp retraction of the boundary between the sea and the lagoon resulting in a structure that has been maintained over subsequent years. From 1970 onwards, therefore, we have seen recent development of the coastal areas and that of the sandbars in particular.

The evolution of the sandbars that delimit the Sacca in the south can therefore be described starting with the coastline configuration as revealed in the 1967 bathymetric survey. In this situation (Figure 6) the borders of the Sacca are made up of a main sandbar to the northeast (*Scanno del Palo*) detached a short distance from the *Punta Barricata* (where a shallow passage between the Punta and the sandbar can clearly be seen) and stretching in a southwesterly direction, straightening slightly and partially covered at high tide – the formation is completed by a secondary sandbar found to the south corresponding with the *Punta della Polesine*, slightly behind the coastline. This configuration is essentially that seen in the 1977 aerial survey (Figure 15).

From 1977-2000 the northern sandbar got gradually stronger, first joining the coast at the *Punta Barricata* (1983) and then slowly increasing in size. This

Figure 14: comparison of the position of the sandbars as derived from the aerial photos. Note the significant decline between 1955 and 1977.



KEY:

- IGM 1949
- GAI 1955
- IGM 1977
- ReVen 1983
- ReVen 1990

Aerial photo CBDPA
February 2008

process, mainly in reference to the defense interventions and consolidation as a whole realized by the *Magistrato del Po* in those years, was accompanied by a slight rotation of the sandbar by a few degrees, leaving the center at the mouth of the *Po di Tolle*.

The opening of the new *Bocca Nord*, protected by quays and built in 1966 by the *Consorzio di Bonifica Delta Po Adige*, appears to have had a modest overall influence on the evolutionary process of the sandbar. However, the presence of the quays reduced the solid sediment transport of coastal currents to the south, weakening and thinning the stretch of sandbar to the south of the new mouth.

During the same period, the south sandbar (*Punta del Polesine*) stretched southward toward the inside of The Sacca and migrated slowly south. The movements were accompanied by a slight rotation, by only a few degrees, in a counter-clockwise direction. This trend appears to be largely due to the lagoon mouth's shift southwest, determined by the lengthening of the main sandbar (*Scanno del Palo*).

From the sequence in Figure 15, it is evident that violent storms between the years 2000 and 2003 produced considerable damage. The *Scanno del Palo* gave in at its weakest point leaving a wide-open space just south of the *Bocca Nord* (See aerial photo 2003). The southern sandbar was not exempt from the effects of sea storms as can be seen when comparing aerial photographs taken in 2000 and 2003.

In recent years both sandbars have gradually assumed a configuration similar to that of 1999 as a result of interventions carried out by the *Consorzio Delta Po Adige*, which on the one hand, focus on the reconstruction of the *Scanno del Palo* through repasturing, and on the other, maintaining the use of the *Bocca Sud* by periodic dredging interventions and movement of the sands.

When considering the transitional zone between the lagoon and sea, it is certainly of interest to analyze the evolution of the morphological characteristics of the beach opposite the sandbars. Up to the first half of last century valid indications were summarized in the often-cited work of the *Magistrato alle Acque* (1950). In particular, a series of topo-bathymetric profiles reconstructed along orthogonal sections of the bank show that the progressive growth of the Delta at the mouth of the Po di Tolle developed intensely during the nineteenth century with the advancement of the coastline and the rising of the seabed.

At the end of the century, however, data shows that this tendency has reversed and from the early years of the twentieth century we see a prevalence of erosive processes. The data after 1950, highlighted by the differential maps in Figure 8 and Figure 9, show that this trend is still in progress, and indeed underwent a sudden acceleration in the years between 1950 and 60 as a result of subsidence.Most recently two detailed bathymetric surveys have been carried out by the *Consorzio Delta Po Adige*, in February 2005 (Figure 16) and January 2009.

These surveys were assembled with measurements performed inside the lagoon in March 2008 to obtain a single digital model of the entire basin and the stretch of sea front of it (Figure 17). The 2005 *DEM* (Figure 16) highlights the morphological variety of the seabed in front of the *Sacca degli Scardovari.*

Figure 15: synthetic representation of the 'sandbars' and 'salt marshes' superimposed over the Regional Technical Map.

Firstly, the most significant elements are represented by the cusp located on the western extreme of the *Scanno del Palo* that documents the accumulation of sediments transported along the coast in a northeast-southwesterly direction along the edge of the channel mouth.

Secondly, the morphology of the seabed in front of the *Scanno del Palo* is very articulate and is characterized by a series of bars running almost perpendicular to the coastline, showing intense transport and erosive processes in action affecting the area from the southern most part of the sandbar to the *Bocca Nord*.

The 2008-2009 *DEM* (Figure 17) is more detailed because, in the range of sea front of the sand bar, it is derived from a bathymetric survey using a constant 50 m-step grid as opposed to one


1949


1955


1977


1983


1990


1999


2003


2008

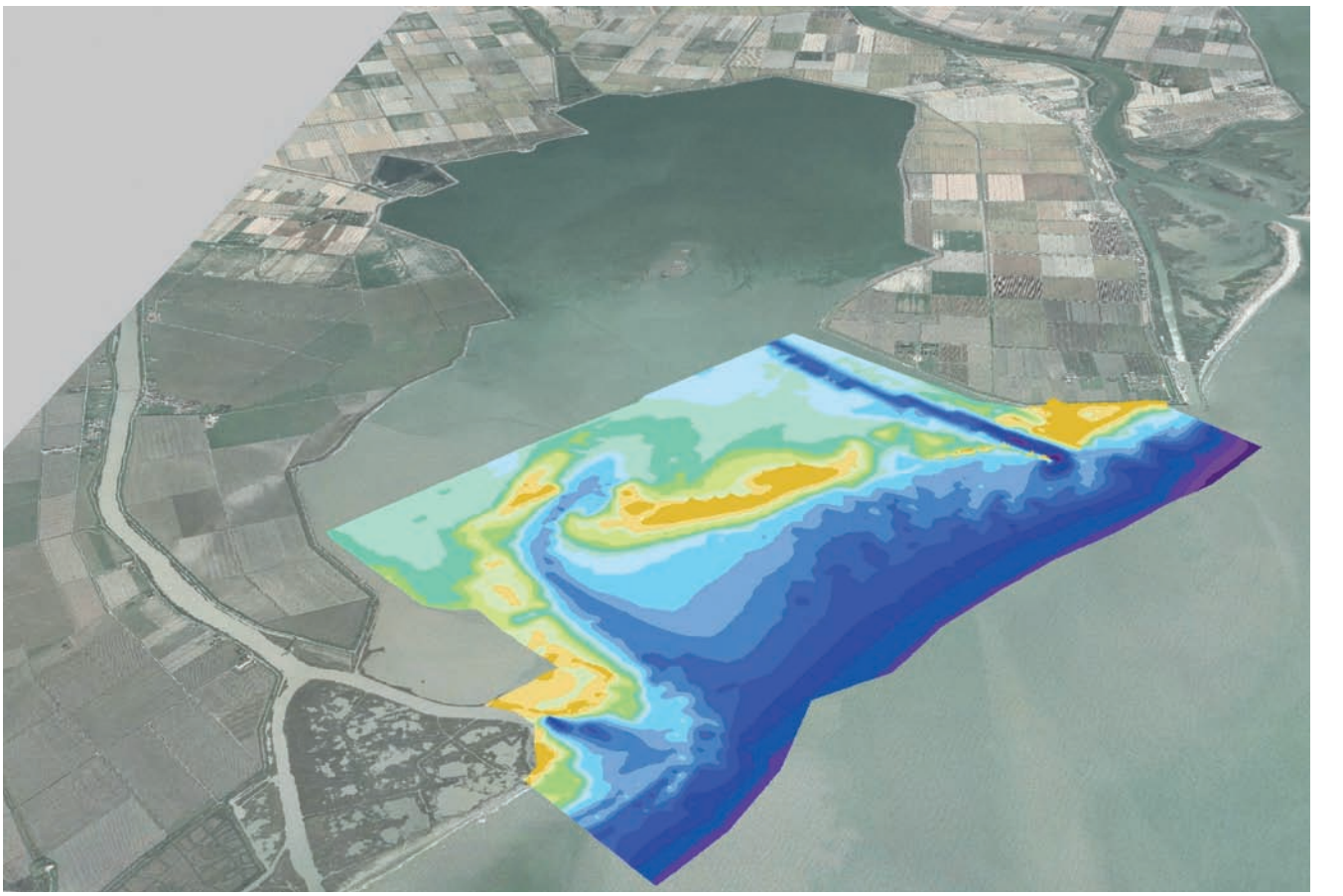


Figure 16: digital altitudinal model of the coastal strip of the S*acca degli Scardovari* derived from the 2005 bathymetric surveys.

using orthogonal sections of coast. The reading of changes in value of the area of study should also be made bearing the interventions carried out by the *Consorzio di Bonifica Delta Po Adige* during between the February of 2005 survey and that of January 2009 in mind. In particular, dredging interventions were carried out in the channel of the *Bocca Sud*, counteracting the channels tendency to move westward and prolonging the extension towards the inside of the lagoon. In addition to the extension of the stone defense works along the south side of the *Scanno del Palo*, the gap opened by the sea storms was closed completely.

It's interesting to note that in Figure 16 and Figure 17, as seen along the stretch of submerged beach opposite the sandbar, the previously mentioned transverse bars form according to a periodical sequence, at an average distance of 150÷200 m from each other and a height of about 1,5÷2,0 m. This system of bars is testament to the intense morpho-dynamic processes associated with the transport of solid phenomena determined by swells and currents created by the Sirocco.

This morphological arrangement is due to the combination of sediment transport parallel to the coast and above all, that which is perpendicular to the coastline, consisting of erosion and transport material triggered by a so-called *rip-current* and a weak transport

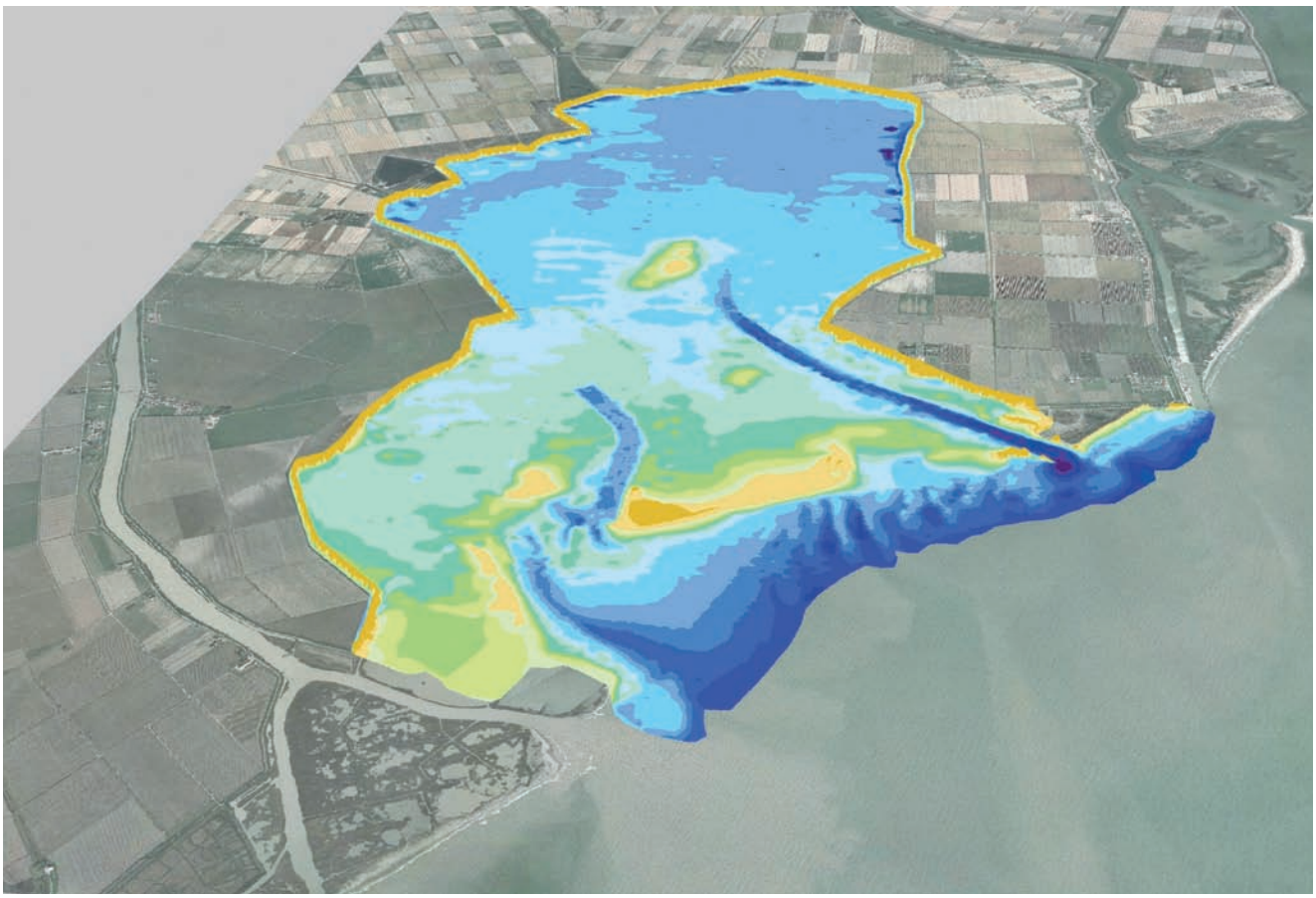


Figure 17: digital altitudinal model of the coastal strip of the *Sacca degli Scardovari* derived from the 2008/2009 bathymetric surveys.

towards the coast brought about by returning currents.

The presence of these seabed phenomena indicates extensive transport and erosive processes that primarily affect areas spanning from the easternmost part of the sandbar to the *Bocca Nord*. Due to the differing spatial resolution between the 2005 and 2009, the differential model of the seabed in front of the lagoon mouths was uninterpretable and is therefore not represented.

Figure 18 shows a map of areas affected by erosion/deposit phenomena obtained from this model, and a graphic representation of the average changes to the bed value obtained by the subdivision of the area into 6 zones in order to delimit the areas in which, at first look, seem to be characterized by similar dynamics.

In general, it appears that after four years, the previously mentioned erosion phenomena seem to be prevalent on those depositions because the entire area is generally lower. The phenomenon however, appears to be differentiated because, according to the subdivision adopted, two substantially balanced areas can be distinguished.

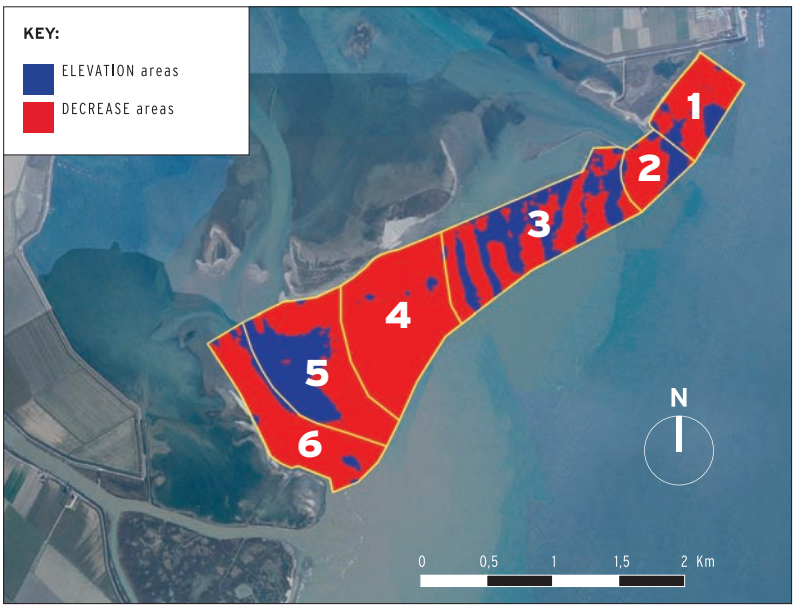
The first is zone 3, which extends in front of the sandbar's defense line, where the depths are characterized by the afore mentioned orthogonal bar

system running perpendicularly to the coast. Even though an accurate quantitative assessment is made difficult by different spatial resolutions of the measurements, the data shows, on the one hand, that the bars have changes their planimetric positions, and on the other, that generally the bumps are elevated and the furrows constitute the depths. The second is zone 5, where prevailing erosion in the east, and a significant accumulation of sand in western part, near the channel of the *Bocca Sud* is highlighted.

There is evidence of the lowering of the beds in zones 1 and 2, in front of the northern-most part of the *Scanno del Palo* seemingly attributable to a deficiency of contributions from the north, rather than the intensity of coastal transport induced by wave motion.

In this case we can mostly refer to the reduced liquid carrying capacity (hence also solid) which presumably, as opposed to the past, comes from the southern branch of the *Po di Tolle* (mouth of *Punta Barricata*) compared to the northern branch (*Busa Storiona*) that was recently upgraded by dredging of the mouth.

Lowering is also evident in the whole of zone 4, located just adjacent to central part of the *Scanno del Palo*, which appears to be the area most exposed to erosion because it is at the junction between the rocky defense line the beach of the *Scanno*. Finally lowering is evident in zone 6, which corresponds to the channel of the *Bocca Sud*. In this case, we see from the data that the axis of the channel itself has undergone a significant shift towards the west, assessed in its southernmost part, to be more than 100 m, confirming the trend already highlighted by data from the past.



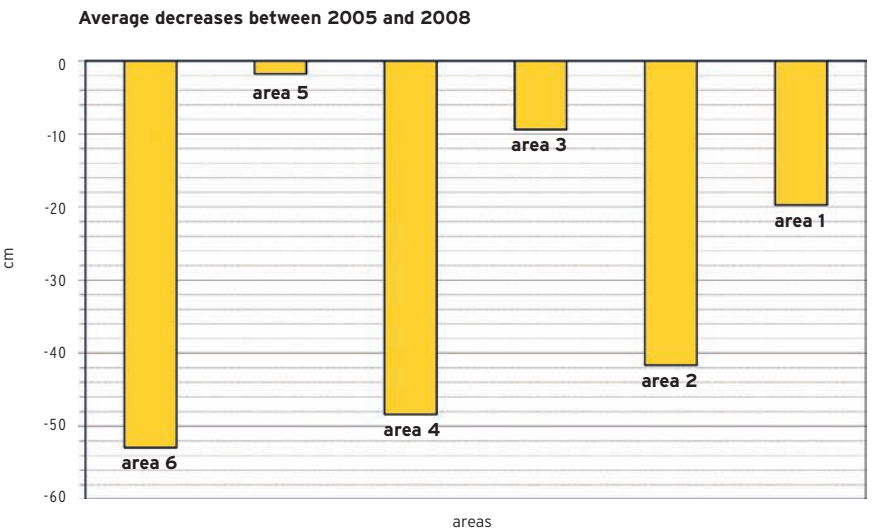


Figure 18: altimetric variations of the seabeds in front of the *Sacca degli Scardovari* 2005-2009.

The lagoon mouths

The comparison of the bathymetric data enables one to also obtain indications about evolution of lagoon mouths, especially in terms of the liquid section and how it is related to the volume of water exchanged with the sea in every tidal cycle.

From a planimetric point of view, over the years, the position of lagoon mouth was essentially determined by the process of evolution of the sandbars already described in the preceding paragraph. It is to be noted in particular that after the breakthrough of the sandbar between 1950 and 1967, the natural mouth of the Sacca slowly migrated southward in relation to the growth of the sandbar.

The current situation is the result of a combination of the aforementioned natural tendencies with the variations of coastal sediment transport principally inducted by the change of the mouths of the *Po di Tolle* and with the complex of interventions carried out in the lagoon canals and central sandbar in order to revive the *Sacca degli Scardovari*.

The interventions focused on the opening of the *Bocca Nord*, the excavation of the lagoon canal that leads into it and the dredging of the canal that leads into the *Bocca Sud*. The analysis of the evolution of the mouth shape, size and the maximum depth that characterize it over time is of interest. The analysis was conducted based on the altimetric digital models from which certain representative profiles of lagoon mouth sections were made for each of the available bathymetric surveys (Figures 19-22).

By comparing the mouth sections extracted by the bathymetric surveys and

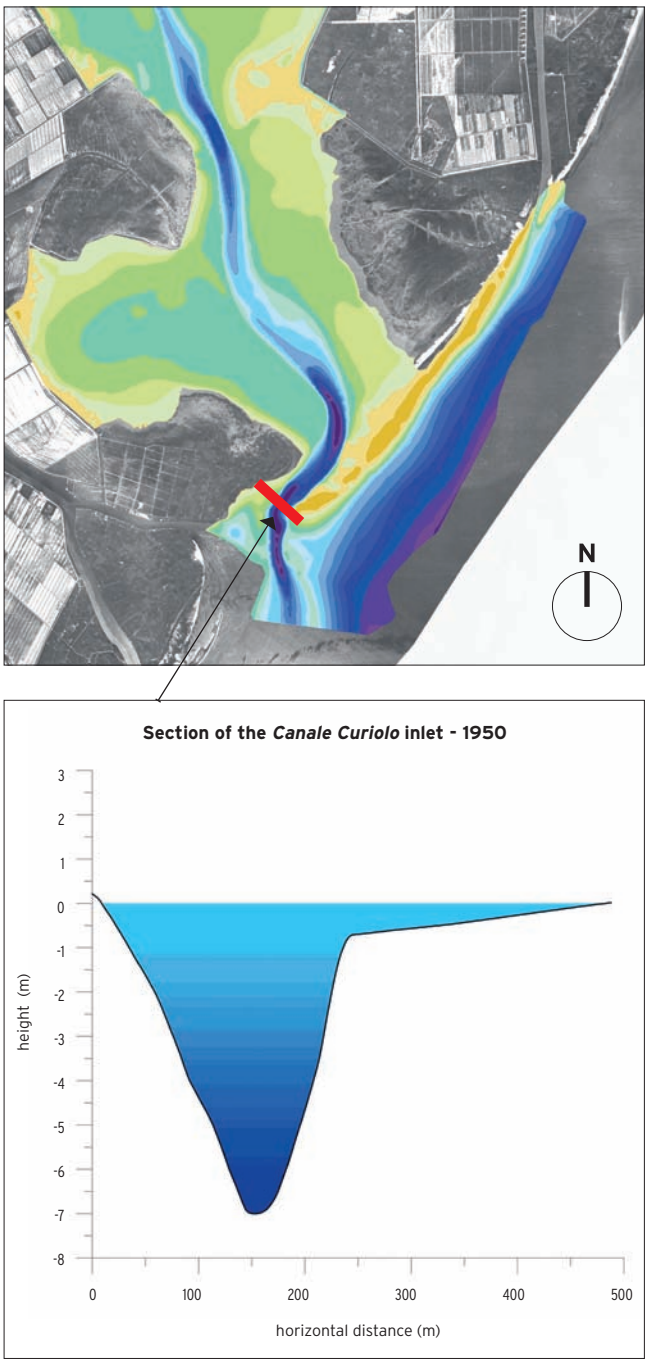


Figure 19: bathymetric profile of the lagoon mouth in 1950 (towards the sea), the red line on the *DEM* indicates the location of the section. Background: GAI Flight 1955.

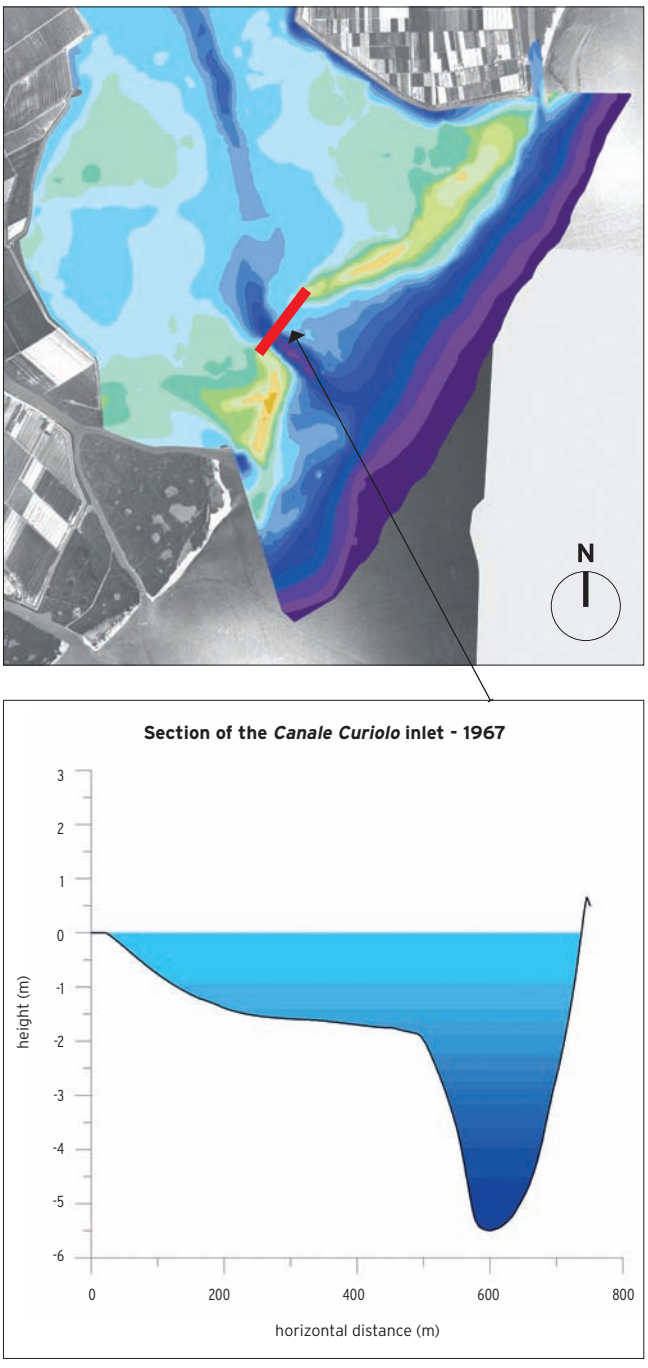


Figure 20: bathymetric profile of the lagoon mouth in 1967 (towards the sea), the red line on the *DEM* indicates the location of the section. Background: IGM Flight 1977.

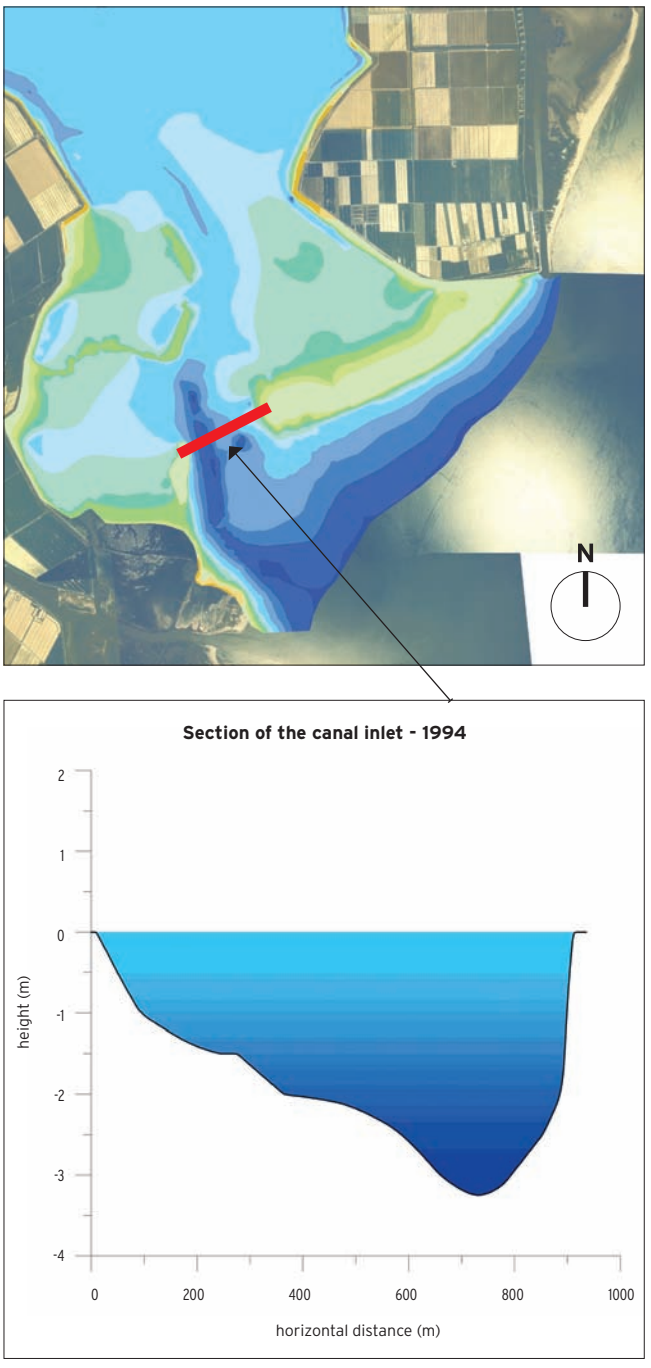


Figure 21: bathymetric profile of the lagoon mouth in 1994 (towards the sea), the red line on the *DEM* indicates the location of the section. Background: Flight ReVen 1990.

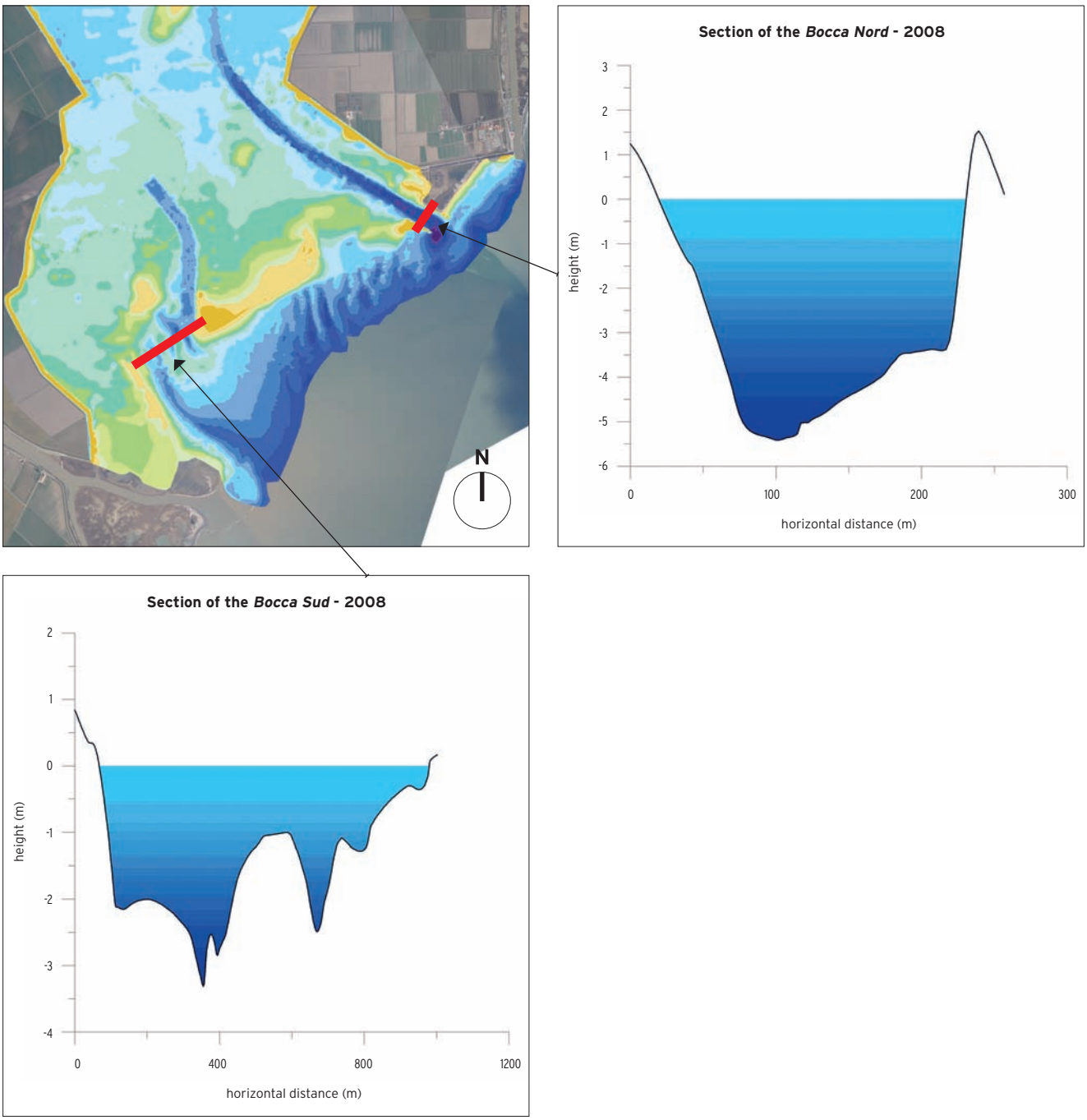


Figure 22: bathymetric profile of the lagoon mouths in 2008 (towards the sea), the red lines on the *DEM* indicate the location of the sections. Background: *Consorzio Delta Po Adige* Flight February 2008.

considering the *Bocca Sud* in 2008, (the *Bocca Nord* being 'artificially' bordered by piers), we are able to see an initial stage between 1950 and 1994 showing a gradual reduction in depth and an enlargement of the cross section. This is a clear indication of evolution dominated by the profound changes undergone by the sandbars in the 1950s. At that time, as we have seen, due to the effect of subsidence and sea storms the sand barrier was almost completely demolished and the section of water available for the exchange of tidal waters grew dramatically, progressively taking on a large shallow formation.

In recent years, the progressive eastward lengthening of the *Scanno del Palo* has not caused a notable reduction in size of the section, also because as mentioned before, there was simultaneous erosion along the western edge of the mouth with an eastward migration of the canal.

In this process a key role was obviously played by the opening of *Bocca Nord*, which currently exchanges volumes of water comparable with those of the *Bocca Sud*, with the sea. It is for this reason that the maximum speed of tidal currents flowing through the *Bocca Sud* has reduced since the excavation of the second mouth and there has been general reduction of the depths of the seabeds.

Based on the profiles, the areas of the sections were calculated, in the end, below the hydrometric level of 0 m and the corresponding values were reported on Table 2. It is apparent that from 1950 on, the lagoon mouths gradually expanded, and that the current section total (determined by the sum of the areas of the *Bocca Sud* and *Bocca Nord*) is more than double that of its original composition.

	1950	1967	1994	2008
Area (m^2)	979	1530	1811	2191

Table 2: area of the sections of the mouths of the *Sacca degli Scardovari*.

Conclusions

The digitization and interpretation of nine series of aerial photographs ranging from 1949 to 2008, and four bathymetric surveys, covering essentially the same period, has enabled the analysis of the morphological evolution of the Scardovari lagoon and the group of sandbars that have separated it from the sea for the last 60 years. The GIS elaborations conducted on the digitized base allowed one to obtain certain quantitative estimates on the variations in size of the lagoon and its emerged sandbars and salt marshes. Using the figures from the four bathymetric surveys we have been able to reconstruct a *DEM*, hereby facilitating the analysis of and comparisons of different configurations that have developed over the last sixty years.

It has been noted that over a short period of time (1950-1967), the lagoon underwent profound changes and in particular, was subject to a general, consistent deepening of its beds accompanied by a loss of morphological heterogeneity and almost complete disappearance of the *Canale Curiolo* which initially ran longitudinally from the mouth of the lagoon to the pools of water on the inside of the lagoon. In the southern part, a significant retraction of the sandbar separating the lagoon from the sea has also been noted.

These profound changes, as has been said, are mainly attributable to subsidence that, in this period, is characterized by a fast lowering of the land. These changes are due to extractions covering more or less the whole of the delta area and Sirocco winds and sea storms like those seen in the 1950s and in November 1966 in particular. The latter, when coming into contact with weakened natural

***Sacca degli Scardovari*: central part of the *Scanno del Palo*.**

defenses, resulted in the sinking of the sandbar and in this particular case, the flooding of large parts of the *Isola della Donzella*, as well as the development of intense erosive processes in the internal part of the lagoon, thus contributing to a deepening of this part of the Sacca.

The same period also saw the almost complete disappearance of the salt marsh areas, shrinking from an area of approximately 7 km^2 in the 1955 survey to just a few hectares distributed along the southern side of the *Sacca di Bottonera* in the 1977 survey. As discussed below, this loss has had and still has a significant and negative impact on the processes of water exchange and renewal as well as general biological and environmental aspects of the lagoon. The construction of dyke defenses clearly demarcating the lagoon from the mainland without a transitional band contributed to the morphological development of the Sacca completely independent from that of the surrounding land. In subsequent years, the loss of morphological heterogeneity continued and resulted in, especially in the interior of the bag, the augmented flattening of the lagoon beds and the complete disappearance of the *Canale Curiolo*, other canals and submerged ridges.

This process can be attributed to the phenomenon of wave motion, in particular that generated within the lagoon accompanied by the Sirocco. Indeed, with a depth of 2.0÷2.5 m, wind speed often exceeding 10 m/s and a fetch of 3÷4 km, waves of up to one meter may develop in the northern part of the lagoon capable of moving lagoon bed sediment and levelling values.

***Sacca degli Scardovari*: eastern part of the northern inlet (*Bocca Nord*).**

From an environmental point of view, the absence of salt marsh areas, periodically flooded during high tides, and the general lack of heterogeneity of the seabed produces homogeneity of the kinetic characteristics of the field of motion and a therefore a significant reduction in the diffusion process resulting in a reduced self-depuration capability of lagoon waters. For these reasons, as of 1996, interventions were implemented in order to improve and intensify the process of lagoon-sea water exchange: the *Bocca Nord* was opened, protected by short quays, and access canals were dug at the mouths from which the resulting material was used to construct an island in the middle of the Sacca.

These interventions, though effective, cannot be regarded as conclusive mainly due to the particular shape of this lagoon, being greatly elongated in the direction of the coast, the hydraulic exchange of water starting further from the mouths remains significantly limited.

In particular, the occasional entry of fresh water into the sea via the *Po di Tolle* and *Po di Gnocca* results in conditions of low salinity that remain in the internal part of the Sacca for long periods, causing environmental conditions that are harmful to aquaculture activities and those involved in such activities.

The analysis of data collected in the GIS highlights and allows for the quantification of a second important aspect that has characterized the recent morphological evolution of the *Sacca degli Scardovari* connected to the sandy barrier separating the lagoon from the sea

(the *Scanno del Palo*). In this case, the analysis was based mainly on results of the digitization of the shorelines based on the sequences of aerial photographs. The comparison between the different morphological situations that developed over periods of time, relative to the sandbars bordering the sea side of the *Sacca degli Scardovari* has shown over time, a marked variability in both size and position of these structures (Ipros, 2008).

In particular, there is a clear correlation between the reduction of emerged land and events that have had the greatest impact in the past, on the one hand, subsidence and strong sea storms between 1950 and 1970 and on the other, the sinking of the central part of the sandbar due to sea storms in 2000-2003. It is noted however, that these stages were followed by periods of growth of these same sandbars resulting in a partial return to their previous dimensions. We can therefore conclude that the Sacca's sandbars are characterized by a tendency, once damaged, to naturally rebuild themselves.

It is taken into account however, that in recent years and more precisely, since the end of the 1980s, the reconstruction of damaged sandbars and those partially damaged by stronger sea storms has been supported by consolidating excavations carried out in different stages. It should be noted that this ongoing tendency is accompanied by a high spatial variability. In fact, these morphological structures have developed in progressively more internal positions in the Sacca highlighting an overall tendency to migrate towards the southwest.

This constant, conspicuous retraction of the shoreline from 1949 to date suggests overall, in the dynamics of the movement of sediment-related to the interaction between canal inlets and wave motion, that erosive phenomena are more prevalent than the depositional phenomena.

This trend, according to the assessments conducted, appears to have slowed down in recent years. However, it should be viewed with some caution, for as we have repeatedly seen, the evidence and evaluations made, based primarily on the analysis of aerial photographs, suffer from some limitations mainly related to uncertainties in the digitization process and tidal conditions which may differ from one flight to another.

While having verified that, because of the digitalization criteria adopted, the differences between pictures taken in different maritime situations are smaller, the aforementioned limitations might affect the accuracy of the results especially when highlighting, as in this case, small variations between different scenarios.

Following the notable retraction of the sandbars in the period 1949-1999, it was estimated that the area of the *Sacca degli Scardovari* had shrunk from approximately 32.5 km^2 in 1949 to just under 28 km^2 in 1999, a difference of approximately 4.1 km^2 over the last 60 years. This reduction is even more significant when one looks at the same period (1949-1999) taking into account the increase in surface area caused by the loss of a large part of the *Sacca di Bottonera* (*Canestro* area) due to subsidence.

The comparison between the most recent bathymetric surveys in the stretch of sea in front of the *Scanno el Palo* in 2005 and 2009 showed, although the picture is not homogeneous, that the sea beds had generally deepened. The area more exposed to erosion seems to be the central part adjacent to the recently completed defense works. These circumstances could be related to the intense coastal currents caused by sea storms that can be explained principally by a solid sediment transport running directly from NE to SW, and the deficit of solid material coming from the North, mainly due to decreases at the mouth of *Po di Tolle* at the *Punta Barricata*.

Ultimately, with the construction of a digital base map and a geographical database with tests carried out cross-referencing different available information, we are supplied with a fairly detailed overall study of the evolutionary processes that have characterized the *Sacca degli Scardovari* over the last sixty years, that could prove to be a valuable tool not only in the planning of interventions, but the revitalization and defense of the area be it in the monitoring or tracking of natural evolutionary trends, as well as those resulting from eventual interventions that may be carried out.

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Western part of the *Sacca degli Scardovari*'s southern inlet (*Bocca Sud*).

Above: a connecting "*paradelo*" (narrow navigable canal) in the *Laguna Basson*.

Below: lighthouse (*faro di Pila*).

Above: small lake in *Oasi di Ca' Mello*.

Below: former *Valli della Donzella*: *Oasi di Ca' Mello*, rice fields, *Sacca degli Scardovari*.

_STUDY

NATURALITY VALUE AND INTERVENTION MANAGEMENT IN THE LAGOONS OF THE PO DELTA

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The Po delta is a complex of highly valuable environments and the maintenance thereof must be a priority in the management of the lagoon areas. Hence, the measurement of the degree of naturality and the quantification of the effects that anthropic activities have on it are of particular importance.

The aim of this project was to set up a specific GIS model for the quantification of delta environmental properties. The model, applied to the *Isola della Donzella* and the *Sacca degli Scardovari*, enabled the identification and classification of habitats, quantification of their natural value and integration of the collected information into an effective tool for the planning and management of the lagoon areas.

The method, satisfactorily applied to the *Isola della Donzella* over a time frame of the last 130 years, revealed a dramatic decrease in the degree of naturality since the 1950s. The overall evaluation of the delta's environmental quality confirmed that the wetlands and transitional areas have the highest values, probably due to the fact that over the last few decades they have been subject to the most invasive anthropic modifications.

Introduction

The Po delta is made up of various extremely dynamic environments, its hydrology being shaped by natural events and human interventions. With this in mind, measuring the degree of the environmental naturality and quantifying the effects that anthropic activities have on it have become a priority in maintaining equilibrium in these extremely vulnerable areas. Further to ecological issues and in accordance with growing social concern, the respect and protection of nature are now considered fundamental aspects of contemporary culture.

To apply the concept of environmental sustainability (Brundtland, 1987) and to manage the balance between the negative effects of human activities, usually considered non-sustainable, and positive compensatory interventions of renaturalization, it is necessary to use an index of naturality. In this article, the term **nature** or **naturality** refers to everything that makes life possible, and the maintenance thereof. The concept of naturality brings together the ecological notion of climax and the biological concept of biodiversity, i.e. the variety of living organisms, from genomes making up the hereditary base quantity and relative frequency of the species, to the way in which they organize themselves into communities.

The term **habitat** is used for "plant and animal communities as the characterizing elements of the biotic environment, together with abiotic factors (soil, climate, water availability and quality, and others), operating together at a particular scale" (EUNIS, 2002). The habitats in this study cover an area of at least 20m^2 without an upper limit and are defined by their vegetation (e.g.

reeds beds of *Phragmites*), substrate (e.g. inter-tidal sand) or by a combination of both. An environment characterized by a homogenous habitat recognizable on a 1: 500 scale map is defined as a **territorial unit**.

For this article, the habitat database of the *Consorzio di Bonifica Delta Po Adige* was used to estimate the value of the naturality of the Po delta. In particular, it presents the application of a model based on the *Carta degli Habitat dell'isola della Donzella* to estimate the natural value of the territory (Potential Natural Value, PNV) and aquatic lagoon environments (Potential Quality Value, PQV), as tools to be used in the management of interventions in the Delta's Lagoons.

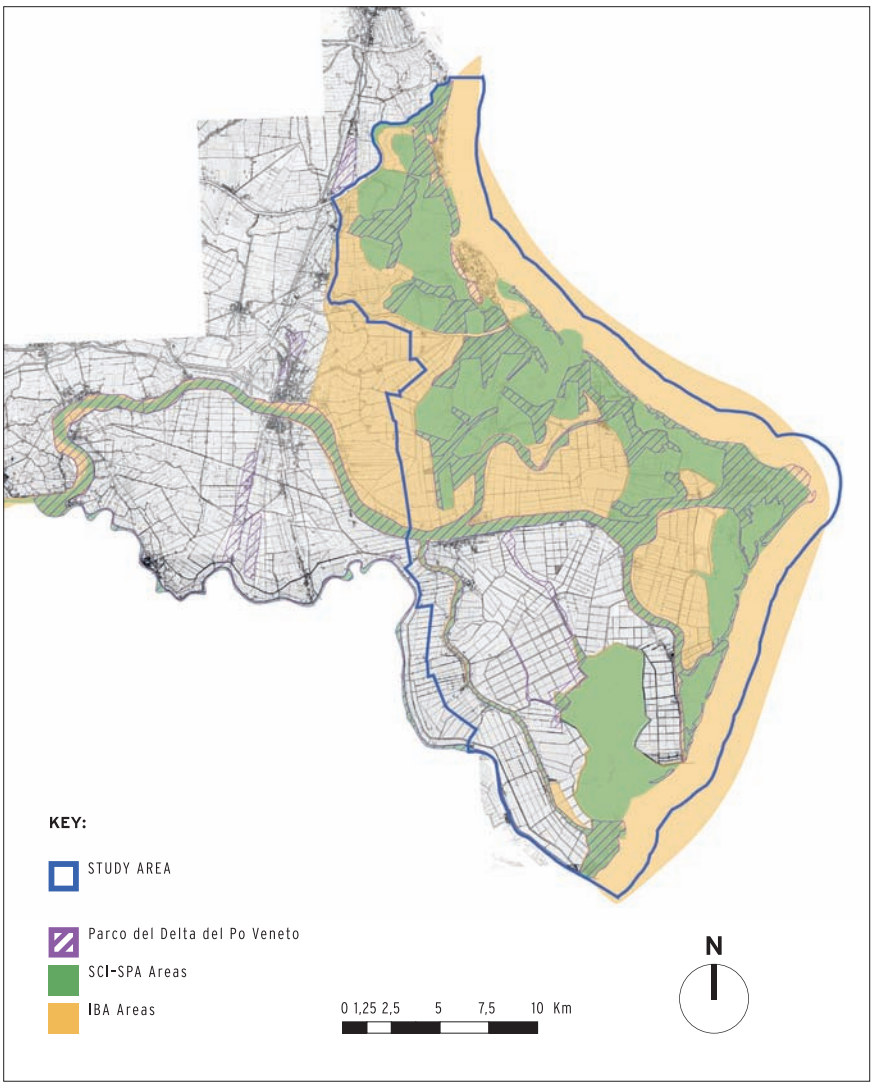


Figure 1: the study area (blue outline) and protected areas of the Po delta. The borders of the *Parco del Delta del Po* (in purple), the SPA-SCI zones (in green) and IBA areas (in ochre), that extends beyond the limits of the study area.

The study area

At the end of the sixteenth century, the Po River flowed into the so-called *Delta Rinascimentale* at Rosolina. Venetian hydraulic engineers, fearing that the branches of the Po River could close the mouths of the Venice lagoon, deviated its terminal branches towards the southeast. The so-called *Taglio di Porto Viro*, completed in 1604, marked the beginning of the construction of the modern Delta. The Venetians closed all the Delta's northern branches, thereby increasing the efficiency of the southern branches - the *Po di Gnocca* and *Po di Tolle*, the later being the biggest branch at the time, while today it is the *Po di Pila*. These interventions led to the development of two large peninsulas making up a lobe-shaped area to the south side of the Po delta that we know today: the *Po di Goro* and *Po di Gnocca* peninsula formed in 1730, and the *Po di Tolle* peninsula formed in 1810. These two peninsulas made up two lagoons, the *Sacca di Goro* and the *Sacca degli Scardovari*.

Today, the Po delta covers an area of the Veneto Region spanning 96 000 ha from the *Po di Goro* in the southwest and the Romea state road in the north, all the way to the mouth of the Brenta river. This area includes a 3-mile stretch out to sea, 8 600 ha of *valli da pesca* (embanked fishing lagoons), 8 150 ha of lagoons, 4 000 ha of branches of the Po River (including lanche – half-moon shaped perifluvial ponds, floodplains and river islands) and thousands of hectares of croplands consisting of reclamation canals, rice paddies, sandy fossil dunes and inhabited areas.

The study area, which extends for 52 600 ha (Figure 1) includes, in addition to the river delta (bordered on the south by the *Po di Goro* and on the north by the *Po di Maistra*), the wetlands between the *Po di Maistra* and the mouth of the Adige.

Part of the ecosystems with high levels of naturality are to be found in the *Parco Regionale Veneto del Delta del Po* (Figure 1). Established in 1997, this territory covers 12 000 ha - 9 126 in the study area, including braches of the Po River, 40% of the surface of every valle da pesca, the lagoons, the *Isola di Batteria*, and the mouth of the *Po di Gnocca*, Spe-

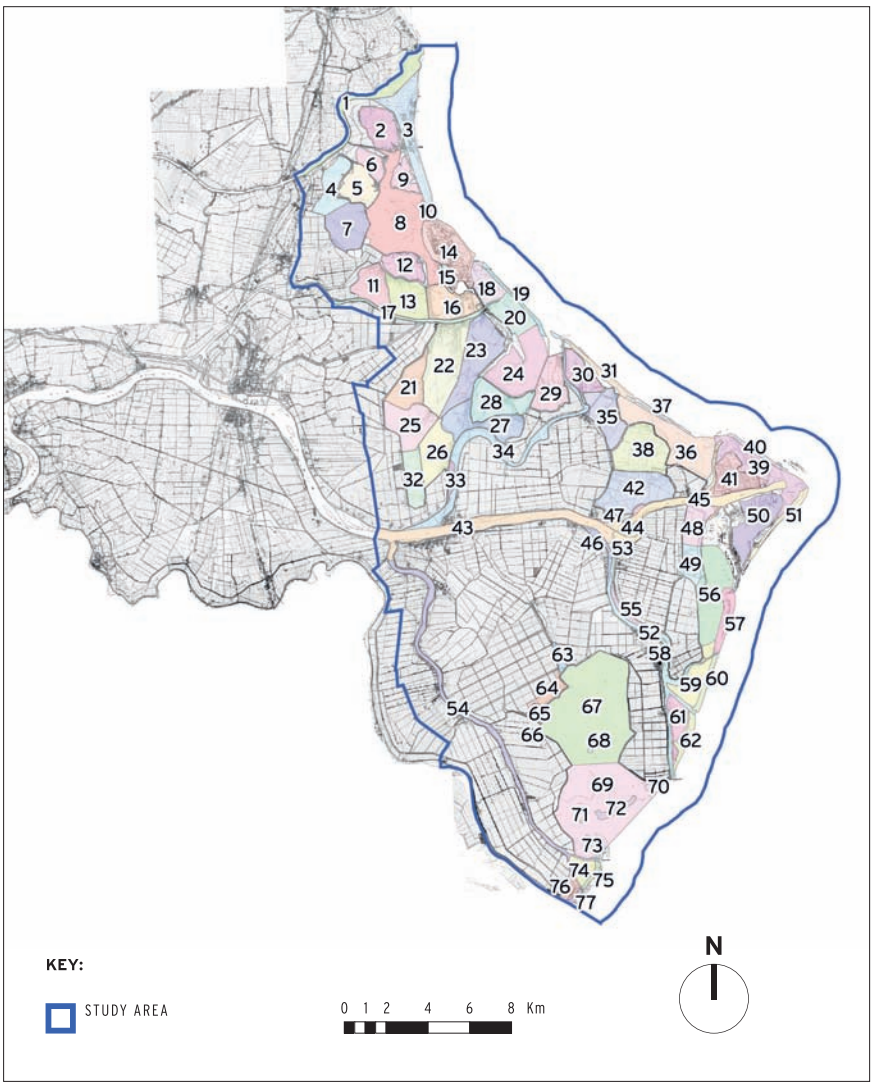


Figure 2: the Po delta's macro-areas inside the study area. See Figure 1 for key.

ID	Macro-area name	ID	Macro-area name
1	Foce Adige	40	Scanno della Batteria
2	Valle Boccavecchia	41	Isola Batteria
3	Pineta di Rosolina	42	Valle Ca' Zuliani
4	Valle Morosina	43	Po di Venezia
5	Valle Spolverina	44	Bonello Ca' Zuliani
6	Valle Cannelle	45	Po della Pila
7	Valle Segà	46	Bonello di Tolle
8	Laguna di Caleri	47	Oasi di Volta Vaccari
9	Valle Passarella	48	Centrale ENEL
10	Giardino botanico di Porto Caleri	49	Lustraura
11	Valle Veniera	50	Laguna Basson
12	Valle Capitania	51	Scanno Boa
13	Valle Sagreda	52	Po di Tolle
14	Isola Albarella	53	Bonello di Polesine Camerini
15	Valle Vallesina	54	Po di Gnocca
16	Valle Pozzatini	55	Golena Giarette Nord
17	Po di Levante	56	Sacca del Canarin
18	Laguna Marinetta	57	Scanno Bastimento Nord
19	Scanno Cavallari	58	Golena Giarette Sud
20	Sacca Cavallari	59	Bonelli Levante Nord
21	Valle Canocchione	60	Scanno Bastimento Sud
22	Valle Sacchetta	61	Bonelli Levante Sud
23	Valle Bagliona	62	Scanno Barriccata
24	Laguna Vallona	63	Oasi di Ca' Mello
25	Valle Moraro	64	Bosco della Donzella
26	Agricola Val Pisani	65	Biotopo Bonello
27	Agricola Ravagnan	66	Pineta di Cassella
28	Valle S. Leonardo	67	Sacca degli Scardovari
29	Valle Scanarello	68	Isola Centro Scardovari
30	Valle Chiusa	69	Sacca di Bottonera
31	Scanno Palo	70	Scanno Barriccata Sud
32	Valle Ca' Pasta	71	Scanno Piccolo Scardovari
33	Golena Ca' Pisani	72	Scanno Centrale Scardovari
34	Po di Maistra	73	Scanno della Bottonera
35	Valle Ripiego	74	Bonello Bacucco
36	Laguna Barbamarco	75	Scanno del Bacucco Nord
37	Scanno Gallo	76	Bonelli Gorino Sullam
38	Valle S. Carlo	77	Scanno del Bacucco Sud
39	Laguna Burcio		

Table 1: macro-areas identified in the Po delta.

cial Protection Areas (SPA) and Sites of Community Importance (SCI) account for 22 282 ha (Figure 1); SCI IT3270017 - Po delta: main branch and Veneto delta; SPA IT3270023 - Delta del Po.

The SPA/SCI areas comprise all the *valli da pesca*, inlet areas, sand bars and lagoons. Other areas of natural importance are those salt marsh areas interfacing with the sea. Brackish water lagoons are protected from the sea by sandbars, thin, long sandy islands extending for tens of kilometers around the whole of the Delta.

A large portion of the Po delta's wetlands - 50 240 ha – is on the list (Brunner *et al.*, 2002) of Important Bird Areas, coded as IBA070 – Po delta and IBA070M - Marine zone of the Po delta (Figure 1): among the more valued species are *Circus cyaneus, Circus pygargus, Caprimulgus europaeus, Lanius collyrio, Lanius minor* (Fracasso *et al.*, 2003). The *Riserva Naturale Bocche di Po*, the *Giardino Botanico di Porto Caleri* and the *Oasi di Ca' Mello* are also to be found in the area.

All of these types of environments and principal physiographic characteristics (e.g. banks of major waterways, major banks of the *valli da pesca*, sand bar shorelines, bordered biotopes, etc.) allow (Figure 2) for the definition of the **macro-areas** as in Table 1, on a larger scale to that of the habitats.

The value of the naturality of the Delta

Applied ecology has developed two lines of methodology for quantifying the ecological value of an environment: the first, more simple approach is based on ranking indicators of ecological value class indicators; the second more complex approach is based on the mathematical modeling of the ecosystem in order to obtain quantitative ecological value indices (Socco, 2008).

Both techniques, being useful in different ways to the different scales, have been used in this study.

What we currently know about the habitats of the Delta is fragmentary (Gariboldi *et al.*, 1997). In making a preliminary estimate of the value of the delta's naturality, an approach similar to that used by Corticelli *et al.* (2004) in the *Parco Regionale del Po dell' Emilia-Romagna*, was taken, conducting a land use survey on the 1:50 000 CORINE Land Cover 2000 map, as provided by the *Ministero dell'Ambiente* and *APAT* on: http://www.clc2000.sinanet.apat.it.

The classification of land use, mainly based on photo interpretation, reveals a hierarchical structure that allows for the attribution of potential natural values to the CORINE LC 2000 Level 4 classes (e.g. Industrial environments = nil; agricultural areas = low naturality; natural wetlands = high naturality, etc.).

CORINE code	CORINE description	ref1	ref2	ref3	ref4	Medium Naturality Value
1.1.2	Discontinuous urban fabric	1	1	1	2	1
1.2.1	Industrial or commercial units	1	1	1	1	1
1.3.1	Mineral extraction sites	1	1	1	1	1
1.4.1	Green urban areas	1.75	1	1	3	2
1.4.2	Sport and leisure facilities	1.75	1	1	3	2
2.1.2.1	Simple cultivations in permanently irrigated land	2.5	2.8	5.5	4	3
2.1.3	Rice fields	2.5	2.8	5.5	5	3
2.2.2	Fruit trees and berry plantations	2.5	2.8	5.5	4	3
2.2.4.1	Poplar plantations	3.25	4.6	5.5	4	4
2.3.1	Pastures	5.5	4.6	5.5	6	5
3.1.1.1	Broad-leaved homl-oak forests	7	10	10	8	9
3.1.1.6	Broad-leaved hygrophilous forests	7	10	10	8	9
3.1.2.1	Mediterranean pine forests	8.5	10	10	7	9
3.2.1	Natural grasslands	8.5	10	10	7	9
3.2.4	Transitional woodland-scrub	8.5	10	10	8	9
3.3.1	Beaches, sand, dunes	nc	nc	10	9	10
3.3.3	Sparsely vegetated areas	nc	nc	10	9	10
4.1.1	Inland marshes	nc	nc	10	9	10
4.2.1	Salt marshes	nc	nc	10	8	9
4.2.3	Intertidal flats	nc	nc	10	10	10
5.1.1	Water courses	nc	nc	10	9	9
5.2.1	Coastal lagoons	nc	nc	10	9	10
5.2.3	Sea and ocean	nc	nc	10	10	10

Table 2: naturality value levels attributed to the Veneto Delta's CORINE biotopes (level 4) by: Pizzolotto & Brandmayr (ref1, 1996); Mancebo Quintana *et al.* (ref2, 2007); Ayad (ref3, 2005), and values attributed to the CORINE classes based on criteria defined by Machado (ref4, 2004). The index of average naturality is obtained from the average values of ref1, ref2, ref3, ref4. nc= not classified.

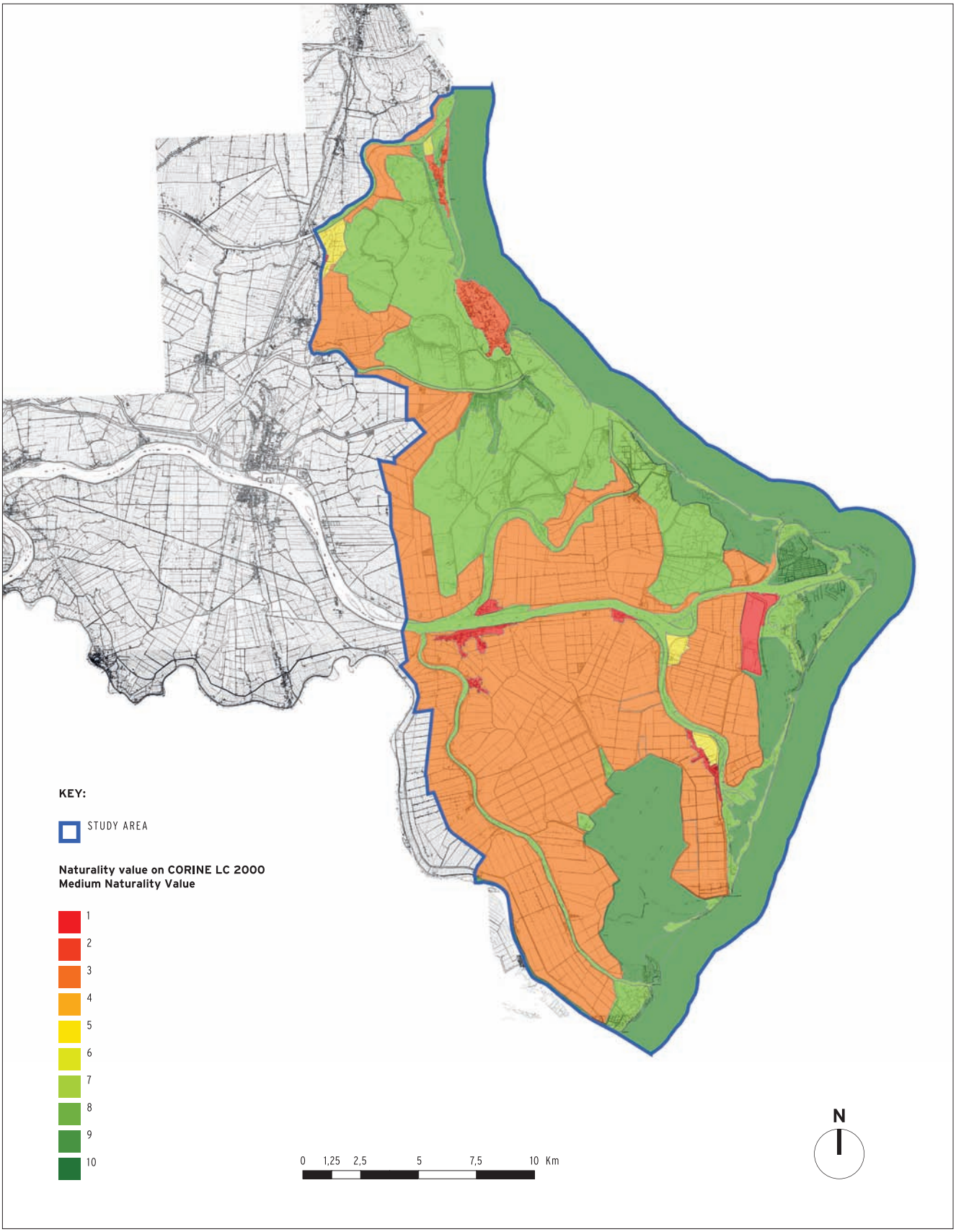


Figure 3: study area's Medium Naturality Values as estimated in the CORINE LC 2000 database.

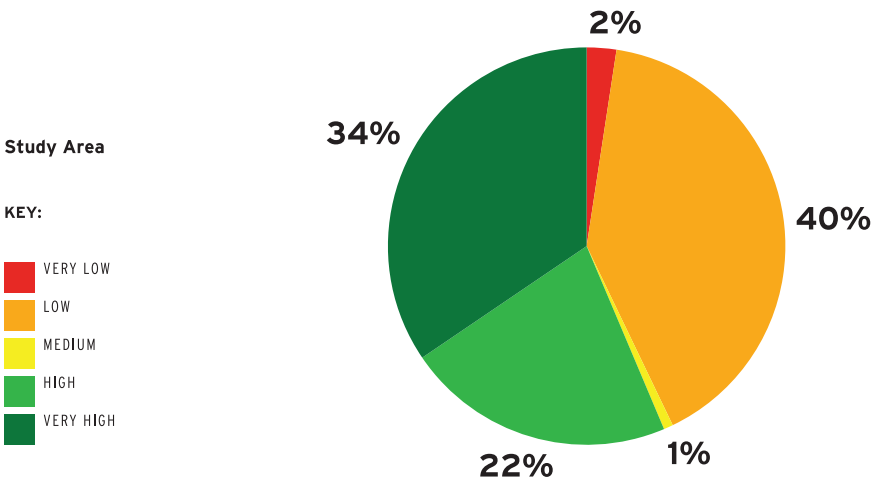


Figure 4: total coverage (in hectares) and relative coverage (% coverage) of the study area by CORINE LC 2000 classes.

Naturality	Area (ha)	Coverage (%)
VERY LOW	1268	2%
LOW	21311	40%
MEDIUM	403	1%
HIGH	11525	22%
VERY HIGH	18166	34%
Total	**52671**	

The map was obtained by attributing a natural value to each class found in the area, according to the descriptions as defined by CORINE LC (Pizzolotto & Brandmayr, 1996, Machado, 2004, Ayad, 2005, Mancebo Quintana *et al.*, 2007). The values provided by different authors were standardized and mediated (Table 2).

The different types of land use clearly separate the urban and agricultural environments, the latter mainly consisting of intensive arable land, and the lagoon delta *valli da pesca* environments which are more natural and are less affected by human intervention.

Naturality values (Figure 3) are higher in areas connected to water environments, those interfacing with the sea (the sandbars and salt marshes) and in the wetlands and branches of the Po River and its floodplains.

Intermediate values are found mainly in areas such as paddy fields, and low values are widespread in agricultural areas and residential areas. In terms of land use, the industrial area of the power plant of *Porto Tolle* and the *Isola di Albarella*, classified as a "sports and leisure activities" area, are categorized as areas with a high anthropogenic influence that the methodology tends to penalize in terms of naturality.

Figure 4 shows the coverage areas (in ha and in%) for classes with average naturality, identified by grouping them into categories of "VERY LOW" values of naturality 1-2; "LOW", 3-4; "MEDIUM",

5-6 "HIGH," 7-8; and "VERY HIGH", 9-10.

The method used in the allocation of values (Table 2) is inadequate when considering coastal environment classes. Naturality values attributed to very large portions of territory like those identified by the CORINE LC 2000, lead to broad approximations in the results, acceptable only if the analysis is conducted on a large scale (e.g. 1:250 000).

This approach may be useful in planning on a regional scale, however, it does not help in defining environmental problems related to the presence of protected species or habitats. The ranking technique, being fairly reliable and easy to apply, is useful in preliminary project assessment or when quickly comparing different locations.

However, this technique shows its limits when it comes to more sophisticated evaluations, such as those accompanying the final draft of a project: therefore in this case a true index of the degree of naturality is required, which is of course a mathematic model of a theory of naturality (Socco, 2008).

The naturality value of the *Isola della Donzella*

The *Isola della Donzella*, located between the *Po di Gnocca* in the west, the *Po di Venezia* in the north, and the *Po di Tolle* in the east, in addition to the inlet areas between the *Po di Gnocca* and *Po di Goro* (*Bonello Bacucco*, *Oasi Gorino-Sullam* and their relative sand bars) as well as the *Sacca degli Scardovari*, covering an area totaling 15 857 ha, make up the study area.

The classification of habitats of the *Isola della Donzella*

In the case of the *Isola di Donzella*, the principal European Community-recognized environmental and territorial classification and coding systems were used in obtaining information on (a) the primary form of land use, according to CORINE LC data, (b) the possible presence of habitats and/or species of community interest and the level of conservational importance thereof, according to the presence of Natura 2000 habitats and (c) information on the dominant type of vegetation, vegetation associations, and/or on the major animal communities, according to the EUNIS classification (EUNIS, 2002).

The classification procedure of the habitats was as follows:

1. the acquisition of geo-referenced orthophotos: Flight IT2003, Agea Flight 2006, Flight CDBPA 10/08/2008;

2. the acquisition of land use map 1:50 000 CORINE Land Cover 2000, provided by the *Ministero dell'Ambiente* and *APAT*;

3. the acquisition of Nature 2000 maps and codes, provided by the *Parco Regionale del Delta del Po Veneto*;

4. the application of EUNIS classification criteria: visual identification of territorial units based on uniform coverage of a particular soil or vegetation type and the application of coding criteria derived from the online database http://eunis.eea.europa.eu;

5. the analysis and matching of EUNIS - CORINE LC - Natura2000 codes through the use of the online database http://eunis.eea.europa.eu;

6. territorial analysis surveys: field surveys carried out by fauna and vegetation experts in 2008, and verifications of orthophoto interpretations.

Having obtained a total of 81 types of habitat, the results of this work are shown in the following paragraphs.

Semi-submerged marine areas and lagoon habitats

These are the most dynamic of ecosystems and are subject to rapid changes on a weekly basis. They are areas with high faunal diversity values, higher than that of the flora, but biogeographically, they are among the rarest of habitats and have a particularly high trophic function for avifauna.

As interfacing habitats between terrestrial and water areas, the naturality tends to be very high. Sediment is predominantly composed of sand or a mixture of sand and mud (Figure 5). Vegetation is sparse and loosely structured offering little shelter for fauna, but is characterized by high-quality flora due to the ecological characteristics of the pioneer vegetation species. The invertebrate community occupying the sandy sediments and those made up of a mixture of sand and mud maintain a well-structured trophic network that is home to a wide range of species. The finer, more cohesive sediments tend to host few species because of the difficulties in oxygen penetration. Human interaction is sporadic. These habitats also include *Phragmites australis*, very abundant reeds characterizing large parts of the brackish estuary (*Bonelli*).

EUNIS code	Description
A2.2	Littoral sand and muddy sand
A2.324	Saltmarsh pools
A2.4	Littoral mixed sediments
A2.52	Upper saltmarshes
A2.522	Mediterranean *Juncus maritimus* and *Juncus acutus* saltmarshes
A2.526	Mediterranean saltmarsh scrubs
A2.532	Mediterranean halo-psammophile meadows
A2.53C	Marine saline beds of *Phragmites australis*
A2.55	Pioneer saltmarshes
A2.5513	*Salicornia* spp. Pioneer saltmarshes
A2.552	Mediterranean coastal halo-nitrophilous pioneer communities
A5.2	Sublittoral sand
A5.21	Sublittoral sand in low or reduced salinity
A5.31	Sublittoral mud in low or reduced salinity
A5.541	Vegetation of brackish waters dominated by *Phragmites australis*

Table 3: principal marine and lagoon habitats.

Figure 5: salt marsh surrounded by *Sarcocornia fruticosa* on the *Scanno Palo* (photo by Danilo Trombin).

Beach and dune habitat areas

Coastal habitats are those above the line of the spring tides. Being close to the sea, they are affected by a moderate salinity content brought by the spray carried by the wind. The marine deposit lines and dune pioneer communities are floristically particularly precious even if the vegetation is not highly diverse or structured. The complexity of the vegetation generally increases from the lines of dunes moving into the areas behind them, but not in the site surveyed. In these environments unique, specialized, and highly adapted vegetation elements (*Cakile maritima* and *Ammophila arenaria*) and animals (the amphipods *Talitrus saltator* and several species of *Coleoptera Carabidae*), which are often peculiar to only these habitats (Figure 6) are selected by environmental stress. The coastal communities' natural value is due to the coexistence of multiple elements of different biogeographical origin, yet which are united by high levels of trophic specialization, exclusivity and fidelity to the habitat, and are good "indicators" of the overall biological quality of the ecosystems that they have in common.

Biogeographically speaking, these are among the least common habitats and they have especially good trophic function and in some cases are essential to the breeding of some species, such as the little tern (*Sterna albifrons*). The rear areas provide good shelter for birds, small mammals and some specimens of herpetological fauna.

EUNIS code	Description
B1.1	Sand beach driftlines
B1.2	Sandy beaches above the driftline
B1.21	Unvegetated sand beaches above the driftline
B1.24	Sandy beach ridges with no or low vegetation
B1.31	Embryonic shifting dunes
B1.32	White dunes
B1.74	Coastal brown dunes covered with natural or almost natural thermophilous pines

Table 4: principal habitats of the beach and dune environments.

Figure 6: dunes with *Ammophila arenaria* - perennial grass that plays an important role in the formation and strengthening of the dunes (photo by Emiliano Verza).

Habitat areas of inland waters, marshes and ponds

Internal fresh water not affected by seawater includes a variety of natural or semi-natural environments that sometimes support very rich communities of both plants and animals. From a naturalistic point of view, the natural reservoirs, which vary in volume near the beds in the floodplains of the Po River, and are characterized by rich flora and fauna, especially on margins that at times provide shelter for many herpetological species, are of particular importance.

The bodies of fresh water in the Po delta are often characterized by the presence of marsh reed (*Phragmites australis*), which functions as a refuge for birds and breeding ground for some species, such as purple heron (*Ardea purpurea*). This class also includes the *Ca' Mello* marsh basins, one of the areas with the highest levels of conservational value on the *Isola della Donzella*. There are also aquaculture ponds that have maintained some semi-natural characteristics in that these habitats, characterized by low faunal and floral diversity, may have a trophic and refuge function for some species of avifauna.

EUNIS code	Description
C1.3	Permanent eutrophic lakes, ponds and pools
C1.3	Permanent eutrophic lakes, ponds and pools
C1.5	Permanent inland saline and brackish lakes, ponds and pools
C3.2111	Freshwater *Phragmite* beds
J5.4	Highly artificial non-saline running waters
X01	Estuaries

Table 5: principal habitats of the internal water environments, marshes and ponds.

Figure 7: reeds in the *Po di Gnocca* (photo by Danilo Trombin).

The main waterways, represented by irrigation canals or land reclamations form a well-developed grid. They support all trophic components (ichthyofauna, herpetofauna, avifauna) and fundamentally, serve as ecological corridors: these are areas to which high functional values are attributed, with low values for floristic diversity and medium to high for wildlife diversity. The artificial canals are characterized by human management and are therefore categorized as "artificial" (Class "J" of EUNIS nomenclature). Even if they rarely present quality vegetated margins, they are fairly rich in fish fauna, although depleted and altered in specific composition. The allochthonous species are diminishing both in number and in abundance, while native species that are more competitive and more resistant to various forms of pollution are becoming more common. (Castaldelli *et al.*, 2008). The branches of the Po River are also an exception to the EUNIS nomenclature, classifying them in macro-class "X, estuaries" dedicated to complex mosaic systems. This is due to the distribution of the complexity of vegetation associations (Figure 7) and their varying locations as a result of alternating dry and flowing river periods, which in turn generates ephemeral microhabitats that are hardly mappable.

Habitats of the grassland areas

These natural habitats are extremely variable in value. On the one hand there are the Mediterranean salt steppes, characterized by associations to hypersaline plants varying with degrees of salinity. These habitats are ecologically highly valuable, not so much for their diversity which is limited by environmental stress, but for their ecological functions, especially for the avifauna that use them as nesting and breeding sites. Reptiles, being saline tolerant, are also well represented in this area. On the other hand, this group includes communities of nitrophile anthropogenic grass commonly found in areas which are subject to more disturbance like those close to buildings or in industrial areas as well as meadows, gardens and parks in urban and semi-urban contexts, both situations being characterized by very low naturality values.

The grass areas on the humid, tree-lined fringes of the river floodplains are of medium-high value, while only of medium value are the meadows found mostly along the banks of the Po River (Figure 8). These environments are in fact closed to many amphibians while hosting many species of reptiles, birds and mammals that nest in these fields and feed on a wide variety of insects and invertebrates.

EUNIS code	Description
E2.22	Sub-Atlantic lowland hay meadows
E2.6	Agriculturally-improved, re-seeded and heavily fertilized grassland, including sports fields and grass lawns
E5.14	Weed communities of recently abandoned extractive industrial sites
E5.43	Shady woodland edge fringes
E6.1	Mediterranean inland salt steppes
E6.112	Adriatic sea-lavender steppes
E6.112, A2.2	Adriatic sea-lavender steppes on littoral sand and muddy sand
E6.112, A2.522	Adriatic sea-lavender steppes with Mediterranean *Juncus maritimus* and *Juncus acutus* saltmarshes

Table 6: principal habitats of the grassland areas.

Figure 8: grass meadows near the banks of the Po River (photo by Danilo Trombin).

Shrub habitat areas

This habitat category is characterized by bramble (*Rubus ulmifolius*) and comprises of native or alien, often plurispecific shrub species that develop spontaneously especially in mesophilic environments. They provide places of refuge for a rich micro and macro fauna, and bring together elements of the plain's ecological network (Figure 9). The floristic and faunal diversity values are equally medium.

EUNIS Code	Description
F3.1	Temperate thickets and scrub
F9.313	Mediterraneo-Macaronesian tamarisk thickets
FB.4	Vineyards

Table 7: principal shrub habitat areas.

Figure 9: shrubberies dominated by *Amorpha fruticosa* near a *Po di Gnocca* floodplain (photo by Danilo Trombin).

Wooded habitat areas

The wooded habitats are made up of riparian hygrophilous forests of the Po River's floodplains (Figure 10), where the structure and diversity of undergrowth provides shelter for many herpetofaunal and avifaunal species and mammals. The ecological value of these areas tends to be very high, like that which contains the *Bosco della Donzella* on the northern edge of the *Sacca degli Scardovari*. In the reforested areas of agrarian habitats, elements in the latter evolutionary stages have intermediate flora and fauna diversity values while maintaining a high functional value for nesting and shelter.

Elements of a more artificial and linear nature, like the rows of trees lining the roads, are characterized by low floral and faunal diversity and function values.

EUNIS code	Description
G1.224	Po *Quercus - Fraxinus - Alnus forests*
G1.3	Mediterranean riparian woodland Woods
G1.A	Meso- and eutrophic *Quercus, Carpinus, Fraxinus, Acer, Tilia, Ulmus* and related woodland
G1.C	Highly artificial broad-leaved deciduous forestry plantations
G1.C1	*Populus* plantations
G1.D4	Fruit orchards
G5.1	Lines of trees
G5.2	Small broad-leaved deciduous anthropogenic woodlands

Table 8: principal wooded habitats.

Figure 10: hygrophilous woods predominantly made up of *Salix alba* on the banks of the Po River (photo by Danilo Trombin).

Agricultural habitats

These are the dominant habitats in terms of coverage (Figure 11). Intensive agriculture, developed in the early 1970s, led to the realization of agricultural land without appreciable vegetation margins. For this reason their floristic diversity value is very low. Some bird species and small mammals take advantage of the feeding possibilities (granivorous animals and their predators).

Even if, according to the EUNIS nomenclature, the rice fields (I1.4) are incorporated in the agricultural habitats class, due to their ecological characteristics it is possible to class them with the ponds' bodies of water since, despite being only temporary habitats, they are subject to flooding, making them extremely peculiar. The changing over time of hydrological conditions brings from an initial oligotrophic condition to a high eutrophic condition. This characteristic makes them temporary sites of added value due to their high trophic function for the avifauna (Fasola & Ruiz, 1996), herpetofauna and the trophic network in general.

EUNIS code	Description
I1.1	Intensive unmixed crops
I1.2	Mixed crops of market gardens and horticulture
I1.4	Inundated or inundatable croplands, including rice fields
I1.5	Bare tilled, fallow or recently abandoned arable land
I2.23	Small parks and city squares

Table 9: principal agricultural habitats.

Figure 11: agricultural areas cover more than 60% of the Delta's territory (photo by Andrea Bocchi).

Urban and highly artificial habitats

In these habitats, there is total anthropologic inhabitation (Figure 12). The surfaces are totally or largely artificial and animal and plant species are introduced or opportunistically synanthropic. The naturality value and general support values for the ecosystem functions are minimal, if not zero.

EUNIS code	Description
J1.2	Residential buildings of villages and urban peripheries
J2.1	Scattered residential buildings
J2.4	Agricultural constructions
J1.4	Urban and suburban industrial and commercial sites still in active use
J1.51	Urban and suburban derelict spaces
H5.61	Unsurfaced pathways
J4	Transport networks and other constructed hard-surfaced areas
J5	Highly artificial man-made waters and associated structures
J2.53	Sea walls
J4.5	Hard-surfaced areas of ports
J2.7	Rural construction and demolition sites

Table 10: principal urban and highly artificial habitats.

Figure 12: the artificial surfaces of buildings and roads characterize the towns (photo by Danilo Trombin).

The mapping process of habitats in Tables 3-10 was carried out using the GIS, resulting in the vector format digitization of territorial units, i.e. the individual portions of land containing the identified habitat types. Overall, **this procedure led to the digitization of 1944 units**. Based on the described method of analysis, a 1:5 000 scale map of the *Isola della Donzella*'s habitats was produced (Figure 13).

The land coverage in hectares of the principal EUNIS habitat types corresponding to the 1st level of the classification was evaluated by means of the GIS.

Habitats corresponding to agricultural areas represent more than half of the territory, while marine and coastal habitats represent 29%. Note the low proportion of habitat classes B, D, F and H, which at present, are confined to ecotonal bands in the Po delta's environments.

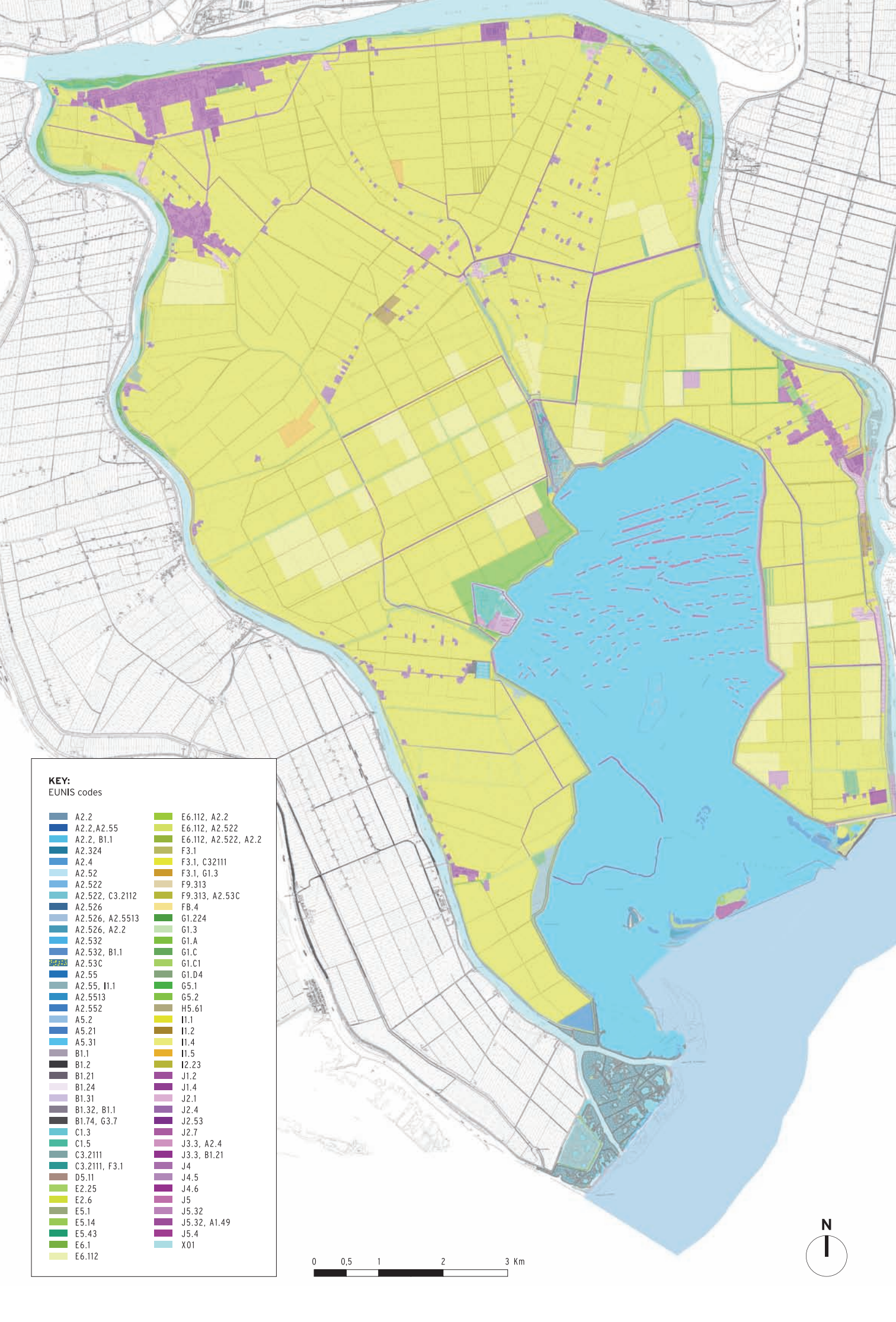
The Potential Natural Value (PNV) of the *Isola della Donzella*

The above presented identification with minor modifications and location of habitats is the first step in evaluating the degree of naturality. Then, a synthetic index based on the analytic approach of Berthoud *et al.* 1989, is applied to each habitat type (Tables 3-10 to estimate its **Potential Natural Value (PNV)**. The methodology is based on the critical analysis of the pre-existing bibliography and on the experience of researchers of vegetation, fauna and their functions in the territory, in this way identifying the **principal factors** (Quality, Capacity and Function) that contribute to the definition of the ecological value of the habitats. Each factor is evaluated through the estimation of **parameters** (Table 12) selected on the basis of operational simplicity in order to be quantified as said through (i) direct observations, (ii) literature/data and/or (iii) fauna and vegetation experts' knowledge of the environment.

Figure 13: habitats of the *Isola della Donzella* in 2008 coded according to the EUNIS system. For a description of the codes refer to Tables 3-10.

EUNIS 1st level classes	Definition	Coverage (ha)	Coverage %
A	Marine habitats	4583	28.90%
B	Coastal habitats	15	0.10%
C	Inland surface waters	252	1.59%
D	Mires, bogs and fens	35	0.22%
E	Grasslands and lands dominated by forbs, mosses or lichens	464	2.93%
F	Heathland, scrub and tundra	69	0.44%
G	Woodland, forest and other wooded land	225	1.42%
H	Inland unvegetated or sparsely vegetated habitats	2	0.01%
I	Regularly or recently cultivated agricultural, horticultural and domestic habitats	8543	53.87%
J	Constructed, industrial and other artificial habitats	697	4.40%
X	Habitat complexes	971	6.12%
	Total	**15857**	

Table 11: EUNIS 1st level habitats in hectares and percentual coverage of the *Isola della Donzella*.


KEY:
EUNIS codes
A2.2
A2.2,A2.55
A2.2, B1.1
A2.324
A2.4
A2.52
A2.522
A2.522, C3.2112
A2.526
A2.526, A2.5513
A2.526, A2.2
A2.532
A2.532, B1.1
A2.53C
A2.55
A2.55, I1.1
A2.5513
A2.552
A5.2
A5.21
A5.31
B1.1
B1.2
B1.21
B1.24
B1.31
B1.32, B1.1
B1.74, G3.7
C1.3
C1.5
C3.2111
C3.2111, F3.1
D5.11
E2.25
E2.6
E5.1
E5.14
E5.43
E6.1
E6.112
E6.112, A2.2
E6.112, A2.522
E6.112, A2.522, A2.2
F3.1
F3.1, C32111
F3.1, G1.3
F9.313
F9.313, A2.53C
FB.4
G1.224
G1.3
G1.A
G1.C
G1.C1
G1.D4
G5.1
G5.2
H5.61
I1.1
I1.2
I1.4
I1.5
I2.23
J1.2
J1.4
J2.1
J2.4
J2.53
J2.7
J3.3, A2.4
J3.3, B1.21
J4
J4.5
J4.6
J5
J5.32
J5.32, A1.49
J5.4
X01
0
0,5
1
2
3 Km
N

Parameter	Acronym	Value range	Criteria
Vegetational diversity	*DiV*	1-10	Vegetation diversity estimate of species protected under Annex II, IV and V of the Habitats Directive
Faunal diveristy	*DiF*	1-10	Faunal diversity estimate for species protected under Annex II, IV and V of the Habitats Directive
Rareness	*Ra*	1-10	Estimate of the rareness of the habitat in the referenced bio-geographical region, in our case corresponding to the *Alto Adriatico* basin
Vegetation structure	*St*	1-4	Structural complexity estimate based on prevalent vegetation (eg, bare, grassland, shrub, tree)
Surface areas (m^2)	*Sp*	20-1,000,000	GIS calculation of the area
Useful ecotones	*Ca1*	0-5	Margin quality estimate in terms of receptivity of flora and fauna
Ecological corridor	*Ca2*	1-5	Ecological corridor function estimate in terms of the movement of animal species
Absence of humans	*Ca3*	1-5	Estimation of the degree to which anthropogenic disturbance is absent
Reproduction function	*FRi*	1-5	Estimation of the function of guide species' reproductive sites
Refuge function	*FRf*	1-5	Estimation of the function of guide species' refuge sites
Trophic function	*FNu*	1-5	Estimation of the function of the guide species' trophic site

Table 12: parameters for the calculation of each habitat PNV, showing the symbols, maximum and minimum values attributable to each parameter.

Table 13: definition of the quality (Q), capacity (C) and function (F) based on the parameters of Table 12.

	Q = Quality index	C = Capacity index	F = Function index
The PNV index is: **PNV=$\prod$ (Q,C,F)** where Q, C and F are:	$Q=\frac{\sum(Di, Ra, Ca)}{3}$ with: Di= MAX (DiF, DiV) $Ca=\frac{\sum(Ca1, Ca2, Ca3)}{3}\cdot 2$	$C=\frac{Log_{10}(Sp \times St)}{6.6}\cdot 10$	$F=\frac{\sum(FNu,FRi,FRf)}{3}\cdot 2$

The habitats' Quality (Q), Capacity (C) and Function (F) have values ranging from a minimum of 1 to a maximum of 10, leading to a PNV index with values ranging from 1 (least natural) to 1000 (maximum naturality).

Some parameters (*CA1, Ca2, CA3, Sp, FRi, FRe, FNu*) express the habitats' topological characteristics or spatial properties closely related to their position in the area (e.g. surface area) as well as the relation between adjacent habitats (e.g. linear meters of margins the two habitats have in common) and the functional properties of a territorial unit. The decision to assign the function value to each portion of the territory was made in order to highlight the natural and ecological dynamics that, in terms of vegetational cover are not homogeneously distributed.

The habitat type "deciduous bushes mixed with reeds" may have little functionality in one portion of territory, while having a high value in another (e.g. an egret roost). For these reasons, the determining of parameter values *CA1, Ca2, CA3, Sp, FRi, FRe, FNu* for each territorial unit takes into account the types of habitats it contains and the possible presence of "guide species".

Species	Preferential habitat		
	Description	Dir. 92/43/CEE	CLC
Ichthyofauna			
Knipowitschia panizzae	Lagoons and valleys, and small pools of water	1150*	521
Rutilus erythrophthalmus	Fresh, slow water rich in vegetation	3150 - 3260	
Herpetofauna			
Emys orbicularis	Bodies of freshwater or slightly saline water	3150	512
Natrix natrix	Bodies of fresh water	3150	512
Teriofauna			
Suncus etruscus	Fossil dunes and thermophilous woods	2270* -	3121
Micromys minutus	Hygrophilous woods and reed beds	91E0* - 3150	512 - 3116 - 512 - 4111

Table 14: excerpt from the guide species from ichthyofauna, herpetofauna and teriofauna.

Species	Preferential habitat			Reproduction habitat	Seasonal refuge habitat	Nutritional habitat
	Description	92/43/CEE code	CLC			
Gavia arctica	Marine waters and lagoons	1150* - 1130 - 1110	521 - 523	TUNDRA ARTICA	1150*, 1130, 1110	1150*, 1130, 1110
Ardeola ralloides	Rivers and pools of fresh water	3150 - 91E0*	512 - 3116	91E0*	3150, 91E0*	3150
Haematopus ostralegus	Pioneer vegetation of sand bars	2110 - 2120	3311	2110, 2120	2110, 2120	1140, 1150*, 1310

Table 15: example excerpt from the avifauna guide species used in evaluating the ecological functionality of habitats.

The guide species were selected on the basis of both their function as ecological indicators and their inclusion on protected species lists (e.g. Habitats Directive, Annex II). Among the selected species, seven are from herpetofauna, seven from ichthyofauna, and six from teriofauna (Table 14).

Eighteen guide species of avifauna, typically capable of, in an extremely specialized manner, taking advantage of different habitats according to their needs in that specific point of their life cycle, were chosen and for each one, apart from their preferred habitats, potentially useful habitats for trophic, reproductive and refuge functions were evaluated (Table 15).

Another method of quality evaluation specially developed for the evaluation of lagoon environments will be applied to EUNIS classes A5.2, A5.21, A5.31, being submerged areas, in the following paragraph (3.2). A Potential Natural Value (PNV) (Figure 14) for each habitat and hence each territorial unit was obtained with reference to 2008 by assigning values to the parameters based on the prevailing land use and according to the in-the-field experience of researchers interviewed and bibliographic research.

The PNV values were classed into a 20 class gradient using the algorithm of the "natural breaks" provided in ArcGIS in order to determine the best separation of values into classes, iteratively comparing the sum of squared differences between the observed values in each class and the average of each class.

In this way it is possible to achieve a subdivision of classes suited to the best graphic representation (Jenks & Coulson, 1963). The lower PNV values (in red) are mainly found in urban and agricultural areas, while the highest values (in green) are distributed throughout the Po's floodplains, in the *Bonello Bacucco*, on the *Oasi Gorino-Sullam*, in the *Oasi di Ca' Mello* and in the *Bosco della Donzella*.

The highest values are the *Bonello Bacucco*'s reed areas (VNP=881). The theoretical maximum (VNP=1000) was not reached in any habitat. Figure 15 shows the distribution of PNV values calculated in the *Isola della Donzella* territory.

The distribution shows very high frequencies for values below 600 and very low frequencies for those above. This is essentially due to the fact that the habitats within agricultural and man-made areas (EUNIS classes I and J) with low natural value cover a large part of the analyzed territory (Table 11).

The weight of agricultural areas in the PNV analysis is very because the result does not account for the classes corresponding to the areas covered by water (Classes A and X), which constitute 5345 ha (33.7% of the territory), and which are analyzed using another method in the next paragraph.

Figure 14: Potential Natural Value of habitats of the *Isola della Donzella* as seen in 2008. The water bodies have been excluded from the analysis.

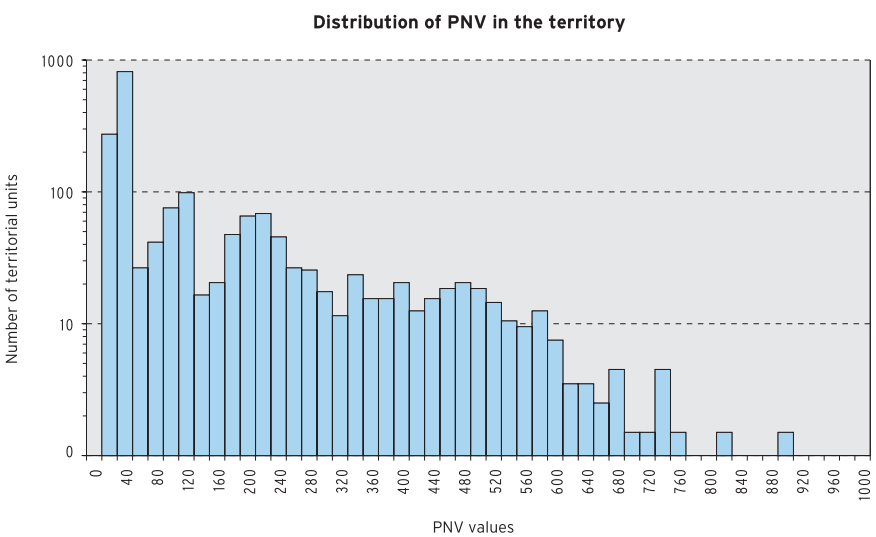
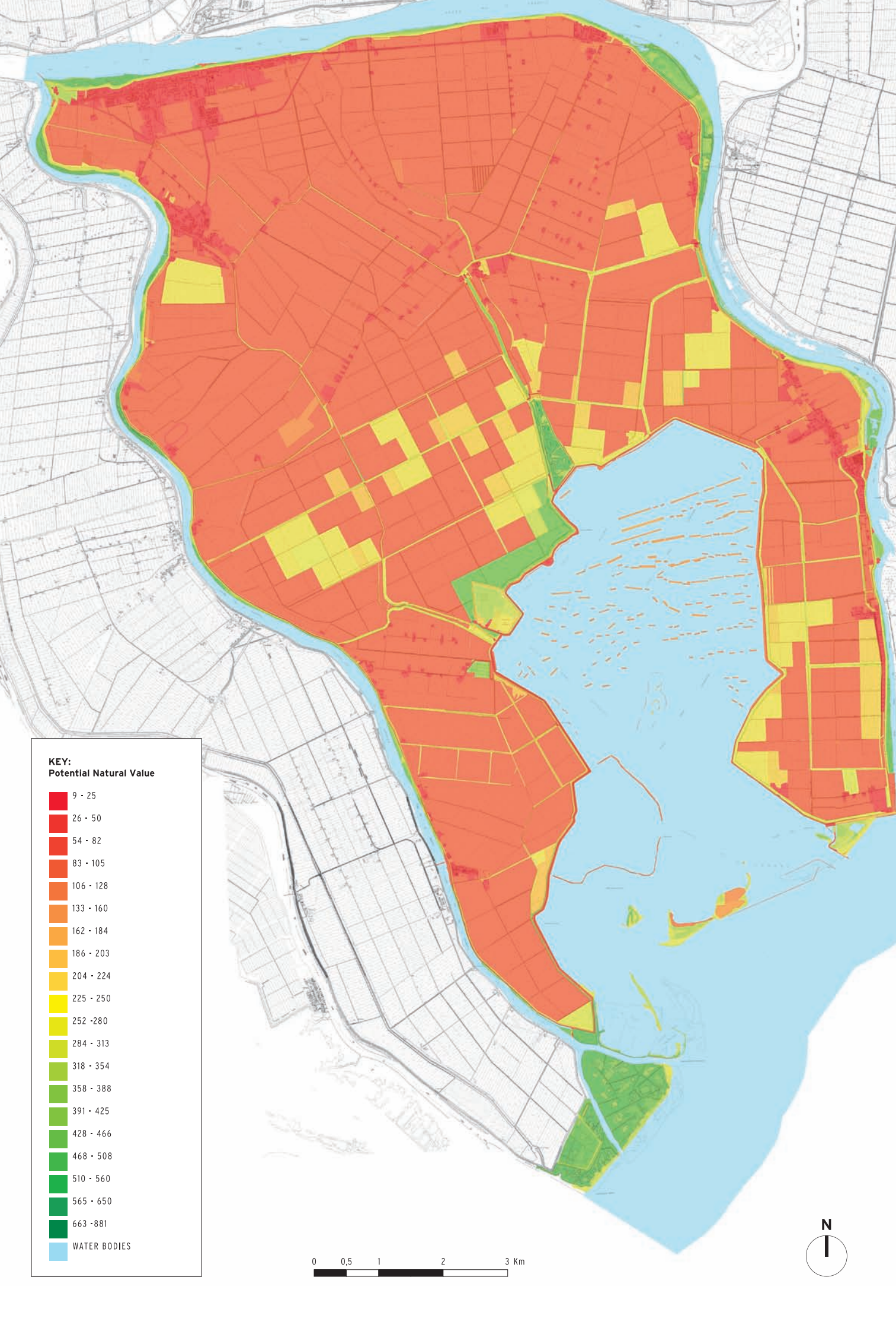


Figure 15: distribution on the logarithmic scale of PNV values calculated for each territorial unit.


KEY:
Potential Natural Value
9 - 25
26 - 50
54 - 82
83 - 105
106 - 128
133 - 160
162 - 184
186 - 203
204 - 224
225 - 250
252 -280
284 - 313
318 - 354
358 - 388
391 - 425
428 - 466
468 - 508
510 - 560
565 - 650
663 -881
WATER BODIES
0
0,5
1
2
3 Km
N

The estimation of the Potential Quality Value (PQV) of the lagoons

The method of calculating the Potential Natural Value (PNV) requires parameters that are poorly suited to assess transitional water quality. At the moment there is no standard methodology for estimating the quality of the aforementioned waters, and the theme is still the subject of intense debate in scientific literature (Magni *et al.*, 2009, Mistri *et al.*, 2009, Uriarte and Borja, 2009).

Anyhow, the DL 152/06 acknowledges the European directive (Water Framework Directive, WFD, 2000/60/EC) which says that, in order to achieve "good water status" by 2015, the Member States are required to submit the evaluation of the ecological status of water bodies (Ecological Quality Status, EcoQ) defined as the ratio between reference conditions and the current conditions of the water bodies (Heiskanen *et al.*, 2004). The EcoQ of transitional waters will be quantified (Vincent *et al.*, 2003) based on the biological, hydromorphological and physical-chemical characteristics. In particular, phytoplankton, macro-algae, angiosperms and benthos and ichthyofauna are to be taken into consideration.

Due to the fact that a reference method is not available as yet, this article proposes the use of a simplified method, utilizing data from studies on the *Sacca degli Scardovari,* in which the principal water quality parameters are being continuously monitored, and for which there is a vast amount of literature dating back to the 1980s (Ceccherelli *et al.*, 1983, 1985, Rossi *et al.*, 1984, Casellato & Caneva, 1992, Franzoi *et al.*, 1993, Fornasari *et al.*, 1995, Munari & Mistri, 2008).

Maps, graphs, tables from the literature have been interpreted in order to reconstruct the main parameter space/time trends through the geo-referencing of sampling points, to which the available data have been associated. Geostatical techniques (e.g. kriging) were used in the spatial interpolation producing maps of likely spatial data distribution, to which a color gradation was applied in order to analyze the general trend of the said datum. When the spatial distribution was not interpretable, an analysis of the temporal trends of the parameters in the northern and southern portion of the Sacca was carried out.

The water quality assessment model used in this work could only take into account parameters for which data already existed, as discussed in the following paragraphs.

Hydro-dynamism: the general hydrodynamic model developed by IPROS for *Consorzio di Bonifica Delta Po Adige* quantifies the speed of the surface currents entering and exiting the lagoon in the absence of wind and in spring tide conditions. The model does not take into account local phenomena, for example the presence of draining pumps, or other elements that cause localized hydrodynamism. Figure 16 shows the map of fields of speed expressed in m/s with incoming tide.

The water replacement rate is one of the main limiting factors in the more confined areas of transitional water bodies. Low hydrodynamics not only have an impact on the characteristics of the water column (dissolved oxygen, salinity, temperature, etc.), but also on sediment texture. Tidal current movements only slightly affect the northernmost part of the lagoon. This increases the water residence time and has a negative impact on ecological processes on the water column and sediment.

The northern part appears to be more vulnerable and exposed to dystrophic phenomena that may occur during the summer months when there is a physiological increase in temperature. In the south, the situation instead appears to be more dynamic with water replacement and recycling that allows for better revitalization.

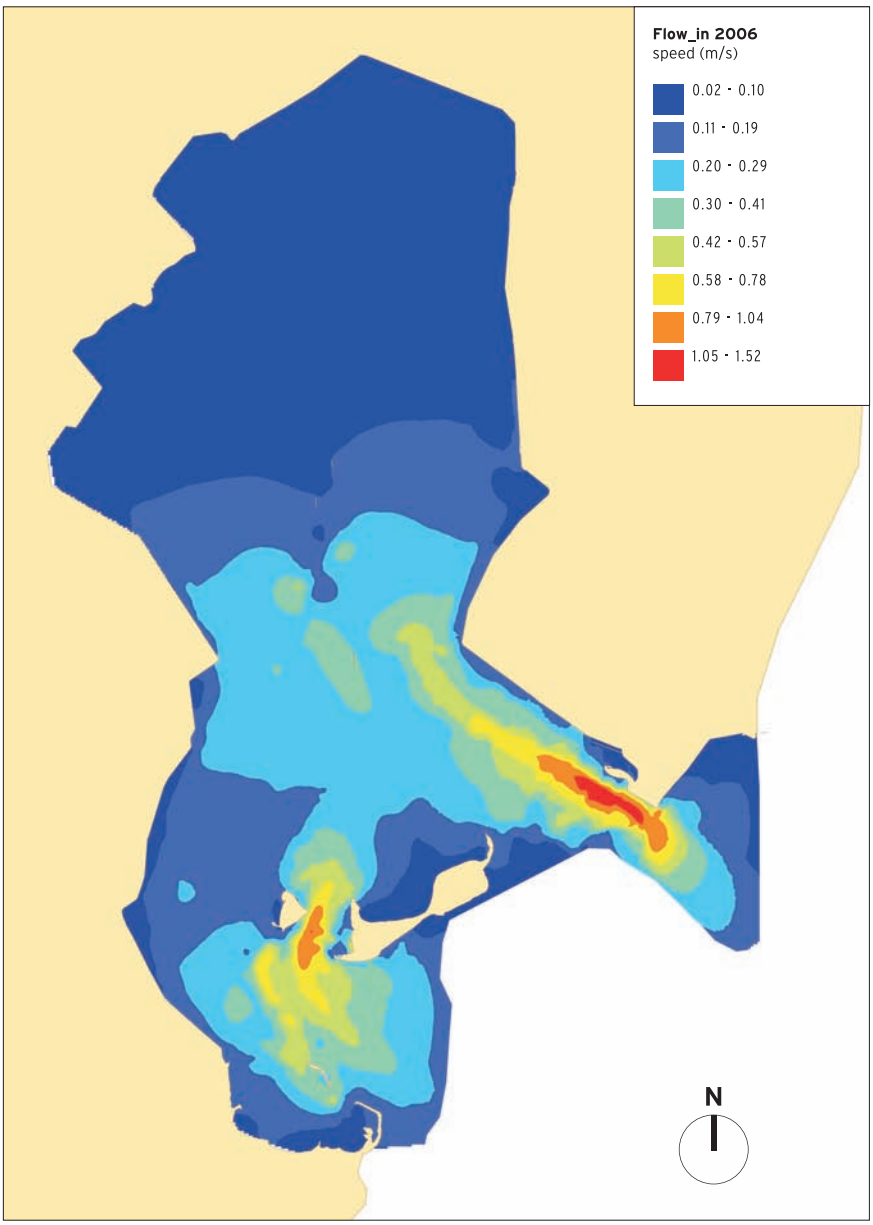


Figure 16: two-dimensional hydrodynamic model of the *Sacca degli Scardovari* showing the incoming spring tide at maximum flow.

Depth: the bathymetric surveys (March 2008) were corrected referring to the mareograph of the *Diga Sud Chioggia*, managed by *APAT*. Bathymetric bands corresponding to submerged areas with depths of 0.5, 1.0 and 1.5 m compared to the average sea level were identified. These areas that, depending on tide, wind and atmospheric pressure that can temporarily emerge, are very important interfaces that contribute to the quality of the water surface area (Figure 17).

At the sea inlets in the southern area the coastal dynamics create extensive interfacing areas especially around the *Scanno Centrale* and the semi-submerged *Scanno della Bottonera*. In the central area there are a few outcropping tidal flat residues resulting from interventions carried out by man, which despite this, are of ecological value and are undergoing a process of renaturalization. In the north, following the construction of the defense embankment along its border, there are almost no interfacing areas.

Granulometric sediment measurement: granulometric sediment size was investigated in the 1976-1982 period by Ceccherelli *et al.* (1985) and in 2005 by Mistri *et al.* (2007) (Figure 18).

Salinity: sampling at the internal station and at the sea is only partially overlapping. Over a period of 3 years, the values of the internal station were stable, fluctuating between a minimum of 16 ppt in May 2008 and salinity values close to that of seawater during the warmer months. On the contrary, the station at the mouth to the sea is affected by fresh water flowing from the mouth of the *Po di Tolle* and shows more accentuated fluctuations, even in sum-

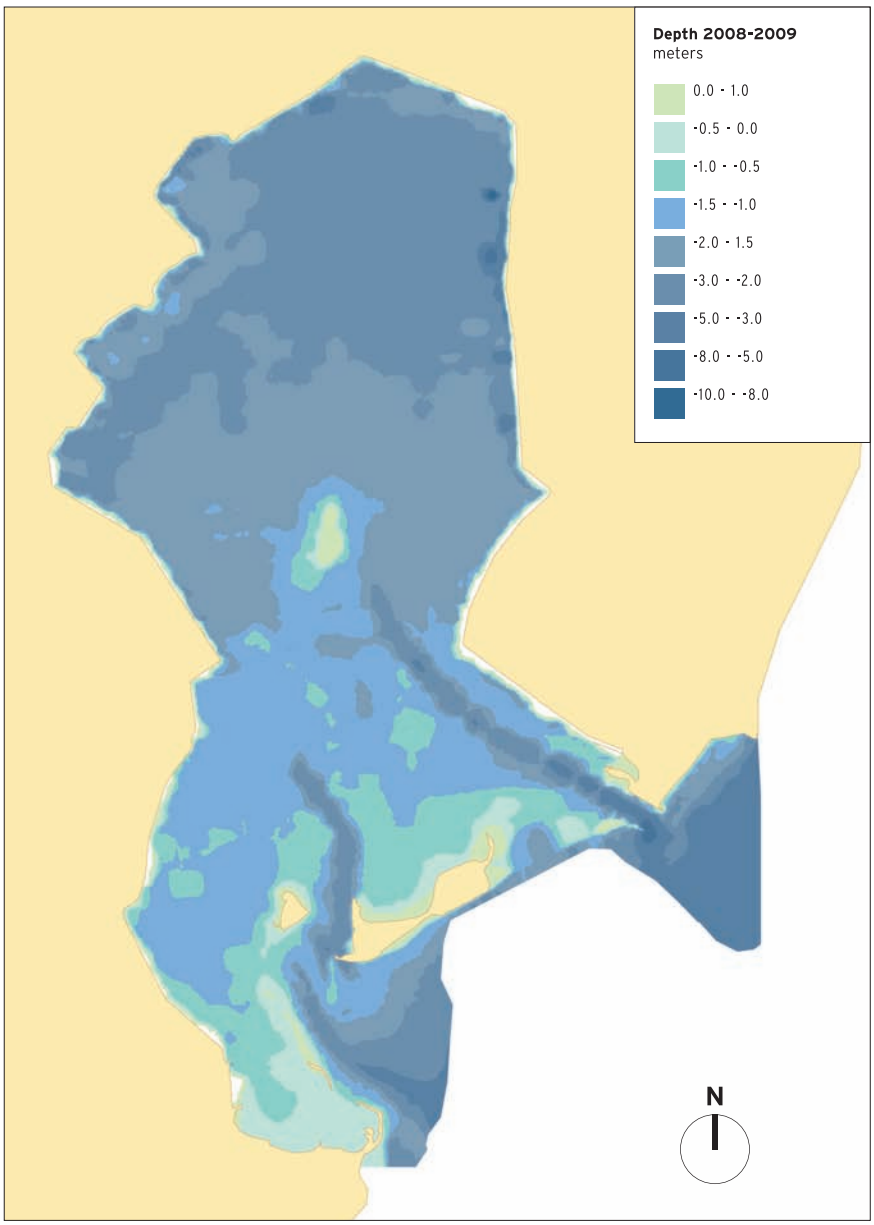


Figure 17: depths surveyed across the whole of the *Sacca degli Scardovari* between March 2008 and March 2009. Areas with low water coverage have been highlighted.

mer, with a minimum close to 5 ppt during spring 2008.

Temperature: the reduced number of measurement points does not allow for the interpolation of values in the Sacca. Over the years the data show a comparable trend with temperatures peaking in July, at both the interior and sea stations. The absolute temperature is higher inside the Sacca compared to the sea, with an average difference of +2 ° C.

Dissolved oxygen: here too, the reduced number of measurement points makes it difficult to extrapolate data on the Sacca. It should be noted an anoxia phenomena occurred in June 2006 in the northern part of the Sacca without affecting the sea inlets.

Macro-algae: the bibliography reports the presence of extensive beds of *Ulva* sp. and *Gracilaria* sp., especially in warmer months, but no data are available relating on biomass and coverage. However the macro-algae sector is so important to deserve monitoring.

Phanerogams: Beds of *Zostera marina*, *Zostera noltii* and *Cymodocea nodosa*, can be found in the lagoons, but not in the *Sacca degli Scardovari* (Marchini *et al.*, 2008; D. Trombin, pers. comm.). Furthermore, their presence is not shown in data collected over the last 30 years.

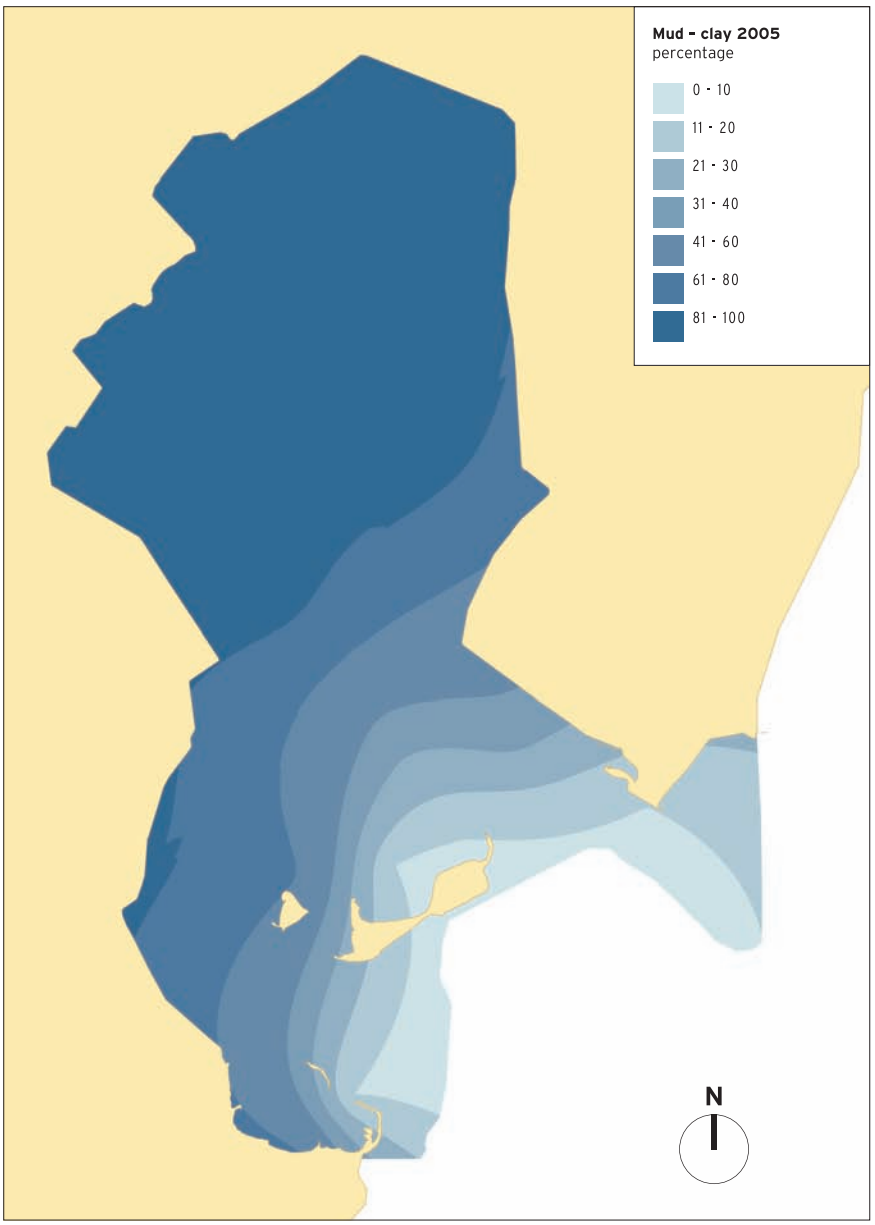


Figure 18: distribution of mud and clay in the *Sacca degli Scardovari* 2005 (by Mistri *et al.*, 2007).

Ichthyofauna: Data reported by Rossi *et al.* (1984), stressed the importance of the basin's function as a nursery area for juveniles of the euryhaline species. More recent data are available on the *Carta ittica della Provincia di Rovigo* (Bettini *et al.*, 2006, Mistri *et al.*, 2007, 2008).

Benthos: the available data was that of Ceccherelli *et al.* (1985), Munari & Mistri (2008) as well as that produced during the realization of the *Carta ittica della Provincia di Rovigo* (Bettini *et al.* 2006, Mistri *et al.*, 2007, 2008).

Shellfish activities: at the moment, no large-scale mapped data are available but only signs of punctiform clam and mussel culture activity.

Culture plants of *Mytilus galloprovincialis* are easily locatable from orthophotos. A map (Figure19) representing the potential production and the habitat suitability for clam culture in different areas of the *Sacca degli Scardovari* was produced, in the same way as Vincenzi *et al.* (2006) did with the *Sacca di Goro*, by Graziano Caramori and Giulio De Leo. If, for oxygen and salinity, data collected by the two buoys placed in the Sacca in 2008 were referred to, the granulometric measurements dating back to 2003, having few points in the northern area, and in particular, the absence of a hydrodynamic model keeping account of local phenomena make the representation quite limited.

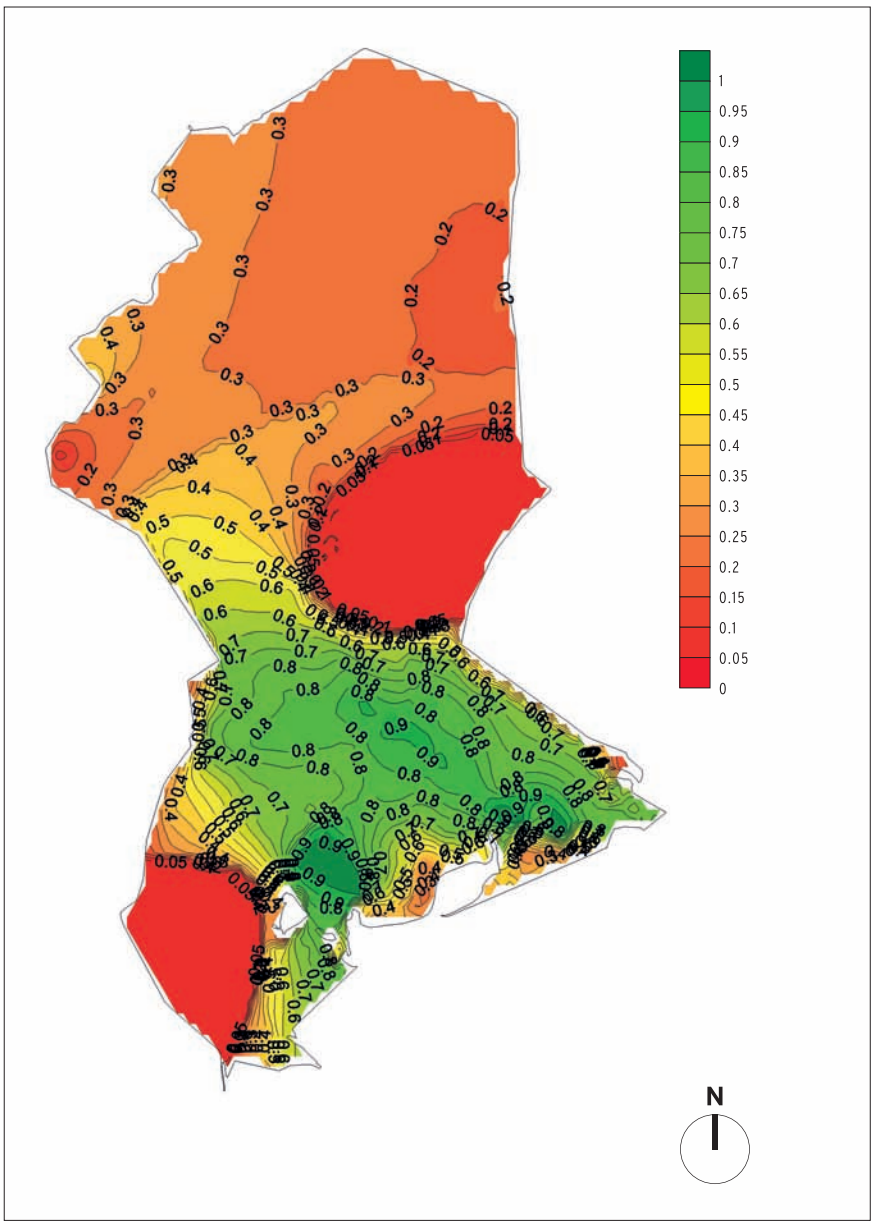


Figure 19: verace clam's production suitability (zero - lowest suitability and 1 - highest suitability).

Water quality evaluation model

The water quality evaluation model of the above listed parameters exploits the most indicative factors - hydrodynamic, depth and particle size - excluding those at higher temporal variability and those for which the scientific community has yet to reach a shared point of view. Interval values that have clearly identifiable effects on environmental components, biotic and/or abiotic, were defined for each of the three parameters.

The determining of threshold values upon which the ordinal classes of the parameter are defined is fundamental for the structure of the model, bearing in mind that environmental factors often change the characteristics of the environment with non-linear processes (Turner, 1989).

Hydro-dynamism: the threshold level for determining the erosion of the surface layers of the sediment varies from 0.1 to 0.7 N/m^2 depending on the type of sediment (Paterson & Black, 1999), which corresponds to a range of current velocity between 0.3 - 0.5 m/s for medium sand (Soulsby, 1998).

The threshold value of 0.1 m/s is the limit below which the sediment erosion process occurs with very low probability, regardless of the granulometric texture. The current velocity of 1 m/s is the point above which erosion occurs with high probability, whatever the texture of the lagoon sediment. The threshold values that determine the three classes are shown in Table 16.

Depth: the semi-submerged habitats are important ecotones for benthic invertebrate species and are trophic sites for shorebirds and avifauna in general (Erwin, 1996). Although the importance of the depth in these environments is evident, it is equally difficult to establish precise limits to the spatial effects on abiotic factors (degree of stratification, oxygen diffusion, light penetration), biotic factors (development of algal and bacterial microfilm) and ecological factors (Padis & Reynolds, 2005).

Threshold values were chosen considering sediment depth that, with the varying tides of the Po delta, may be exposed to air or remain covered by a thin layer of water (< 0.5 m) in spring tide conditions (Table 16).

Granulometric sediment measurement: the values selected in separating the three classes correspond with the limits in the Shepard diagram, which from an ecological point of view, are indicative of the general sediment conditions (degree of cohesion, oxygenation, organic content, etc.), and the associated benthic community.

		Intensity of the parameter measured		
Parameter	**Unit of measurement**	**LOW**	**MEDIUM**	**HIGH**
Hydrodynamism	m/s	< 0.1	0.1 – 1.0	> 1.0
Depth	m	< 0.5	0.5 – 1.5	> 1.5
Granulometric sediment size	% mud-clay	< 25%	25% - 75%	> 75%

Table 16: the three intensity classes of the parameters, defined for each unit of measurement taking into consideration the main effects on ecology and sediments and estimated from data in the literature.

The 3 class ordinal scale obtained for each factor was superimposed on the map of the *Sacca degli Scardovari* identifying 3 types of functional areas for each factor.

For each intensity level of the principal parameters, a value of 1 to 3 was assigned based on the functions that describe the environmental quality level in relation to the levels of intensity of the single parameters. Figure 20 shows the **potential contribution of the factors to lagoon environmental quality**.

With the depth, the quality is inversely proportional to the intensity classes. The functions for the other parameters are not linear. For the hydro-dynamism, it is assumed that a LOW level contributes to the low environmental quality (equal to 1), but with the increasing velocity of the water, the quality of the area increases noticeably (MEDIUM hydro-dynamism, high quality, equal to 3), while when the velocity gets too high it can cause erosion problems on the bottoms lowering the environmental quality. (HIGH hydro-dynamism, medium quality, equal to 2).

As for the percentage of mud and clay, it is assumed that a prevalence of mud produces a fairly rich environment; a prevalence of sand produces predominantly poor environments, while the best situation in terms of flora and fauna is that with average percentages of sand and clay.

The ordinal, 3-class quality scale obtained for each factor was superimposed on maps of the *Sacca degli Scardovari* relative to the hydro-dynamism (Figure 16), depth (Figure 17) and type of sediment (Figure 18): Potential Quality Value (PQV) is the sum of the values of the individual parameters' environmental

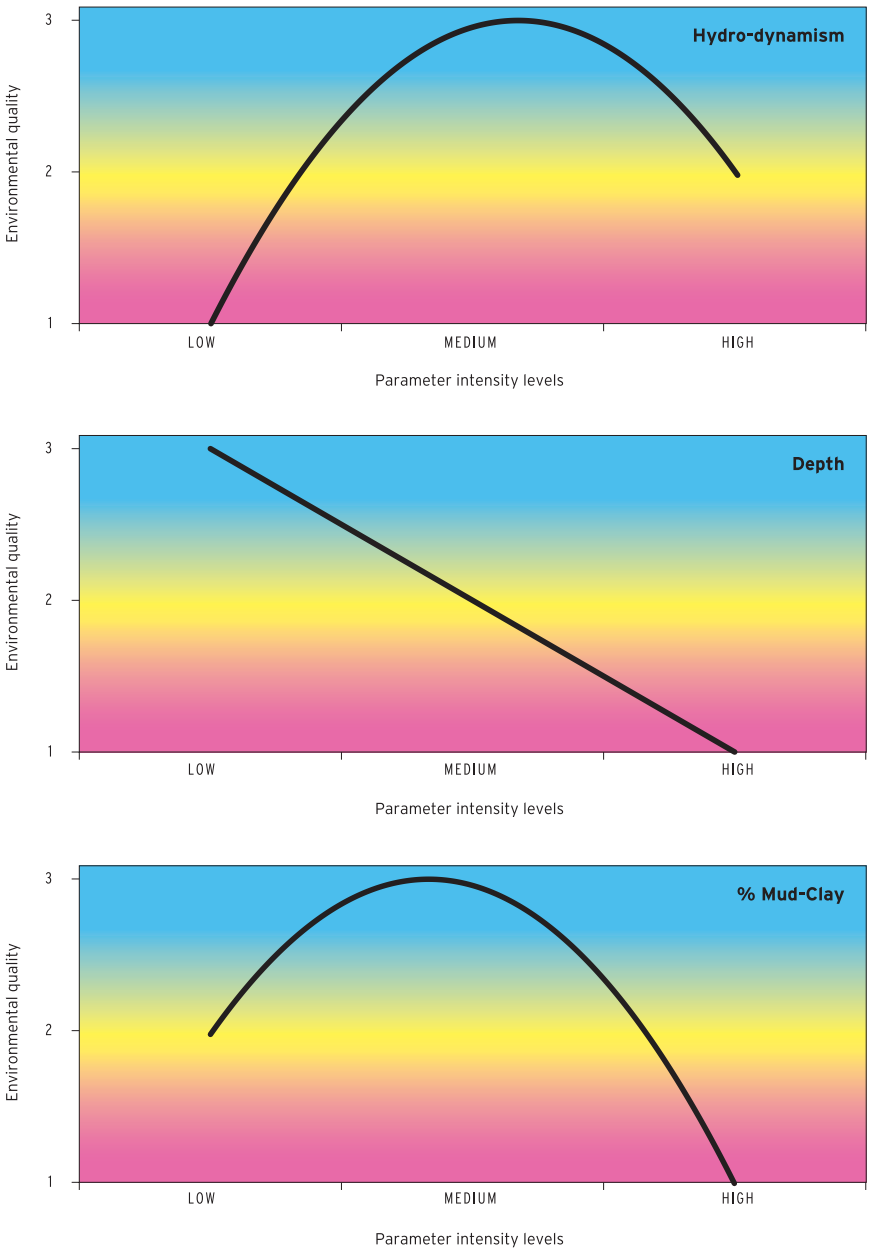


Figure 20: environmental quality functions used for intensity levels of the parameters (see Table 16).

contribution at every point of the water body (Figure 21).

By subdividing the distribution of the values obtained into 5 classes of equal amplitude, ranging between a minimum of 3 and a maximum of 9, we obtain the Potential Quality Value (PQV) defined as:(i) VERY LOW values = 3 to 4.2, (ii) LOW, from 4.2 to 5.4, (iii) MEDIUM, from 5.4 to 6.6, (iv) HIGH, from 6.6 to 7.8, (v) and VERY HIGH, from 7.8 to 9.

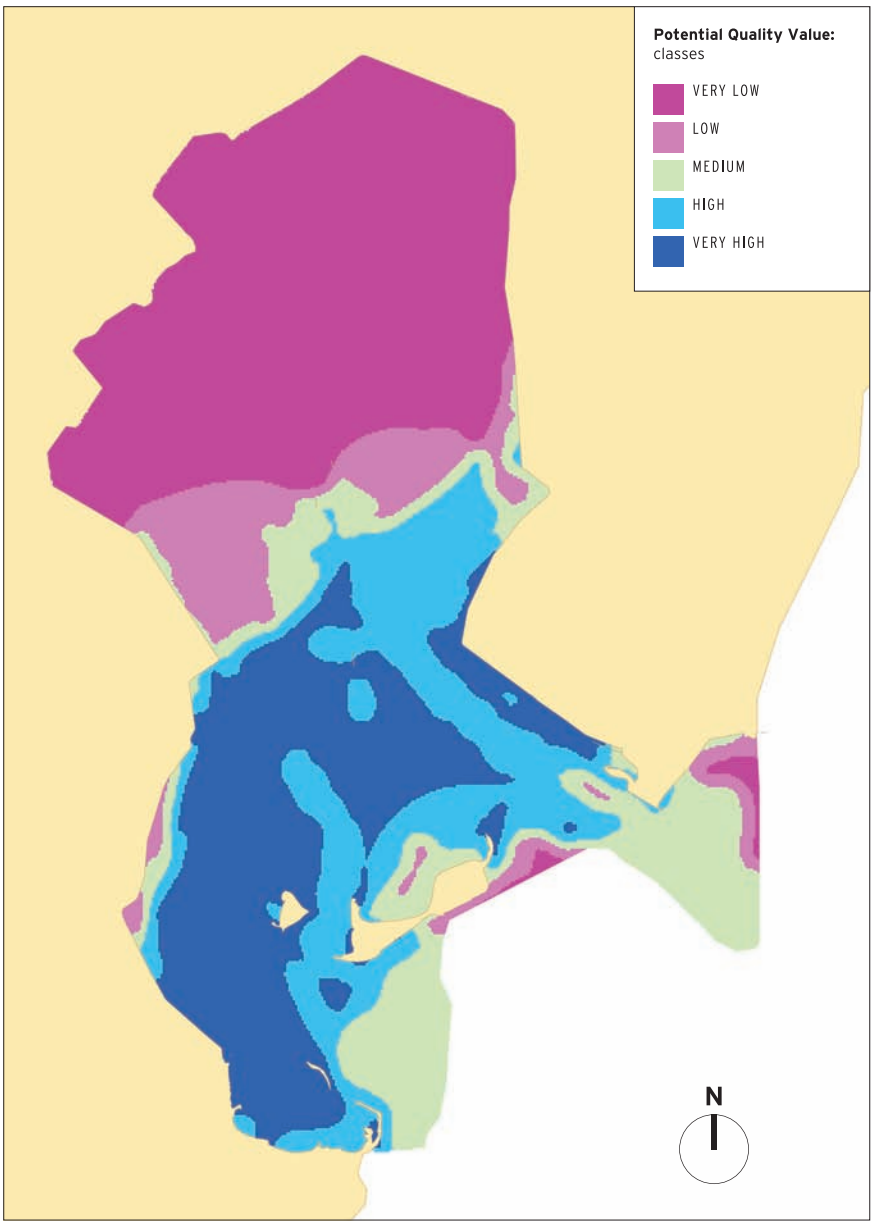


Figure 21: Potential Quality Value of water bodies inside the *Sacca degli Scardovari* based on the sum of the assessments of the hydrodynamic and bathymetric factors as well as granulometric sediment measurement.

The integration of the Potential Natural Value (PNV) and the Potential Quality Value (PQV) methods

In order to obtain an overall insight into the state of the aquatic and terrestrial ecosystems within the *Isola della Donzella*, the Potential Natural Value (PNV) map, representing emerged areas (Figure 14) and Potential Quality Value (PQV) map for aquatic water bodies (Figure 21) were merged together. To make the two scales uniform (5 PQV quality levels against 20 value classes for the PNV), the latter were grouped in five groups of four.

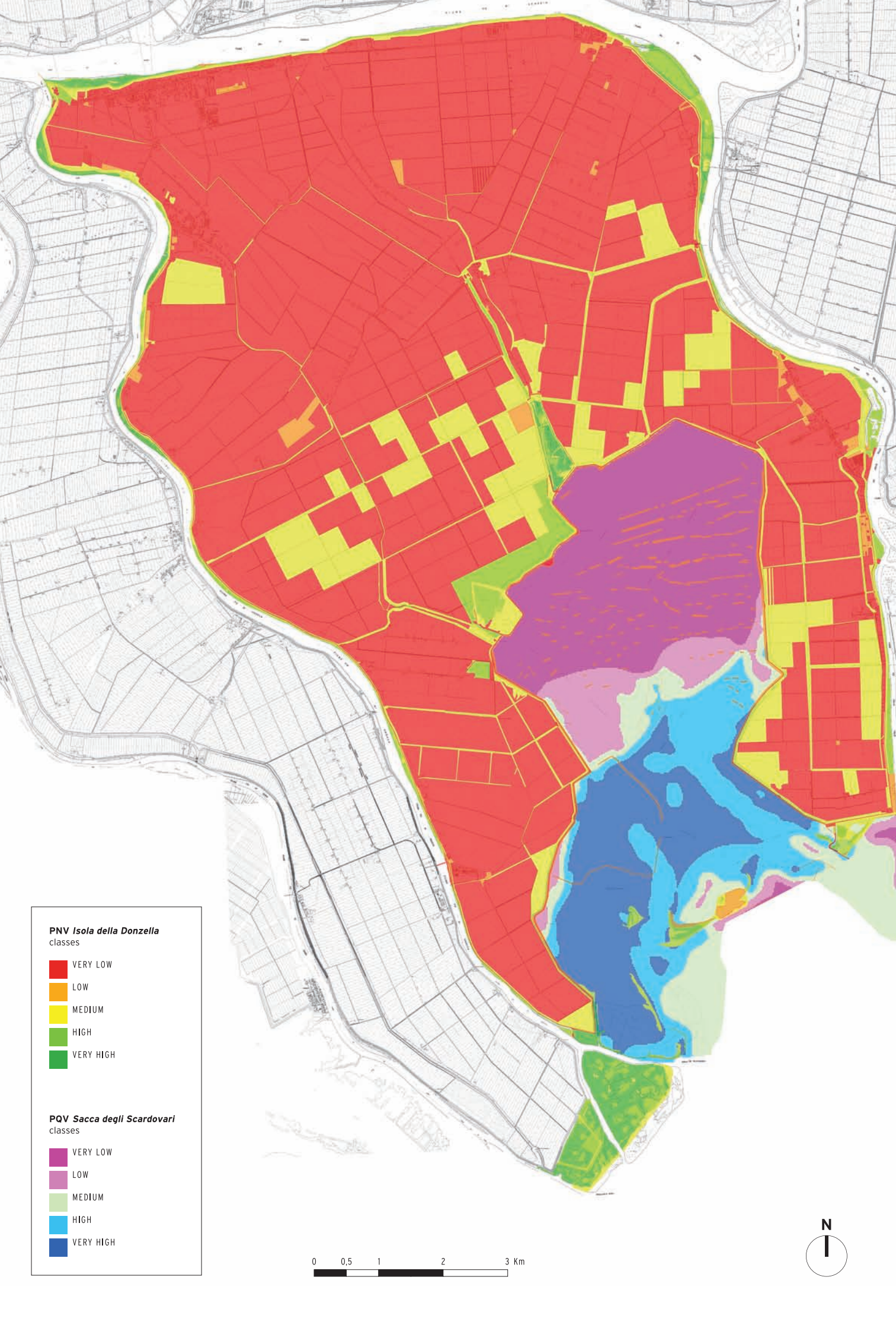
The PNV and PQV quality classes were highlighted in two different colors indicating emerged or submerged environments (Figure 22). We must take into account that the two methods are not directly comparable with each other, so the diagram seen in Figure 22 is limited in that it represents an overview of the ecological values on the ground and in the water bodies of the study area.

Most of the scientific studies over the last 30 years define the *Sacca degli Scardovari* as a system consisting of three subsystems whose ecological status is mainly influenced by hydro-dynamism. The eastern most part of the northern basin is characterized by silt sediments and low hydrodynamics because the circulation is essentially a backward and forward shifting of the same water mass. In the middle part there are, at times, sand textured sediments and benthic communities that seem to undergo minor disturbances by organic loads and an increased turnover of water masses.

The southern basin, however, is more marine in character. The bottoms are made up of a mixture of clay and sand that varies in percentage depending on the zone. The water exchange is intense and the environment is influenced by the constant ebb and flow of the tide. There is also a natural periodic modification of the lagoon mouth in relation to the mechanical action caused by the movement of shoals of sand produced by the waves.

In terms of environmental quality there is no doubt that the part of the *Sacca degli Scardovari* with higher ecosystem quality is that of the south.

Figure 22: PNV (terrestrial habits) and PQV (lagoon habitats) quality classes.


PNV *Isola della Donzella*
classes
VERY LOW
LOW
MEDIUM
HIGH
VERY HIGH
PQV *Sacca degli Scardovari*
classes
VERY LOW
LOW
MEDIUM
HIGH
VERY HIGH
0
0,5
1
2
3 Km
N

Historical evolution of the naturality value in the Po delta

The PQV, the instrument for assessing the environmental quality of terrestrial areas, after having been appropriately adjusted and simplified, was used to estimate the evolution of the value of the natural habitats on the *Isola della Donzella* over a period spanning the last 130 years. The historical analysis of the territorial evolution was essentially carried out on cartographic maps. The identification of the main types of land use in the past, the reconstruction of digitized maps and the definition of the predominant types of habitats was made possible with the use of IGM maps from the end of the nineteenth and early twentieth century. The area in question includes the current *Sacca degli Scardovari* and certain macro-areas of interest (*Ca' Mello, Biotopo Bonello, Pineta di Cassella*) and was chosen because of the availability of map data spanning the period that was to be analyzed.

The historical analysis of the quality of the environment was confined to the emerged environments due to the almost total absence of information on changes in the submerged areas. The following maps were analyzed:
I.G.M. 1877 – 1:75 000 scale
I.G.M. 1893 – 1:25 000 scale land use
I.G.M. 1911 – 1:25 000 scale land use
I.G.M. 1936 – 1:25 000 scale land use
1949 I.G.M. Flight orthophoto
1955 G.A.I. Flight orthophoto
1977 I.G.M. Flight orthophoto
1983 ReVen PD-RO Flight orthophoto
2008 *Consorzio Delta Po Adige* Flight orthophoto.

Each and every map and orthophoto was geo-referenced using identifiable fixed reference points (main road junctions, bridges, historic buildings). In interpreting the maps dated 1877, 1893, 1911 and 1936 the work of Dalpasso (1990) was also referred to.

Types of land use

When interpreting the type of land use, uncertainties in the interpretation of data should be taken into account, especially with periods before 1949 where it is not possible to validate these interpretations using aerial images.

In order to make comparisons spanning the whole time scale of analysis, the various types of habitats (Tables 3-10) were reduced in detail and merged into generic **macro-classes** through the division of the data into two time frames, one for the period 1949-2008 and one for the period 1877-1936.

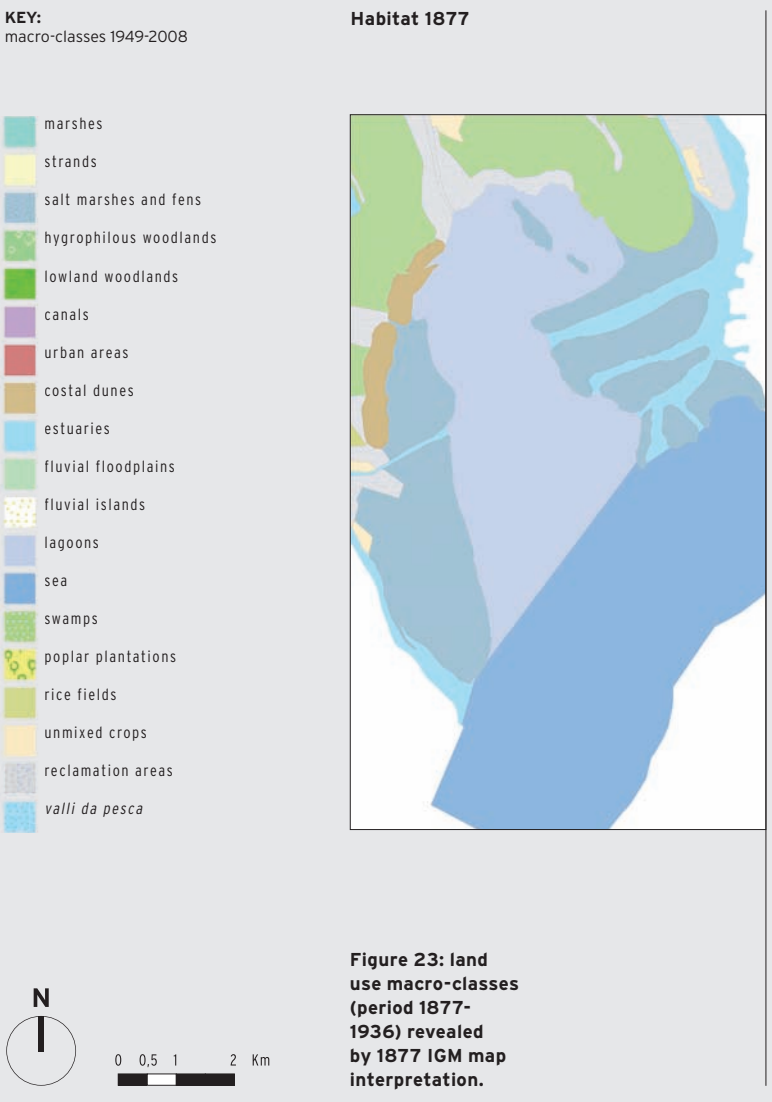


Figure 23: land use macro-classes (period 1877-1936) revealed by 1877 IGM map interpretation.

The interpretation of land use in macro-classes covering the period **1949-2008** involved (i) the grouping of the habitat types identified at present (Tables 3-10) into a set of macro-classes (Table 17), (ii) the interpretation of the land use using historical maps (orthophotos 1949-2008), and the establishment of the shapefile (one for each map). For the period **1877-1936** the 1949-2008 set of macro-classes was further reduced (Table 17) and the historical maps were used to establish the land use. Figures 23 through 31 show the land use maps relative to the historical IGM maps and orthophotos from 1877 to 2008. On the 1877 map (Figure 23), a high degree of uncertainty and spatial inaccuracy is evident due to imprecision of the maps of the era.

Nevertheless it is possible to note the very low presence of environments affected by man and the predominance of completely naturally evolving marsh and salt marsh areas. Over the years, with the increased reliability of structural mapping, the maps show the types of land use and their geographic positions more accurately. However, it remains difficult to attribute land use macro-classes in habitats with higher naturality.

Habitat 1893

Figure 24: land use macro-classes (period 1877-1936) revealed by 1893 IGM map interpretation.

Habitat 1911

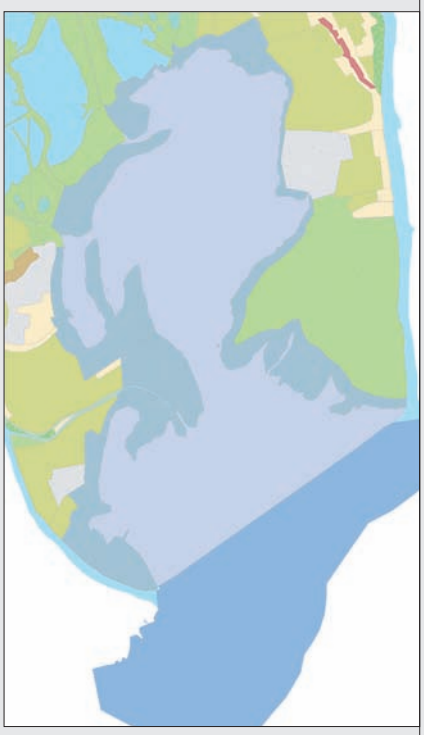


Figure 25: land use macro-classes (period 1877-1936) revealed by 1911 IGM map interpretation.

Habitat 1936

Figure 26: land use macro-classes (period 1877-1936) revealed by 1936 IGM map interpretation.

KEY:
macro-classes 1949-2008

- marshes
- salt marshes and fens
- strands (non vegetaded)
- strands (sparse vegetated)
- strands (dense vegetated)
- hygrophilous woodlands
- lowland woodlands
- canals
- urban areas
- costal dunes
- estuaries
- fluvial floodplains
- fluvial islands
- lagoons
- sea
- swamps
- poplar plantations
- river bank meadows
- pastures
- rice fields
- unmixed crops
- reclamation areas
- *valli da pesca*

N

0 0,5 1 2 Km

Habitat 1949

a

b

Figure 27: (a) 1949 IGM orthophoto and (b) on the survey interpretation according to macro-classes of land use (period 1949-2008).

Habitat 1955

a

b

Figure 28: (a) 1955 GAI orthophoto and (b) on the survey interpretation according to macro-classes of land use (period 1949-2008).

Habitat 1977

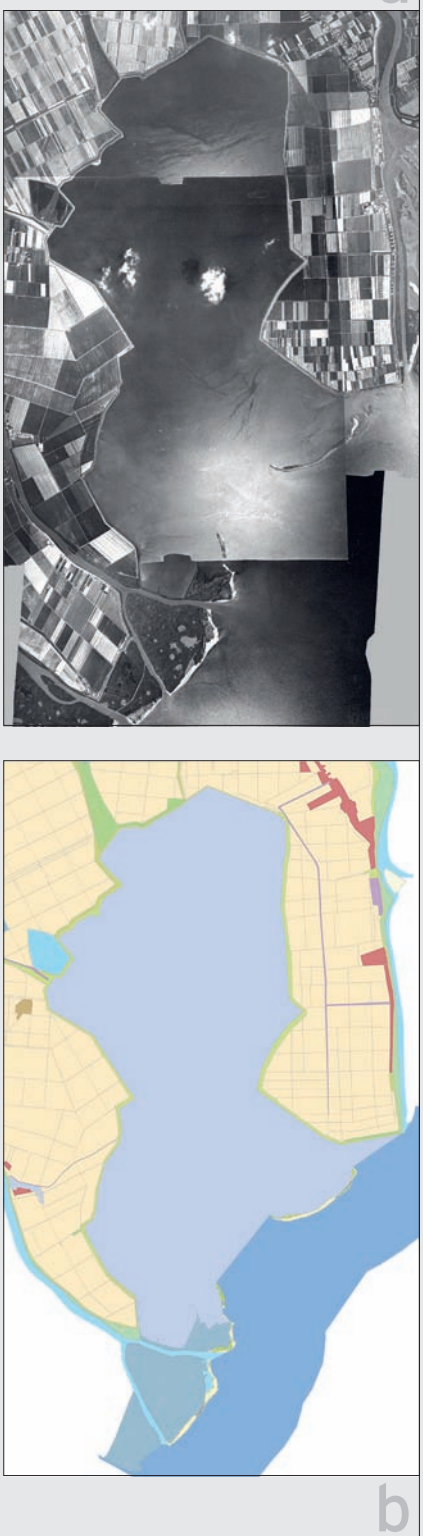


Figure 29: (a) 1977 IGM orthophoto and (b) on the survey interpretation according to macro-classes of land use (period 1949-2008).

Habitat 1983

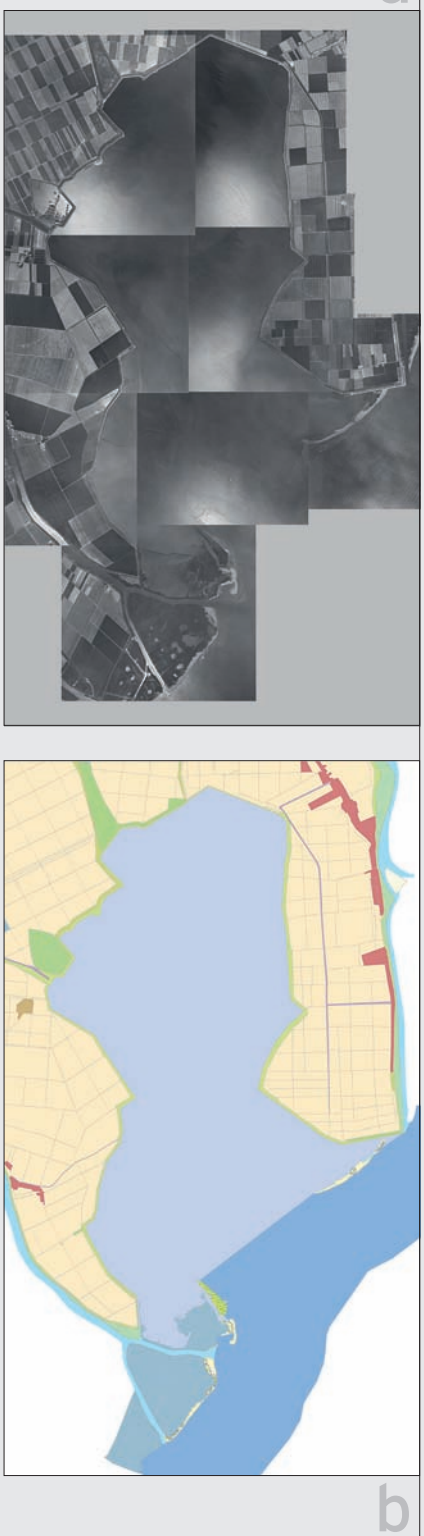


Figure 30: (a) 1983 Veneto Reg. orthophoto and (b) on the survey interpretation according to macro-classes of land use (period 1949-2008).

Habitat 2008

Figure 31: (a) 2008 Delta Po Adige Flight orthophoto (b) on the survey interpretation according to macro-classes of land use (period 1949-2008).

2008 habitat	1949-2008 macro-classes	1877-1936 macro-classes
Sandy beaches above the shoreline	Strands (non vegetated)	Strands
Unvegetated sands above the shoreline		
Artificial littoral deposits of mixed sediment		
Sandy sediment (sand >75%) emerging during low tide		
Mixed sediment emerging during low tide		
Early vegetation on intertidal muddy and sandy stretches		
Mediterranean praries and fruit trees on emerged sediment at low tide		
Halo-psammophile mediterranean grasslands	Strands (sparse vegetation)	
Embrionic mobile dunes		
Annual halo-psammophile vegetation on marine deposit lines		
Annual vegetation on marine deposit lines		
Sparsely vegetated sandy beach margins		
Halo-psammophile mediterranean grasslands		
Ammophila community on white dunes and marine deposit lines	Strands (dense vegetation)	
Dunes with *Pinus pinea* and *Pinus pinaster* forests		

Table 17: example of the grouping of habitat types of Tables 3-10 in the creation of macro-classes used for the time frames 1949-2008 and 1877-1936.

When comparing maps from 1893, 1911 and 1936 (Figures 24 to 26), we see a rapid evolution of the marsh areas interfacing with the sea and the *Sacca degli Scardovari,* which were at that time generally divided into a northern and a southern portion (*Sacca di Bottonera*).

The expansion of the Delta territory followed reclamation activities that led to the recuperation of increasingly significant portions of territory. The land reclamation began with the structuring of *valli da pesca*, the recovery/transformation of wetlands into rice fields, and their final transformation into agricultural land.

From the years 1949 and 1955, thanks to aerial photography techniques, it's possible to have a more detailed insight into the territorial elements and attribute land use classes more precisely (Figure 27 and 28). In 1949 geo-morphological evolution of the sandbar shows a lengthening trend along the coast of the sand arrow to the partial closure of the *Sacca di Bottonera*'s inlet. In the period between 1949 and 1955 reclamation activities continued to turn much of the territory surrounding the two sides of lagoon into paddy fields and agricultural land. However, there were still large areas of unreclaimed marshes subject to natural processes near the Sacca and *Po della Donzella* inlets.

In the period between 1955 and 1977 the reclamation processes and use of the land by man became more prevalent than the natural dynamics. The result is a complete transformation of the land in the study area (Figure 29) into agricultural use, leaving only a few isolated residual areas of brackish water at the *Po della Donzella* inlet and some areas of relict land (*valli da pesca* of the *Biotopo Bonello* and freshwater swamps of the *Oasi di Ca' Mello*).

It is to be noted that the loss of salt marsh and swamp areas was largely due to subsidence (Fig. 32), which peaked in the period between 1960 and 1970. The definitive submersion and loss of the salt marsh areas came with the catastrophic 1966 flooding of the area. In the years following 1977 (Figure 30), the situation remained virtually unchanged, resulting in the current situation (Figure 31).

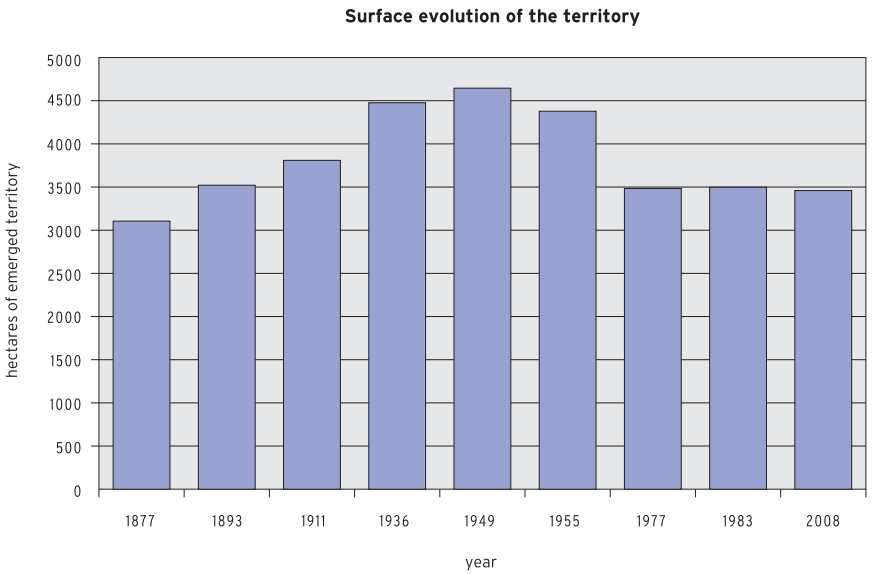


Figure 32: evolution of emerged surfaces in the area of study. The Delta's growth in the study area remained unchanged up to 1949, in the following two decades the subsidence led to a loss of emerged land and the interruption of the Delta's progradation process. From 1977 to 2008 the situation remained fairly stable.

Evolution of the Potential Natural Value (PNV)

Similarly to the study conducted to assess the current state of naturality of the territory, a map of the Potential Natural Value (PNV) showing the land use macro-classes was realized for every historical map. In this way an estimate of the evolution of the PNV in territories in the area of study over the last century was obtained.

The evaluation matrix for the calculation of the PNV macro-classes identified in the period 1949-2008 and 1877-1936 was obtained by associating perimeter values needed for the calculation of the PNV (*DiV, DiF, Ra , St, CA1, Ca2, CA3, FRi, FRf, FNu*) to each macro-class. These values have been assigned considering the habitat macro-classes at their highest level of floral, faunal, structural and functional evolution.

The algorithm calculation of the PNV was applied to each map based on the evaluation matrix. The PNV quality classes were identified using the method illustrated before. The maps are represented in Figure 33 and Figure 34.

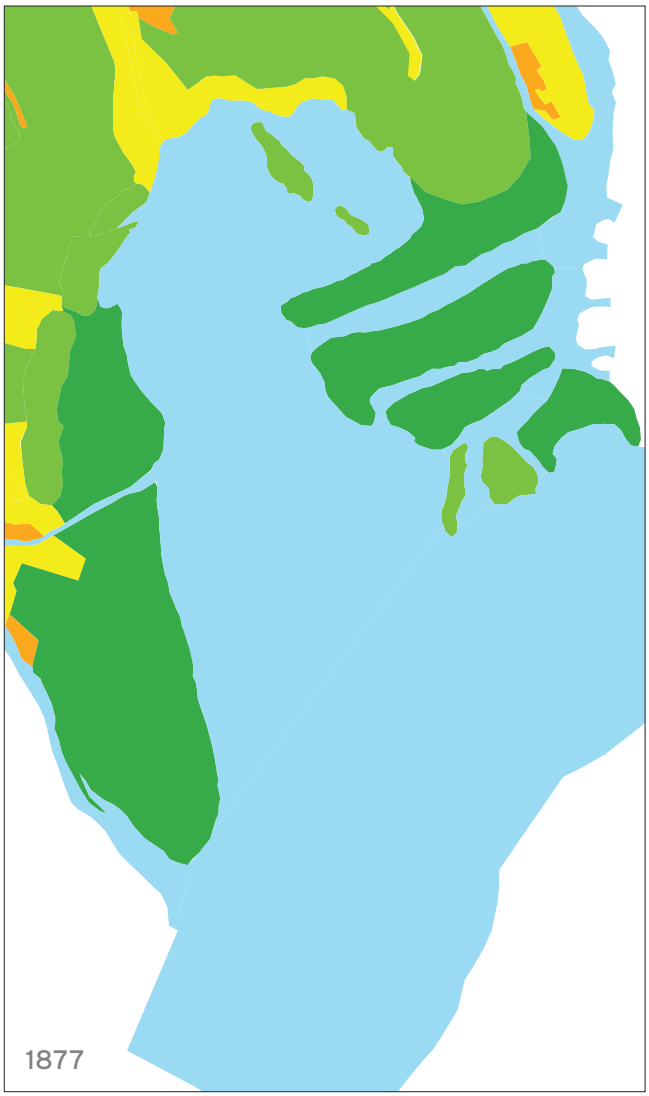
The results for each map show the percentage of land covered by the different PNV quality classes and a comprehensive assessment of the state of naturality of the macro-habitats investigated. The 1877 map (Figure 33) shows the almost complete dominance of natural dynamics in the study area. The most valuable macro-classes occupy 85% of the territory, but there is a high degree of spatial uncertainty, as is the definition of the habitat macro-classes.

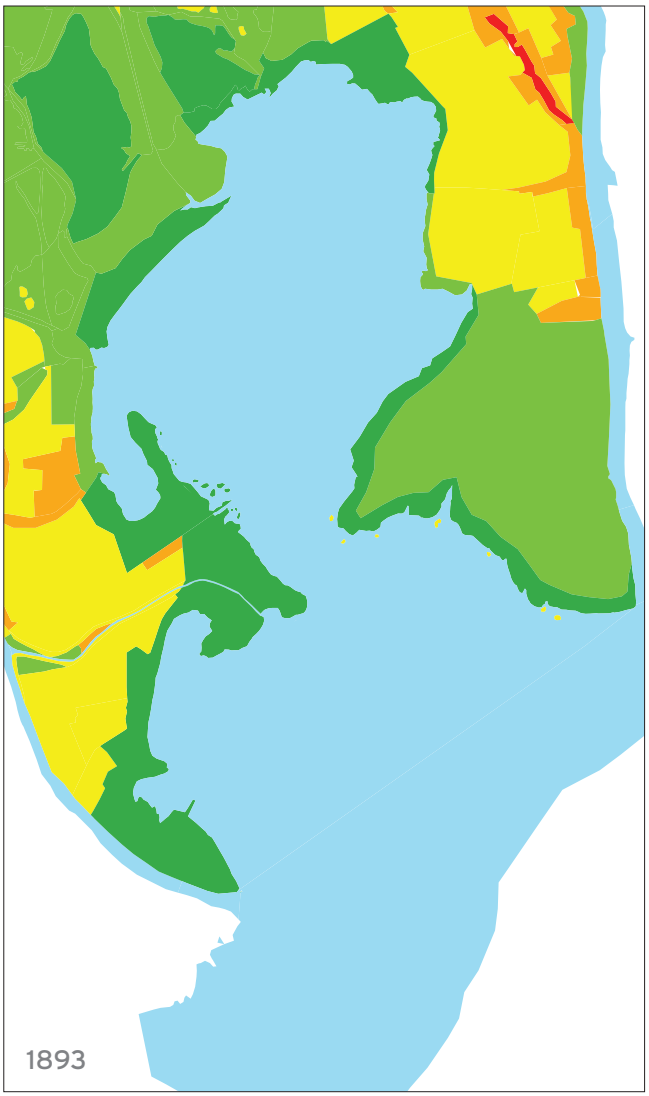
Nevertheless, the very low presence of territories occupied by man, the predominance of marsh and salt marsh areas and the completely natural evolution is evident. Due to reclamation activities and the transformation of large portions of land into rice paddies, the time frame 1893, 1911 and 1936 (Figure 33) saw an increase in intermediate quality classes.

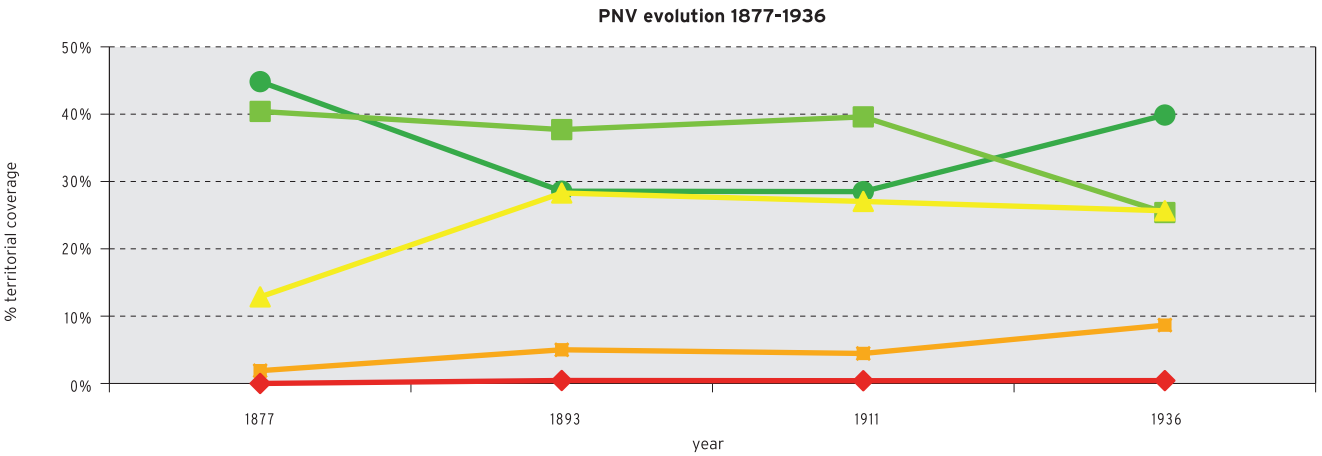
These activities however, do not affect the establishment of a high degree of overall naturality, thanks to the natural dynamics of sediment deposition enabling the recovery of large portions of territory in the estuary and at lagoon inlets. The growth of agricultural areas over the years following (1949 and 1955, Figure 34) resulted in an increasingly intense loss of naturality value.

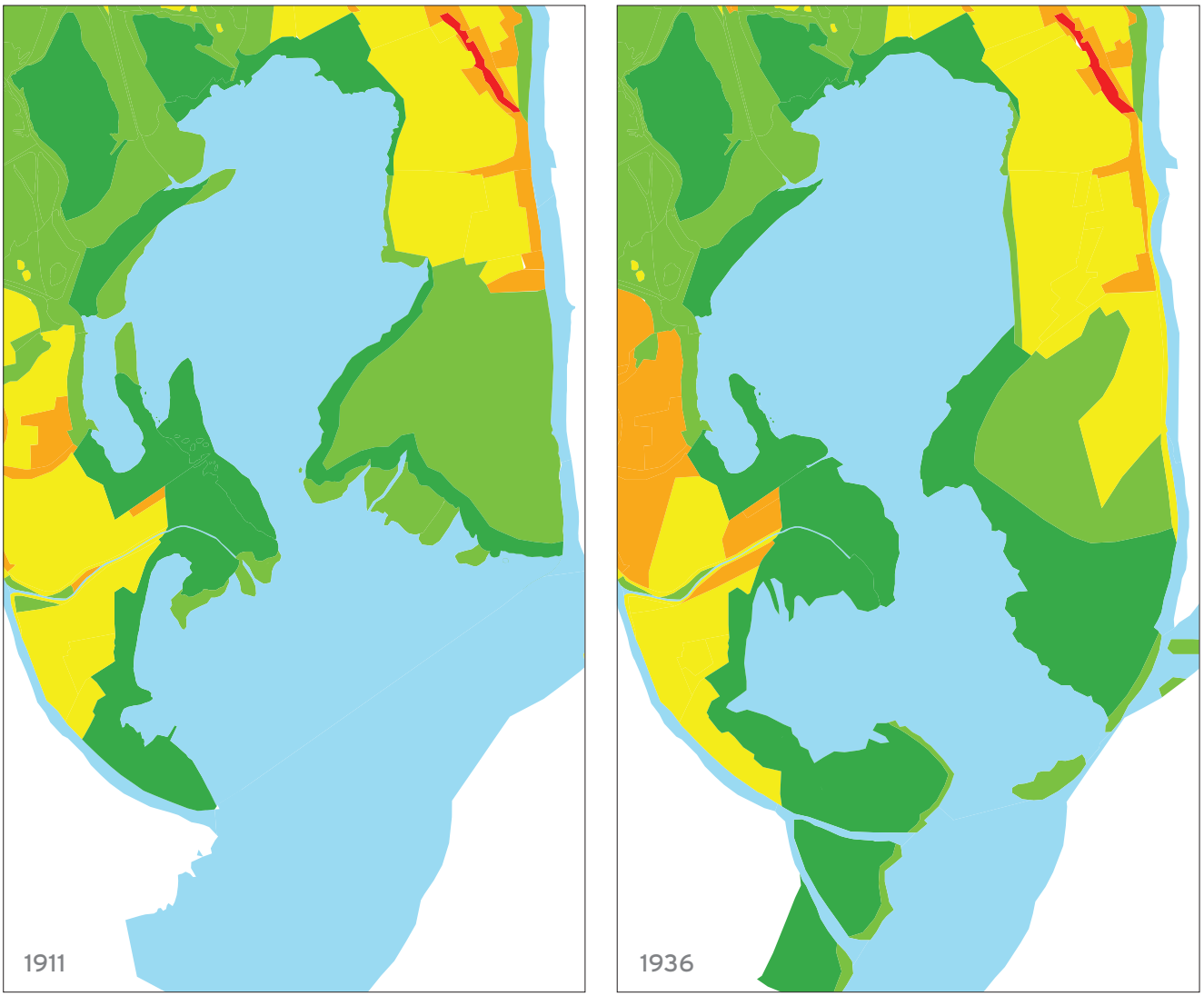
The situation worsened in the years prior to 1977, where a more drastic reduction of natural areas is seen compared to the previous period, partly transformed by human activity and partly destroyed by the phenomena associated with subsidence.

An improvement on the situation of 1977-1983 seems to have emerged in recent years through the establishment of protected areas and the recovery and environmental restoration of some habitats (e.g. *Bosco della Donzella*), designed to limit operational decisions of the past.


1877


1893

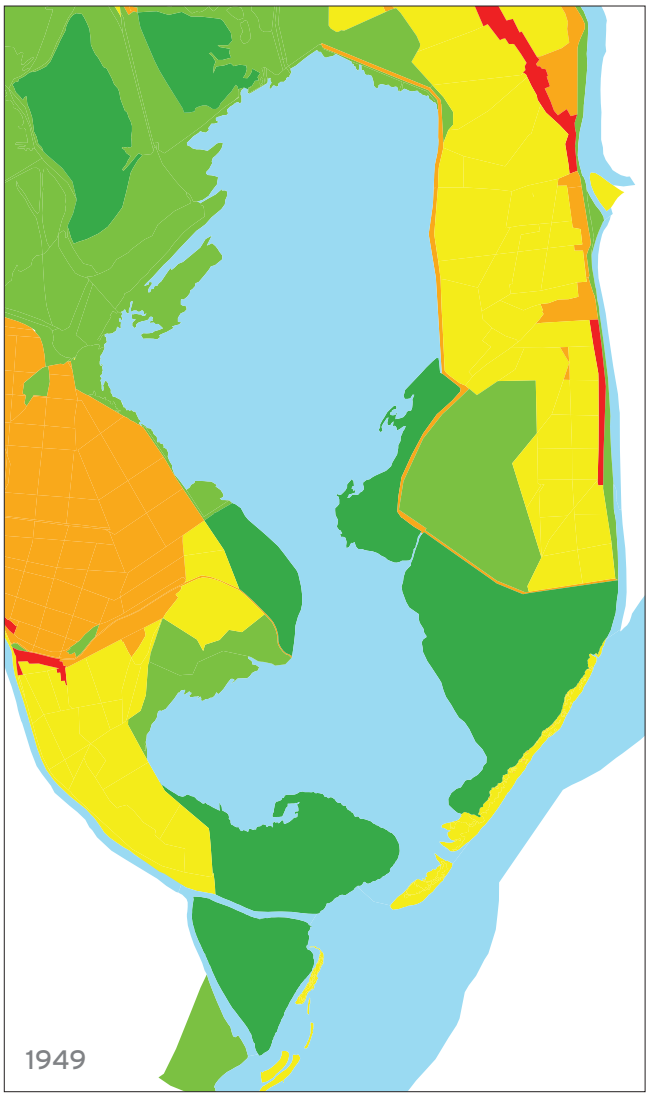

PNV evolution 1877-1936
50%
40%
30%
20%
10%
0%
% territorial coverage
1877
1893
1911
1936
year

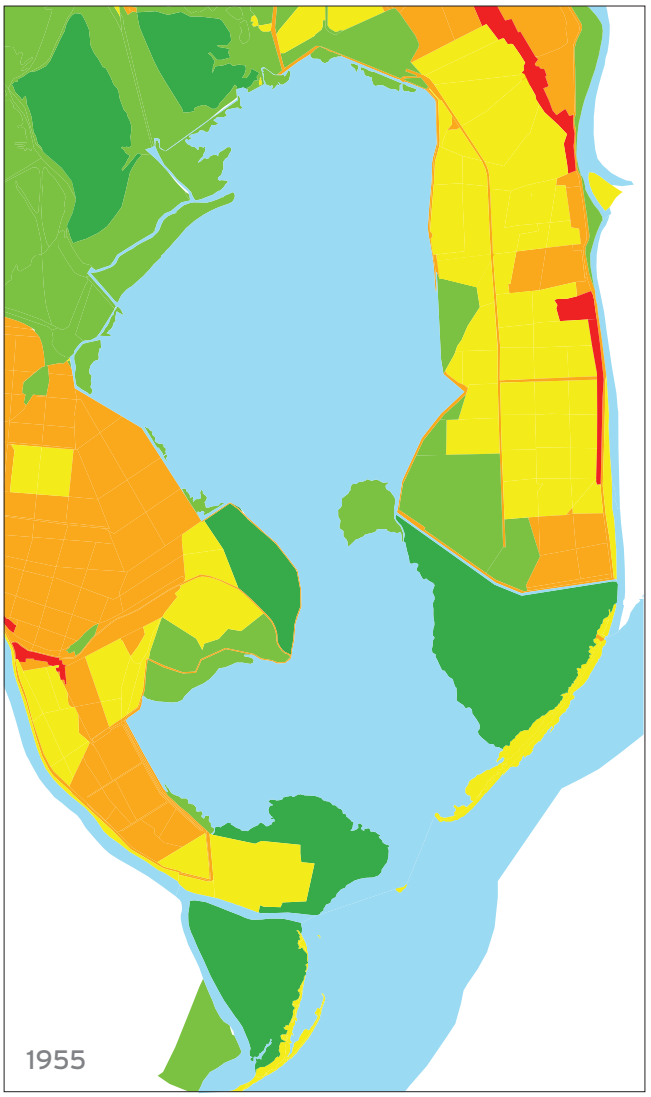


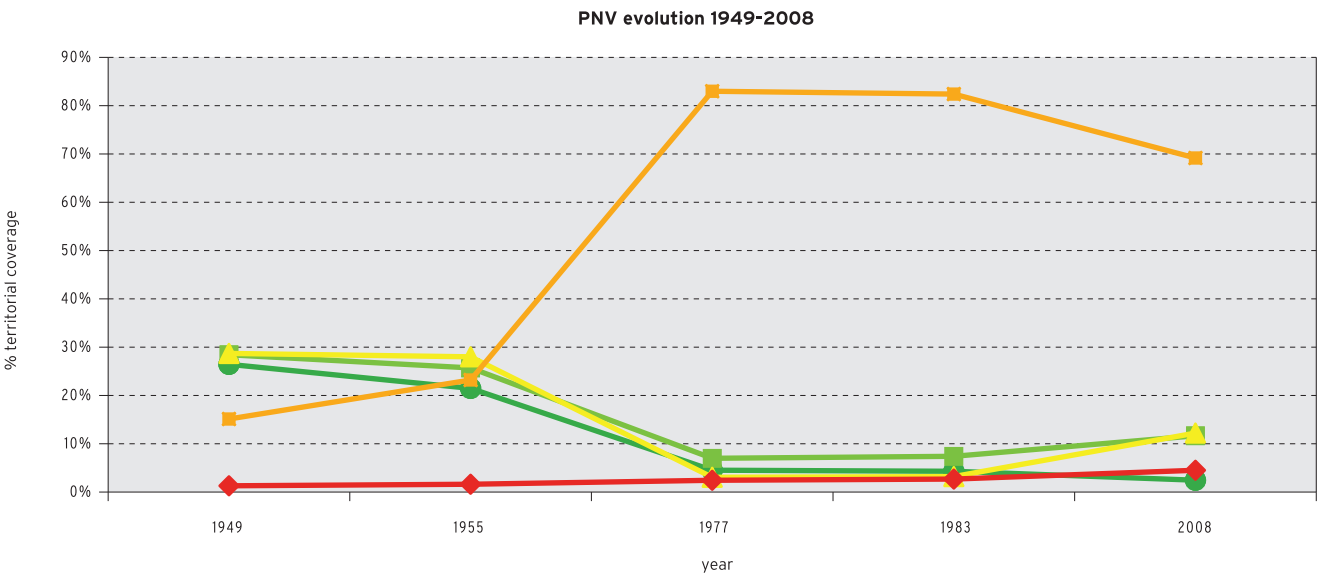
KEY:
PNV macro-classes 1877-1936

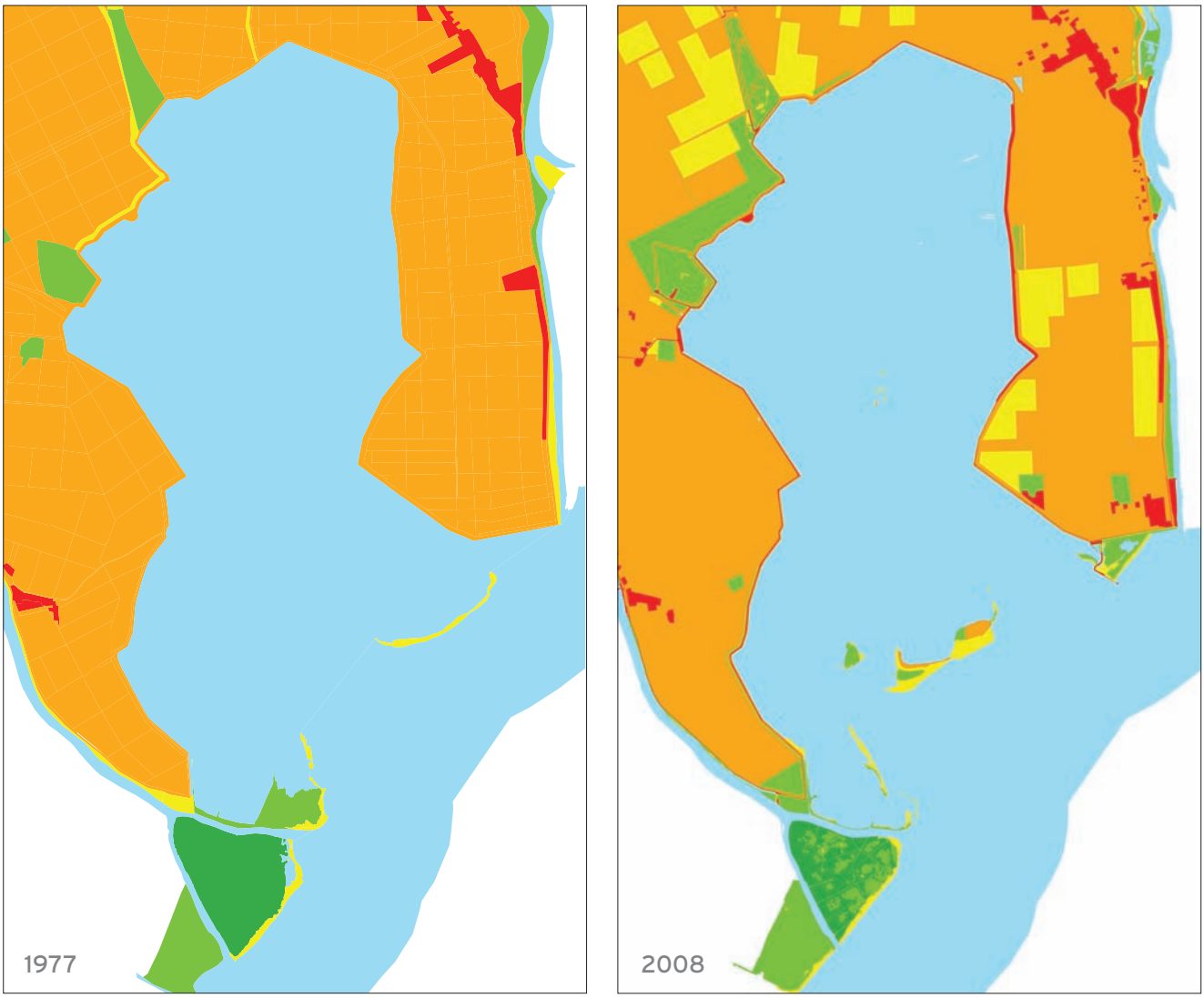
- VERY HIGH
- HIGH
- MEDIUM
- LOW
- VERY LOW
- WATER BODIES

Figure 33: PNV quality for the years 1877, 1893, 1911 and 1936 in the study area. The graph represents the evolution of the territorial coverage of the quality classes.


1949


1955


PNV evolution 1949-2008
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% territorial coverage
1949
1955
1977
1983
2008
year



KEY:
PNV macro-classes 1949-2008

- VERY HIGH
- HIGH
- MEDIUM
- LOW
- VERY LOW
- WATER BODIES

Figure 34: PNV quality for the years 1949, 1955, 1977 and 2008 in the area of study. The graph represents the evolution of the territorial coverage of the quality classes.

Conclusions

The 1:5 000 scale map of the *Isola della Donzella*, the survey method and classification of habitats and territorial units according to the latest European directives, along with the creation of a database and the potential natural value (PNV) evaluation method contributed to the realization of a tool for the management of the Veneto Po delta.

By using easily accessible and multi disciplinary procedures, with a GIS-based approach that permits the real-time updating of the model, flora and fauna modifications to the territory could be followed over time.

The PNV index allowed for the classification of soil in the delta region based on its utilization and anthropogenic effects. In areas with high ecological value the PNV enabled the easy estimation of the decrease in naturality and the consequent planning of adequate compensatory actions. As is evident in the results, the proposed method, in allowing the evaluation of the overall quality of a habitat, may be used as a conservation index of the ecological value of a delta environment, providing a practical support to the planning and management of interventions.

The importance of natural and anthropogenic impacts in a delta region has been extensively highlighted and may become a term of evaluation of the upcoming application of the Water Framework Directive (2000/60 EC). Although wetlands and transition areas have been subjected to heavy modifications in recent decades, environmental quality evaluation has evidenced that they remain characterized by high natural values.

Therefore when preparing maintenance procedures for lagoon areas, the protection of biotypes and ecotonal habitats representing transitional elements (e.g. salt marshes) between agricultural and coastal areas is of primary importance. The second issue is the necessity to preserve or where possible, to limit the fragmentation and compartmentalization of habitats.

Any maintenance activity or Strategic Environmental Assessment (SEA) procedure has to be environmentally sustainable in character considering the often irreversible nature of indirect actions in lagoon territory (e.g. subsidence, salt wedges, *Polesine Camerini* power plants, nautical leisure activities etc.).

According to the documented general reduction of naturality in the delta region and from a perspective of weak sustainability, as defined by Socco (2008), the primary objective of any intervention has to avoid any further reduction of the present value and their potential to recover or, from a perspective of strong sustainability - which considers the environment not only as a residual variable – interventions have to provide for an increase in overall naturality.

Based on the model of other European countries (e.g. the Netherlands), the principles of "no-unless" (the Environmental Impact Assessment – EIA - principle that nothing is transformed without being conditioned by the alteration and without undergoing some form of irreversibility) (Pileri, 2007) and "no-net-loss of ecological values" (every transformation produces irreversible environmental and ecological damage, to be contrasted by (A) mitigation or, where not enough, (B) compensation) has to be promoted.

Type of compensation	Environment space (Delta reference area)	
	On site	External area of defined intervention
Real compensation	Restoration	Substitution
Compensation with/in other habitats **Evaluation of existing habitats**	Creation of new environments Evaluation of existing environments Management of specific environments	Creation of new environments Evaluation of existing environments Management of specific environments

Table 18: types of compensation applicable to areas of the Po delta.

In conclusion, it should be pointed out that:

A) mitigation is necessary to reduce the effects of reversible damage to the habitats of highest natural value. The management has to avoid any further irreversible damage and take into account the need for different procedures depending on the different periods of the year.

B) compensation depends on time and space as variables. Spatially, the re-establishment (namely the in loco compensation of high natural value areas) represents the priority action. Only successively, the substitution (namely, compensation in other areas of high natural value) may occur, either by improvement – in terms of content or function – of other potentially interesting habitats or by the creation of ex novo highly valuable habitats.

Table 18 summarizes the feasible alternatives. As far as the time scale is concerned, the criteria to be followed regard: (i) the necessity to include compensation in the overall context of the project, in this way assuring that compensative actions are carried out before other interventions causing a reduction of ecological value; (ii) the necessity to provide for an over-compensation of the impacts of actions or interventions. For example, in terms of area planted and or number of plants when an action of planting is planned. As already pointed out, both mitigation and compensation have to be included in every aspect of the management procedure, from the assessment of impacts (VincA, VIA), to the coordination with other activities (VAS) or cost estimates. In practice, the principal aim of this work is to make an easily implementable contribution to those involved at various levels in the delta, especially to the *Parco Regionale Veneto Delta del Po*, and the Administrations both for long and short-term projects like the gas terminal along the *Porto Levante* coast or the *Polesine Camerini* power plant.

In conclusion, the final and almost provocative request to the Administration is to evaluate the proposal for the Delta to be declared a regional compensation area by introducing, for example, a mitigation bank (based on the US model) or as an area of preventative ecological compensation (based on the German model). All the experimental trials could be carried out by the *Laboratorio internazionale delta e lagune Ca'Vendramin* in accordance with the universities of the territory.

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Squacco Heron (*Ardeola ralloides*) in mating plumage.

Pied Avocet (*Recurvirostra avosetta*) frequent the shallow internal brackish valleys.

Embryonic shifting dunes and shifting dunes with *Ammophila arenaria* are habitats of Community interest characterizing the coastal strip behind the foreshore.

***Salicornia Veneta* species of Community interest in occasionally submerged salt marshes.**

The Delta's *valli da pesca* (embanked fishing lagoons) provide an ideal feeding habitat for flamingos (*Phoenicopterus roseus*).

Blossom of *Limonium sp.*, a plant characterizing certain habitats of Community interest in the Delta.

The common juniper (*Juniperus communis*) is a species characterizing the consolidated dunes.

THE DELTA MED ASSOCIATION

MANEL MASIÁ MARSÁ
Delta Med Association President

LINO TOSINI
Delta Med Technical Committee

What is Delta Med?

The Delta Med is an association founded on initiatives of the *Comunidad General de Regantes del Canal della Derecha del Ebro* (Spain) and the *Consorzio di Bonifica Delta Po Adige di Taglio di Po* (Italy). It brings together legal representatives of the deltas and coastal wetlands of the Mediterranean with the aim of exchanging experience and knowledge on land, environmental and sustainable agriculture issues.

The Delta Med was established on December 6, 2002 with the signing of the Statute at the *Instituto Agroambiental de les Terres de l'Ebre* in Amposta (Spain).

The Delta Med's primary objectives are:

- the organization of meetings and conferences to deal with interdisciplinary scientific issues relating specifically to the deltas and wetlands;
- the drawing up of appropriate proposals in order to resolve problems of coastal erosion and retraction, subsidence, salinification, climate change and environmental damage;
- the support and promotion of proposals made by associations, foundations and organizations that carry out activities in the delta and coastal wetlands, with the aim of promoting sustainable development of economic activities and improving the quality of life;
- the drawing up of proposals, projects, plans and programs relating to the sustainable development of delta areas and coastal wetlands requested by any government office or organization with an interest in these areas;
- the consolidation of an organized exchange network between the members of The Delta Med and other similar territorial entities throughout Europe and the world.

The Ebro Delta (Spain).

Common problems of the deltas and projects underway

The most important common problems affecting deltas in the Mediterranean are:

- the management of water resources and water quality;
- water salinification and salt stratification;
- coastal erosion;
- subsidence and marine eustatism;
- the preservation of wetlands and lagoons;
- sustainable agriculture;
- conservation and sustainable development.

Coastal subsidence and erosion (or regression) phenomena and how their causes and effects are interconnected are of particular concern in the deltas. The Association's members have presented several projects on the European area and are currently carrying out preliminary investigations on a project regarding the *"Cooperation in the planning and development of socio-economic activities and promotion of good environmental management in the Mediterranean basin"*.

The Association's first objective was to achieve the designation of rice cultivation as an area of special interest by the EU. This request lays the foundation for the protection and enhancement of 450 000 ha of rice paddies in the Mediterranean basin, since the sustainable cultivation of rice allows for the preservation of a wide variety of environments and guarantees the enrichment of the territories and landscape.

Rice cultivation, an area of environmental special interest.

The *Laboratorio internazionale delta e lagune Ca' Vendramin*: Technical & scientific headquarters of the Delta Med Association

The *Laboratorio internazionale delta e lagune Ca' Vendramin* is considered to be the operative body and the technical & scientific headquarters of the Association.

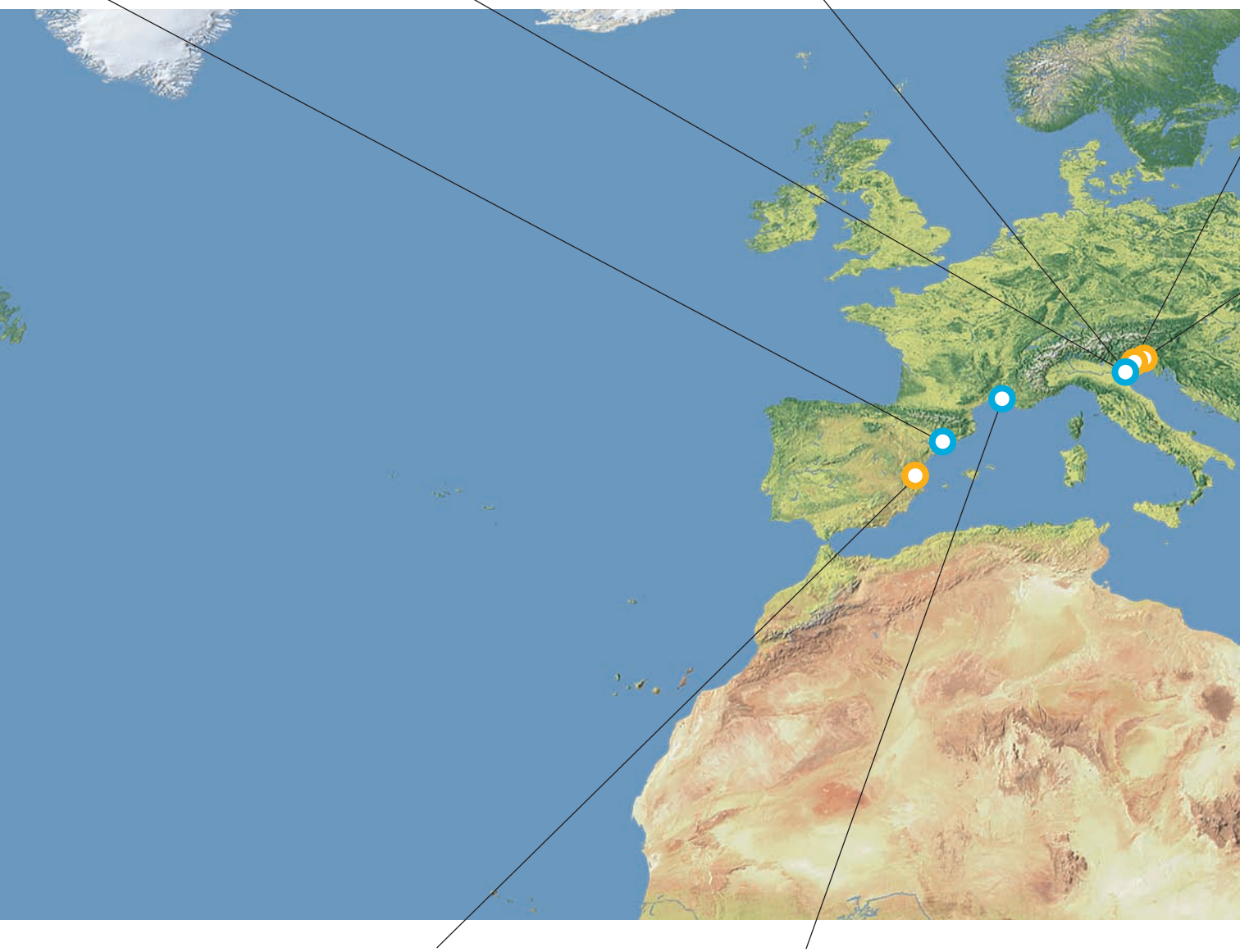
Thanks to its network of universities and professional orgaizations, the "Ca' Vendramin Laboratory" is able to ensure the effective exchange of issues and experiences regarding the deltas and lagoons as well as those relating to river deltas, lagoons or coastal wetlands throughout the world which may be similar to those represented by the Delta Med.

Museo della bonifica Ca' Vendramin.

Ebro delta (Spain)
Surface area: 33 000 ha
Represented by the *Istituto Agroambiental de les Terres de l'Ebre (IATE)*, the *Comunidad General de Regantes del Canal de la Derecha del Ebro* and by the *Comunidad de Regantes Sindacato Agricola del Ebro*.

Ca' Vendramin (Italy), the technical and scientific headquarters of the Delta Med Association.

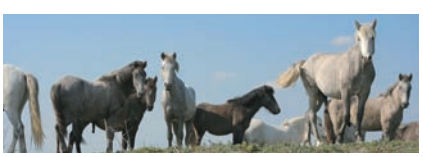
Po delta (Italy)
Surface area: 150 000 ha
Represented by the *Consorzio di Bonifica Delta Po Adige* of Taglio di Po (Rovigo), by the *Consorzio di Bonifica I Circondario* and by the *Consorzio di Bonifica II Circondario* of Ferrara.



DELTA MED MEMBERS

- Delta
- Coastal wetlands

Albufera de Valencia (Spain)
Surface area: 20 000 ha
Represented by the *Comunidad de Regantes de Sueca Y la Acquia Real del Jùcar*.



Rhone delta (France)
Surface area: 86 300 ha
Represented by the *Syndacat des Riziculteurs de France e Filiére*.

Venice lagoon (Italy)
Surface area: 50 000 ha
Represented by the *Consorzio di Bonifica Venezia Nuova* and by the *Consorzio di Bonifica Dese Sile* of Mestre.

Carole lagoon (Italy)
Surface area: 3 000 ha
Represented by the *Consorzio Pianura Veneta* of Portogruaro (Venice).

Danube delta (Romania)
Surface area: 580 000 ha
Represented by the *Danube Delta Biosphere Reserve Authority*.

Nile delta (Egypt)
Surface area: 622 000 ha
Represented by the *Field Crops Research Institut and Research Program*.

Evros delta (Greece)
Surface area: 20 000 ha
Represented by the *Association for the Protection & Promotion of Evros Delta y Evros Prefecture*.

THE FAO-IMOLA PROJECT ON THE HUE LAGOON - VIETNAM

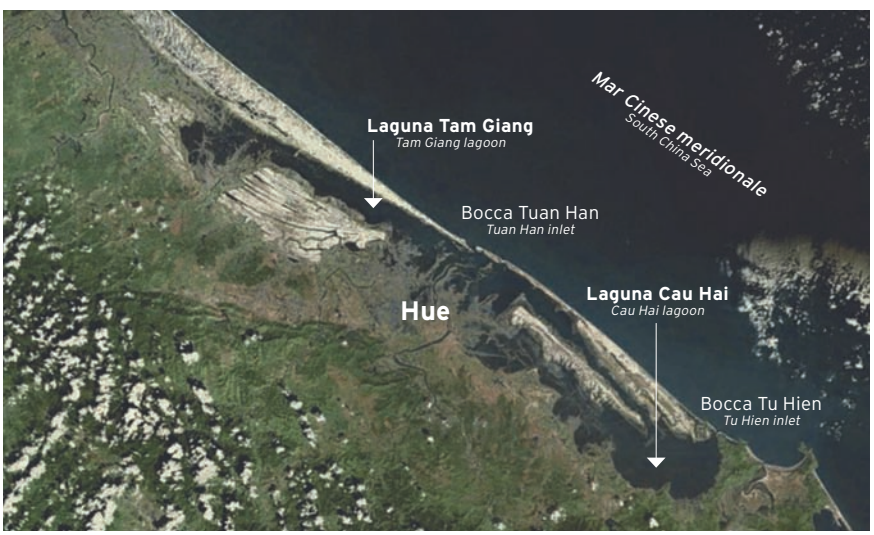
Edited by the Scientific Committee

In 2006, a delegation of Vietnamese representatives from Thua Thien Hue, the Province encompassing the Tam Glang-Cau Hai Lagoon, visited the *Consorzio di Bonifica Delta Po Adige*. The Tam Glang-Cau Hai Lagoon, located in central Vietnam at the mouth of the Perfume River, is the largest lagoon system in South East Asia, stretching nearly 70 km along the coast and consisting of 22 000 ha of bodies of water. It is a complex and unstable system, which is used for rice cultivation, aquaculture and fisheries, providing livelihoods to around 300 000 inhabitants, representing almost one third of the population of the province of Thua Thien Hue.

However, due to a number of factors including the risk of flooding, rapid hydro-morphological changes related to the action of rivers and sea storms, intensive and unstructured agricultural and fishing activities, the lagoon environment is degraded and the use of natural resources is precarious and inadequate. These problems have been compounded in recent years because of the increased pressure on the lagoon as a result of a government program to support aquaculture that has deeply affected the growth of activity and resulted in a reduction and elimination of mangrove areas and has lowered the quality of the lagoon margins.

Hue province in central Vietnam.

The Vietnamese authorities have shown great interest in the management practices and interventions carried out in the Po delta, expressing the desire to initiate a working relationship with Italy and the Veneto Region in particular, in order to incorporate the experience acquired in the Veneto lagoons and use our support to improve lagoon management and conservation of the environment.



The Giam Tan - Cau Hai lagoon.

The *Consorzio Delta Po Adige*, which manages the Delta lagoons on behalf of the Region, is also interested in collaborating with the Vietnamese, on one hand to gain knowledge from the particular experience of the Vietnamese, and on the other, to promote the use of its environmental models and methods through the "*Laboratorio internazionale dei delta e delle lagune*" of Ca' Vendramin.

It was on this basis, through Prof. Massimo Sarti, Manager of the project for integrated management of the lagoons (IMOLA Project), started in 2005 and funded by the Ministry of Foreign Affairs through the FAO, that the Vietnamese authorities invited an Italian delegation to Vietnam. Therefore in the period 27 June to 3 July 2009, a mission was undertaken by a delegation made up of representatives of the *Regione Veneto*, the *FAO*, *Consorzio di Bonifica Delta Po*, the *Delta Med Association* and *Generalitat de Cataluna*.

On this mission, two days of field surveys were carried out at the mouth of the Perfume River (Song Huong) and at the two lagoon inlets, Thuan Han and Tu Hien, where representatives of the IMOLA project illustrated the Hue lagoon system's features and management issues with reference to flooding, over-exploitation of fisheries, poor water quality and the precarious stability of the inlets in particular.

Following the field trip a technical meeting was organized in which, in addition to the Italian delegation and IMOLA Project management, representatives of the local Provincial Administration and Department of Agriculture and Rural Development took part. This technical session allowed for a productive exchange

Fishing nets in the Cau Hai lagoon.

The Tu Hien mouth.

of experiences and knowledge on the realities of the respective regions. The Vietnamese representatives showed particular interest in the delegation's presentation of its positive experiences in the management of lagoons and wetlands of the Po delta, Venice Lagoon and lagoons belonging to the Delta Med Association, and welcomed the prospect of implementing and benefiting from the Italian initiative through a project of relevant ethical and environmental experience gained in the Veneto.

At a meeting at the Thua Thien Hue provincial headquarters, the delegation officially invited the Vietnamese to join the Delta Med Association network and to take part, representing the Hue Lagoon, in the "*1° Conference on the Lagoons*" to be held in October 2009. The provincial authority expressed great interest and decided to send a delegation to participate in both initiatives.

Signing of the Declaration of Intent.

The delegation also had productive talks with the Deputy Rector of Hue University of Agriculture and Forestry, and met with him to present the mission objectives and the *Laboratorio internazionale delta e lagune Ca' Vendramin*'s activities. The collaboration between the "Laboratory" and the University of Hue, which has recently initiated important monitoring and study programs mainly concerning fishing, will prove fundamental in future collaborative projects.

The mission was concluded on 2 July, at the provincial headquarters, with the signing of the Declaration of Intent between Mr. Andrew Speedy, FAO Representative, Mr. Nguye Van Cao, Vice President of Thua Thien Hue Province and Arch. Giancarlo Conta, Minister of the *Regione del Veneto*. The document establishes the intention of undertaking technological and cultural cooperation initiatives between Thua Thien Hue Province and the *Regione del Veneto*, and the collaboration in mutual fields of interest.

On 3 July, the delegation was able to meet both the former Vietnamese Ambassador to Italy Nguyen Van Nam, and Italian Ambassador to Vietnam Andrea Perugini in the capital, Hanoi. Both diplomats greatly appreciated the Italian initiative, stressing the importance of collaborating on infrastructural development and environmental protection projects in particular. Whilst showing the great potential of the Vietnamese economy, they also bring to light current opportunities for existing businesses and Italian investors, that until now have played a marginal role.

DICHIARAZIONE D'INTESA

I Rappresentati dell'Organizzazione per l'Agricoltura e l'Alimentazione (FAO), della Provincia di Thua Thien Hue e della Regione del Veneto,

- preso atto dell'evoluzione del Progetto Imola realizzato tra FAO, Governo italiano e Governo del Vietnam, finalizzato a promuovere la gestione integrata delle attivita' lagunari nell'area costiera della Laguna di Tam Giang Cau Hai;

- preso atto che la FAO e la Provincia di Thue Thien Hue hanno accolto favorevolmente la disponibilità ad un diretto coinvolgimento nel Progetto Imola del Consorzio di Bonifica Delta Po Adige, che operando nell'ambito di un comprensorio in cui sono presenti aree umide e bacini lagunari ha acquisito da molti anni notevole esperienza nella realizzazione di investimenti nella gestione di tali aree;

- preso atto dei positivi risultati realizzati nella missione congiunta FAO/Regione del Veneto, dei sopralluoghi effettuati alla foce della Laguna di Thuan An, degli incontri ufficiali del 29 giugno con il Vice-Chairman Nguyen Van Cao del Comitato del PPC della Provincia di Thua Thien Hue e del meeting operativo con rappresentanti del PPC in data 1 luglio 2009;

- preso atto dell'interesse emerso riguardo alle iniziative ed alle attivita' dell'Associazione internazionale Deltamed e del Laboratorio internazionale dei delta e delle lagune in corso di costituzione a Ca' Vendramin in Provincia di Rovigo;

condividono

l'intenzione di avviare, nel rispetto degli ordinamenti nazionali italiano e vietnamita, le procedure per la sottoscrizione di una Intesa tra la Regione del Veneto e la Provincia di Hue, per lo sviluppo della collaborazione nei settori di attività di reciproco interesse, ivi incluse quelle attinenti al citato Progetto Imola, con particolare attenzione all'identificazione di attività nell'ambito del Programma di Cooperazione Decentrata Italia/ FAO.

Hue, 2 luglio 2009

For the Food and Agricultural Organization of the United Nations

.....
Mr Andrew Speedy
FAO Representative in Vietnam

People's Committee of the Thua Thien Hue Province

.....
Mr Nguyen Van Cao
Vice-Chairman

Veneto Region of Italy

.....
Mr Giancarlo Conta
Regional Councillor

1 . 2 . 3 Ottobre 2009
Museo Ca' Vendramin - Taglio di Po (Rovigo)

1° Convegno internazionale sulle lagune

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