THE PO DELTA LAGOONS

BY THE CONSORZIO DI BONIFICA DELTA DEL PO

THE PO DELTA AND THE HYDRAULIC EFFICIENCY OF ITS DISTRIBUTARIES AND OUTLETS: THE STATE OF THE ART OF STUDIES AND KNOWLEDGE

MONITORING THE WATER QUALITY IN THE PO DELTA LAGOONS: ANALYSIS OF CHEMICAL-PHYSICAL PARAMETERS MEASURED BETWEEN 2005 AND 2010

SHELLFISHING IN THE PO DELTA LAGOONS, VENETO: SOCIO-ECONOMIC ASPECTS

ELEMENTS OF ENVIRONMENTAL ENGINEERING IN THE STABILIZATION OF THE SACCA SCARDOVARI

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PREFACE

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The common element that characterizes the territory of the Po Delta, more so than any other area, is its richness in surface water, an element that is large enough and important enough for it to be called a "place." A place that is present both in the cultivated lands of the valleys, as well as the coastal lagoons, and that is made up of the scope that is the relationship between land and water. In its extensive fields, this scope of the relationship between land and water is present where the channels and ditches border the patches of land that make up farms at rhythmic intervals, while in the valleys and lagoons it is present along the thin strips of land bordering the stretches of water in valleys or those separating the lagoons from the sea.

Those who have worked in the Po Delta environment for a long time know that, whatever the field, the most delicate point of a hydraulic intervention and/ or vivification is the point where the land meets the water, one conditioning the other, in fact in the Delta one intervenes on the land in order to have an effect on the water and on the water in order to modify the land. It is in this close relationship between the irrigation water and the agricultural land that the fertility of the arable land in the Delta is expressed; likewise the success of delta mussel fishing is due to the link between salt & brackish water and the lagoon bottoms.

The future also holds another equally important meeting point for the Po Delta area. A place of intangible relationships, where management and maintenance choices regarding the Delta area should be shared and, more importantly, guidelines should be identified for managing the effects that productive activities and climate change in the large hydraulic basin of the Po will have upon this delicate environment in the coming years. This new meeting point, which has its origins in the community system as implemented by national legislation, as expressed in the Contract of the mouths, which enables "those who govern, use and live off the water of the rivers, the lesser hydrographic network, the valleys, lagoons and sea, to achieve the goal of setting up local projects that are shared and verified in their environmental, economic and financial feasibility."

As far back as the late 1980s, the Veneto delta was recognized as a laboratory for interventions in the lagoon areas, for which a special Interdisciplinary Commission was established in order to address the many planning and monitoring activities and the carrying out of interventions, whilst acknowledging that this is a difficult territory, one that is prone to unpredictable transformations and adaptations caused by storms and the flooding of the Po.

With the passing of the Contract of the mouths for the Delta area, the original intervention implemented through the Interagency Committee will be replaced by the adoption of a system of shared rules for the integrated management, the exploitation of land, and water resources management. The Contract of the mouths Action Program will be used as a point of reference for all actions resulting from voluntary agreements and must meet environmental sustainability criteria. It is with great enthusiasm that one welcomes this new institution that, in institutional terms, reintroduces the importance relationships between different systems, on which nature frequently relies, allowing those who are lucky enough to spend time in the Veneto delta to appreciate the uniqueness, richness and beauty of this area.

THE MANAGEMENT AND STUDYING OF THE PO DELTA

FABRIZIO FERRO
Consorzio di Bonifica Delta del Po President

The Consorzio di Bonifica Delta del Po's previous publication regarding the wetlands were very well received due to the scientific content of the topics dealt with regarding above all, the monitoring activities and studies carried out in the Management of the Po Delta Lagoons for which the Consorzio di Bonifica Delta del Po has been responsible for over 25 years.

Despite the previous issues being print editions of excellent quality and design that were also easy to consult, the *Comitato Tecnico Scientifico*, which advises the *Consorzio* on lagoon vivification activities, suggested a new format, no longer printed but published online and downloadable from the *Consorzio di Bonifica Delta del Po* and the *Fondazione Ca' Vendramin* websites, as well as the website specially created by the Consorzio in order to promote the Geographical Information System on the lagoons (http://sil.deltapo.it). The reason for this choice lies in the possibility of greater exposure for the product, reaching institutions, scholars, experts, and students who use the Web as an archive for information.

In this issue important studies carried out by the *Consorzio* are described with particular regard to the Sacca degli Scardovari, in which we look into issues concerning the adaptation of the mathematical model that simulates the hydrodynamics of the Sacca in order to assess the impact and effectiveness of interventions and planning, the analysis of the economic aspects associated with and resulting from the implementation of interventions, and a description of interventions carried out on the sandbar, aimed at their environmental restoration, with environmental engineering and the planting of pioneer species.

In lagoon areas that are sensitive to the flow of the Po distributaries, with their mouths located only a few hundred meters from the lagoon mouths, it was necessary to identify the surrounding conditions and therefore the flow discharged from each mouth, which is why distribution measurements were carried out in the Pontelagoscuro section on the various distributaries under the differing hydraulic conditions of the river.

Another issue relates to the synthesis of the results of years of monitoring the quality of the lagoon waters carried out in cooperation with *ARPAV*. This real-time monitoring is useful in predicting anoxia and eutrophication in the study of ingression phenomena in lagoons with an excess of freshwater and the monitoring of the lagoon's "breathing".

It is important to continue in efforts aimed at studying the Po Delta wetlands, a wonderful area from a naturalistic point of view and a source of income for the local people.

_STUDIES & RESEARCH

THE PO DELTA AND THE HYDRAULIC EFFICIENCY OF ITS DISTRIBUTARIES AND OUTLETS: THE STATE OF THE ART OF STUDIES AND KNOWLEDGE

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Introduction

The availability and the acquisition of useful information for the hydrologic characterization of the Po River Delta plays a pivotal role in improving and integrating the cognitive framework of an extremely complex, and constantly evolving system. In fact, there are numerous factors involved in the evolution of the Delta plain, where geo-morphological processes linked to fluvial dynamics and factors related to subsidence, tidal regimes and wave action, as well as structural interventions and related works carried out over the years by the institutions in charge of maintaining its watercourse are strongly interconnected.

Adequate knowledge of the hydrodynamic regime in the Po's terminal stretches under different hydrologic conditions is certainly a basic element in defining and designing structural interventions in order to, on one hand, ensure the hydraulic safety of the surrounding area, and on the other, to predict and prevent the intrusion of salt wedges along the river courses in low water regimes. It should also be noted that these studies are of particular importance to the analysis of hydrodynamic flow and coastal morphology in relation to the dynamics of inherently fragile ecosystems such as the Po Delta lagoons. The hydraulic efficiency of the individual distributaries, as well as the various outlets to the sea, is closely connected to the way in which sediment is transported along the river's course, and its resulting distribution along the coastal arch, and therefore plays an important role in the evolutionary dynamics of the delta coast and lagoon inlets. In fact, delta distributary sedimentation, along with the tides, determines fresh and salt water mixing processes and is therefore among the principal factors in the delicate balance of transitional aquatic ecosystems, that consequently influence the numerous human activities (fishing, aquaculture, tourism) that revolve around these unique and highly vulnerable areas. Therefore, it is exactly in such contexts that in-depth knowledge brings significant implications to the quality planning and designing of structural interventions, be they on the main branch of the Po, along the coast, or within the lagoon.

In order to update and broaden the base knowledge of the phenomena that govern the dynamics and behavior of the Po River in the terminal stretch which makes up the Delta, *ARPA Veneto*, *ARPA Emilia Romagna* and *Consorzio di Bonifica Delta del Po* have collaborated in the carrying out of hydrological surveys consisting of the measurement of flow rates and sediment transport along the various distributaries that make up the Delta. This article, based on available data (as documented by *Ufficio Idrografico del fiume PO*, *UIPO* and *ENEL* as of the 1930s up to 1989) and on new hydrological information acquired between 2002 and 2011, aims to provide a contribution to the quantification of the various Po Delta distributaries' hydraulic efficiency through the evaluation of the distribution of river discharges.

Measuring Campaigns 2002–2011

Recently conducted measuring campaigns have enabled the updating of knowledge on flow rate distribution in the various delta distributaries. The *Consorzio di Bonifica Delta del Po* carried out monitoring campaigns in Sep-

Figure 1: overview of measurement section locations on the main distributaries of the Delta.

tember 2002 and November 2007. The September 2002 campaign concerned the main distributaries of the Delta and the *Po di Pila* sea outlets, while that of November 2007 also investigated the distribution of the *Po di Tolle* outlets. The average flow recorded at *Pontelagoscuro* in these monitoring activities was close to 2,300 m^3/s. A measuring campaign was carried out in May 2007 with the participation of *ARPA Emilia-Romagna*, *ARPA Veneto*, *ARNI*, the *Provincia di Ferrara*, the *Consorzio di Bonifica Delta del Po* and the *Consorzio I° Circondario Polesine di Ferrara* regarding the measuring of the Po river's low water outflow (*Pontelagoscuro* average Q equal to 657 m^3/s). Measurements taken over a tidal hemicycle (12 hours) made it possible to determine the average flow rate along the delta distributaries in sections also monitored during other campaigns. Two more campaigns were carried out in 2010 (June and November) that saw a productive collaboration between *ARPA Veneto*, *ARPA Emilia Romagna* and the *Consorzio di Bonifica Delta del Po*.

The measurements looked into the distribution phenomenon during the falling discharge phase, as explained in more detail below, monitoring high flow rates never previously measured. In conjunction with flow measurements, samples aimed at the quantification of suspended sediment transport were also taken during the 2010 campaigns. Finally, a survey involving flow distribution of the *Po Grande* between *Po di Goro* and *Po di Venezia* was carried out in November 2011 that coincided with flooding, with a peak flow rate of about 5,900 m^3/s at *Pontelagoscuro*.

Figure 2a: ADCP sensor towed by boat used for conducting flow rate measurements.

Figure 2b: view of hydrometric monitoring installation (hydrometer stem and ultrasonic hydrometer) on the *Po di Gnocca*.

This survey was conducted by *ARPA Veneto* in collaboration with *AIPO*. With the exception of that conducted in May 2007, all the monitoring campaigns were carried out in hydrologic conditions characterized by high water stages (average Q average at *Pontelagoscuro* between 2,300 and 5,900 m^3/s). Under these circumstances the measurements were carried out by instantaneously monitoring the flow rate along the various distributaries while attempting to plan and execute the surveys in conditions that were as synchronous as possible, also in relation to the various propagation times of hydrometric disruptions along the various distributaries. In this way it was possible to get a snapshot of a situation that resembled, as closely as possible, the conditions along the various stretches.

It should also be noted that the survey methodology is perfectly consistent with the operational methods adopted for past campaigns, to which the results are compared below. Figure 1 shows the sections in which measurements of flow and sediment transport were carried out in the various Delta distributaries between 2002 and 2011. Figure 1 also pinpoints the river sections equipped with hydrometer stems or in which there are automatic hydrometric stations. These stations are equipped with ultrasonic hydrometers that are part of the *Regione Veneto* real time network. Unfortunately due to technical problems not all the hydrometers were functioning when measuring was carried out. In addition to the hydrometers in Figure 1, hydrometric data from *Polesella* (RO), and *Pontelagoscuro* (FE) were available. As previously mentioned, the outflow rate for the latter section is available. The data from these stations are useful as a reference for the flow rate in the upstream sections for the relative propagation times of hydrometric variations along the river course.

In order to measure the outflow, trimaran mounted Doppler flow meters were towed along a section as orthogonally as possible to the direction of flow. In particular, for the measurements carried out during the falling discharge phase (2010 and 2011), an ultrasonic ADCP sensor (Figure 2a & Figure 2b) equipped with four transducers operating on two different frequencies in order to determine vertical speed, and a transducer dedicated to bathymetric measurement, was used.

The equipment also had two RTK GPS receivers: a "base" on the shore and a "rover" mounted on the trimaran in order to permit the location and geo-referencing of the equipment's movements along the section of riverbed being investigated. This technological device eliminates the uncertainties in the estimation of speed and bathymetry in moving riverbed condi-

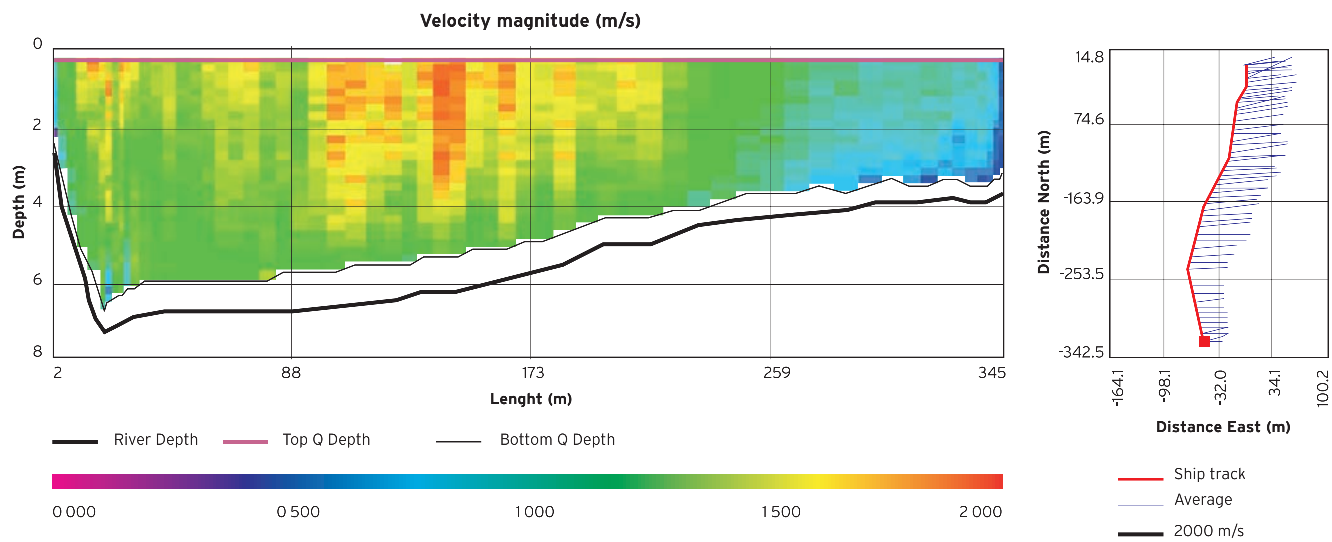


Figure 3: ADCP measurements of the S4-b (*Po di Pila*) section on 06/11/2010 between 10:57 and 11:02: showing the course (right) and speed distribution graph (left).

tions. In the 2002 and 2007 studies, the ADCP equipment used did not utilize GPS technology. It should be stressed that, given the low flow rates detected in these measuring campaigns, the slower speeds reduce the effects of riverbed movement in the bathymetry and speed estimation. The flow measurements performed in various studies and distribution percentages in the various distributaries of the Delta (*Po di Goro*, *Venezia*, *Gnocca*, *Maistra*, *Tolle* and *Pila*) in relation to the total flow (calculated from the sum flow measured along individual distributaries) are summarized in Table 1. Values in italics are the net difference while the last column shows the average daily flow at *Pontelagoscuro* as a reference value of the specific hydrological regime during the monitoring.

Similarly, Table 2 represents the *Po di Pila*'s three outlets to the sea (*Busa di Scirocco*, *Tramontana* and *Busa Dritta* or *di Levante*) as well as those of the *Po di Tolle* (*Busa di Bastimento*, *Storiona*, and *Bocca del Po di Tolle*). The results of the analysis carried out on samples of available data in order to compare

Measurement date	Po di Goro (S0)		Po di Venezia (S1)		Po di Gnocca (S2)		Po di Maistra (S3)		Po di Tolle (S4)		Po di Pila (S4b)		Po at Pontelagoscuro
	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s (average daily)
14 Sept 2002	*542*	23.5	1,782	76.5	338	14.7	77	3.3	390	16.9	954	40.5	2,300
30 May 2007	34	5.2	*623*	94.8	74	11.2	9	1.4	103	15.7	437	66.6	657
27 Nov 2007	*282*	11.6	*2,140*	88.4	387	15.9	102	4.2	492	20.3	1,158	47.8	2,422
22 June 2010	668	13.8	4,093	84.4	743	15.3	208	4.3	1,037	21.4	2,193	45.2	4,936
6 Nov 2010	655	13.6	*4,139*	86.3	789	16.45	215	4.5	993	20.7	2,141	44.7	5,102
11 Nov 2011*	748	13.5	4,785	86.5	-	-	-	-	-	-	-	-	5,803

Table 1: flow measurements carried out along the various distributaries and flow percentages for each section compared to total flow calculated from the sum of flow measured along the various branches (*Goro*, *Gnocca*, *Maistra*, *Tolle*, *Pila*) (italics represent the net difference). *The measurements were taken at Serravalle, monitoring the flow of the *Po Grande*, *Po di Venezia* and *Po di Goro* over a reduced time frame. The quantity of data acquired is confirmed by the small differences in percentage in terms of balance: the difference between the sum of the two distributaries (*Goro* and *Venezia*) and the flow rate measured on the *Po Grande*, again at *Serravalle*, is 1.1%.

Measurement date	Busa di Tramontana		Busa di Levante		Busa di Scirocco		Busa del Bastimento		Busa Storiona		Bocca Po di Tolle	
	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%
14 Sept 2002	247	25.9	623	65.3	84	8.8	-	-	-	-	-	-
27 Nov 2007	263	22.7	809	69.9	86	7.4	*27*	6.7	*322*	76.2	73	17.2
22 June 2010	671	31.1	1,215	56.2	275	12.5	-	-	-	-	-	-
6 Nov 2010	661	28.9	1,337	58.5	286	12.5	*48*	4.4	845	77.7	194	17.8

Table 2: flow measurements carried out along the *Po*'s various outlets to the sea. The *Po di Pila* percentages refer to total flow calculated from the sum of the individual measurements while the percentages for the mouths of the *Po di Tolle* refer to the *Po di Tolle* total flow at *Scardovari* (S4c) (italics represent the net difference).

the percentage of flow currently absorbed by the individual distributaries of the Delta with that of the past can be seen below. Separate analysis was conducted on the Delta's six main distributaries (*Po di Goro*, *Po Venezia*, *Po di Maistra*, *Po di Tolle*, *Po di Gnocca* and *Po di Pila*), the mouths of the *Po di Pila* (*Busa Dritta*, *Busa di Tramontana* and *Busa di Scirocco*) and on the three mouths of the *Po di Tolle* (*Busa del Bastimento*, *Busa Storiona* and *Bocca del Po di Tolle*).

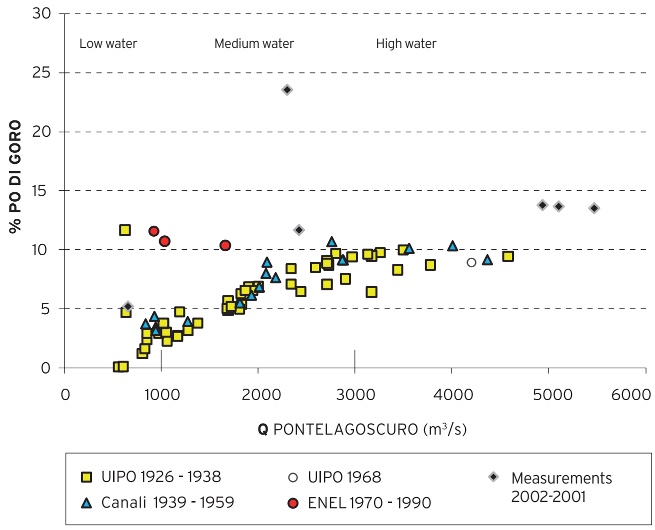
Distribution of Flow along the Main Distributaries of the Delta

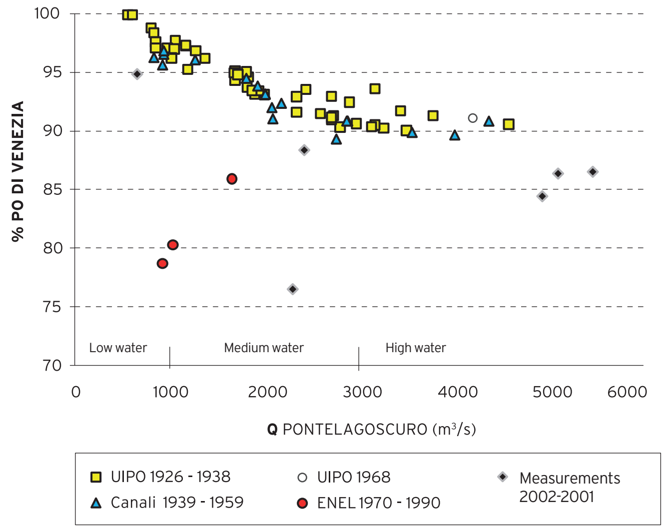
For each main distributary, all available measurements are once again proposed showing the flow percentage of each distributary in relation to average daily flow at *Pontelagoscuro*. In terms of quality, the distinction is made between "low stage" (flow less than 1,000 m^3/s at *Pontelagoscuro*), "medium water"(flow between 1,000 m^3/s and 3,000 m^3/s at *Pontelagoscuro*) and "high stage" (flow of more than 3,000 m^3/s at *Pontelagoscuro*), as proposed by *Visentini* and subsequently adopted for all analysis that followed. In Figure 4, for the various distributaries of the *Po Delta*, data relating to distribution percentage of flow are compared to the average value estimated at *Pontelagoscuro*.

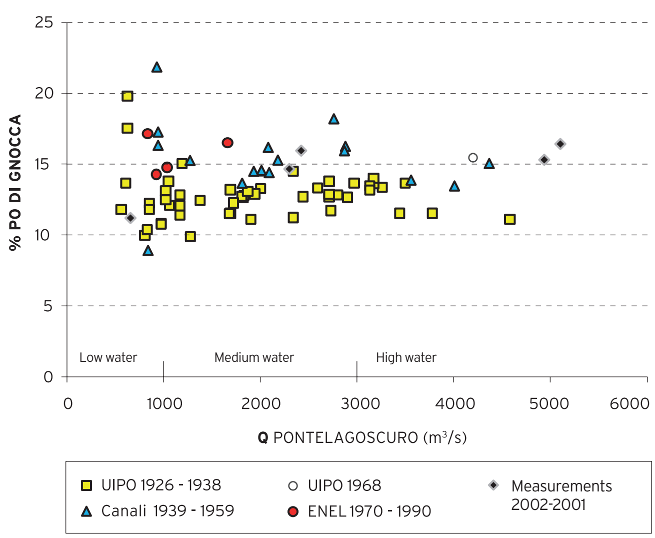
The data available up to the end of the 1960s (*UIPO* and *Canali*) show the hydraulic efficiency of the *Po di Goro* to be very consistent and stable over time (Figure 4). The few measurements from 1970 to 1990 (source: *ENEL*) show an apparent change in the tributary's behavior pattern with an increase in efficiency in relation to low/ medium water regimes. The only recent available data (regarding "low stage" regimes) tends to strongly realign past behavior patterns while showing a trend of increased efficiency for this distributary. This behavior pattern is even more pronounced in "high stage" regimes where the historical data tends to show an asymptotic tendency in which, for high flow rates, the *Po di Goro* was able to dispose of close to 10% of the total runoff of the Po River.

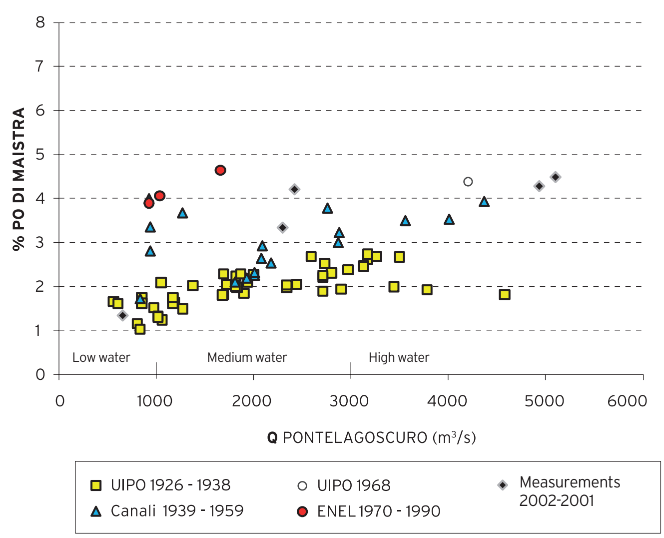
However the recent 2010 and 2011 studies show the capacity of the distributary to drain about 13-14% of the total runoff of the *Po* River. This trend was also evident in the *Fiorotto* study (2002) based on a physical model of the *Po di Venezia*-*Po di Goro* hydraulic intersection node, which estimates average efficiency percentages of the *Goro* distributary that range from 10.8% for incoming flow of 3,000 m^3/s to values close to 14% for that of over 8,000 m^3/s.

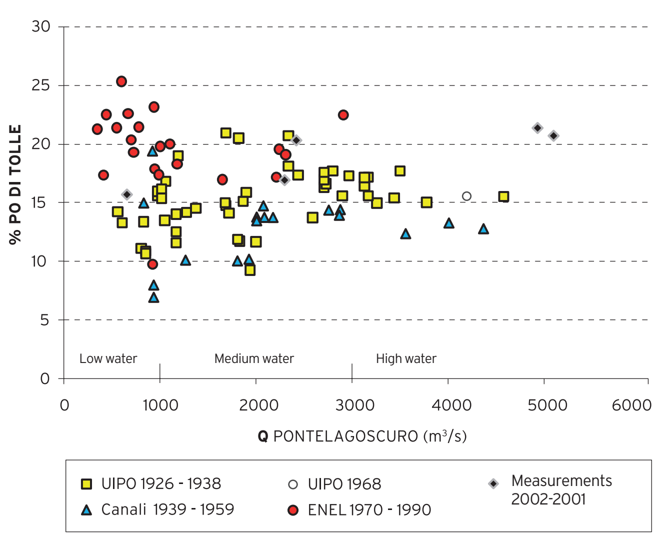
Figure 4: flow rate in the various distributaries of the *Po* compared to the average flow of the *Po* at *Pontelagoscuro* with respect to the total flow of the *Po*: comparison of the historical data available.


% PO DI GORO
Q PONTELAGOSCURO (m³/s)
Low water
Medium water
High water
UIPO 1926 - 1938
UIPO 1968
Measurements 2002-2001
Canali 1939 - 1959
ENEL 1970 - 1990


% PO DI VENEZIA
Q PONTELAGOSCURO (m³/s)
Low water
Medium water
High water
UIPO 1926 - 1938
UIPO 1968
Measurements 2002-2001
Canali 1939 - 1959
ENEL 1970 - 1990


% PO DI GNOCCA
Q PONTELAGOSCURO (m³/s)
Low water
Medium water
High water
UIPO 1926 - 1938
UIPO 1968
Measurements 2002-2001
Canali 1939 - 1959
ENEL 1970 - 1990


% PO DI MAISTRA
Q PONTELAGOSCURO (m³/s)
Low water
Medium water
High water
UIPO 1926 - 1938
UIPO 1968
Measurements 2002-2001
Canali 1939 - 1959
ENEL 1970 - 1990


% PO DI TOLLE
Q PONTELAGOSCURO (m³/s)
Low water
Medium water
High water
UIPO 1926 - 1938
UIPO 1968
Measurements 2002-2001
Canali 1939 - 1959
ENEL 1970 - 1990

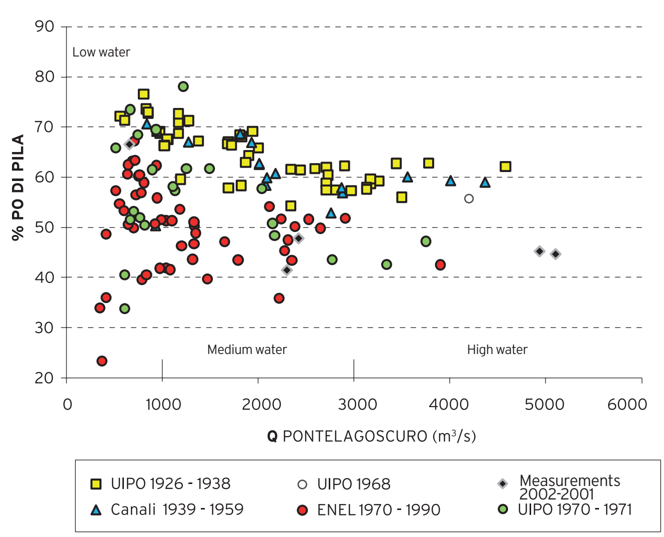

% PO DI PILA
Q PONTELAGOSCURO (m³/s)
Low water
Medium water
High water
UIPO 1926 - 1938
UIPO 1968
Measurements 2002-2001
Canali 1939 - 1959
ENEL 1970 - 1990
UIPO 1970 - 1971

Figure 5: the evolutionary trend of the *Po Grand*e highlights a progressive weakening in efficiency to the advantage, in differing ways, of all the lateral distributaries. This behavior is opposite to that of the effect following the realization of the significant systemization interventions carried out between the 1980s and today (straightening and widening of the bed). Right: Creation of the new bed in the *Corbola* and *Bottrighe* coves. Left: Artificial straightening bar (drizzagno) realized at the *Volta Vaccari* cove.

Finally one notes how, during the 2002 and 2007 campaigns relating to the "medium water" regime, this branch of the Po was not subject to direct measurement. All this suggests that on the whole, in this distributary of the Delta, there is an evolutionary trend that tends to increase in importance in the overall outflow of water to the sea from the *Po* River. The progressive trend of increasing efficiency in the Goro distributary is also confirmed by the estimates made by *Canali* in 1959, according to which at the beginning of 1900 the flow rate percentage in that distributary in "high stage" regimes was 7%, which later increased to 9.3% in the period between 1926 and 1939, after which it remained more or less constant for the next twenty years (9.9% in 1958-1959), while today it boasts percentages close to double those estimated at the beginning of the last century.

The hydraulic behavior of the *Po di Venezia* (downstream from where the *Goro* distributary branches out) is obviously a mirror image of the *Po di Goro*'s behavior described above. Therefore, according to the data shown in Figure 4, there is an apparent decrease in the efficiency of that distributary over all regimes investigated. On the other hand it should be noted that, like the data provided by *ENEL* between 1970 and 1990, there were profound differences with that

which had been monitored in the past, even if such behavior was enhanced by an "overestimation of flow in the *Pontelagoscuro* section, as verified in 1988-1989, when outflow rate checks were carried out (by *ENEL*) in this section" (*Grego*, 1990). Regarding the division between the *Goro* and *Venezia* distributaries, one must emphasize the importance of extending flow monitoring (in particular in the medium water hydrometric regime for which there is no recent available data), through simultaneous measurements at the inlet to the two distributaries, in order to minimize possible uncertainty due to propagation phenomena along the course of the river.

Regarding the *Po di Gnocca*, it is evident how the percentage of the portion of the outflow discharged to the sea through this distributary maintains fairly stable in the face of the Po's significant flow rate variations. On average this percentage amounts to values between 10 and 15%. Historical data also show that, over time, there has been an increase in efficiency in this class, a variation that came to the fore over a twenty-year period from 1939 to 1959, compared to the preceding period, as reported by *Canali* (1959). In the years that followed, and up to this day, there have been no apparent significant changes in the efficiency of this distributary.

The *Po di Maistra*, of all the main distributaries, is certainly the least significant in terms of the percentage of contributions to sea of the total outflow of the Po River. The *Canali* report (1959) emphasized that, based on a period of a hundred years, it was evident how the mouths of the Po oriented towards the *Scirocco* would, over time, become less active, as opposed to those oriented toward the *Bora* quadrant. This phenomenon is common to all the rivers with significant sediment transport with outlets along the *Padano-Veneto* coast, which tend to divert their mouths in the quadrant between N and E. The main cause of this trend according to *Cialdi* (see *Canali*, 1959), are the prevailing winds and sea induced currents, elements that govern the accretion of sand near the mouth.

The *Po di Maistra*'s hydraulic behavior pattern is quite clearly in line with this trend, as one notes from the data in Figure 4, how this distributary's hydraulic efficiency has grown significantly over the different monitoring periods. The recently performed "medium stage" and "high stage" measurements, although small, again suggest an increase in efficiency of this distributary, when compared to the results of the last systematic measurements relating to the period 1939-1959 (*Canali*). In such regimes, the flow rate percentage through the Po di Maistra would have been between three and four percent. Regarding the "low water" regime, as in the case of the *Po di Goro*, the measurements carried out by *ENEL* (1970-1990) are contrary to the behavior patterns observed in the only recent campaign. In fact, the data from May 2007 shows a very limited outflow through that distributary. In this context the need for further instrumental studies in order to analyze these behavior patterns, especially in "low stage", is clear.

The *Po di Tolle* distributary has showed variable behavior patterns over time, in fact, for a period at the beginning of the last century (1926-1938), it was characterized by an outflow capacity of close to 15% of the total, followed by a decrease in hydraulic efficiency in the 1939-1959 period.

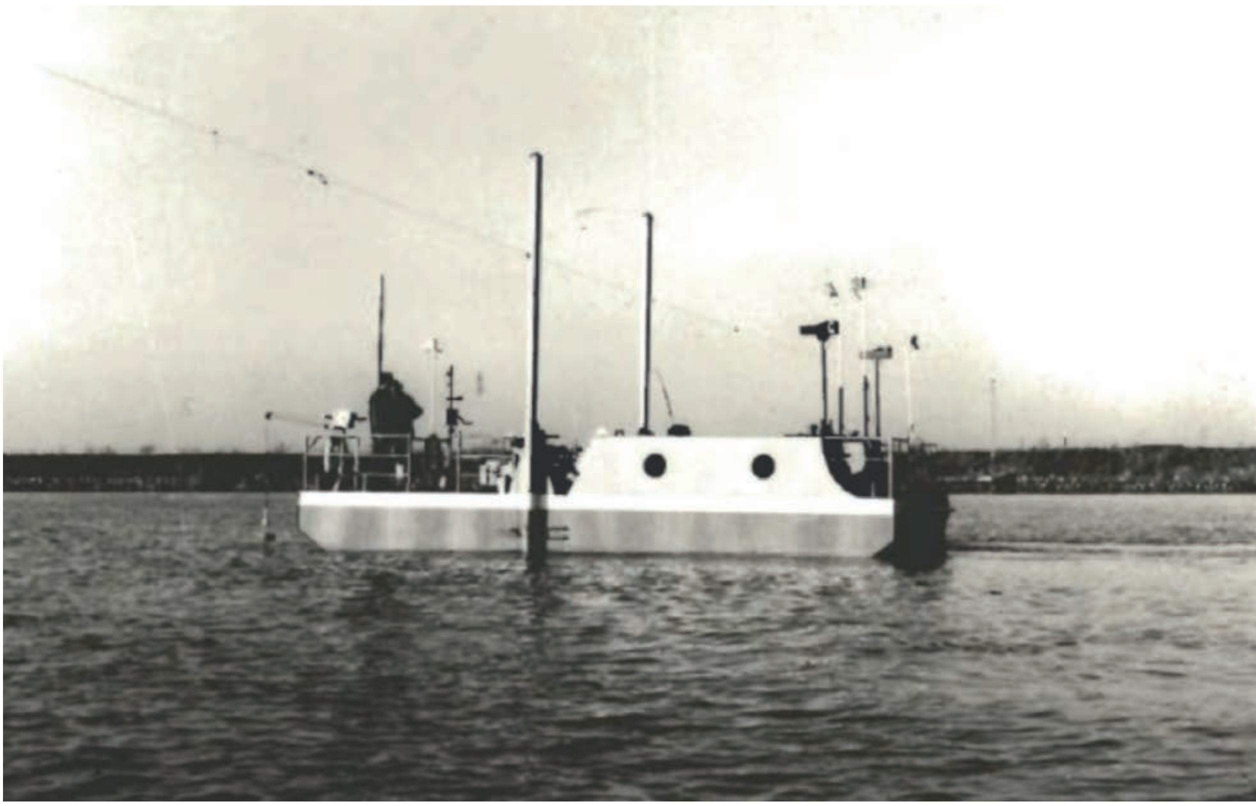
This variation had already been reported by *Canali* (1959), thus confirming this evolutionary trend in the Delta characterized by a "gradual decreasing over time of the southern distributaries as a result of, as previously mentioned, winds and subsequent wave induced currents." Following interventions for the realization of the *Polesine Camerini* station, this distributary was more closely monitored by *ENEL* in the period 1970-1990. Given the specific investigation aims, to look into the effects of the intervention on the Po River in shallow water conditions, monitoring focused mainly on "low and medium stage" regimes.

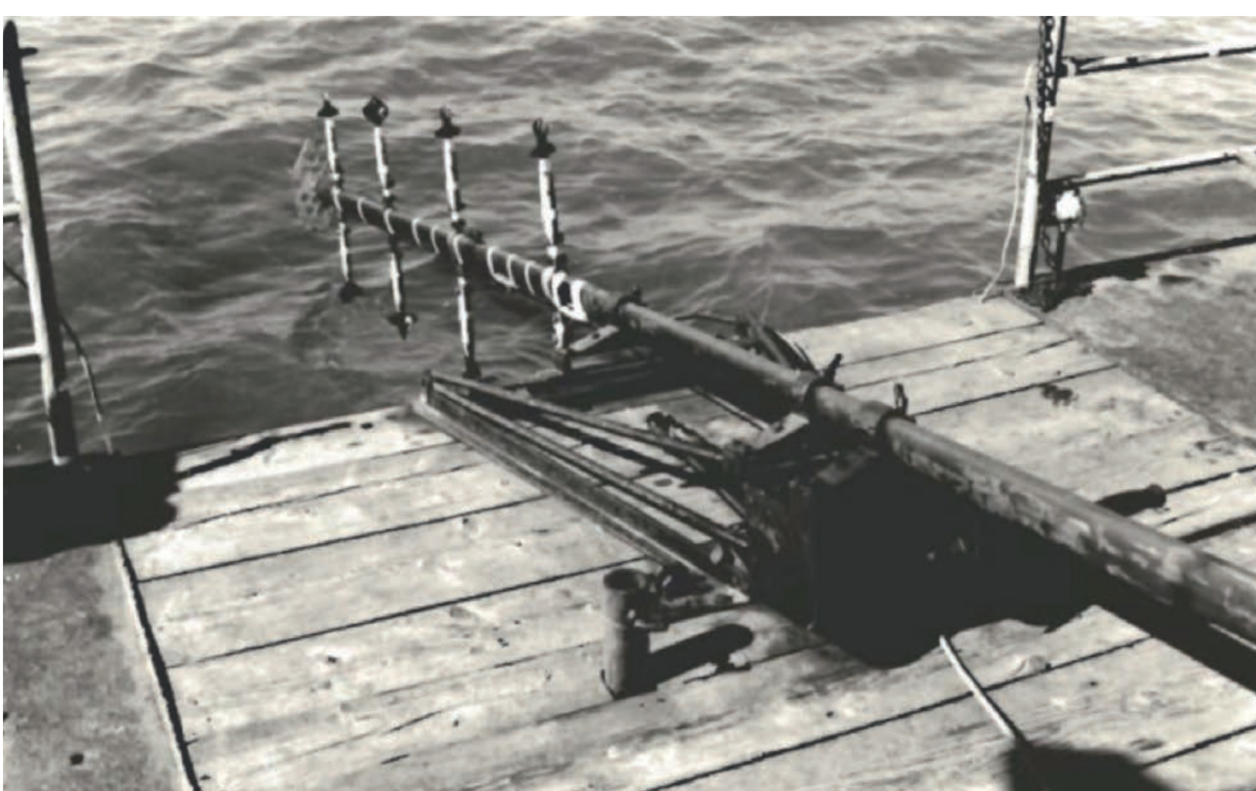
In this context, there was a notable net increase in this distributary's efficiency with values that were even slightly higher than those representing the period 1926-1938 (18-20%) regarding "medium water" and well above the 20% (some even as high as 25%) in "low stage". This trend and similar values were also confirmed by recent studies (even if a single value relating to "low stage" regime is not sufficient to draw any definitive conclusion). However, regarding "high stage" regimes, it is evident how modern work means have enabled the monitoring of a much higher "range" of flow rates than in the past. Hence, past measurements that could be considered useful in making a uniform comparison are not available for this "range". However, for high flow rates, as the data in Figure 4 shows, it is clear how the efficiency of this distributary, in the falling discharge phase, is certainly superior to that of the past, resulting in about 20% of the total flow of the *Po* river being let out to sea.

The *Po di Pila* distributary has progressively and significantly decreased in efficiency over the last century.

From the data in Figure 4 one notes how, in view of a substantial lack of behavior pattern variation recorded up to the end of the 1950s (even if, as reported

Figure 6: historical Measurements. Anchored measurement pontoon (above). Rod mounted reels (below). *ENEL*, 1973.





by *Canali*, signs of a certain reduction in efficiency in " medium water " regimes were already evident), the following two decades were characterized by a significant drop across all regimes. It should be pointed out how, as of the 1970s, the intensive monitoring program in the *Po di Pila* (*UIPO* 1970-1971 and *ENEL* 1970-1990) includes measurements that only focused on this distributary of the delta. As a result, the uncertainty regarding the outflow rate at *Pontelagoscuro*, which provided the flow reference, has resulted in the propagation of uncertainties in the evaluation of the hydraulic efficiency in the *Po di Pila*. *Grego* (1990) highlighted how the reduction of efficiency in the *Pila* distributary was actually amplified by the overestimation of flow at *Pontelagoscuro*, a phenomenon that came to light in checks carried out on the outflow rate in 1988-1989. The last two available measurements, especially regarding the "medium water", regime suggest a possible further reduction in efficiency of this distributary that seems however, to remain unchanged compared to the two extreme regimes of "low stage" and "high stage". It is also clear how the relative lack of available measurements does not permit the univocal definition of hydraulic behavior patterns of this distributary, but only suggests a possible evolutionary trend. On the other hand it is evident how, over approximately 100 years, the efficiency of this distributary, being the main course for outflow to the sea, has decreased by more than 10% with peaks close to 15% in "high stage" conditions. This behavior, as noted above, was offset by a progressive increase in hydraulic efficiency in all the other distributaries.

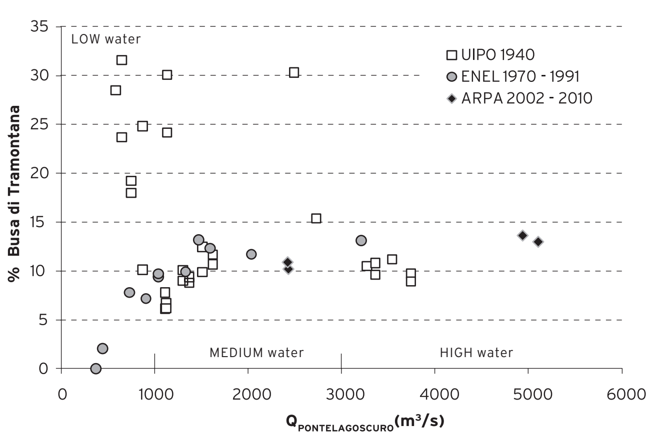


Figure 7a: percentage of average daily flow at *Pontelagoscuro* carried into the sea from the *Busa di Tramontana*. Graphic comparison between the measurements and the recent data available.

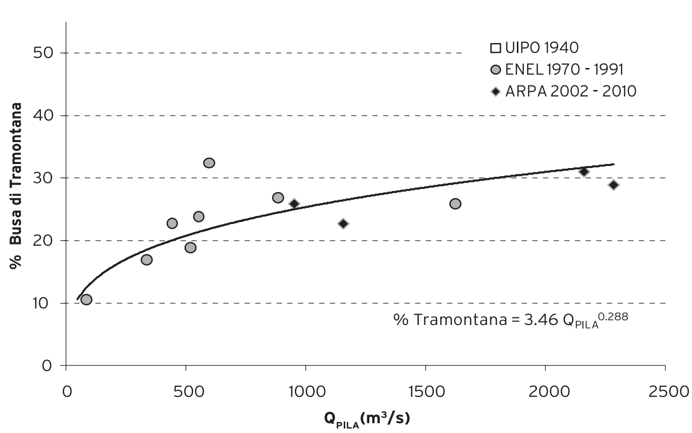


Figure 7b: percentage of flow carried by the *Busa di Tramontana* compared to the total flow of the *Po di Pila*. The results of the comparison were obtained by interpolating the available data from 1970 to 2010. The flow rate obtained from the sum of the measured values in the three mouths is indicated as QPILA.

A final consideration puts together data analysis relating to all distributaries up to now considered precise. In all the graphs proposed, there is a strong dispersion of the "low stage" regime data; such behavior patterns are connected to difficulties in systematically monitoring all the Po's distributaries in hydrometric conditions markedly dominated by the effect of the tide, under homogeneous conditions (over an entire tidal cycle). Therefore, in such conditions, it is difficult to find a function that is able to univocally summarize the patterns, while it is certainly easier to assess an "average efficiency" in these distributaries.

Distribution in the Mouths to the Sea

The hydraulic efficiency of the Pila and Tolle distributaries' mouths to the sea has been investigated with less continuity over the last century (Figure 7) compared to surveys conducted to estimate the flow rate distribution along the main distributaries. There is however data for measurements carried out on the three *Po di Pila* (UIPO 1940) mouths from 1927 to 1938, those provided by *ENEL* (1990, 1991) relating to the measurements carried out from 1972 to 1991 on the mouths of the *Po Pila* and *Po di Tolle*.

As of 2002, *ARPA Veneto*, *ARPA Emilia Romagna* and the *Consorzio di Bonifica Delta del Po* have carried out four studies to assess the flow rate distribution of these two delta distributaries. The distribution of the *Po di Tolle* (*Bocca di Tolle*, *Busa Storiona* and *Busa del Bastimento*) was only investigated in the 2007 and November 2010 campaigns (Table 2).

The *Po di Pila* Mouths: *Busa di Tramontana*, *Busa di Levante* and *Busa di Scirocco*

From the data available for the *Busa di Tramontana* (Figure 7) one can see that, except for some measurements carried out in the 1930s by *UIPO* that show higher distribution, there is a growth trend between the flow at *Pontelagoscuro* and the hydraulic efficiency of the *Busa di Tramontana*. This trend, on the basis of available historical data, shows flow of less than 1,800 m^3/s at *Pontelagoscuro* to be more pronounced. For outflow of up to 5,000 m^3/s, there is a reduction in the hydraulic efficiency increase rate of the *Busa di Tramontana* (also confirmed by the most recent surveys), which tends to be reflected in values between 10 and 13 % of flow at *Pontelagoscuro*.

The higher distribution levels of collected data with flow of less than 1000 m^3/s at *Pontelagoscuro* (the experimental data seem to indicate a significant reduction in hydraulic efficiency from 1940 to 1990 in "low stage" conditions) may in part be due to the inherent difficulties in carrying out flow measurements in river sections subject to tidal regimes and frequent changes that affect the riverbeds near the mouths. It should be underlined that the hydraulic efficiency of the *Busa di Tramontana*, expressed as a percentage of the average flow at *Pontelagoscuro*, is also affected by morphological changes and variations to hydraulic efficiency in the *Po di Pila* distributary as a whole. It is possible to partly exclude these effects when comparing flow values measured at the *Busa di Tramontana* with the flow of the *Po di Pila* (see Figure 7b. The availability of data relating to measurements carried out over the past 40 years, in this case allows the calculation of the flow percentage difference between the *Busa di Tramontana* and the *Po di Pila* by means of a power law, the results of which are shown in Figure 7b.

The *Busa di Levante* or *Dritta* is the central mouth of the *Po di Pila* and most of the flow that comes from this distributary is carried out to sea. The comparison between the recent measurements and the historical data (see Figure 8) shows a marked reduction in hydraulic efficiency over time of the *Busa* which, compared to the average daily flow at *Pontelagoscuro*, now stands between 20 and 30%. In the 1920s and 1930s, the *Busa di Levante* was capable of disposing of up to 50-60% of the total flow of the Po River. Measurements carried out by *ENEL* from the 1970s to the 1990s had already revealed a significant decrease

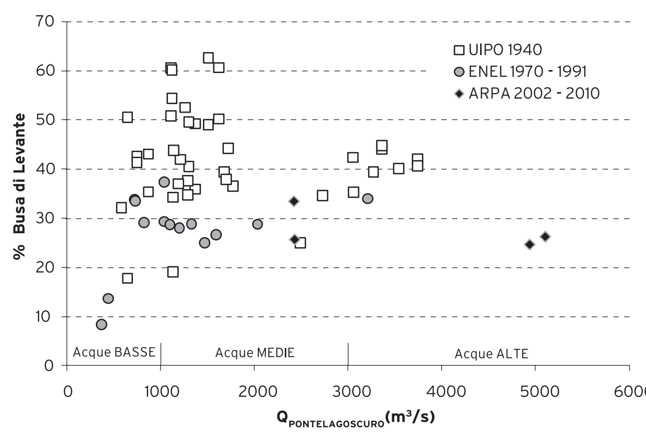


Figure 8a: percentage of average daily flow at *Pontelagoscuro* carried into the sea from the *Busa di Levante*. Graphic comparison between the measurements and the recent available data.

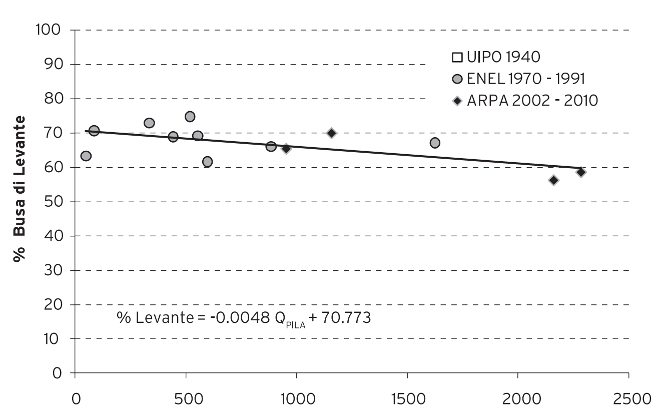


Figure 8b: percentage of flow carried by the *Busa di Levante* compared to the total flow of the *Po di Pila*. The results of the comparison were obtained by interpolating the available data from 1970 to 2010. The flow rate obtained from the sum of the measured values in the three mouths is indicated as QPILA.

in efficiency compared to the values recorded in from previous studies, mainly for flow of less than 2,000 m^3/s at *Pontelagoscuro*.

Such a marked reduction in the efficiency of the *Busa di Levante* compared to flow at *Pontelagoscuro* is partly linked to the reduction in overall efficiency of the *Pila* distributary. By comparing the flow values measured at the *Busa Dritta* with total flow of the three mouths it is clear how, as of the 1920s up to today, the hydraulic activity of the *Busa di Levante* has generally decreased, except for low water hydrometric conditions (with an overall flow of less than 500-600 m^3/s) in which the data collected by *ENEL* seem to show an increase in hydraulic efficiency at the mouth, compared to the *Visentini* historical data. Analyzing the most recent data (1970 to 2010) one can see a certain inertia of the flow capacity of the *Busa di Levante* in all hydrometric river conditions, with a slight tendency to decrease with flow channeled to augment the total flow of the *Po di Pila* (Figure 8).

The *Busa di Scirocco* is the mouth of the *Po di Pila* characterized by lowest hydraulic capacity. Its efficiency, in general, covers between 1 and 6% of the flow rate at *Pontelagoscuro*, and can be considered fairly stationary over time with weak variations in relation to the *Po* River hydrometric regime (Figure 9).

In more detail, again in Figure 9, one can see that at one time, based on historical data, the efficiency of the *Busa di Scirocco* was greater than 3% in "low stage" conditions, while medium and "high stage" hydrometric conditions reported less than 3%. Today this data has changed slightly due to a growth trend of efficiency in "high stage" regimes. If one analyzes the distribution of flow measured in the *Busa di Scirocco* compared to the total value of the three mouths of the *Po di Pila*, the efficiency of this delta distributary seems to have increased over time. The average value for the period 1927-1939 amounts to 5.2%, while the average value for the period 1970-2010 (excluding the two measurements carried out by *ENEL* in exceptional low water conditions) amounts to 8.5%.

The last studies (2002-2010) seem to confirm a slight increase in the efficiency of the *Scirocco* distributary with higher values than those reported in the historical data for flow in the *Pila* distributary exceeding 900 m^3/s. However, for overall flow of less than 500 m^3/s one detects a sudden increase in hydraulic activity of this delta distributary (in relation to the hydraulic behavior patterns of the three mouths to the sea of the *Po di Pila*), even if the notable tidal motion, which is even more significant in the case of extremely low flow rates, does not always permit for the easy and accurate simultaneous evaluation of flow rates.

Having already provided the relationships between the respective flow per-

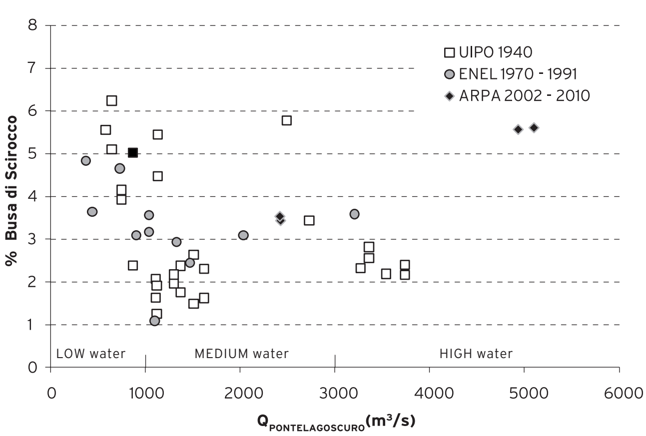


Figure 9a: percentage of average daily flow at *Pontelagoscuro* carried into the sea from the Busa di Scirocco. Graphic comparison between the measurements and the recent data available.

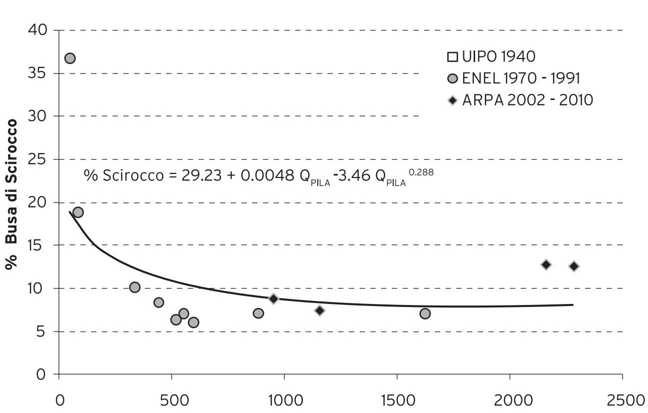


Figure 9b: percentage of flow carried by the *Busa di Scirocco* compared to the total flow of the *Po di Pila*. Comparison trend analytically obtained, based on the comparisons proposed for the other *Po di Pila* mouths. The flow rate obtained from the sum of the measured values in the three mouths is indicated as QPILA.

centages carried by the *Busa di Tramontana* and *Levante*, compared to the total flow of the mouths of the *Po di Pila*, one can analytically refer to the relationship that shows, once again as a percentage, the flow that is discharged into the sea via the *Busa di Scirocco*. Figure 9 shows how well the obtained relationship fits with the experimental data.

Mouths of the *Po di Tolle*: *Busa Storiona*, *Busa del Bastimento* and *Bocca del Po di Tolle*

Two recent measuring campaigns (Table 2) were carried out on the mouths of the *Po di Tolle* (2007 and 2010). The measurements found in the historical data were from two surveys conducted by *ENEL* in 1991 and 1992. The recent measurements are not easily comparable to the available historical data, as a result of the different methods of data acquisition and the significant changes that the *Sacca dei Bonelli* has undergone over the last forty years. In more in detail, the 2010 measurements were carried out when the flow rates of the *Po di Tolle* at *Scardovari* were approximately 1,100 m^3/s, and in 2007 when the discharge at *Scardovari* was about 400 m^3/s, while the *ENEL* measurements were conducted when the discharge at *Scardovari* was between 70 and 450 m^3/s.

The comparison of the distribution data from the last two surveys did not show any particular changes in hydraulic efficiency of the mouths of the *Po di Tolle*, while there were some values that conflicted with those recorded by *ENEL*. In November 2010, the *Sacca dei Bonelli* was completely flooded, preventing the direct measuring of flow carried by the *Busa del Bastimento*, which was calculated as the difference from the total of

Figure 10: the evolutionary trend of the *Po Grande* with progressive weakening in efficiency to the advantage, in differing ways, of all the lateral distributaries. Possible effect of growing sediment deposit more and more evident in numerous stretches of the main distributary of the *Po* (in the entire *Veneto* stretch).

the *Po di Tolle*: the result was a hydraulic capacity equal to 4.4% of the flow of the *Po di Tolle*, as opposed to the average value of the measurements carried out in 2007 which were equal to 5.7%, albeit under a different hydrometric regime. However, the average of the *ENEL* data recorded 1.5 km upstream of the mouth of the *Busa del Bastimento* between 1972 and 1976 is equal to 20.3% of the *Po di Tolle*'s total flow.

These variations can be explained by interventions carried out in the late 1980s/early 1990s also relating to the reopening of the connection to the lagoon corresponding to the branching off of the *Busa del Bastimento*. This work was carried out as part of management works in the *Volta Vaccari* cove (Figure 5), with the aim of maintaining the distribution percentage between the two branches of *Pila* and *Tolle*.

The *UIPO* report (1940) shows that, according to measurements taken in 1938 and 1939, the *Po* di Tolle's flow distributed between the mouths of *Tolle* and *del Bastimento*, equaled 27.3% and 72.2% respectively. At that time, the adaptation of the mouth of the *Po di Tolle* through the construction of the *Busa Storiona* in order to facilitate flood outflow to the sea had not yet been fully realized.

According to measurements taken in 2007 and 2010, the *Bocca di Tolle* carried 17.2% and 17.8% of the *Po di Tolle* flow measured at Scardovari, close to *ENEL*'s 1992 value (12.5%). According to surveys carried out in 2007 and 2010, the *Busa Storiona* currently shows considerably high hydraulic efficiency with about 77% of total incoming flow being carried to the sea.

Comparison of Field Measurements and Hydraulic Modeling of the Events of 2010

A further phase of the investigation involved the comparison of flow measurements taken during low water/ flood events in June and November 2010 and the output hydrographs obtained from simulations carried out using two hydraulic models. The first is the one-dimensional (1D) DELFT Hydraulics Sobek model implemented by A*RPA Emilia Romagna* on behalf of AIPO (model implementations in order to predict flooding along the *Po* river course), while the second is a two-dimensional (2D) finite elements model of the *Consorzio Delta Po* (*D'Alpaos* e *Defina*, 1993, *D'Alpaos et. al.*, 1994, C*onsorzio Delta Po Adige*,

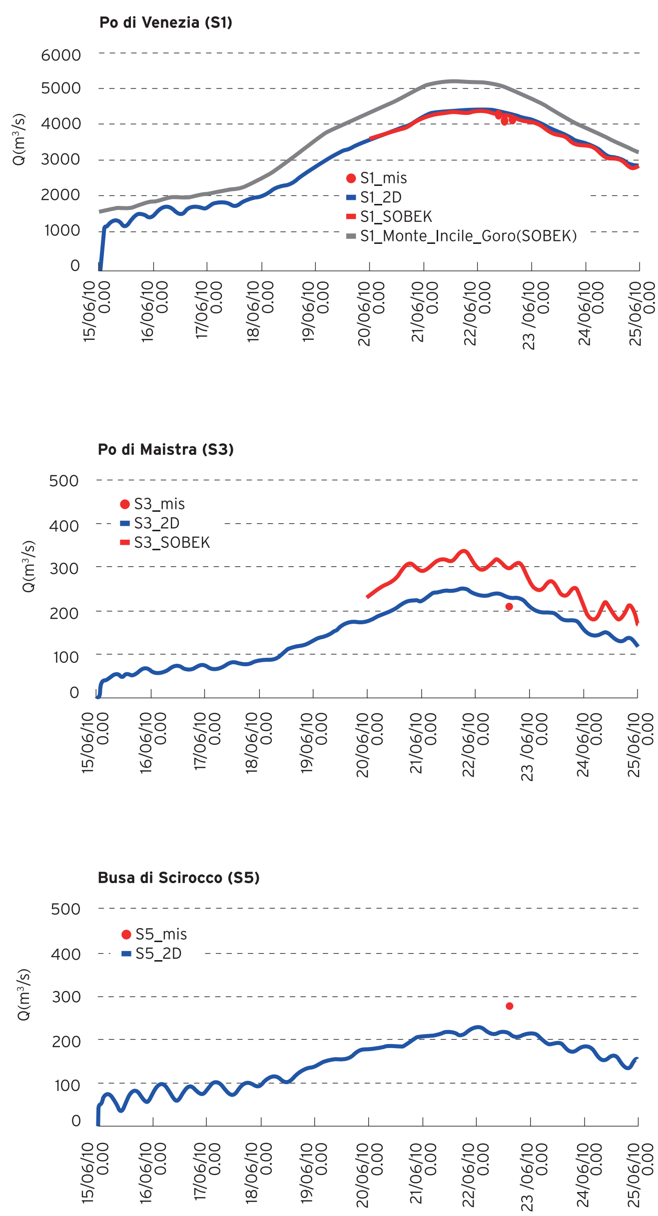
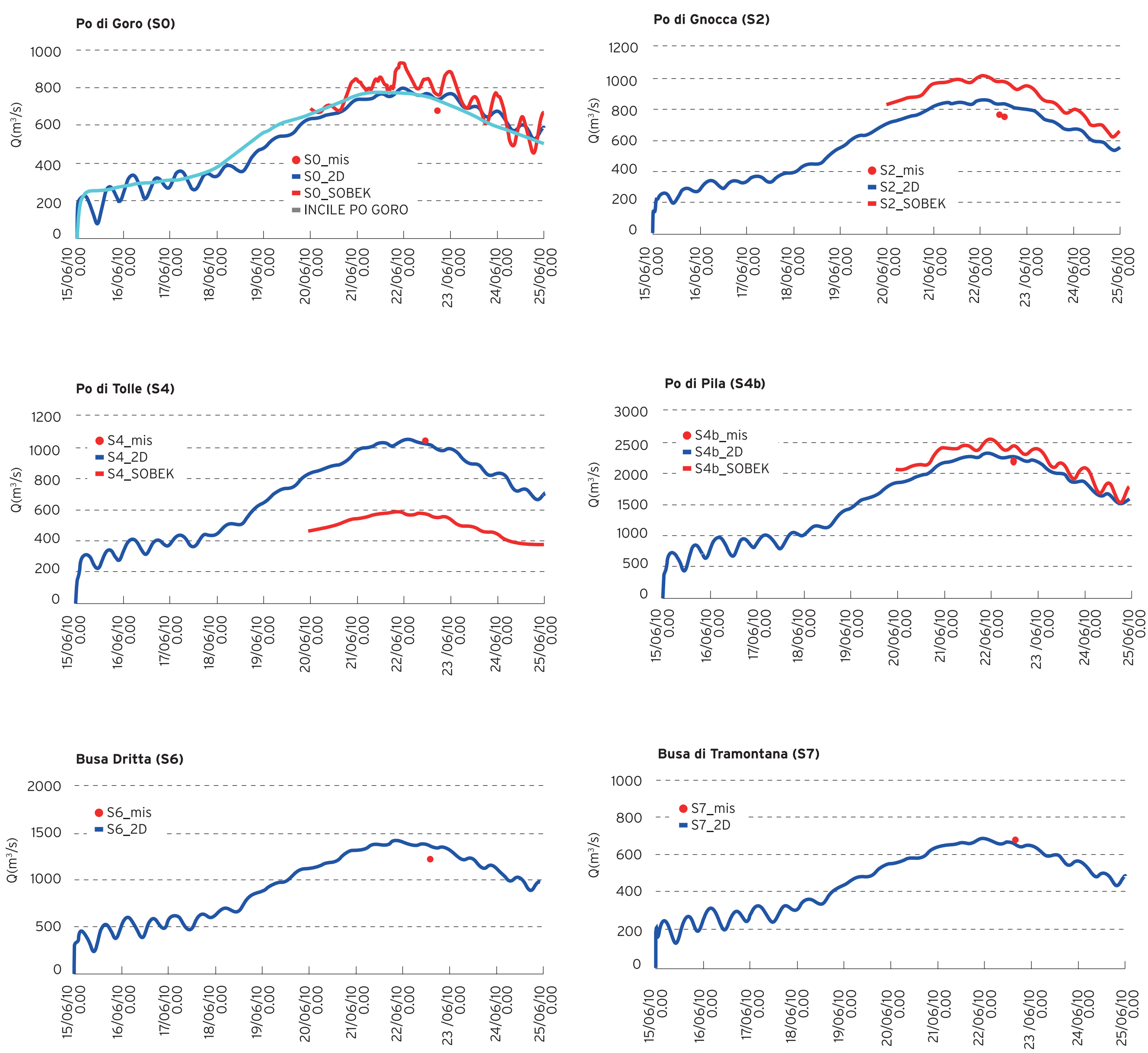


Figure 11: comparison between the results of the model and data obtained in the field regardin the June 2010 event.

2006) implemented by *Ipros Ingegneria Ambientale* in the Delta area.

The Sobek model used the ADRIA-ROMS model tide data as downstream boundary conditions, which had in the past provided good results with the available observation points. The 2D Consorzio model was applied to a section of the river that extends from about 3.5 km upstream of the *Po di Goro* branch (at *Berra*, about 45 km downstream from the *Pontelagoscuro* section) all the way to the sea. The upstream boundary condition is shown in the hydrograph produced from ARPAER's Sobek model.

In Figure 11 simulation results for the June 2010 event are shown. The *Po di Venezia* measured discharges seem well represented by both models with a maximum percentage difference of 6%. However, the *Po di Goro* discharge is overestimated by both models by between 10 and 13%. Since the 2D *Consorzio di Bonifica* model uses the Sobek model upstream flow rates as boundary conditions, this can result in a possible overestimation of the upstream discharge that may af-



fect the modeling results. Regarding the other main delta distributaries, the 2D model seems to be more accurate, with differences between 4 and 12%. In particular, the Sobek model significantly overestimates the hydraulic efficiency of the *Po di Maistra* and underestimates the flow through the *Po di Tolle*. One should also note an underestimation in the 2D model of about 20% of the flow rates of the *Busa di Scirocco*.

Regarding the November 2010 survey, the modeling results seem less accurate when compared to the June data. On the other hand the flow measurements are also somewhat inconsistent because of the presence of some deficits to the balance of the measured outflow. In particular, between the *Po di Venezia* and the sum of outflow monitored in the other distributaries, there is an apparent "loss" of about 700 m^3/s. Both the two-dimensional and Sobek models showed satisfactory flow rate approximations for the *Po di Venezi*a for this event. However, both models' overestimation of the *Po di Goro* flow is confirmed.

For the *Gnocca*, *Maistra*, *Pila* and *Tolle* distributaries, there is a general overestimation with errors of between 15 and 26% in the 2D model, while the Sobek model discrepancies are much bigger and follow the same trend seen in the June event simulations: overestimation of the *Gnocca*, *Maistra* and *Pila* and underestimation of the *Po di Tolle* outflows. The *Consorzio di Bonifica* model underestimates the *Busa di Scirocc*o's flow by about 20%. The 2D model 's accuracy in predicting behavior patterns relating to the *Po di Tolle* mouths is to be noted. Based on the above data, it is evident how one can configure the *Consorzio Delta Po*'s 2D model in order to be a useful analysis tool that can also be applied in predictive phases, with the appropriate foresight required by the noted differences between the observed data and model predictions. On the other hand, the observations obtained may serve as an additional means of contributing to the refinement of the model.

Conclusions

The recent measuring campaigns carried out in different hydrological regimes ("low stage", "medium stage", "high stage") on the *Po Delta* distributaries highlight the significant potential of new available technology that enables the acquisition of current and flow rate data using more accurate and less expensive systems than in the past. On the other hand, the campaigns showed the concrete possibility of retrieving and updating the relevant available knowledge base, which consists of a large number of surveys carried out between 1920 and 1990, in order to reconstruct trends that describe the hydraulic operation of the different distributaries, in terms of evolution.

The information provided by the surveys also allowed for the identification of specific needs to improve knowledge regarding behavior patterns of certain distributaries in different hydraulic regimes. The acquired experience is fundamental to the planning and execution of further measuring campaigns aimed at better defining the cognitive framework only partially updated here.

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_STUDIES & RESEARCH

MONITORING THE WATER QUALITY IN THE PO DELTA LAGOONS: ANALYSIS OF CHEMICAL-PHYSICAL PARAMETERS MEASURED BETWEEN 2005 AND 2010

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Since 2005, yearly monitoring campaigns have been carried out to record the water quality in the lagoons of the Po River Delta. Measurements of various chemical-physical parameters (temperature, conductibility/ salinity and concentration of dissolved oxygen) were taken at regular intervals, especially in the summer months, in an increasing number of lagoons over the years. Today, these measurements make up an important database of the quality of the deltaic waters and, after their reanalysis preceding publication, are also available to scientific research activities.

On one hand this contribution is therefore motivated by the will to broaden our knowledge of physical, chemical-physical and biological dynamics in the Delta lagoons. On the other hand, it aims at further qualifying the widespread commitment to the creation of this database, showing the importance of careful measuring and interpreting for a range of users.

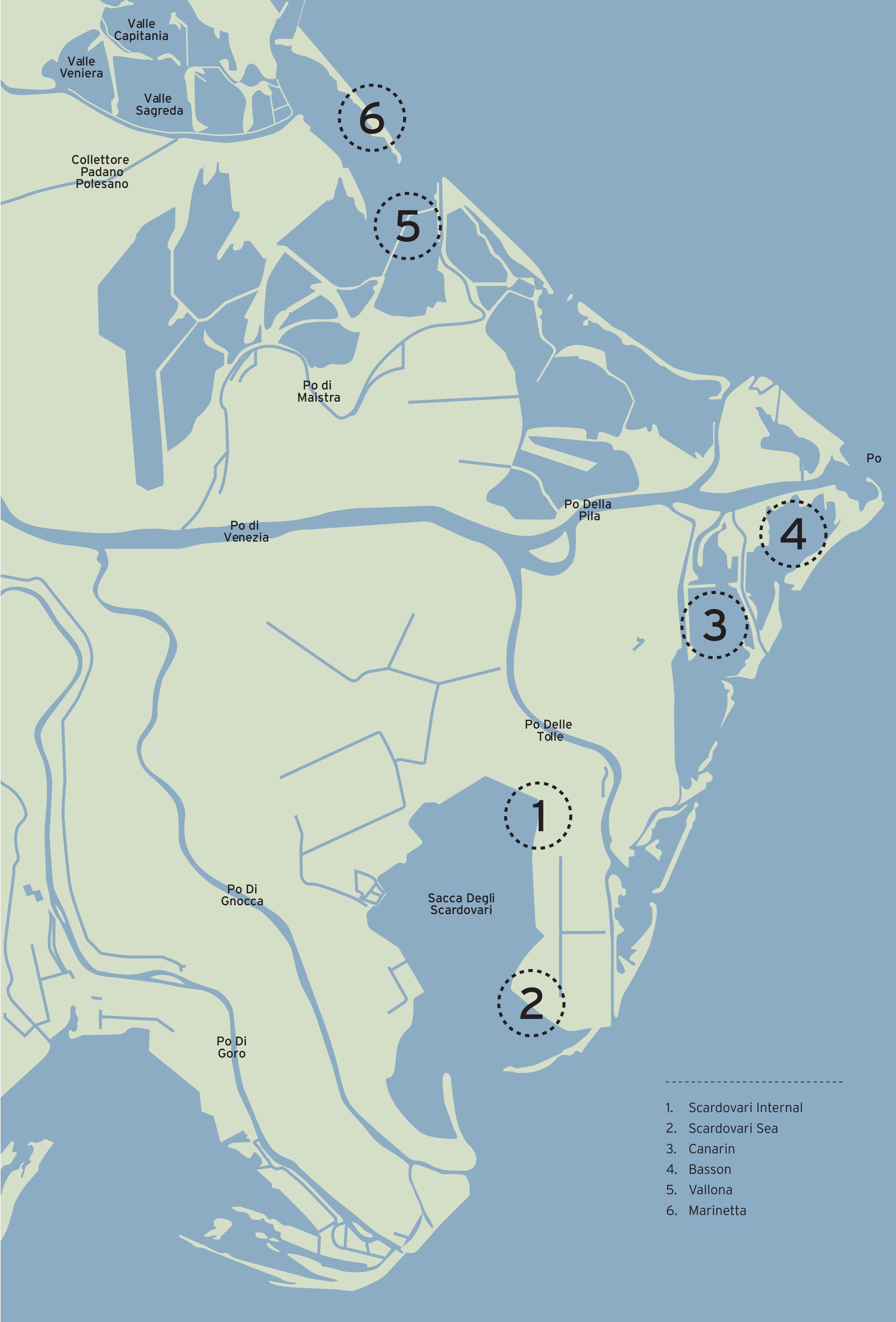
In particular, this overview analysis highlights the complexity of the interactions between different physical parameters within the Po Delta lagoons. It further reveals the existence of notably strong responses to external factors and the variety of phenomena that are at the origin of the aforementioned interactions and responses. A continued flow of information on the parameters describing the water quality in the Po Delta lagoons is therefore indispensable in such a highly dynamic context that is so responsive to external perturbations, not only in order to gain a deeper understanding of the variability of the system, but also from the perspective of future usage of this increasing flow of quantitative information for the management of such a significant area.

Knowledge of a system implies first of all, availability of data (primarily experimental, but also data simulated using numerical models) relating to it. The natural environment in particular, is a dynamical system: the evolution of its descriptive variables and parameters is continuously shaped by multiple factors, some of which act locally, while others remotely (think for example, about atmospheric and oceanic teleconnections). This characteristic of the system poses problems of both a theoretical and practical nature, involving primarily the data sampling. Theoretical problems are particularly relevant in extremely dynamic and varied environments as in the case of the lagoon ecotones.

Here in fact, the preferential use of monitoring sites at fixed locations inevitably leads to problems of representativeness of the data. It is known that in these "transition" areas physical-chemical and biological conditions may vary substantially within both relatively small areas and temporal frames. Thus limited (in space and time) representativeness of observational data represents a major difficulty in their interpretation, i.e., their insertion within a well-defined theoretical framework. This implies a considerable logistical and therefore also economic effort in the activation of the greatest possible number of monitoring sites capable of sampling at a sufficient frequency (and for a sufficient time) in order to record the dynamics of interest and their variability.

The complex system of lagoons and "*sacche*" that characterizes the Po Delta area provides several emblematic examples (in particular the *Sacca*

Figure 1: 2005-2010 monitoring site positions.



Valle Capitania
Valle Veniera
Valle Sagreda
Collettore Padano Polesano
6
5
Po di Maistra
Po Della Pila
Po
4
Po di Venezia
3
Po Delle Tolle
1
Sacca Degli Scardovari
Po Di Gnocca
2
Po Di Goro
1. Scardovari Internal
2. Scardovari Sea
3. Canarin
4. Basson
5. Vallona
6. Marinetta

del Canarin and the *Sacca degli Scardovari*) of the heterogeneity and extreme variability typical of transitional habitats both from a biochemical and ecological point of view. In fact, in the different portions of each lagoon the evolution of the physical-chemical characteristics and degree of vivification is inextricably tied to hydrodynamics, and it is in turn influenced by atmospheric circulation, tides, local inflow of freshwater from the different distributaries of the Po and its water towers, morphology / bathymetry and so on.

The hydrodynamics therefore also contribute on the one hand, to the propensity of the different lagoons (and of different regions within a lagoon) to experience prolonged periods of significant stagnation or, on the other hand, to their different exposures to the inflow of riverine freshwater during flooding events. In particular, deviations from the natural functioning of the system linked to the above mentioned factors are of major interest, since they may lead to disruptive anoxic events like that affecting the most internal portion of the *Sacca degli Scardovari* during the summer of 2009. In order to provide an evermore complete picture of the environmental conditions in the Po Delta lagoons, the monitoring system of water quality has evolved over the years, from the two stations initially set up in the *Sacca degli Scardovari* (2005 campaign) to the six active stations in the *Sacca degli Scardovari*, *Sacca del Canarin*, and in the *Marinetta*, *Basson* and *Vallona* lagoons during the 2008, 2009 and 2010 campaigns.

Table 1 summarizes the characteristics of the monitoring system for the different campaigns, highlighting the two main sampling methods used: 1) pole-mounted multiparameter probe, with sensors constantly submerged in lagoon waters and sampling at a fixed height from the bottom, 2) buoy-mounted multiparameter probe equipped with hydraulic extraction/washing system, sampling at a fixed depth below the surface.

Station	2005	2006	2007	2008	2009	2010
Scardovari Internal	B*	B*	B	B	B*	B*
Scardovari Sea	B	B	B	B	B*	B*
Canarin	-	B	B	B	B	B
Vallona	-	B*	B	B	B	B
Basson	-	-	-	P	P	P
Marinetta	-	-	-	P	P	P

Table 1: active sites over the course of the monitoring.

B: Buoy site;
B*: Buoy site with deeper extraction;
P: Pole site.

In the table, and generally in this text, the different monitoring sites are referred to as follows:

1. ***Scardovari* Internal** for the buoy monitoring site in the inner portion of the *Sacca degli Scardovari*, in the vicinity of the dock;
2. ***Scardovari* Sea** for the buoy monitoring site in the outer portion of the *Sacca degli Scardovari*, near the mouth to the sea, a few meters from the eastern edge of the *Sacca*;
3. ***Canarin*** for buoy monitoring site in the central portion of the *Sacca del Canarin*, north of the northern mouth to the sea, a few meters from the strip of land which separates the artificial canal west of the lagoon;
4. ***Basson*** for the pole monitoring site in the central portion of the *Sacca del Basson*, a few hundred meters north of the southern mouth to the sea;
5. ***Vallona*** for the buoy site monitoring in the central portion of the *Laguna di Vallona*, north of the bend;

6. ***Marinetta*** for the pole monitoring site in the central portion of the *Laguna di Marinetta*.

The approximate location of the monitoring sites is shown in Figure 1. The data described and analyzed in this paper refer to the following parameters: temperature, salinity, and dissolved oxygen, sampled at three-hour intervals or less.

Based on the framework outlined above and in order to minimize, or at least greatly limit the inevitable uncertainties related to the spatial and temporal constraints of the sampling, we chose to focus on an overview analysis of the available data using, above all, statistical methods designed to identify correlations not only between the different variables measured, but also between them and additional variables, be they local or representative of larger-scale conditions. In this way it is possible to contextualize the measured variability in the quality and characteristics of the lagoon waters with local and larger-scale weather and climate dynamics. In this context, this study focuses on the analysis of daily-average values, which are included in our database if calculated on a basis of at least five measurements throughout the day.

However, it glances over the more technical aspects, such as the detailed description of the sampling systems or the validation phase prior to publication of data. For these technical aspects, the reader should refer to the technical reports produced at the end of each campaign.

Figure 2 compares the data measured in the *Sacca del Canarin* during the 2007, 2008 and 2009 campaigns. The evolution of water temperature is characterized by notable similarities between the different years, originating in the prevalence of the seasonal cycle over the other sources of variability: between August and September, for example, temperatures can be on average up to 10 °C warmer

Comparison of temperature data (temp), salinity (sal) and dissolved oxygen (DO)

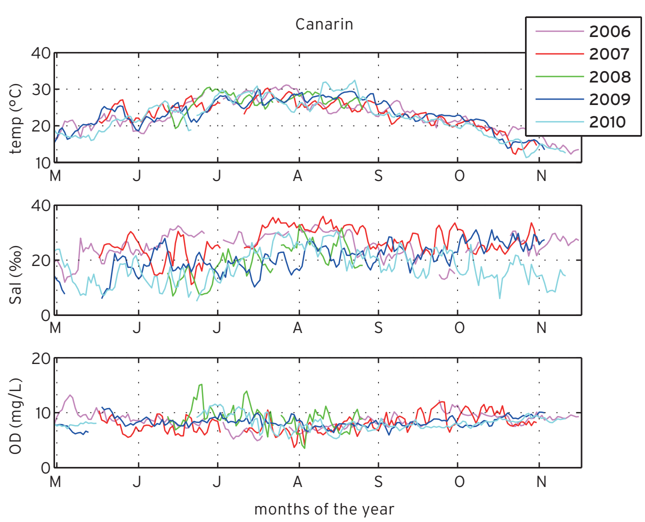


Figure 2: comparison of temperature data (temp), salinity (sal) and dissolved oxygen (DO) measured at *Canarin* over the 2006-2010 monitoring period.

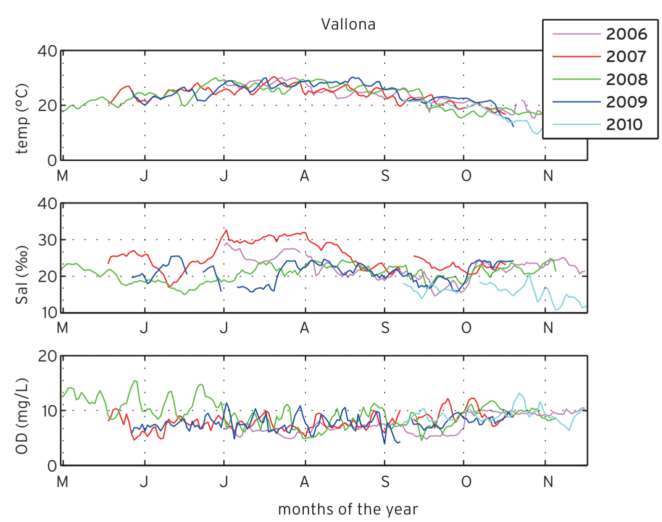


Figure 3: comparison of temperature data (temp), salinity (sal) and dissolved oxygen (DO) measured at *Vallona* over the 2006-2010 monitoring period.

than those recorded in early spring and late autumn. As we shall see, dominance of the seasonal cycle is a common feature of temperature evolutions in all the monitored lagoons. The temperatures consistently indicate values of above or around 25 °C from late June to late August, only occasionally exceeding the threshold of 30 °C (with the exception of 2006 and 2010, when there were several cases of consecutive days with temperatures higher than this threshold). Autumn is generally characterized by rapid decreases in temperature (of up to almost 10 °C within a couple of weeks) interspersed with seemingly stationary phases that were less apparent in 2010.

The salinity shows marked differences between the different years, especially in July-August and in the autumn, when the gap between the individual years reaches values above 10 parts per thousand. This variability is partly due to the variability in the freshwater inflow from the river Po, and in part due to the sampling location at the front, of tidal origin, between internal and open-sea waters. On site surveys have in fact shown that in the area surrounding the sampling site variations in surface salinity (as sampled at 0.5 m depth) in the order of tens of parts per thousands can occur within just a few meters.

This situation of great frontal variability is common in areas near riverine mouths or estuaries. The seawater-freshwater front is sometimes very sharp, and is generally linked to phenomena of convergence of the surface velocity field and/or to the accumulation of material floating on the surface. Such discontinuity can thus often be monitored via remote sensing, in particular radar-based tools, which measure the modulation of small-scale waves generated by the presence of substances at the surface or by alterations of the surface velocity field.

The dissolved oxygen data provide a substantially consistent picture of the general temporal evolution over the course of the various monitoring campaigns. This is characterized by minimal seasonal variations (the data generally remain around 7-8 mg/l over the course of the year) with a tendency to produce minimum values (about 5 mg/l, still higher however than anoxia risk levels) in July and August. Nonetheless, like the other parameters dissolved oxygen is sampled close to the surface and in an area exposed to flow/ebb tide. The inner zones and deeper layers of the *Sacca del Canarin* may have experienced periods in which the values of dissolved oxygen fell well below those monitored.

Figure 3 compares the data measured in the *Vallona* lagoon during the 2006-2010 campaigns. Considerations about the observed interannual variability are similar to those made for the *Sacca del Canari*n. Water temperature evolution is characterized by a substantial dominance of the seasonal cycle over the other sources of variability. Over the five years of monitoring, the temperature consistently reaches values above 25 °C between late June and late August, only occasionally exceeding the threshold of 30 °C. Autumn is characterized by rapid decreases in temperature similar to those found in the *Sacca del Canarin*, though of lesser intensity. The salinity shows marked differences between the campaigns, especially in July. The salinity data are consistent in relative values with those measured in the *Sacca del Canarin*: the waters are markedly saltier in July 2007 and fresher in July 2009.

As with the *Sacca del Canarin*, dissolved oxygen data provide a substantially consistent picture of the general temporal evolution over the course of the various monitoring campaigns. The yearly evolution is characterized by minimal seasonal variations, with values generally remaining around 7-8 mg/l. Interestingly, the data collected during the late spring of 2008 indicate a progressive decrease in dissolved oxygen with marked peaks likely highlighting algal bloom episodes. We remark that dissolved oxygen is sampled at the surface, like the other parameters. The inner zones and deeper layers in the lagoon may have experienced periods in which the values of dissolved oxygen fell well below those monitored.

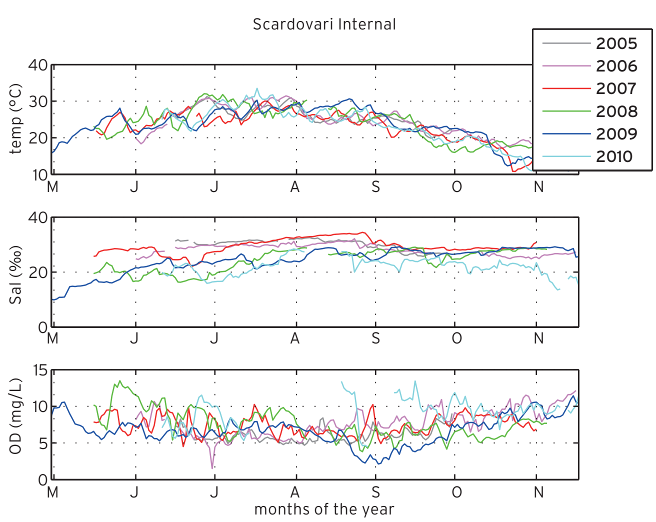
Figure 4 compares the data measured at the *Scardovari* Internal site during the 2005-2010 campaigns. The yearly evolution of water temperature is characterized by the typical dominance of the seasonal cycle over the other sources of variability. Unlike the previously examined lagoons, large inter-annual variability is observed during hot periods, with differences reaching 7-8 °C in late June and in August. Moreover there is evidence of episodes of several days, in which the temperature exceeds the threshold of 30 °C. These occurred once or more times a year (as in 2005) and in different periods in the different years (for example between June and July in 2008 and in the second half of August in 2009).

This indicates a greater susceptibility of this portion of the lagoon to extreme weather events, such as prolonged periods of warming calm conditions. This portion of the lagoon is in fact only marginally affected by tides and turns into a stagnant pond during calm periods. The dissolved oxygen data, and the anoxia episode of late August 2009 in particular, confirm this picture. We remark again that, like the other parameters, dissolved oxygen was sampled at the surface. Autumn is characterized by rapid decreases in temperature similar to those found in the *Sacca del Canari*n and *Vallona*. These episodes can be attributed to the sudden intrusion of cold air typically brought by autumnal weather perturbations.

The salinity shows marked interannual variability up to the month of August. With the exception of 2010, a phase of extremely reduced interannual variability sets in autumn, with average values of 28-29 parts per thousands and deviations, in individual years, of only a few parts per thousands. The strong mixing forced by the autumnal winds is the likely explanation for this behavior. The onset of quasi-homogeneous conditions through the water column implies that salinity is essentially determined by the mass balance of water in the region (precipitation - evaporation + external sources/sinks), which typically shows a lower interannual variability.

As with the *Sacca del Canarin* and *Vallona*, the salinity data indicates markedly saltier waters in 2007, with comparable values in July 2005-2006. Opposite trends in July characterize the years 2008 and 2009, specifically with an increase in the former and a decrease in the latter. Salinity values measured at the beginning of the 2009 campaign are decidedly low and concurrent with high values of dissolved oxygen, which may be due to both, the particularly rainy preceding winter (that of 2008-09) and the

Comparison of temperature data (temp), salinity (sal) and dissolved oxygen (DO)



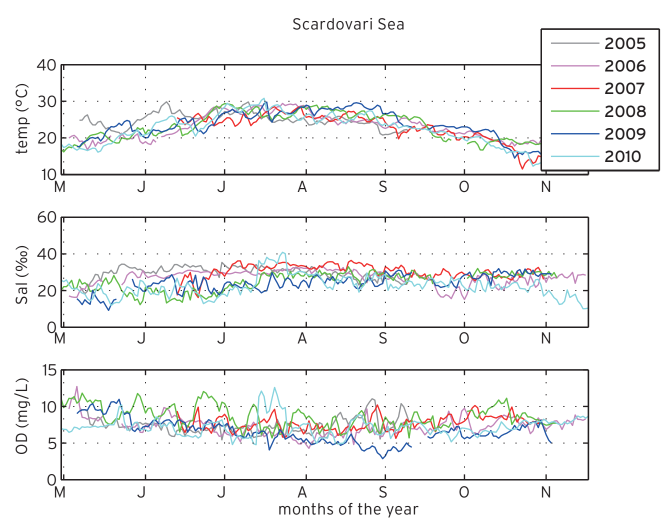


Figure 4: comparison of temperature data (temp), salinity (sal) and dissolved oxygen (DO) measured at *Scardovari* Internal over the 2005-2010 monitoring period.

Figure 5: comparison of temperature data (temp), salinity (sal) and dissolved oxygen (DO) measured at *Scardovari* Sea over the 2005-2010 monitoring period.

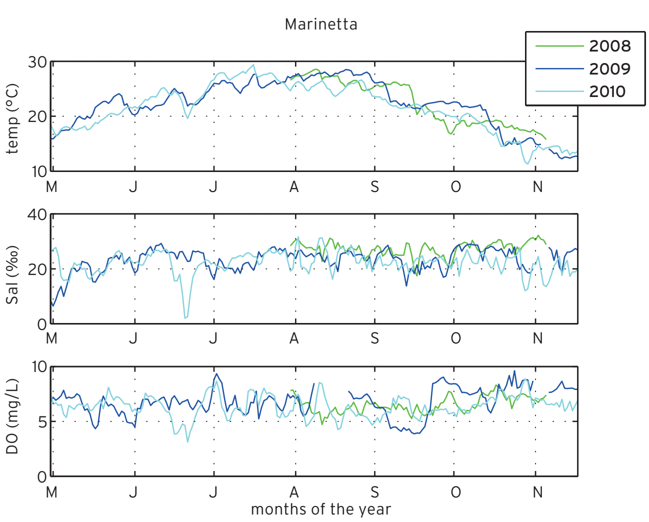
accentuated recirculation of waters artificially induced during that period. Unlike the *Sacca del Canarin* and *Vallona*, a seasonality is noticeable in the dissolved oxygen data from *Scardovari* Internal, with minimum values typically occurring in the hottest months (July-August). This period of scarce oxygenation is followed by a growth phase (several mg/l) in September.

Figure 5 compares the data measured at *Scardovari* Sea during the 2005-2010 campaigns. Despite the data bearing similarities, in their general traits, to those measured in the innermost portion of the *sacca* (Figure 4), substantial differences between the two datasets emphasize the different dynamics that characterize the two portions of the lagoon. Temperature evolution is characterized by the typical dominance of the seasonal cycle over other sources of variability. The year 2005 is characterized by a seemingly anticipated seasonal cycle, with a warmer June and colder August compared to the other years.

This distinctive feature occurred, however, within a context of large interannual variability with differences of up to 3-4 °C between the values measured in individual years. Unlike the inner portion of the lagoon, and similar to *Canarin* and *Vallona*, the maximum temperature does not exceed the threshold of 30 °C over the course of the year, if not sporadically.

Autumn is characterized by the typical rapid cooling events observed in the other lagoons. Like the innermost portion of the lagoon, interannual variability in the annual evolution of salinity is markedly large until August and strongly reduced in autumn, when values range between about 27 and 30 parts per thousands. Also in this site, generally lower salinity values make the year 2010 exceptional compared to previous years. Like *Canarin* and *Vallona*, the salinity data show markedly saltier waters in 2007, with values comparable to July 2005-2006 and, if only for a short time, July 2010.

Comparison of temperature data (temp), salinity (sal) and dissolved oxygen (DO)



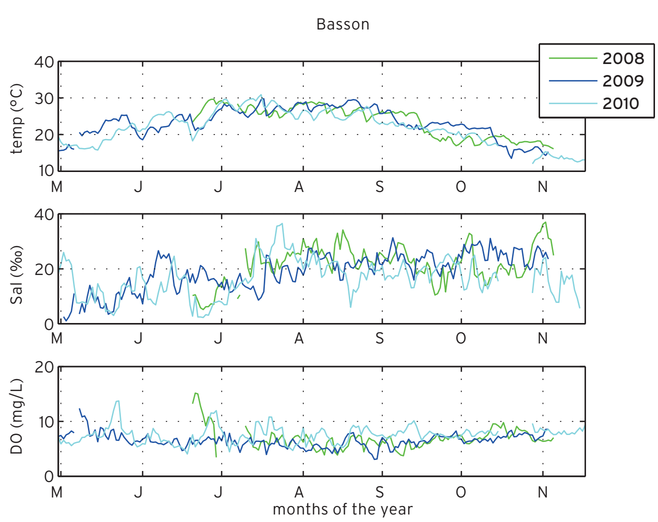
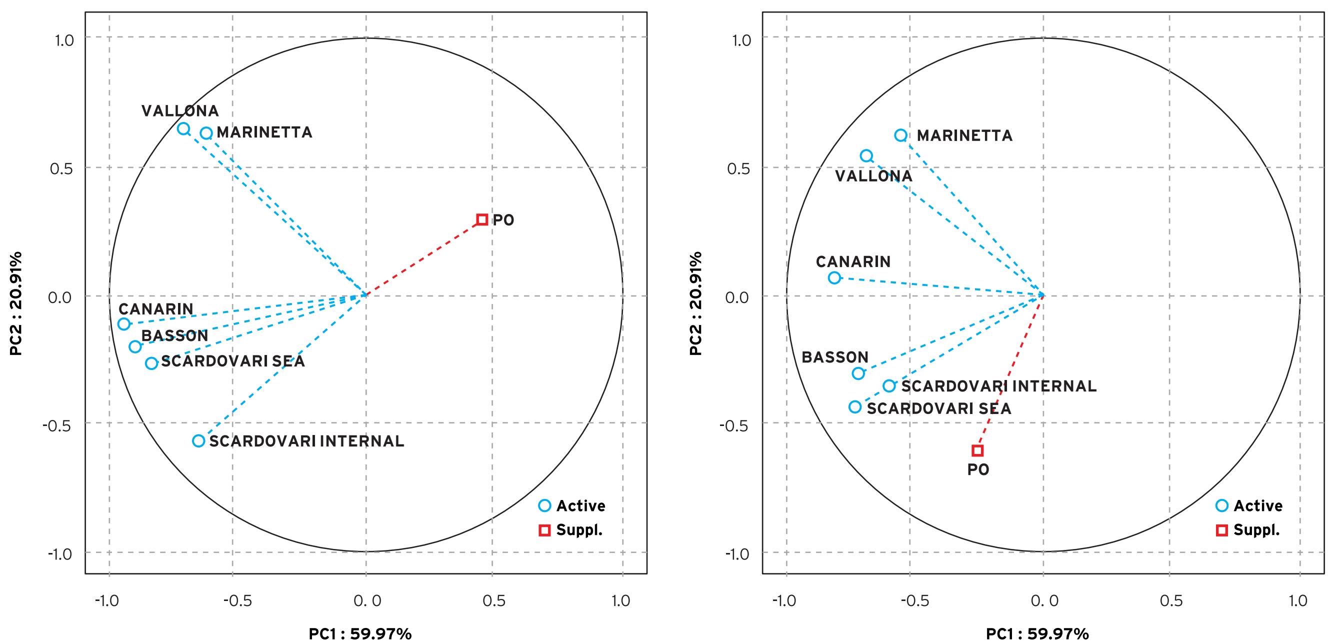


Figure 6: comparison of temperature data (temp), salinity (sal) and dissolved oxygen (DO) measured at *Marinetta* over the 2008-2010 monitoring period.

Figure 7: Comparison of temperature data (temp), salinity (sal) and dissolved oxygen (DO) measured at *Basson* over the 2008-2010 monitoring period.

Salinity
Projection of the variables on the factor-plan (PC1xPC2)

Dissolved oxygen
Projection of the variables on the factor-plan (PC1xPC2)



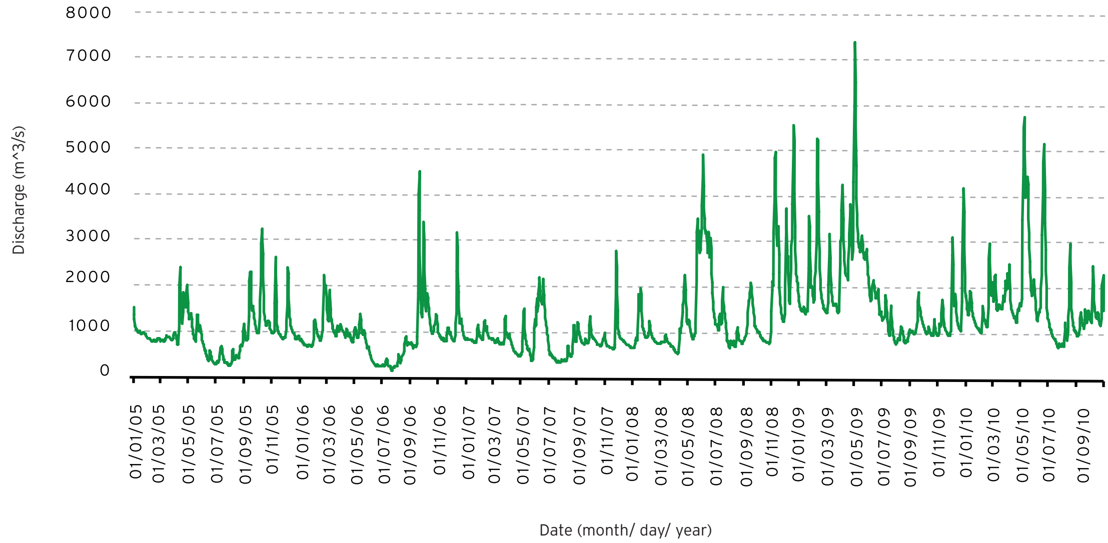
Slightly saltier waters are furthermore noticeable in July and August 2009 compared to the same period in 2008. The low salinity values measured at the beginning of 2009 further support the hypothesis of a particularly rainy 2008-09 winter. Like the inner portion of the *sacca*, a seasonal component is discernible in the dissolved oxygen data. A noticeable feature is the gradual depletion of oxygen measured in 2009 and culminating at the end of August, with minimum values of almost 5 mg/l below those observed in the same period in other years.

Figure 6 compares the data measured in the *Marinetta* lagoon for the period 2008-2010. Temperature evolution is characterized by the typical prevalence of the seasonal cycle over the other sources of variability. As confirmed by the 2008 data, the autumn generally features rapid decreases in temperature similar to those found in the other lagoons. Salinity does not typically show marked variations over the three years of monitoring, settling in the July to October period with values of 27-30 parts per thousands. The 2009 and 2010 data indicate that extremely low salinity values can be measured during spring, in episodes (as in 2010) as well as over longer periods (as in 2009). In fact this lagoon is among those that are more exposed to flooding by the Po River freshwaters, especially coming from the *Po di Levante* branch, which serves as a collector for the *Fissero*, *Tartarus* and *Canalbianco* canals. The dissolved oxygen data show a certain stability throughout the year, with values typically around 6-7 mg/l.

Figure 7 shows the data measured in the *Basson* lagoon that are only

Figure 8: projection of the variables (different monitoring stations in this case) in the plan defined by first and second principal components (PC1 and PC2) extracted from the salinity (left) and dissolved oxygen (right) data. The position (x,y) of each variable in the factor-plan reflect its correlation with PC1 (x coordinate) and PC2 (y coordinate). "PO" indicates the position of "the daily Po River discharge at *Pontelagoscuro*" in the factor-plan.

Figure 9: time series of daily Po River discharge at *Pontelagoscuro* for the period January 2005-October 2010.



available, like those of *Marinetta*, for the period 2008-2010. Temperature evolution resembles that found in other lagoons. In particular, temperatures stabilize above 25 °C in July and August, never exceeding (except for one episode in 2010) the threshold of 30 °C. Autumn is characterized, especially in 2008 and 2009, by the same typical rapid decreases in temperature observed in the other lagoons. The limited amount of available data (from only three monitoring campaigns) does not allow for a clear assessment of the interannual variability of salinity. In the long term, one notes the substantial stability between August and October, superposed by several positive and negative excursions. The spring and early summer periods, for which data are only available for 2009 and 2010, are characterized by a positive trend in salinity, in which large approximately weekly and bi-weekly fluctuations overlap. The extremely low salinity values measured in June confirm the hypothesis of a strong influence of the particularly wet springs of 2009 and 2010 on the dynamics of the lagoon. In fact this *sacca* is among those that are most exposed to flooding by the waters of the Po as it borders the *Pila* distributary. The dissolved oxygen data show a marked stability throughout the year, with values typically around 5-10 mg/l.

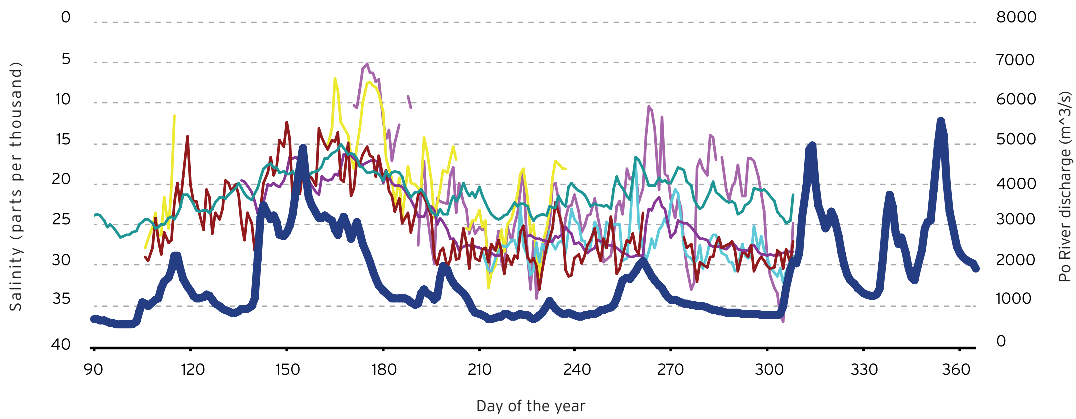
There are therefore various temperature, salinity and dissolved oxygen data for the Po Delta area, "simultaneously" available for the various lagoons. Multivariate statistical analysis techniques permit the analyzing of these various, often correlated or interacting descriptors. The aim is often to reduce the size of a multivariate system in order to simplify the interpretation of it functioning as a whole. Principal component analysis (or PCA), in particular, is a statistical technique aimed at the simplification of multivariate data. It allows one to extract a new set of "latent" variables (called principal components) from an original set of data through a linear transformation. The advantage of the technique lies in the fact that the latent variables are mutually orthogonal, or describe linearly independent portions of variability in a descending order of explained variance.

Focusing the analysis on the first variable/s extracted, it is therefore possible to reduce the complexity of the phenomenon described by the initial data, neglecting minor contributions to the total variability (i.e. the higher-order principal components extracted). This paper presents a PCA analysis carried out, separately for each parameter, on daily-average data of temperature, salinity and dissolved oxygen from the monitoring campaign in 2009. In fact, only during this campaign data were recorded in all the lagoons over a sufficiently long period (three months or longer, using different parameters) to allow for a robust analysis. Nonetheless, the results of a PCA analysis conducted on the 2010 data will also be discussed where necessary.

Regarding temperature, data meas-

Figure 10: comparison between Po River discharge at *Pontelagoscuro* and salinity measured in the Po Delta lagoons in the 2008 (top table), 2009 (middle table) and 2010 (bottom table) monitoring periods. The axis is inverted for salinity (ordinates on the left).

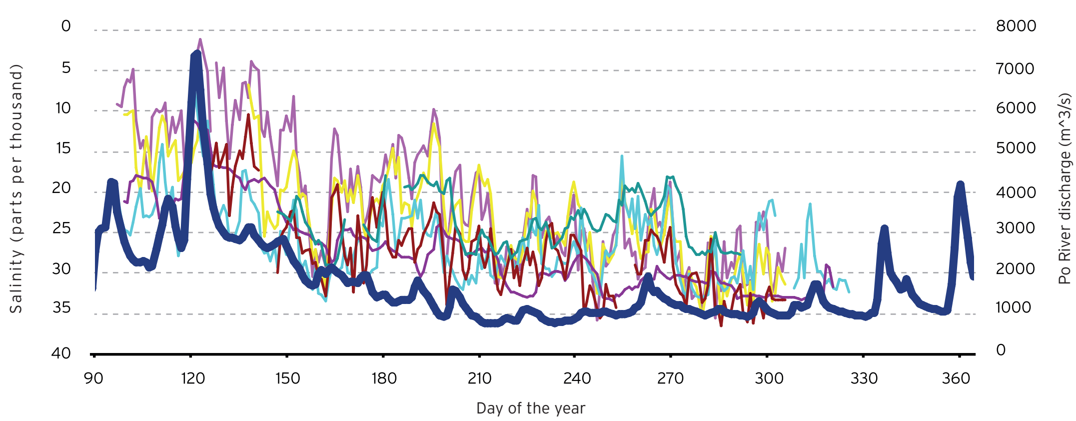
Comparison between Sal and Po River discharge: 2008



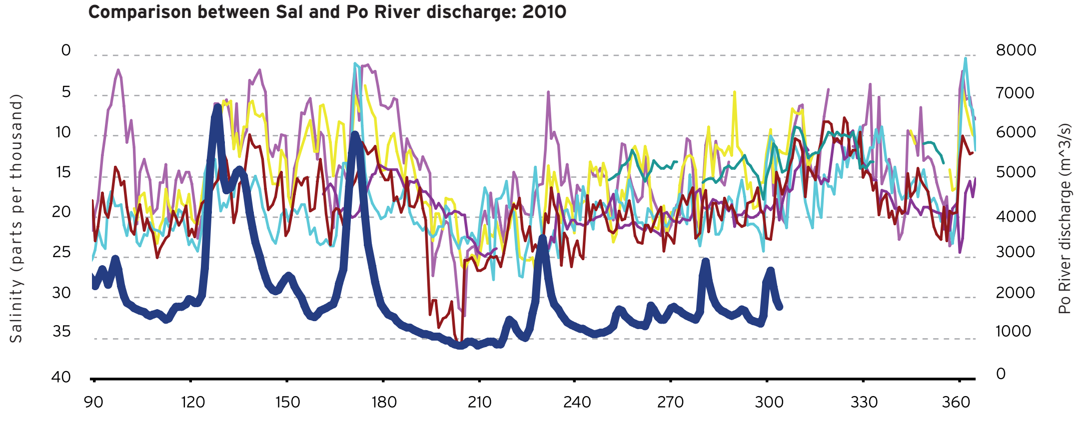
KEY:

- BASSON
- CANARIN
- MARINETTA
- SCARDO INT
- SCARDO SEA
- VALLONA
- PO

Comparison between Sal and Po River discharge: 2009



Comparison between Sal and Po River discharge: 2010



ured during the 141 days in which they are available for all the lagoons were considered. The data are very strongly correlated, which confirms a clear predominance of the seasonal cycle and very small differences, in terms of relative variations, in the evolution of temperature in the different lagoons. These high correlation values are reflected in the calculation of a first principal component (PC1) largely dominating the total variability, and accounting for 98.2% of the total variance. PC1 describes the tendency, common in all the lagoons, to have above or below average temperatures (for this reason it essentially captures the seasonal temperature cycle). The second principal component extracted (PC2) accounts for 0.81% of the total variability. It highlights the existence of two opposing patterns, one represented by *Vallona* and *Scardovari* Internal, and the other by the remaining lagoons. Given the characteristics of the groups of stations obtained in this way, it is possible that this component discrminates between the stations close to the sea and those further away.

Regarding salinity, data measured during the 131 days in which they are available for all the lagoons were considered. In this case, the correlations between the data of the different stations can be close to zero, as for instance between salinity of *Scardovari* Internal and *Marinetta*. This implies greater variability in this parameter in the values simultaneously expressed in the various lagoons. This results in a first principal component (PC1) that accounts for 60% of the total variability of salinity in the Delta lagoons, and which is related to the tendency, common to all the lagoons, to have lower salinity values in spring and higher salinity values in summer (Figure 8).

As for temperature, this variability is associated with the seasonal cycle, which derives from the seasonal cycle of Po River discharges and from the difference between precipitation and evaporation. This hypothesis is supported by the position of the daily Po River discharges1 in the factor-plan indicating good correlation with PC1 and anticorrelation with the salinity data. The second principal component extracted (PC2) accounts for about 21% of the total variance, and therefore describes an important part of the system's variability.

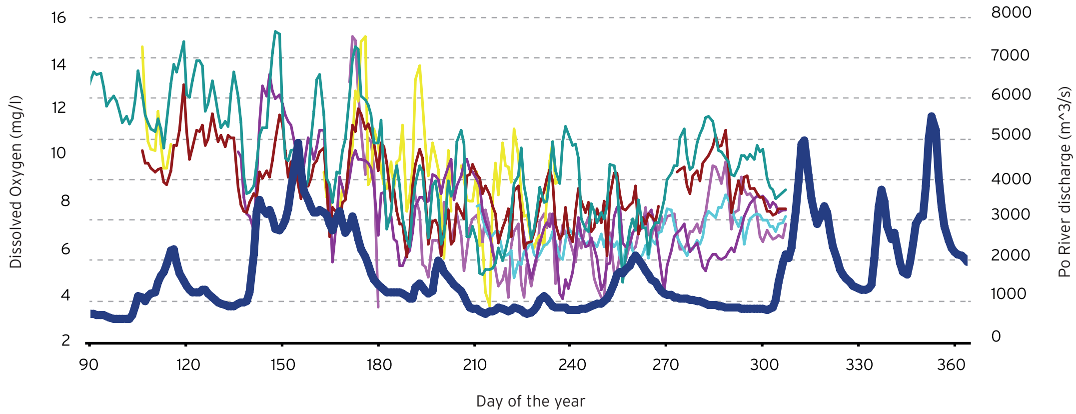
It highlights the existence of two distinct patterns, one represented by *Vallona* and *Marinetta*, and the other by the remaining lagoons, with *Scardovari* Internal particularly "isolated" compared to the other stations and in clear anticorrelation with *Vallona* and *Marinetta* (Figure 8). Given the characteristics of the groups of stations obtained in this way, it is possible that this represents the common dependence of *Vallona* and *Marinetta* on the *Po di Levante* discharge regime. It is conceivable that PC2 also describes the response of the lagoons to the prevailing wind direction during flooding episodes.

Regarding dissolved oxygen, data measured during the 126 days in which they are available for all the lagoons were considered. As for salinity, the data pertaining to the various monitoring stations can be characterized by very low correlations. This is the case, for example, with the correlation between dissolved oxygen measured in Marinetta and in Basson.

[1] Daily-average Po River discharge data are provided by ARPA-Emilia Romagna, Servizio Idrometeorologico. The data refer to the Pontelagoscuro (FE) section, which is located about 90 kilometers upstream of the river delta and is the last measurement site not affected by tides (for an introduction to the Po River discharge data at Pontelagoscuro, see, e.g., Zanchettin et al. 2008).

Figure 11: comparison between Po River discharge at *Pontelagoscuro* and dissolved oxygen measured in the Po Delta lagoons in the 2008 (top table), 2009 (middle table) and 2010 (bottom table) monitoring periods.

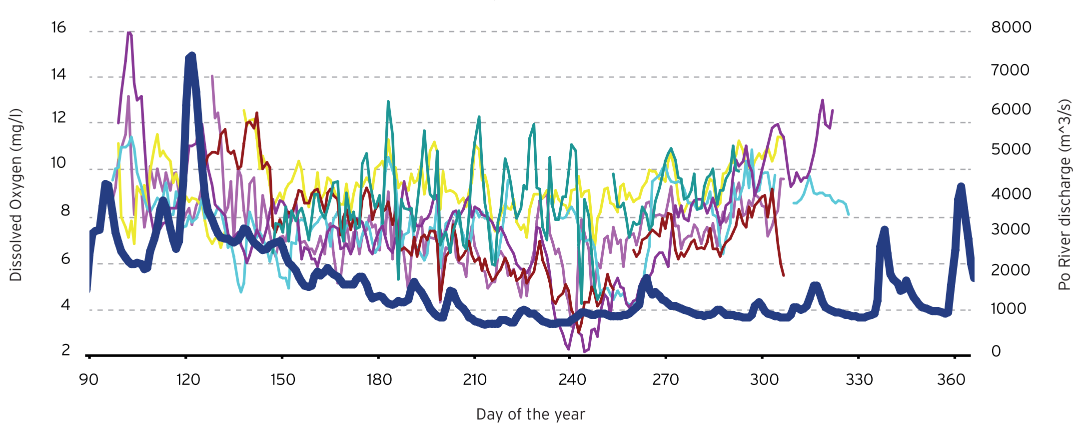
Comparison between DO and Po River discharge: 2008



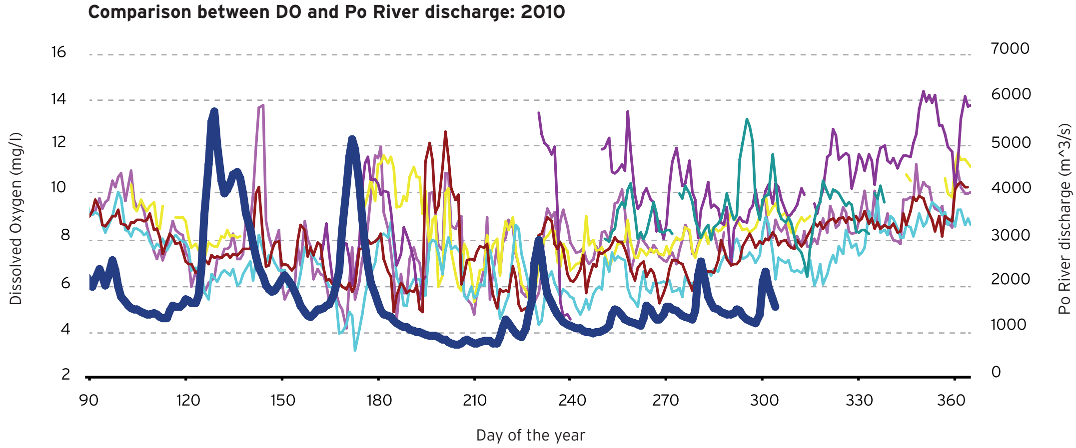
KEY:

- BASSON
- CANARIN
- MARINETTA
- SCARDO INT
- SCARDO SEA
- VALLONA
- PO

Comparison between DO and Po River discharge: 2009



Comparison between DO and Po River discharge: 2010



This implies a considerable variability in the values of this parameter simultaneously expressed in the various lagoons.

Notably, the correlation between the two stations in the *Sacca degli Scardovari* indicates that dissolved oxygen series in the outermost and innermost portions share, linearly, only about 25% of the variability. These correlation values translate to a first principal component (PC1) that accounts for about 45% of the total variability of dissolved oxygen in the lagoons (see Figure 8) and is associated with the tendency, common to all the lagoons, to show lower levels of dissolved oxygen in the summer period.

The second principal component extracted (PC2) accounts for about 20% of the total variance, describing therefore, for the salinity, an important part of the system's variability. It highlights the existence of two practically opposing patterns, that of B*asson* and *Scardovari*, and that of *Marinetta* and *Vallona* (Figure 8). Given the characteristics of the groups of stations obtained in this way, it is possible that, for the salinity, this represents the common dependence of *Vallona* and *Marinetta* on the discharges' regime of the *Po di Levant*e. The position of the daily Po River discharges in the factor-plan indicates that they play a potentially important role in the variability expressed by PC2, but not that of PC1.

The multivariate analysis highlighted several potentially important implications of the Po River freshwaters on the variability of chemical-physical parameters in the Delta lagoons. The Po River discharge data measured over the period 2005-2010 are shown in Figure 9. Even at first glance one can clearly see a trend towards higher discharges, with maximum values in 2009 both in terms of drought and flood events.

The absolute minimum recorded in the period 2005-2010 amounted to 168 m^3/s, measured on 22 July 2006, while the absolute maximum amounted to 7403 m^3/s, measured on 2 May 2009. It is also interesting to note that winter/spring 2008/09 was characterized by a number of major flood events with peaks exceeding 4000 m^3/s. In contrast, the spring of 2005 was characterized by an almost constant discharge below 2000 m^3/s, emphasizing below-average basin precipitation in that period.

Figures 10 and 11 compare, as examples, the Po River discharge in the years 2008, 2009 and 2010 and salinity and dissolved oxygen data measured in the same years in the different lagoons. The salinity time series overlap, once the scale is reversed, with the Po River discharge data (Figure 10), indicating that periods of high discharges generally coincide with a decrease in the salinity of the lagoon waters. This is particularly evident in the case of the late spring floods (April-May), especially in 2009, when the exceptionally high flooding of the Po (over 7000 m^3/s) coincided with salinity values in *Basson* below 5 parts per thousands.

Generally, the dissolved oxygen does not show a clear link to the Po discharges apart from the overlapping of trends in the summer period (June-August) (Figure 11). The amount of dissolved oxygen is in fact strongly influenced by the competition between local biological activity, which is closely linked to temperature and ventilation, which is closely linked to watermass circulation, which is in turn determined by the combined effects of wind and tides. It should be noted that in the event of a major flooding, such as that of spring 2009, the waters of fluvial origin are generally poorly oxygenated because of the considerable turbulence, which makes them muddy, increasing the sediment load and hampering photosynthetic processes.

The propagation of these waters inside the lagoons, although contributing to the recirculation of water, especially closer to the surface, may therefore be associated with relatively low levels of oxygen (as observed in spring 2009 in *Marinetta* and *Canarin*). A lag-correlation analysis (results not shown) between the Po River discharges and salinity and dissolved oxygen around the flooding in April-May 2009, sheds light on the dynamics behind the propagation of saline and dissolved oxygen anomalies in the different lagoons of the Delta.

As for the dissolved oxygen, in some cases (*Scardovari* and especially *Basson*) there is a tendency towards positive correlations when a delay of a few days is imposed upon the discharge data, suggesting that in these lagoons the freshwater input helps to dynamize the circulation in the medium term. It should be noted, however, that in *Canarin* the flooding seems to be associated with a delayed reduction in dissolved oxygen.

This confirms the complexity of possible interactions between Po River discharges and individual lagoons,

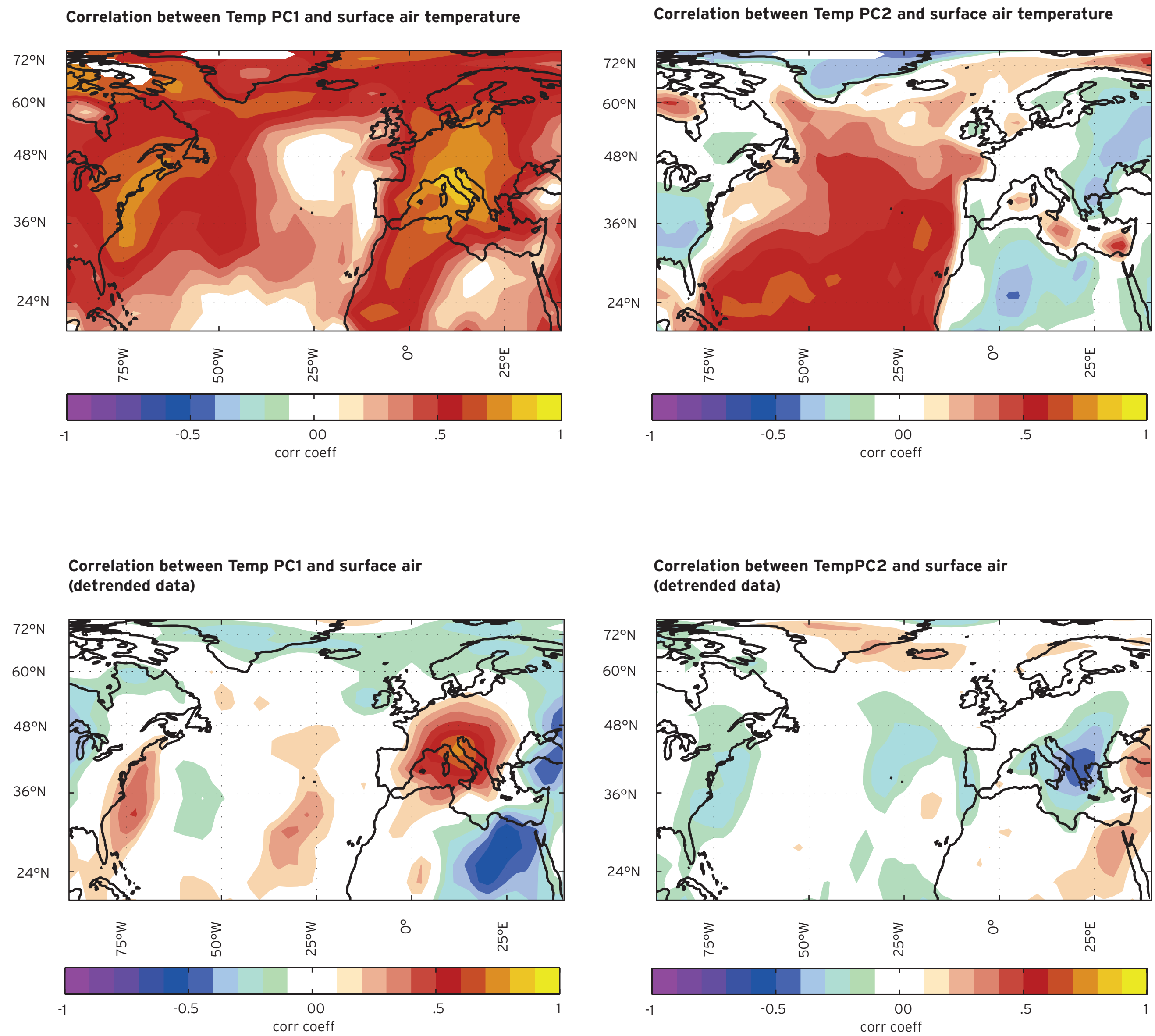


Figure 12: top panels: Correlation between the first and second principal components (PC1 and PC2) extracted from the daily temperature data for the year 2009 and surface air temperature for the Euro/Atlantic sector. Bottom panels: same as top panels, but for data from which the long-term component, as determined by a second-order polynomial fit to the time series, has been removed.

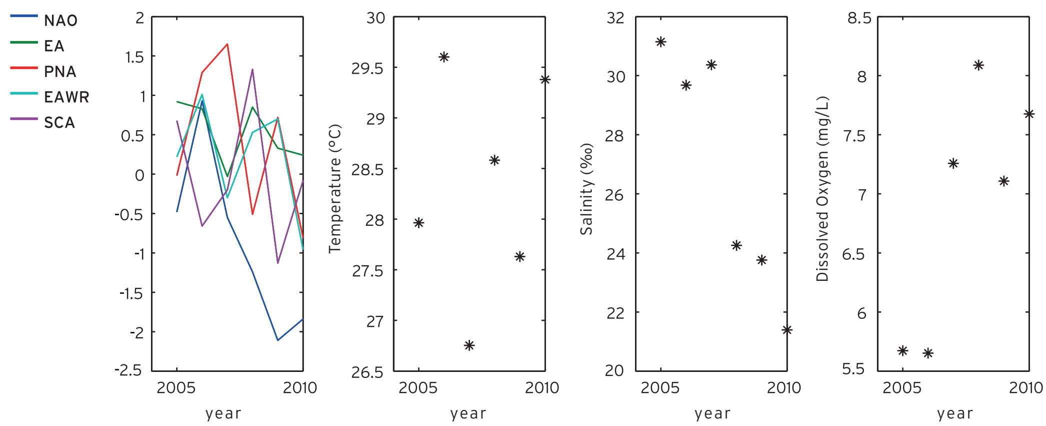


Figure 13: comparison between the near-surface water temperature, salinity and dissolved oxygen at the Scardovari Internal site and a selection of large-scale atmospheric circulation indices (left panel). All data are monthly-averages for the month of July.

which are determined not only by the influence of the riverine waters on local hydrodynamics, but also on other important quality parameters such as turbidity. Regarding salinity, the Po River flooding contributed to a general reduction of salinity in the various lagoons, although correlations are significant only for *Marinetta*.

The lag analysis indicates that fluctuations in the discharge and salinity signals are essentially contemporaneous, with a slight advance of the discharge signal (a few days) in *Basson* and *Canarin*. Local factors, such as the freshwater inflow associated with different wind patterns, are therefore extremely important to the variability and heterogeneity of the physical-chemical properties in the deltaic area. It should be noted that local weather (temperature, precipitation, wind, etc.) is intrinsically linked to the larger scale meteorological dynamics (Zanchettin et al., 2009).

It is interesting for example, to compare the Po Delta lagoons' water temperature data measured throughout 2009 with the surface air grid data available for the Euro-Atlantic region. The climate data are the daily average 'NCEP / NCAR reanalysis 1' (Kalnay et al., 1996) reanalyses for the period from 01/01/2009 to 31/12/2009. The data are provided by NOAA / OAR / ESRL PSD, Boulder, Colorado, USA, and can be accessed at: http://www.esrl.noaa.gov/psd/.

In order to facilitate the description of the relationship between the two variables, principal components extracted from the Po Delta lagoons' water temperature data (PC1 and PC2) were used rather than the original data. In fact this allows one to limit the description to just two variables that nonetheless describe most of the total variability of the original data. In this case, to further facilitate the reading of the spatial correlation structures, PC1, which was inversely correlated with the original data (Figure 8), was inverted before the correlation analysis. The analysis was carried out for all the days for which PC1 and PC2 were calculated.

The spatial structures (patterns) of the correlations for near-surface air temperature in Figure 12 (upper panels) show that PC1 is well correlated, as one would imagine, with the temperature in the Mediterranean area (especially the western basin) and Central Europe. PC1 is also well correlated with the temperature observed along the North American East coast, up to the inner portion of the Labrador Sea. The correlation pattern extends along the coast of Greenland, but near-zero correlations are observed over the tropical and north-east Atlantic, which is rather strongly correlated with PC2.

This distinct pattern is particularly interesting, as it underlines how the evolution (including seasonal) of Euro-Mediterranean regional climates depends strongly on the generation of perturbations in the Atlantic that occurs along the east coast of North America. Similar correlation analysis carried out for PC1 and sea-level pressure grid-data identifies a dipolar structure over the North Atlantic, consisting of a negative correlation centre over Scotland, and a belt of positive correlations over the subtropical North Atlantic. The thus identified dipole resembles the positive phase of a teleconnection (i.e. a mode of large-scale atmospheric variability) known as the East Atlantic pattern (EA).

It is evident that these correlations depend heavily on the seasonality of both PC1 and the grid-data. It was therefore decided to carry out a further analysis on detrended data, i.e., on data

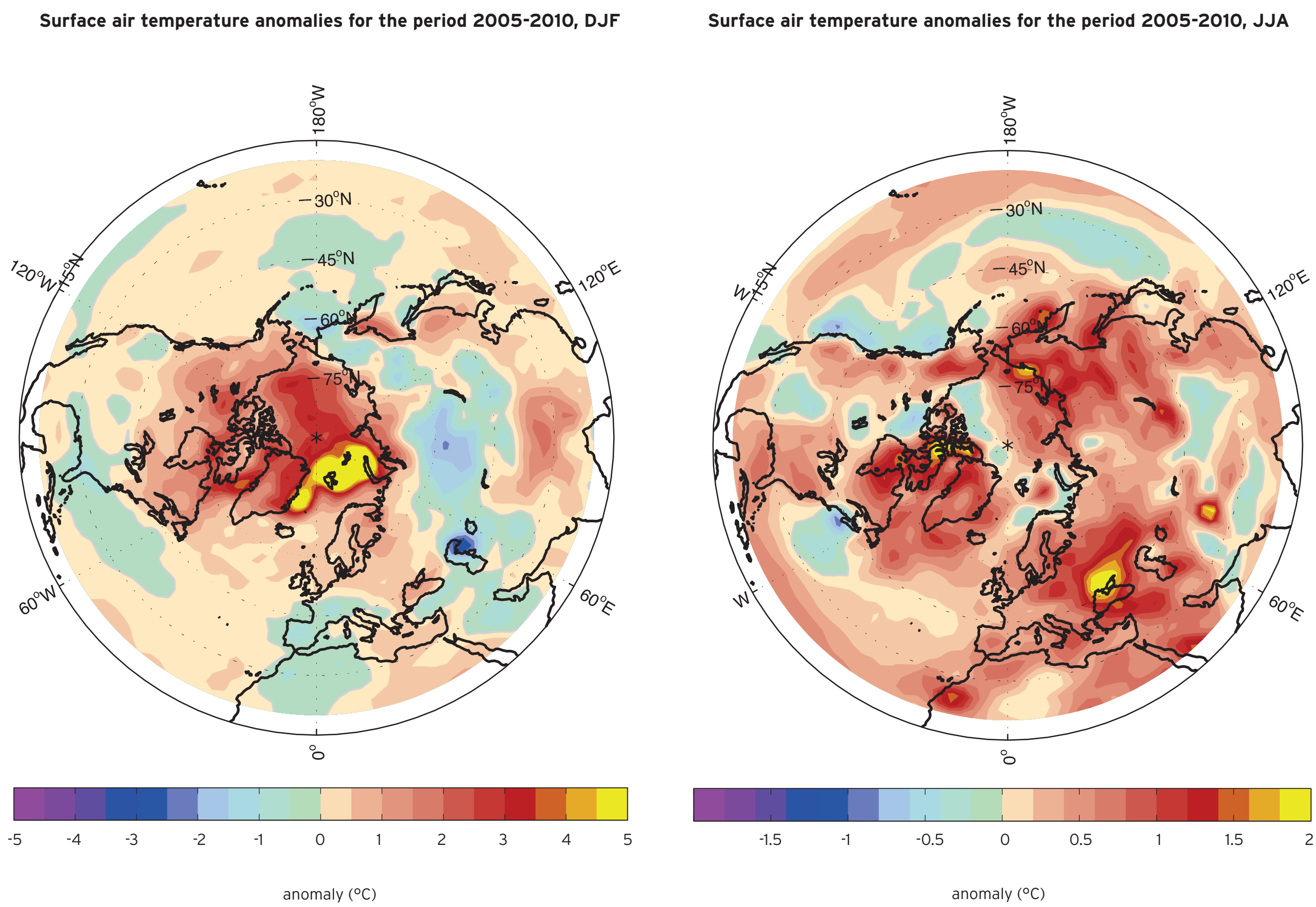


Figure 14: surface air temperature anomalies for winter (December-February, left panel) and summer (June-August, right panel) over the period 2005-2010 relative to the climatology of the last ~ 60 years.

cleared from the long-term variability component (in this case the seasonality), in order to characterize the relationship between local and large-scale dynamics at shorter timescales, particularly those ranging from several days to weekly/multiple weeks. In this case (Figure 12, lower panels), the link between PC1 and surface air temperature becomes much more local, with a strong positive correlation centre above Italy associated with a belt of negative correlations in the south-east.

This structure corresponds to a positive sea-level-pressure anomaly over the Ionian Sea, which contributes to an anomalous anticyclonic circulation transporting warm air from Africa towards North Italy and colder continental air from the Balkans towards Egypt. In an attempt to gather more evidence to support the hypothesis of a strong link between large-scale atmospheric dynamics and changes in the water characteristics of the Po Delta lagoons, the interannual evolution of monthly-average temperature, salinity and dissolved oxygen recorded in Scardovari Internal at the surface for the month of July was compared with that of a selection of indices of large-scale atmospheric variability.

These include the already mentioned NAO and EA indices, the Pacific-North

American (PNA) index, the East-Atlantic/Western Russian (EAWR) index and the Scandinavian (SCA) index. The monthly values of these indexes were made available by the NOAA-Climate Prediction Center at: http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml. The decision to limit the analysis to the month of July and to the Scardovari Internal station is linked to the fact that there is a sufficient amount of average daily data to ensure a reliable monthly-average value for this month and station. Given the small amount of data available, one is limited to a visual inspection and a qualitative discussion of the behaviors.

The comparison is shown in Figure 13. The temperature evolution bears similarities with those of the EA, WP (inverse correlation) and PNA (inverse correlation) indexes. Both evolutions of salinity and dissolved oxygen are characterized by a marked tendency to decrease, but they nonetheless bear similarities with those of NAO, WP and PNA. The dependencies, which are more or less pronounced depending on the parameter analyzed, of the local dynamics on those at the large-scale suggest that the understanding of the latter, together with their contextualization within a longer time period, is preliminary for assessing whether the data collected for the Delta lagoons during the few years so far describe a typical rather than exceptional state.

Figure 14 shows the average winter and summer near-surface air temperature anomalies for the years 2005-2010 compared to their climatological value for circa the last 60 years (NCAR Reanalysis data). In the European context, it is clear that winter temperatures are considerably above average over Scandinavia and continental Europe and below average over the Iberian peninsula and north-western Africa.

Above average temperatures are also observed over the Ionian Sea and over the eastern Mediterranean basin in general. In summer one notes above average temperatures almost everywhere, with anomalies of around one degree centigrade in the Ionian and southern Adriatic regions. Looking at seasonal temperature data on the hemispheric scale, temperature anomalies observed in Europe are clearly part of a global trend. It is in this sense therefore, that the monitoring campaigns carried out in the Po Delta lagoons between 2005 and 2010 allow for the environmental data refering to a particularly important period regarding both regional and global climatic conditions, to be made available today.

Conclusions

Annual water quality monitoring campaigns have been carried out in the Po Delta area since 2005. These have involved a gradually increasing number of lagoons, bringing it to its current monitoring system made up of six sampling sites: the Scardovari (two measuring sites), Canarin, Basson, Marinetta and Vallona.

The temperature, salinity and dissolved oxygen data available today are an important source of information in order to understand the physico-chemical and biological property dynamics of the various lagoons, as well as for their effective management.

This study has shown that much can be observed in the data regarding the characteristics of the "Delta del Po" system. In particular it has evidenced a marked heterogeneity not only between the various lagoons, but also within each of them, and has identified important components of interannual variability, not only on a local scale but also linked to large scale dynamics.

It is therefore essential to continue the monitoring, extending the quantity of observed data to larger areas and over longer timeframes. The fine tuning of numerical models used in the study of hydrodynamics of lagoon areas, gradually allowing the acquisition of greater knowledge of dynamics and local variability could, at the same time, contribute to improving the quality of the monitoring system, by for example, optimizing the choice of measurement site position and enabling an approach to a preparatory analysis phase for the development of the capacity to predict extreme events in the Po Delta lagoons.

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_STUDIES & RESEARCH

SHELLFISHING IN THE PO DELTA LAGOONS, VENETO: SOCIO-ECONOMIC ASPECTS

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The research investigates the costs and benefits of lagoon vivification activities conducted for various motives by the *Consorzio di Bonifica Delta Po*. Estimates are made regarding the benefits of lagoon vivification followed by the calculation of the maximum financial commitment that the producers could afford to make in relation to partially covering the said costs. It also investigates the possibility of expanding the production base to Tapes in the *Sacca degli Scardovari*. This expansion would be aimed at achieving a sustainable income for the workers and increasing locally added value in the Po Delta area. A major Tapes production area totaling 240 ha would allow for, according to our estimates, the reaching of both objectives. At the conclusion of the work an analysis of the *Polesine* Tapes supply chain, and operative multifunctionality of the sector's fishermen is carried out.

Introduction

Most of the Italian Adriatic coast is characterized by shallow and mostly sandy or sandy-muddy alluvial bottoms. The lagoons of the North Adriatic, of which the Venice Lagoon is a typical example, have origins dating back to 6,000 years ago when in the post glacial Wurmian age, the sea invaded the upper Adriatic plains forming its current coastal structure. In this way all coastal lagoons, including those of the northern Adriatic have become aquatic environments that are characterized by variable salinity and the fact that they are separated from the open sea by sandbars or stretches of land. More specifically, delta lagoons, bays formed by large estuaries and coastal wetlands can be considered transition zones between freshwater habitats and marine environments[1]. These characteristics are highly variable, both over time and space, in terms of the main physico-chemical and hydrological characteristics: temperature, salinity and oxygen concentration.

Their high nutrient load, especially with contributions of fresh water of the rivers, along with their particular mode of sedimentation, accumulation and decomposition of organic debris on the bottom, favors the occurrence of dystrophic crisis that, in the summer, is one of the main sources of habitat disturbance. Over the last three years, the *Consorzio di Bonifica Delta Po* has been carrying out vivification interventions in the lagoon habitats, investing around € 2-3 million per year. This work has resulted in a discrete conservation and has also fostered the production of Tapes, despite the absence of specific expansion of the production base.

Research Objectives

The lagoons, valleys and wetlands in general, as well as being productive aquaculture environments characterized by high biological diversity, are highly unstable, therefore if one cannot ensure their continual management, they are bound to be rapidly reduced to their initial conditions. There have always played home to a wide range of activities (fishing, hunting, agriculture, small-scale crafts) brought together by a strong dependence on the environment and functions that are mutually compatible.

In the Po Delta, after centuries of continuous interventions, a good balance has been struck as a result of a "physiological" relationship between territory, the naturality of its physical elements, as well as water system and economic management. This came about by establishing a close relation-

Figure 1: the study covers both the primary activities (agriculture and fishing) and the effects on the production chain (production, distribution and sales).

Tapes fishing area	Water surface area (ha.)	Production area (ha.)	Actual yield 2006-08 (kg/m²)	Tapes per lagoon site (%)
Caleri and Marinetta	1,653.00	423.56	0.72	29%
Vallona	703.00	111.36	0.79	8%
Scardovari	3,000.00	320.00	1.52	32%
Barbamarco	800.00	50.00	3.53	17%
Canarin	850.00	50.00	2.99	14%
Basson	375.00	0.00	0.00	0%
Total Po Delta Veneto Lagoons	7,381.00	854.92	1.23	100%
Consorzio Pescatori Polesine Lagoons	5,025.00	320.00	2.06	63%

Table 1: surface areas and Tapes production in the *Delta Polesano*.

ship between production activities (fishing and hunting) and ecological functions - environmental and water protection, the latter have so far been assured by periodic excavation of canals and interventions aimed at safeguarding and controlling emerging or reclaimed sites. Noting the high production values and existence of these areas thanks to the vivification interventions, research into the socio-economic aspects of the *Delta Polesano* wetlands ecosystems was promoted proposing two main objectives:

- to assess the costs and benefits of carried out interventions or possible interventions in order to preserve and enhance production;
- to estimate, in general, the Economic Territorial Value of the shellfishing industry and its production chain in lagoon habitats.

Assessment of Costs and Benefits

The reference areas for the elaboration of the model are the lagoons that have already been subject to major hydraulic interventions by the *Consorzio di Bonifica Delta Po*. The analysis mainly concerns the Tapes, for which the provision of information useful in making decisions regarding productive investment, conservation and territorial development is intended.

Territorial Economic Value

In addition to the economic value generated by the primary activities (production and fishing), the survey also examined other sectors, to come up with an Added Value estimate for the whole production chain. The data and considerations that emerge could therefore be considered an important starting point for the assessment of the effects of various kinds of changes in lagoon environments, whether attributable to anthropogenic causes or not.

Clam Farming in Lagoon Habitats

Molluscs were among the first aquatic organisms to undergo systematic exploitation. Awareness of their nutritional value has led man to develop ways of collecting, cultivating and using them. The shellfishing industry is engaged in the cultivation of edible molluscs including clam, mussel, scallop and oyster farming; and could be considered an extensive aquaculture activity, i.e. a form of farming and/ or assisted production based on the use of the trophic resources of natural ecosystems.

In shellfish cultivation, production varies depending on the environmental characteristics (nutrient content and water exchange speed) and manage-

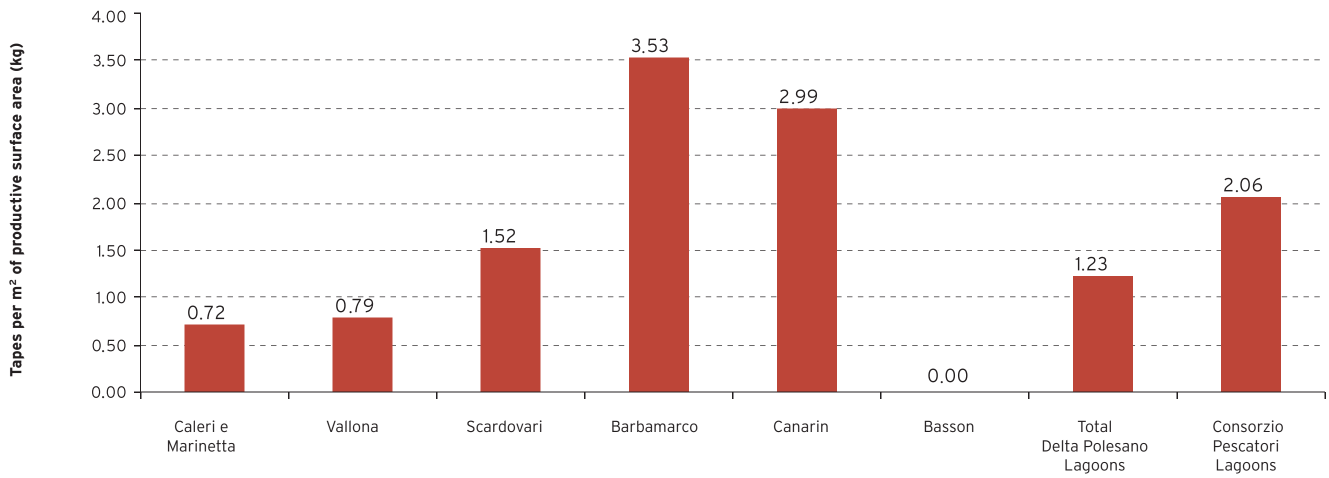

Figure 2: average lagoon yield (in kg of Tapes per m² of actual surface).

ment and protection methods set up by their operators. In the northern Adriatic, the need to find appropriate solutions for the cultivation of the Philippine clam emerged in the mid-1980s, when our local clam stock was in danger of running out.

Clam farming underwent rapid expansion with the introduction of Tapes *philippinarum*[2] (the Philippine clam) to the Venice Lagoon in 1983, a species that quickly spread to most of the Upper Adriatic lagoons (Venice, *Marano*, *Caleri* and the Po Delta). Today, Italy is the leading European clam producing country and its domestic production amounts to 10,500 tons of Tapes per year, of which the Venice Lagoon provides about 47%, the Po Delta in the *Ferrara* area 31%, and the Venetian Po Delta 20%. In addition these lagoons are strategic to the product's high quality that is appreciated across a large part of the target markets.

The Po Delta Lagoons: Surface Area and Production

The survey took into account both the total water surface area of the lagoons and those actually used for productive purposes. Altogether there are 7,381 hectares of water surface areas, of which 11.6% (854.92 ha) are actually used for Tapes production.

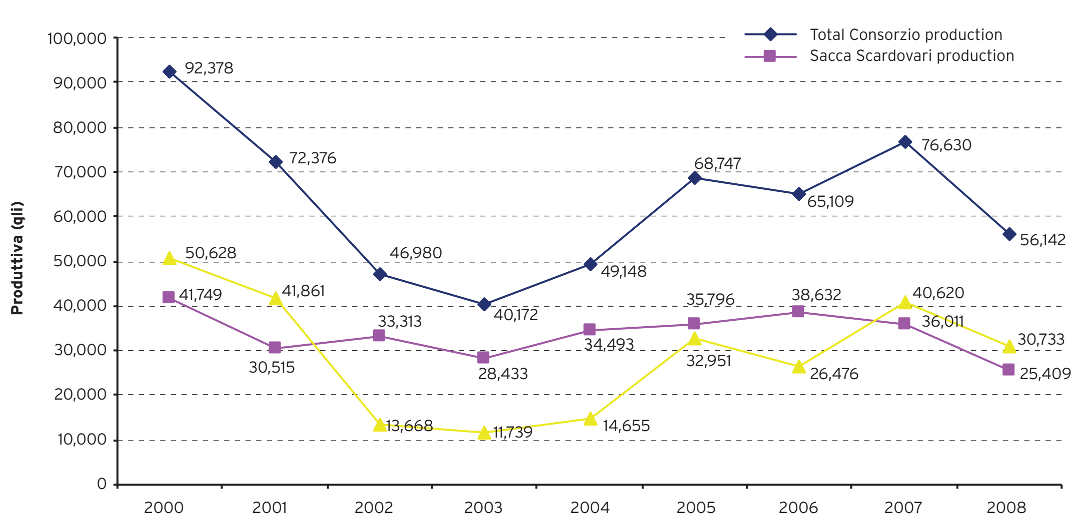

Figure 3: Tapes Production (ql) pertaining to the *Consorzio di Scardovari* between 2000-2008 (R. Rossi, University of Ferrara).

The incidence of the production areas in the total area of the lagoons (Table 1) goes from zero in the *Basson* to a maximum of 29% in northern areas (*Caleri* and *Marinetta*). In particular, with an average of 6.4%, the level of incidence is relatively low in the lagoons managed by the *Consorzio Pescatori Polesine,* with a maximum of 7.3% in the *Scardovari* and a minimum of 5.9% in the *Sacca del Canarin*.

Tapes production estimates in the lagoons was based on data provided by the fishermen, to which we have added information[3], and amounts, for the 2006-2008 period, to 105,176 quintals annually: the northern area accounting for 28.9%, the Vallona 8.4% and areas pertaining to the *Consorzio Pescatori di Scardovari*[4] the remaining 62.7%. The *Consorzio Pescatori di Scardovari*'s production can be subdivided into: 33,350 quintals of Tapes in *Sacca degli Scardovar*i, 17,641 quintals in the Laguna del *Barbamarco* and 14,969 quintals in the *Sacca del Canarin*.

Remarkably, the S*acca degli Scardovari*, with 320 hectares of cultivated land or orti, accounts for approximately 63% of the Delta Tapes. Moving from production totals to unitary yields, one has to proceed with caution, not so much because of the productive data's unreliability, but also because of the criterion assumed in the definition effectively productive area. In particular, the percentage of productive surface area is high in the *Caleri* and *Marinetta* and the south *Vallona* areas (25.6% and 15.8% respectively), whereas, in the areas in which the *Consorzio Pescatori* cooperatives operate, it drops to 6,4%.

Having said this, one observes that the actual yield per square meter has a maximum value in the *Laguna del Barbamarco* (3.53 kg), followed by the *Sacca del Canarin* (2.99 kg), the *Sacca degli Scardovari* (1.52 kg); the *Vallona* (0.79 kg) and the *Caleri* and *Marinetta* 0.72 kg. In the *Basson* lagoon Tapes are only fished when there are no adequate operating conditions in the *Canarin* or *Barbamarco*; the 25 tons of Tapes that are caught annually therein, were divided equally between the quotas of the other two lagoons.

In recent years the production of Tapes has however undergone substantial fluctuations. The least productive year was 2003 when, according to a study by Prof. Remigio Rossi of the University of Ferrara, only 300 ha of water surfaces were judged to be suitable for clams, with the surface area being reduced by 50% compared to 1999.

The *Consorzio di Bonific*a, through systematic lagoon vivification interventions, contributed in improving the situation in these lagoons. At the moment, in addition to a systematic vivification plan, fishermen and local communities are also hoping for development interventions and the expansion of the production base. The following chart illustrates Tapes production trends in the *Delta Polesano* (2000-2008). Tapes production in the *Sacca degli Scardovari* shows less movement than in other areas; and this highlights how this lagoon is strategically important to the entire Po Delta.

Tapes[5] Sector Manpower

The fishermen and / or Tapes farmers use small, usually two-man, vessels (*barchini*[6]) to carry out their work. At the end of each collection operation they carry out an initial processing of the product in dedicated huts or on specific platforms. The remaining stages of the production chain: processing and selection, purification, packaging, transportation and sales, are carried out downstream. The *Consorzio Pescatori* purifies and processes almost all of its members' product at its own *Scardovari* plants. The Tapes from other areas are taken to processing centers in *Chioggia* or other villages.

	Occupants		Age group (year)				Sex	
	Total	Per area	< 30	31 - 45	46 - 60	> 60	Male	Female
North Area Cooperative	241	13.36%	17.30%	45.30%	30.70%	6.70%	94.20%	5.80%
Scardovari cooperative consortium	1,496	82.93%	15.90%	44.10%	33.10%	6.90%	49.20%	50.80%
Total cooperatives	1,737	96.29%	16.20%	44.40%	32.50%	6.90%	59.80%	40.20%
Private and Vallona	67	3.71%	15.60%	45.00%	32.10%	7.30%	100.0%	0.00%
Tapes fishermen totals	1,804	100.0%	16.20%	44.40%	32.50%	6.90%	62.00%	38.00%

Table 2: Tapes fishing-cultivation workers in the *Delta Polesano*.

FUNCTION	AREA		
	Individual	Cooperative	Consorzio Pescatori (only for the South Area lagoon fishermen)
Possession and management of fleet	Managed by individual fisherman	Manages administration	Any information about the optimization of fleet
Tapes seeding	Materially carries out the seeding	Draw up consultation plans with the Consorzio	Draws up plans for seeding, sees to the acquisition of the latter and covers seed costs
Tapes fishing	Managed by individual fisherman	Realize fishing plans	Draws up fishing plans in collaboration with the Co-operative
Tapes purification and sales	-	In the North Area lagoons and for private entities, functions are carried out by other bodies	Direct transformation and purification operator; sells the finished product within its competence
Risk Assumption	Production risk and fishing management	There are apparently no specific risks	Assumes the industrial and commercial risks
Cultivation fishery management	Materially carries out the operation	-	Provides financial backing and know-how in its areas of competence
Technical Support	-	-	Manages technical assistance in its areas of competence
Laboratory	-	-	Managed by the Consorzio in its areas of competence

Table 3: Tapes production chain: functions and competencies.

In late 2009, the *Delta Polesano* Tapes sector employment amounted to 1,804 units, for 96.29% for the cooperative associated fishermen and 3.71% for employees of private companies. Regarding the allocation of employees in the fishing area, 13.36% work in the Northern Area lagoons, 82.93% in the *Consorzio Pescatori* lagoons (*Sacca*, *Barbamarco*, *Canarin* e *Basson*), and 3.71 % in the *Vallona* area. Regarding employee gender distribution, 62% are men and 38% women, while in terms of age, 50.6% are under 45 years old and 16.2% under 30. The percentage of workers over the age of 60 is very low and is estimated at around 7%. The large quantity of youth allows for the hypothesizing of both production growth strategies and territorial development. In particular, in the *Sacca degli Scardovari* one could consider multi-purpose interventions that could not only ensure the further development of the clam farming sector, but that would allow for the initiation of leisure activities and for the more efficient conservation and management of resources.

The *Consorzio di Bonific*a, fishing co-operatives and *Parco del Delta*'s future intervention plans therefore need to find common moments of synthesis, with a view to a productive valorization related to the protection of the ecosystem. One should bear in mind that clam and

	Tapes production (2006-2008) (q)	Tapes GMP (2006-2008) P=2.4 € / kg (Millions of €)	Tapes GMP (2006-2008) P= 3.0 € / kg (Millions of €)	Workers (n)	GMP/ Worker P=2.4 € / kg	GMP/ Worker P=3.0 € / kg
Delta polesano Lagoons total	105,175.9	25,242	31,553	1,804	13,992	17,491
Consorzio Pescatori Polesine Lagoons total	65,960.0	15,830	19,788	1,496	10,582	13,227

Table 4: Tapes production and GMP: *Delta Polesano* Lagoons.

shellfish cultivation depend on the natural factor, which should be used in order to support natural cycles and production, thus ensuring sustainable economic production and providing long term stable employment.

Tapes Fishing Systems and Early Stage Production Chain Organization

The *barchini* are generally 40 hp. The Tapes fishing fleet is made up of over a thousand vessels, while that of the *Consorzio Pescatori* cooperatives amounts to 700. In recent years, thanks to the provision of specific contributions, forty boats with upgraded engines (110-120 hp) were purchased, which although faster, consume more fuel and consequently have higher costs.

The Tapes fishermen carry out their fishing activities in the form of sole proprietorships, while in the other management stages they are associated with cooperatives. The cooperatives plan the work of the individuals, in order to maintain a sustainable harvest and contain business and technical risks. The *Consorzio Pescatori di Scardovari* is therefore a third-level entity that, in addition to providing assistance to members (cooperatives and individual), is primarily concerned with the development and marketing of products. The following diagram summarizes the various functions performed by the various entities within the Tapes production chain.

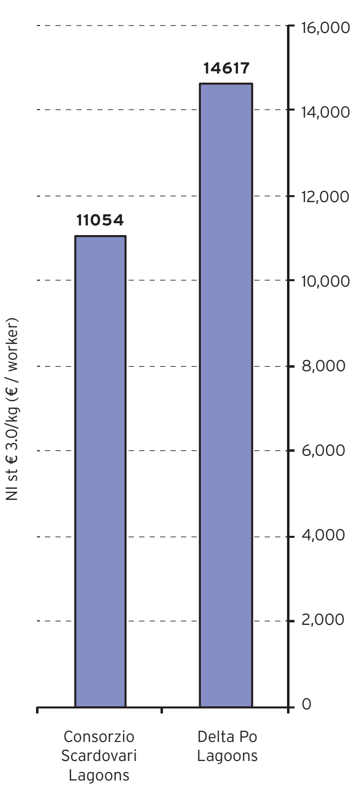

Figure 4: short Term NI (Tapes at €3.0/kg).

Gross Marketable Production and Production Scenarios

The Gross Production (GMP) of the primary Tapes sector in the *Delta Polesano* for 2006-2008 was estimated at two price levels:

- € 2.4/kg, which corresponds to the average production price at the end of 2009; resulting in a GMP of € 25,242 million;
- € 3.0/kg, corresponding to the average price over the 2006-2008 period, resulting in GMP of € 31,553 million.

Calculating the GMP on two price levels underlines the effects of the crisis in the sector at the time of the survey. This crisis could be considered fairly cyclic and in our opinion, depends on both a mismatch between supply and demand with an excess product that determines the low prices of Tapes, and also the inadequate bargaining power of producers in the face of a near oligopoly of distribution. The annual GMP per worker, measured at a price of 2.4 € / kg, was estimated to be € 13,992 on average, with a minimum of € 10,582 for *Consorzio Pescatori di Scardovari* members. Since we are dealing with revenue and not income, in order to calculate the latter, one should subtract the production costs[7]. These costs were calculated over both the short (considering only those variables[8]) and long-term (variable and fixed costs). In lieu of the situation at the end of 2009, it was decided that the short-term Net Income (NIst) parameter would be used as a reference point.

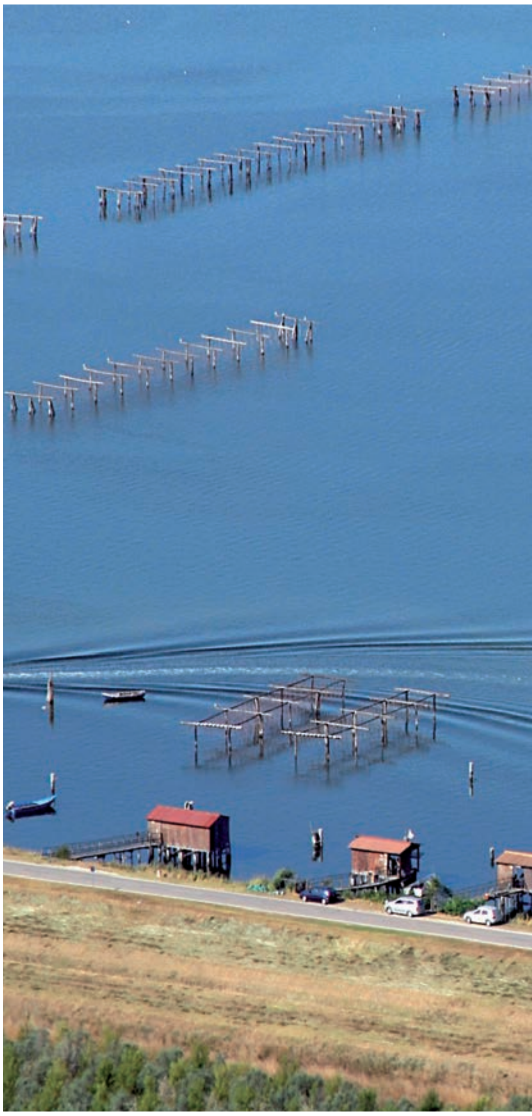

Figure 5: mussel farming in the *Sacca degli Scardovari*.

The average variable costs per employee on average for the lagoons was valued at € 2,873 (€ 2,173 for *Consorzio Pescatori Polesine* members). The Short Term Net Income (NIst) was calculated by subtracting the aforementioned costs from the annual GMP per worker which resulted in a total of € 11,119/worker, with a minimum of € 8,409 in the lagoons attributable to the *Consorzio Pescatori*. Evidently this was not a sustainable Net Income, and was estimated at the time that an integration of at least € 2,500 per year/ worker would be required in order to reach the sustainability threshold.

Calculating the Long-Term Net Income again at the end of 2009, one sees a decrease to € 6,000/ worker, a figure that is way too low to ensure the economic sustainability of the fishermen. Given equal production yield, the selling price is hence the most important parameter in determining economic and social sustainability conditions. Our calculations were therefore formulated corresponding to € 3.0/ kg of Tapes. The Short Term NI for the entire *Delta Polesano* was € 14,617 per year/ worker, with a minimum of € 11,054 in the lagoons attributable to the *Consorzio Pescatori*. Clam farming exclusively was not enough to ensure a minimum of socio-economic sustainability, especially for the members of the *Consorzio Pescatori*. In order to overcome this crisis, partly mitigated by there being two workers per every household, develop-

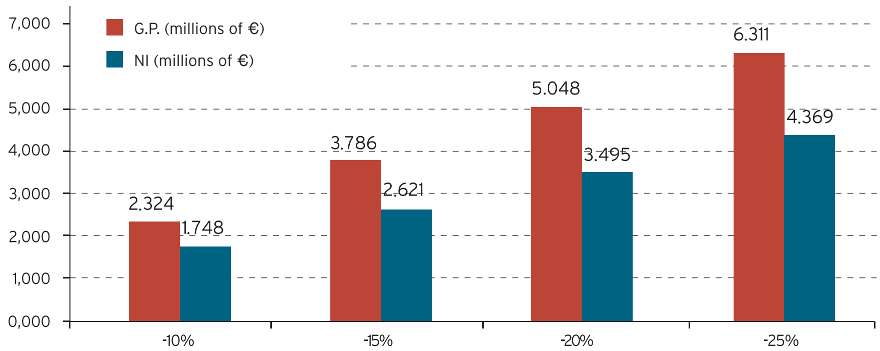

Figure 6: minor GP and minor NI no lagoon vivification.

ment solutions had to be found.

During the on-going crisis there has been an increase in unemployment of about 20%, with 400 employees less in just the primary sector. In light of this threat, the individual manufacturers, the *Consorzio Pescatori di Scardovari* and the *Consorzio di Bonifica* have intensified efforts to not only promote the vivification of the lagoon habitats but also to improve Tapes production in the Delta.

Structural data	Unit of measure-ment	Project data
Project duration	years	10
Employees	number	2005[9]
Average Tapes price	€/kg	3.50[10]
New cultivated surfaces	ha	240

Table 5: structural data hypothesis of the project.

The Effects of Hydraulic Interventions on the Tapes Industry

The hydraulic interventions carried out in recent years by the *Consorzio di Bonifica Delta Po* have had two main effects:

- Maintaining fair sustainability conditions for the fish biomass,
- Safeguarding Tapes production in the lagoons.

A model that investigates the effects of the absence or lack of hydraulic interventions was then prepared. According to our estimates and also in the opinion of various experts, there would have been, soon thereafter, a production regression[9] amounting to a loss of product (Tapes) of between 10% and 25% in the absence of intervention. This regression would have resulted in negative scenarios for producers and for the whole *Delta Polesano* economy. It is believed therefore that in the medium term, only conservation is not sufficient to support the economy of the area, and for this purpose one hopes for interventions aimed at broadening the production base, especially in the *Sacca degli Scardovari*.

Conservation or Vivification Interventions

These allow for production yields to be maintained. In fact, the work carried out by the *Consorzio di Bonifica* for hydraulic order (safety) reasons has ben-

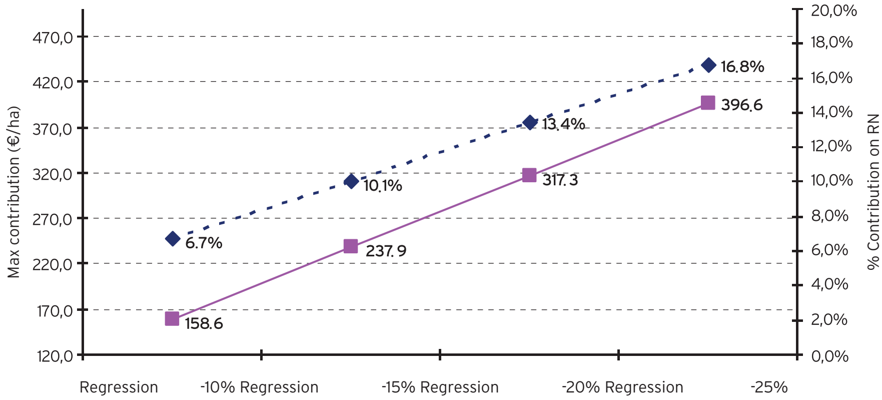

Figure 7: estimate of maximum conservation value of production function per Ha of lagoon.

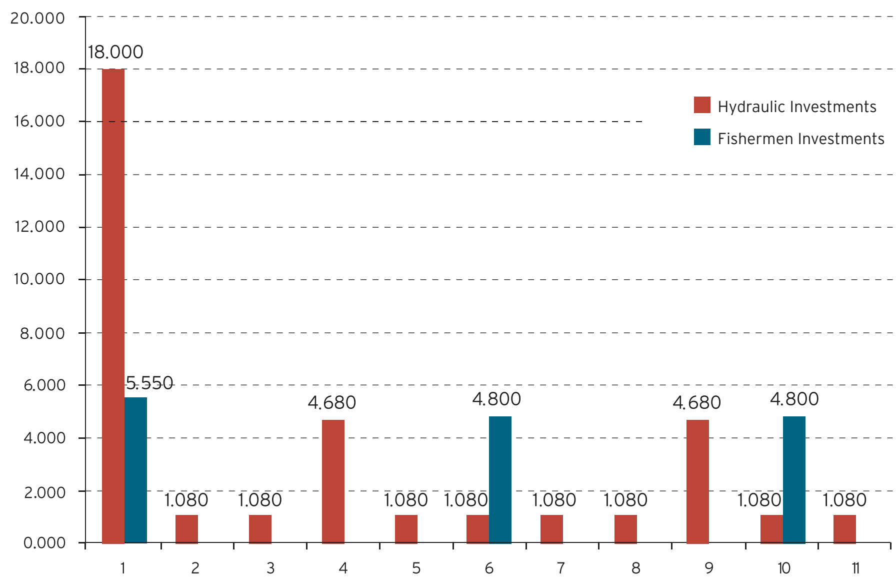

Figure 8: annual investments over the course of the project (in millions of €).

efited the Tapes industry. The costs of hydraulic interventions amounted to around € 2.5 million annually and totaled € 12.5 million over a five year period. In relation to these amounts what can be defined as the conservation benefit is derived from the Tapes, being the primary sector. Our investigation has therefore arrived an estimate of loss of product that would be recorded in the absence or deficiency of a vivification intervention. This estimate was made according to four levels of possible regression:

- mild (-10% of the product);
- medium - low (-15%);
- average (-20%);
- medium-high (-25%).

At the price of € 2.4 /kg of Tapes, these production regressions would result in a loss of GMP ranging from a minimum of € 2.524 million per year (-10%), up to a maximum of € 6.310 million. A lower GMP also involves reduction of variable costs so by subtracting the savings on variable costs from the minor GMP, we were able to arrive at an estimate for the lowest annual income which ranged from a minimum of € 1.748 million per year to a maximum of € 4.369 million depending on the level of regression expected. One should also consider that in the lagoons, the Tapes fishermen are also involved in the management of collective assets which have a positive impact on the community. We therefore attempted to come up with an approximate value for this environmental management that we estimated to be a third of the value of the minor income. Subtracting the amount attributable to environmental management carried out by the producers from the minor NI, we were able to estimate the pure value of maintaining the function of Tapes production. For the lagoon environments this value corresponds to the net benefit for the private sector in the face of maintenance and hydraulic vivification interventions. In theory it corresponds to the maximum level of contribution that the Tapes fishermen would be able to make, if the price allowed, in order to maintain production. On average in the *Polesine* lagoons, this benefit would range from a minimum of € 158.6/ ha of lagoon (slight regression[9]),to a maximum of € 396.6 /ha (medium-high regression). Private contribution hypothesis were not compatible with the producers' disbursement capacity at the time of the survey. It was deemed appropriate to postpone any contributive hypothesis to a later date. However, the problem of low profitability per worker remained unresolved at the time. In order to increase profitability one could, in theory renegotiate the price and contractual power of producers.

We consider it opportune therefore to direct the producers towards a broadening of the production base that should be compatible with environmental conservation as well as the dynamics of Tapes demand. By applying a supply-demand model designed for the domestic Tapes market, we predicted that the relationship between supply and demand could have normalized within three to five years. At the end of this period, we foresaw the sale of an increased production of about 15-25%. Veneto Po Delta clam farming would have been able to claim a fair quota of the increased demand considering the high quality of their product.

Project years	0	1	2	3	4	5	6	7	8	9	10	Total
Hydraulic works	18.000	-	-	3.600	-	-	-	-	3.600	-	-	25,200
Maintenance project	-	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	9.000
Project overheads	-	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	1.800
Total Consorzio Delta Po	**18.000**	**1.080**	**1.080**	**4.680**	**1.080**	**1.080**	**1.080**	**1.080**	**4.680**	**1.080**	**1.080**	**36.000**
Barchini investment	2.880	-	-	-	-	2.880	-	-	-	2.880	-	-
Engine investment	1.920	-	-	-	-	1.920	-	-	-	1.920	-	-
Hut investment	0.750	-	-	-	-	-	-	-	-	-	-	-
Total fishermen investment	**5.550**	**-**	**-**	**-**	**-**	**4.800**	**-**	**-**	**-**	**4.800**	**-**	**15.150**
Fuel (+40%)	-	1.615	1.615	1.615	1.615	1.615	1.615	1.615	1.615	1.615	1.615	16.151
Barchini maintenance	-	0.366	0.366	0.366	0.366	0.366	0.366	0.366	0.366	0.366	0.366	3.655
Hut maintenance	-	-	-	-	-	0,150	-	-	-	-	-	0.150
Other private costs	-	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	1.665
Total private management costs	**0.000**	**2.147**	**2.147**	**2.147**	**2.147**	**2.147**	**2.147**	**2.147**	**2.147**	**2.147**	**2.147**	**21.622**
Total project costs	**23.550**	**3.227**	**3.227**	**6.827**	**3.227**	**8.177**	**3.227**	**3.227**	**6.827**	**8.027**	**3.227**	**72.772**
Fishermen income Integration (€2,500/ year per employee)	-	5.013	5.013	5.013	5.013	5.013	5.013	5.013	5.013	5.013	5.013	50.125
Total cash flow to deduct	**23.550**	**8.240**	**8.240**	**11.840**	**8.240**	**13.190**	**8.240**	**8.240**	**11.840**	**13.040**	**8.240**	
Revenue from project development	0.000	4.200	6.300	12.600	12.600	12.600	12.600	12.600	12.600	12.600	12.600	111.300
Public intervention in hydraulic works	11.700	-	-	2.340	-	-	-	-	2.340	-	-	16.380
Total active cash flow	**11.700**	**4.200**	**6.300**	**14.940**	**12.600**	**12.600**	**12.600**	**12.600**	**14.940**	**12.600**	**12.600**	**127.680**
NPV i= 0%	**-11.850**	**-4.040**	**-1.940**	**3.100**	**4.360**	**-0.590**	**4.360**	**4.360**	**3.100**	**-0.440**	**4.360**	**4.783**
NPV i= 4.1% - IRR =4.136%	**-11.850**	**-3.879**	**-1.789**	**2.745**	**3.708**	**-0.481**	**3.419**	**3.283**	**2.242**	**0.305**	**2.907**	**0.000**

Table 6: project cost-benefit analysis (in millions of €) the higher market price.

	P.L. totale (ML di €)	P.L. polesano ML di €	% P.L. polesano	V. A. totale (ML di €)	V.A. polesano ML di €	V.A. extra polesano (ML di €)	% V.A. polesano
Primary Tapes	25.242	25.242	100%	20.194	20.194	0	100%
Secondary Tapes	12.095	9.07	75%	7.256	5.441	1.815	75%
Primary + secondary Tapes	37.337	34.312	92%	27.449	25.634	1.815	93%
Tapes terziario	10.518	2.104	20%	5.259	1.052	4.207	20%
Tapes filiera	47.855	36.415	76%	32.708	26.686	6.022	82%

Table 7: GP and AV at a price of € 2.4/kg in the three production sectors[15].

Figure 9: the fishermen and/ or Tapes farmers use small, usually two-man vessels (*barchini*) to carry out their work.

Productive Development Interventions

In order to plan the expansion of the production base, the *Polesano* district Tapes production chain was analyzed, of which the key elements are summarized below.

The Primary Sector

63% of the *Delta Polesano* Tapes pertains to the plants of the *Consorzio Pescatori del Polesine*. In the area where this *Consorzio* does not work, Tapes are purified outside of the area, or sold to traders who carry out these operations in appropriate places. The expansion of the production base requires both hydraulic interventions carried out by *Consorzio di Bonifica* as well as the investment of private fishermen (barchini, huts, fishing equipment etc.) In the face of these interventions estimates for additional flow of Tapes products and related costs have been made. Our design hypothesis is based on two assumptions:

- an increase in the workers' Net Income;
- The co-financing of the investment by the fishermen.

The Short Term NI per worker was calculated to be € 11,119 per year. With the increase of the production area (240 hectares), with an average yield of 1.5 kg/ m^2 of Tapes, we estimate an increased annual production of 3,600,000 kg of Tapes, which would raise the annual NI to € 2,500 /per worker, a figure that would meet the desired objective of sustainable NI. According to our hypothesis, however, a public intervention amounting to 65% of the costs of hydraulic works would be required. As can been seen from the table below, the project would require, over a ten year period, the hydraulic investment of € 36.0 million. The investment in barchini, huts and other fishing equipment however, would amount to € 15.15 million over the same period.

The Secondary Sector

In areas where the *Consorzio Pescatori* operates, and where the selling of Tapes to traders is well-established, one could continue to work in this way, and new facilities to cope with the planned increase in production would not be needed. Since it is assumed that the interventions relate to the lagoons attributable to the *Consorzio Pescatori*, this consortium has three possible solutions:

- sell surplus product before processing;
- process the new Tapes at the Scardovari facilities, without having to expand structurally;
- expand existing facilities.

In the first case one does not foresee any problems in particular, except for the loss of some territorial added value; in the second case there could be economies of scale as fixed costs decrease per kilogram of product and in the third, the *Consorzio Pescatori* would have to face investments of an industrial nature, acquiring new technology and optimizing organization.

The Tertiary Sector

This sector is divided into transport, marketing and business services. Regarding transport, there should not be any major difficulties, as there are several companies that are well equipped on a national level that are able to deal with production increases, like that which has been hypothesized, without any problems. Regarding the marketing, be it after the fishing phase or after the processing of the product (as in the case of the *Consorzio Pescatori*), one can make a similar argument: the Polesine and / or lower Veneto operators would have no problems in dealing with an increase in Tapes production of up to about 30%.

Regarding the need to expand the network of business services, the assessment is a bit broader: these are services that must be organized based on the district. It is therefore considered appropriate to invest in research, technical assistance and monitoring (human capital rather than equipment), investments that would not only help the new production, but that would also valorize the current one.

In order to quantify the costs referred to in the previous graph, we made use of information collected from key players in the *Polesana* Tapes production chain. The cost-benefit model that follows was prepared in a flexible way, in order to change certain elements while maintaining other values. Different trickle down effects such as workers' income, the sustainable workforce and the expected internal rate of return (IRR) can be assessed, on equal terms, via discontinuous simulations. The principal structural data of the development project are shown below. A cost-benefit analysis was prepared using the above data and by taking design hypothesis developed by sector technicians into account (Table 6), which highlights how the project will be able to repay, over an economic period of one decade, both hydraulic as well as private investments, hypothesizing however, that the community takes on 65% of the cost of water projects. The internal rate of return (IRR), the net of this contribution, taking into account the integration of income guaranteed to the fishermen, would result in an average price of € 3.5/kg of Tapes, equal to 4.1%[12]. In addition to the benefits of the project, the fishermen, while exposing themselves to greater technical and management risks, could also take advantage of a surplus of income owing to.

The Polesine Shellfish Production Chain

The following paragraph presents the Gross Product (GP) and the Added Value (AV)[13] of the Po Delta Tapes pro-

BENEFITS TO THE PRIVATE	SOCIAL BENEFITS	ENVIRONMENTAL BENEFITS
Increased income in the primary sector; better living conditions for fishermen	Employment stability in the Delta polesano	Natural Resources Conservation in synergy with lagoon production areas
Improved management security for the Consorzi Pescatori	Qualification of human capital in the shellfishing sector	-
Economic benefits for the shellfish processing enterprises	More employment	-
Economic benefits for companies that provide the fishermen with productive means	Employment stability	-
Economic benefits for service companies (transportation companies, the Consorzio's various purifiers, distribution companies)	Employment stability	-
Economic benefits for associated businesses (technical assistance, credit)	Social capital; development of service activities related to the production chain.	-
Benefits for tourism operators and catering	Development of environmental tourism; development of culinary tourism	Greater awareness of and attention paid to environmental values
Returns on a general local level and support for multifunctionalism	Improved perception of the image of the Delta region	Valorization of the Delta Polesano lagoons as ecological and productive entities

Table 8: returns on the Tapes production chain.

duction chain, broken down into its three sectors. The primary sector's GP is estimated to be € 25,242,000 at a price of € 2.4 /kg[14], and € 36,812,000 at € 3.5 /kg. The secondary sector's GP is calculated from the management budget of a facility that processes and sells shellfish wholesale; at this stage of the production chain, from the bagged product on the dock to when it is loaded onto vehicles, there is a unit cost of € 0.50 to € 0.60/ kg for purified Tapes and € 1.0-€ 1.3/ kg for those already bagged.

Since the *Delta Polesano* produces 10,517.6 tons of Tapes annually, the GP of the secondary sector is estimated at € 12.095 million. The GP aggregate (primary plus secondary sector) thus amounts to € 37.337 million while it would rise to € 48.907 million fetching an average price of € 3.5/kg.

The GP of the distribution sector located immediately downstream of the processing is estimated to be on average € 1.0/kg of Tapes, and still does not include the last distribution link (large-scale retail channels, fish shops and other outlets). Applying this unit value to the amount of Tapes involved in the first marketing stage, one estimates a tertiary sector GP of € 10.518 million.

For the entire Polesine Tapes production chain, the GP is € 47.855 million, and rises to € 59.425 when fetching a price of € 3.5/kg. The Added Value (AV) was then calculated, which for Tapes at € 2.4 /kg, amounts to € 20.194 million in the primary sector, € 7.256 million in the secondary and € 5.259 million in the tertiary sector. Summing up the three

Figure 10: the processing and preparation of shellfish for sale.

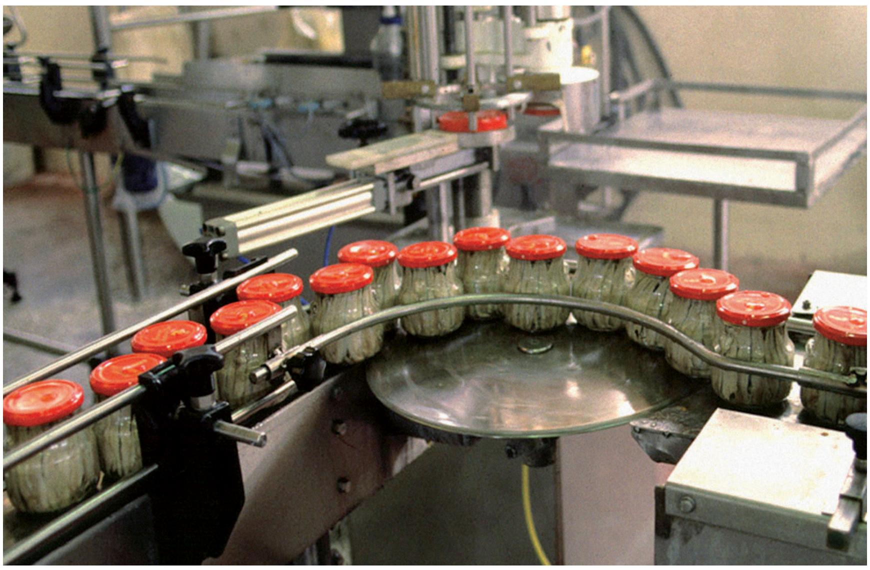

Figure 11: the processing stage.

Figure 12: through co-operatives and the consequent planning of the individuals' work, one can ensure the sustainable harvesting of shellfish.

sectors one arrives at an AV of € 32.708 million which would rise, with an average price of € 3.5/kg, up to € 41.965 million, an increase of 28% compared to 2009.

In Table 7 one can see the GP and AV of the *Polesine* Tapes production chain for 2009. In addition, in the same table, one can see the Tapes' territorial value or that which lies with the operators and the companies in the Polesine. A further consideration regards the possible economics of the production chain. It is foreseeable that bigger production will reduce unit costs in the processing section. For example, if this section were expanded at *Scardovari*, there would be an estimated average unit cost for the new immobilization of € 0.50/kg of product, compared to € 0.66/kg for having created installations from scratch, this shows a discrete advantage in investing in the present location.

The Socio-Economic Impact of the *Delta Polesano* Tapes

The proposed works, for both lagoon conservation and expansion of the Tapes sector, would generate a higher income in the primary sector, higher employment in the manufacturing sector (20-25 new units[16]), in addition to considerable social benefits. In the Delta municipalities involved in the Tapes production chain, these effects combine to significantly improve social stability. One could add that the economic benefits of the privates, of a social and environmental nature, have no clearly defined boundaries.

The development and conservation projects, as well as involving a large part of the Po community either directly and indirectly, are strategically important for the lower Veneto area, and one could conclude that the benefits to the fishermen, businesses and communities of the Delta fully justify the assumed costs of public intervention. The final diagram shows the possible effects related to these interventions. Another fact that emerges from the research is the high level of compatibility between the clam and other activities of the primary sector. Tapes fishermen also often carry out, to a lesser degree, other activities. At the time of survey, according to our estimates, the 1804 workers had 1,269 multifunctional positions. The biggest group, with 949 people, was that of the fishing activities (mussel, small internal fishing fisheries and marine fishing).

One could then synthesize that Tapes fishing plays an important role in ensuring the survival of ancient water trades, while the integration of income from traditional fishing and mussel farming proves decisive for the economic sustainability of the calm fishermen, crucial in these times of crisis. On the other hand, traditional fishing's low income would condemn this activity to all but disappear, if it were not for clam fishing. Putting together all the trades in whichever way the Tapes fishermen are employed, one arrives at 70% for secondary operative positions, a figure that also highlights the working flexibility of the Delta fishermen. Thanks to this multi-functionalism they are able to protect trades that would otherwise no longer survive on their own. It is also for this reason that the lagoon vivification interventions provide essential social benefits to the sustainable development of the area.

[1] (Barnes, 1980; Knox, 1986 Odum, 1988).
[2] An Asian species already introduced along the American coasts between 1930 and 1940 and later introduced to Europe in the 1970s.
[3] Our estimate data are slightly lower than those provided by Turolla (Eduardo Turolla – L'allevamento della Vongola verace nel delta del Po, Istituto Delta Ecologia Applicata, Ferrara, 2008). In our survey, the Tapes production total was obtained by adding the actual data of the Consorzio Pescatori (the average conferral in the period 2006-2008), the estimated data in the Caleri-Marinetta areas and that of the Vallona lagoon. The latter were also collected during a previous survey conducted in collaboration with Prof. R. Rossi of the University of Ferrara, during the filiera ittica polesana project. In order to go back to the Caleri and Vallona's current production data, an average expansion coefficient was applied to the previous data, which took into account the average increase that occurred over the area.
[4] On a national level, the Consorzio Pescatori accounts for approximately 13% of the total production volume.
[5] Table 2 includes manpower data up to the end of 2009. They do not include the 200 Delta fishermen/women that had already applied for Tapes fishing permits, including about 60 women registered with the Cooperative.
[6] *barchini*: a term used by fishermen to refer to small motorboats.
[7] These costs were calculated according to "standard boats" operating 250 days a year with a crew of two.
[8] The variable costs are those that vary with the production and, in theory, amount to zero when production ceases. For the barchini, fuel and maintenance costs of both engines and hulls fall under variable costs. They are fixed management costs that do not depend directly on production volume (depreciation, overheads and insurance). The cost of labor is not included because it makes up part of the operators' Net Income (NI) together with the interest on capital and eventual profits.
[9] By production regression one means a lower annual production of Tapes that is calculated in this report in relation to the average over the years 2006-2008.
[10] In late 2009, there were 1805 workers; the 200 workers waiting to enter the sector were taken into account in the project predictions.
[11] Average expected Tapes price, based on recent prices (2011-2012) and market forecasts.
[12] Rate of return one supposes is approximately equal to the price of money should the fishermen file for facilitated bank loans.
[13] Albeit in an improper manner, the term added value denotes the total of remuneration relating to labor, capital and management, before amortization of capital projects and taxes.
[14] Price at the time of the survey (end of 2009).
[15] In this case the primary sector is calculated using the GMP instead of the Added Value; a methodological adaptation that does not affect the validity of the analysis model proposed however.
[16] The additional investment would result in 20-25 new employees in the secondary sector, with an average immobilization of around Đ 100,000/employee, a fairly low amount since our hypothesis would benefit from economies of scale and the relationship with the already existing Scardovari plant.

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_STUDIES & RESEARCH

ELEMENTS OF ENVIRONMENTAL ENGINEERING IN THE STABILIZATION OF THE SACCA SCARDOVARI

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The stabilization of the sandbar that closes the *Sacca Scardovari* is a priority in the *Consorzio di Bonifica Delta Po*'s vivification of the *Sacca*, within the broader context of the overall maintenance of the lagoons. This article is a summary of the research proposals and operational evolution of the sandbar and the possible integration project involving hydrodynamic, environmental and management aspects aimed at, in particular, the requalification thereof, based on our knowledge of the dynamics characterizing similar coastal systems (Gianoni *et al.*, 2010).

The *Sacca di Scardovari* and its sandbar

The *Sacca Scardovari* sandbar owes its current shape to the ebb of dredged sediments and proposes once again, in the innermost position, the pre-existing *Scanno del Pal*o, a peninsula jutting out from the coast to the north-east (known as *Punta Barricata*). It is for this reason that in this paper the name "*Scanno del Palo*" is used when referring to the previous situation, and *Scanno di Sacca Scardovari* when referring to the geography that followed the ebb that gave rise to the current state.

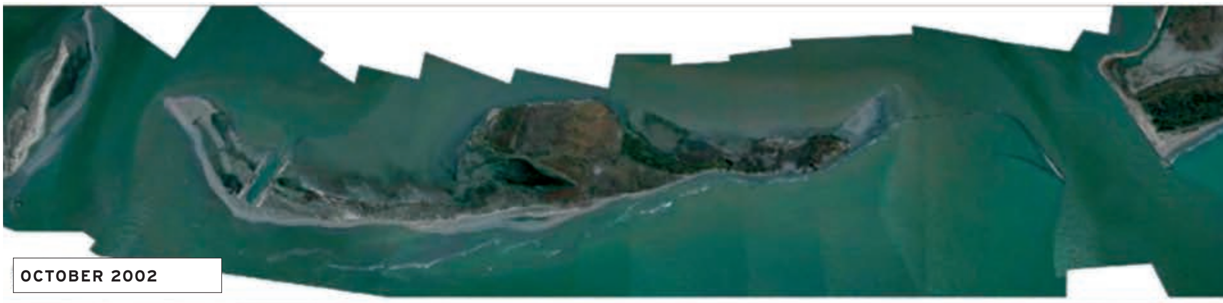
The genesis of the *Scanno del Palo* goes back to the end of the twentieth century when, due the rapid advance southwards of *Po di Tolle* and *Po di Gnocca* mouths, a second outer basin (*Sacca di Bottonera*) that was hydraulically connected to the *Sacca di Scardovari* formed, thus creating a single lagoon.

The southward advance of the mouths of these Po distributaries came to an end around 1900, mainly due to the combined effects of subsidence and the lessening of river sediment. For most of the twentieth century the lagoon was characterized by a planimetric configuration that corresponds to its current perimeter. If however, the margins of the basin, with the exception of some areas on the western side, are the same as those today, the internal morphology is substantially different, being characterized in the past by vast emerged areas along the edges that today have entirely disappeared, and by bottoms with a lot more structure than the current ones. The conformation of the current sandbars separating the lagoon from the sea has also changed profoundly, having undergone considerable changes over the years and gradually withdrawing over time. From the examination of historical maps, it is clear how, as of the early 1950s, the location, shape and size of *Scanno del Palo* have been subject to constant changes, indices of conditions of instability and dynamics subject to, on the one hand, seasonal changes and annual storms, and on the other to the changing intensity of river and coastal sediment transport.

The combined action of subsidence, violent storms, and defensive interventions by several different entities, as well as coastal erosion phenomena are factors behind the important dynamics that have fundamentally changed the sandbar over the last few decades, with a gradual pulling back in recent years towards a configuration closer to that of the late twentieth century, mainly due to interventions being carried out by the *Consorzio Delta Po Adige* which, on the one hand, were aimed at reconstruction via beach nourishment of a sandbar similar to the preexisting *Palo* sandbar, and on the other hand, at maintaining the efficiency the Southern Mouth in its current position by means of periodic dredging and moving of sand (Matticchio, 2009).

Figure 1: the evolution of the Sacca degli Scardovari sandbar (Photo: Consorzio Bonifica Delta Po).

[1] Andrea Bonometto: responsible for geo-morphological and environmental engineering; Lorenzo Bonometto: responsible for ecosystems and wildlife; Pippo Gianoni: responsible for the coordination of methodological systems and ecosystems. This work also called on the expertise Eng. Bruno Matticchio, who collaborated in the study of the morphological and hydrodynamic aspects as described in Issue 0 of the Quaderno Cà Vendramin (Matticchio, 2009).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AUGUST 2008


JUNE 2010

Figure 2a: beached logs and tufts of *Spartina juncea* aligning the shoreline (Photo L. Bonometto, 2009).

In general, within the changes taking place, erosion phenomena outweighs deposit phenomena which overall, appears to be weakening, with very different trends at the two mouths and areas in front of the sandbar:

- in the north one observes significant lowering of the bottoms in the section between the mouth of the *Po di Tolle* (*Punta Barricata*) and the Northern Mouth, likely due to a lack of sediment discharge in turn primarily due to reduced flow (and thus also solid transport) compared to the past, from the southern distributary of the Po di Tolle (mouth of Punta Barricata);

- in front of the sandbar's line of defense, where the bottoms are characterized by a system of bars, recent bathymetric surveys indicate how the bars migrate with remarkable speed, whilst maintaining fairly stable overall bottom quotas of about 2.5 to - 3.0 a.s.l., but causing strong points of discontinuity with major risks to the stability of the front of the sandbar;

- along the coastline around the Southern Mouth something very different seems to be happening, there is a clear westward migration of the axis of the mouth channel with material being deposited. This evolution is also related to the dredging carried out by the Consorzio, which limits the tendency of the channel to move towards the southern sandbar and emerged land of the *Punta del Polesine*, creating a dynamic equilibrium point to guarantee the maintenance of the southern mouth's efficiency favoring the circulation of tidal currents.

The *"Progetto Generale di sistemazione idraulica e di risanamento idrogeologico della Sacca degli Scardovari"* prepared in 1994 by the *Consorzio di Bonifica Delta Po Adige* as part of the *"Programma integrato mediterraneo per le zone lagunari dell'Adriatico settentrionale (EEC Regulation 2088/85)"*, initiated a series of interventions aimed at stabilizing the sandbar and the vivification of the lagoons. In 1997 an intervention was carried out to open the new northern mouth, consisting of the partial dredging of channels branching off from it and the realization of an intertidal emerged embankment (labeled, improperly, as a "salt marsh") in the central part of the *Sacca*. Then in 2003, the *Consorzio* carried out the restoration and stabilization of the *Scanno* through the realization of a defensive reef on its sea facing side, and a filtering structure on its lagoon facing side (recently reinforced, again with reef elements), filling in the areas between

Figure 2b: artificial sandy embankment characterized by abnormal vegetation (Photo L. Bonometto, 2009).

these elements with the material from the dredging of the lagoon.

These interventions are in their final stages, as shown in Figure 1. The interventions for the reconstruction and stabilization of the sandbar in the new location between two existing outlets to the sea are of primary importance in maintaining the separation of lagoon and marine environments and the circulation of tidal currents necessary for the vivification of the lagoons; a condition that is also indispensable to the productivity of the fisheries. The eventual elimination or significant reduction of the sandbar would lead to a radical transformation of the *Sacca*'s lagoon system, affecting the *Sacca della Bottonera* in particular, that would become part of the sea. The changes to the coastline's structure carried out in the past, both the stabilization of the sandbar in the late 1980s and its division in order to open the northern mouth, showed how the inclusion of solid works, even more so in an area as complex and active as that of the Delta, can trigger rapid evolutionary processes both constructive and destructive, associated with the intense transport dynamics along the coast. It is for this reason that future sea defense interventions must be adequately identified and designed, based on an overall evaluation of the affected system, and must be preferably accompanied by experimental pilot interventions followed by appropriate monitoring programs in order to assess effectiveness in comparison with the expected results and possible negative impacts on adjacent coastal waters.

On the other hand, it is likely that the maintenance of the sandbar's configuration, including the two mouths is, in any case, dependent on two factors over time: the completion of construction works to the sandbar, including the stabilization of emerged areas through environmental engineering works; and the management of periodic maintenance and dredging activities in the channels and mouths, sources of sediment to be managed in an increasingly differentiated way, and designed to be sources of enrichment for beach nourishment actions and processes.

The sandbar was conceived in the 1980s as an artificial functional structure created as part of a lagoon vivification project, with multifunctional repercussions (primarily environmental, economic, productive, and natural). As such it is necessary that its management ensures sufficient spatial stability through periodic maintenance (if not, there is the risk of losing the sandbar resulting in the alteration of the whole lagoon system). The management of this environment should, where possible, be integrated with the natural forces and dynamics of the whole system, thereby reducing the workload and maintenance expenses while accentuating the self-conservation capacity similar to that of analogous natural systems. This approach requires in-depth knowledge for the monitoring of often non-linear evolutionary processes and the taking on of a flexible maintenance concept that is able to be continuously adapted depending on the situation.

The current state of the Scanno di Scardovari[2]

The current characteristics of the *Scanno* are the result of evolutionary phenomena induced by human interventions (dredging, ebb tide and some remodeling) and spontaneous processes. The result is a complex of heterogeneous environments in which, starting with far from natural conditions, spontaneous processes tending towards typical beaches environment features progressing in several places at different times and speeds, and also over larger areas, have been triggered. The *Scanno* while remaining mostly by its very origin, a "secondary" habitat with abnormalities in its faunal population and vegetation cover, dynamics and geomorphology, already has some natural habitats of interest and shows enough potential for the system to be brought to a structure that is similar to the natural characteristics of the coastal environments of the Delta.

Environmental specificity and morphogenetic dynamics

A specificity of primary importance, a direct consequence of the origin of the sandbar, can be noted in the geo-pedological characteristics, significantly different to those of natural sandbars and beaches. Unlike natural ones, formed by the accumulation of sand selected and classed by marine and wind energy, the *Sacca Scardovari* sandbar presents heterogeneous sediment with very diverse grain sizes and sand, shells and clayey-silty elements in different layers resulting from the quality and inflow localization of materials at various stages. Only in the areas that have been flattened and reshaped by wave and wind action does the sandbar show, at least on its top layer, sediments that are partially selected, with notable differences between the sea facing surfaces, in which the maritime climatic energies produce profound and rapid remodeling effects by selecting grain size and favoring the triggering of morphogenetic processes best suited to the site, and those on the lagoon facing side, where the energies have a lesser effect on the depth of the fills and show more modest results.

A direct consequence of this can be seen in the abnormalities of the vegetation compared with the well-recorded succession of their own natural sandbars (see for example: Gehu *et al.*, 1984; Fiorentin R., 2007), with the presence of ruderal and nitrophilous species and interior populations that differ from those in the dunes. Abnormalities that have important implications on stability, since coastal dune resistance and resilience are secured by the peculiar relationship between the habitat's geomorphology and vegetation.

It should also be noted that the Adriatic's high sandy coastlines show, on the whole, certain peculiarities due to their geographic position. The location of a narrow and shallow stretch of sea to the north, along a coastline affected by the cooling and sweetening effects of river water, implicates an attenuation of Mediterranean characteristics, with the absence of, among other things, certain typical plant species as opposed to those found elsewhere along the Italian coast; in contrast, similar to other Mediterranean coasts and contrary to what one sees along the European Atlantic coast, the prolonged summer drought that characterizes our climate means that the relationship between vegetation and soil moisture requires, in order to get through critical periods, deeper connections between vegetation and dune sand, held firm by their root systems and, as in the case of *Ammophila*, by the capillary action of moisture in the groups of buried trunks (Bonometto, 1992), leading to evident technical implications.

It should also be noted that the Veneto coastline's geographical location, being in a transitional area between the nearby Alps, the Mediterranean and the gates of Eastern Europe, results in further floral and faunal peculiarity and, in a eco-mosaic where, in addition to some endemic species, there are species that merge together from the continental and Asian steppes, alpine and Mediterranean species for which our dunes make up the geographical limits of their distribution patterns (Bonometto, 1992; Fiorentin R., 2007a, b). This particular and wide diversity in a multi level ecotonal system is an essential point of reference when evaluating the project direction, the current state and dynamics of our dune habitats.

[2]This work is mainly based on a study carried out spanning the years 2009-2010. Some characteristics of the sandbar have undergone subsequent further evolution due to natural dynamics and ebb flow with some modifications compared to the period of investigation.

The sandbars' sediment/ vegetation abnormalities and the simultaneous occurrence of positive dynamics cause large differences to arise, so much so that, as a result of several factors, one can currently see heterogeneous sectors. These include: the different sediment characteristics due, in different stretches, to prior ebb flow; the quotas, profiles and depth of the fills realized; the consequent diversity in spontaneously established vegetation structure; the locations of marine weather and tidal events; quotas and locations of ebb flow in progress; different sediment redistribution due to spontaneously arising dynamics; the recent re-modeling, protection and system interventions; the effects caused by the adjacent shore.

The features mentioned above are also behind specific critical issues regarding the wildlife. The large surface areas of artificial origin are a favorite nesting place for Yellow-legged Gulls that have colonized the areas to such an extent that they have had a serious impact on other birdlife not only by excluding them, but by preying on other species' chicks; while at the same time, the insularity prevents colonization by the native herpetofauna and teriofauna. In this regard it is worth noting, by way of comparison, what happens in the nearby sandbar to the south-west, which is characterized by significant active embryonic dune systems: these favor an important presence of friar that, due to the fact that there is a high number of couples, enables them to protect themselves and the colony from the Gulls.

An important specific aspect that is common to the Delta sandbars is the lack of depth that is at times almost visible on the sea and lagoon sides, as is clearly visible in figure 4. From a preliminary analysis of recent morphological surveys carried out on the Delta coastlines (*Regione del Veneto* 2009), one can see how the sandbars require, as a guideline, a depth of about 300-350 m in order to have stable structures hosting adequate ecological successions. Due to the sandbar's limited depth, together with the sedimentological and morphological abnormalities, affects the possible development towards the inside of typical coastal ecological successions and hence the formation of mature stabilized dune habitats. Along the natural sandy coastlines, proceeding from the sea and moving inland, one finds a typical series of increasingly mature habitat groups, from the shoreline to the embryonic dunes and the first real groups of dunes, to those situated in the internal areas that are stabilized and interspersed with fairly wet lowlands. This succession can be seen in a very partial and abnormal way in the Scardovari sandbar, there are however some valuable peculiarities, and good possibilities of intervening to steer the processes toward natural, conforming structures.

In short, proceeding from the sea and moving inland, the habitat succession has the following characteristics as well as abnormalities and peculiarities. The strip of shoreline highlights a major importance owed to the large quantity of beached logs aligning the sea level reached by the winter storms (Figure 2a): exactly the same situation as that which occurred on beaches in ancient times, and which today has been almost completely lost as a result of beach "cleaning", an activity which creates specific habitats and has important functions involving sand appropriation and retention. A specificity that differentiates this sandbar from the other Delta sandbars and that characterizes the shoreline is to some extent, its "lagoon" character of the sea facing side, possibly connected to the inner most position compared to the preexisting "*Scanno del Palo*", and of an offshore protective reef running parallel to the coastline. One of the effects of this was seen in unusual autumn populations of *Spartina juncea* (Figure 2a, left) in the zone that tides and waves usually reach, having a visible stabilizing effect on the sands.

The zone corresponding to the embryonic dunes on the sandbar only shows initial formations, with spread out Cakile maritima populations accompanied to the south-west by more strips of Spartina juncea, sparse *Agropyron junceum* (= *Elymus farctus*) and halophilic species, with Inula chrithmoides being particularly frequent. In the zone corresponding to the first barrier of dunes, there is an absence of spontaneous formation, seeing as the dunes are not the result of morphogenetic processes caused by the progressive deposition of classed sands, but of the artificial accumulations of heterogeneous sediment (Figure 2b, right), on which only recently remodeling and naturalization interventions have been carried out.

Hence the abnormalities in the quotas, dynamics and vegetation: there is an absence of the more typical first barrier dune species, including *Ammophila arenaria* (= *A. littoralis*) and *Calystegia soldanella*, while the environment is now dominated by the under developed presence of *Cakile* associated with *Chenopodiaceae ruderal nitriphilous* (*Atriplex tatarica a*bove all) populating the area in covering strips. The formation of a habitat similar to that of the first barrier of dunes is achievable however, as clearly shown by the recent results of some planting of *Ammophila* that were able to activate typical morphogenetic dynamics and vegetation.

Even more noticeable is the absence of stabilized dunes. Even in the area just east of the centre, where the depth of the sandbar would theoretically allow for them, there is instead, a high artificial plateau, dominated by sand towards the sea and land which is drenched in the winter and spring months and compact in the summer in the internal areas, with extensive beds of reeds interspersed with nitrophilous vegetation and soil elements with extreme differences in moisture. This habitat is free of dunal characteristics although small groups of dunal and retrodunal species show potentially positive trends.

Even more so for the lack of vegetated dunes (shrubs and trees are limited to a few artificially planted tamarice trees while even the initially present *Amorpha fruticosa*, is underdeveloped), which would indicate that conditions similar to the natural ones can only be obtained over similar periods through remodeling, with localized soil adjustments, necessary for the insertion of the dunes' own vegetation. The retrodunal depressions are different in that, there is an absence of low salinity humid habitats (there are only a few elbow depressions mixed with reeds), while halophilic habitats are widespread over large parts of the sandbar and its contiguous areas, in connection with the transition intertidal surfaces facing the lagoon.

Zoning the sandbar[3]

As a result of the realization process and phases, some areas of the sandbar are characterized by a wide diversity in values and criticality. The western extreme (Figure 3, Sector a) is characterized by very low quotas. It has a high natural value, with shores that are subject to largely natural geomorphologic and vegetation dynamics forming embryonic dunes with structured and differentiated halophilic low lying areas, as well as a brackish pond. The massive presence of beached logs increases the beach naturality and stability values, while the only area with a higher quota is an internal zone at the extreme western edge of the earthy extensions that characterize the areas that follow. The area does not currently need priority interventions apart from the maintenance of its structures and active dynamisms.

From the west extreme it passes through a long bottleneck (Figure 3, Sector b) where the sandbar tapers off into an earthy diaphragm covered with discontinuous nitrophilous ruderal vegetation and grassland (Figure 4). In the internal concave slope the transition zone towards the lagoon waters is particularly important, dominated by the extensive and extremely shallow area with a sheltering formation of the bordering embankment and progressively advancing tidal stretches. The sea facing side has recently been subject to a vast ebb flow, which reduced criticality due to the extremely thin isthmus.

The next area (Figure 3, Sector c) is characterized by the presence of a broad and deep artificial embankment (Figure 3, c1), to which excessively high and poorly differentiated quotas induced abnormal dynamics compared to the natural reference dynamics.

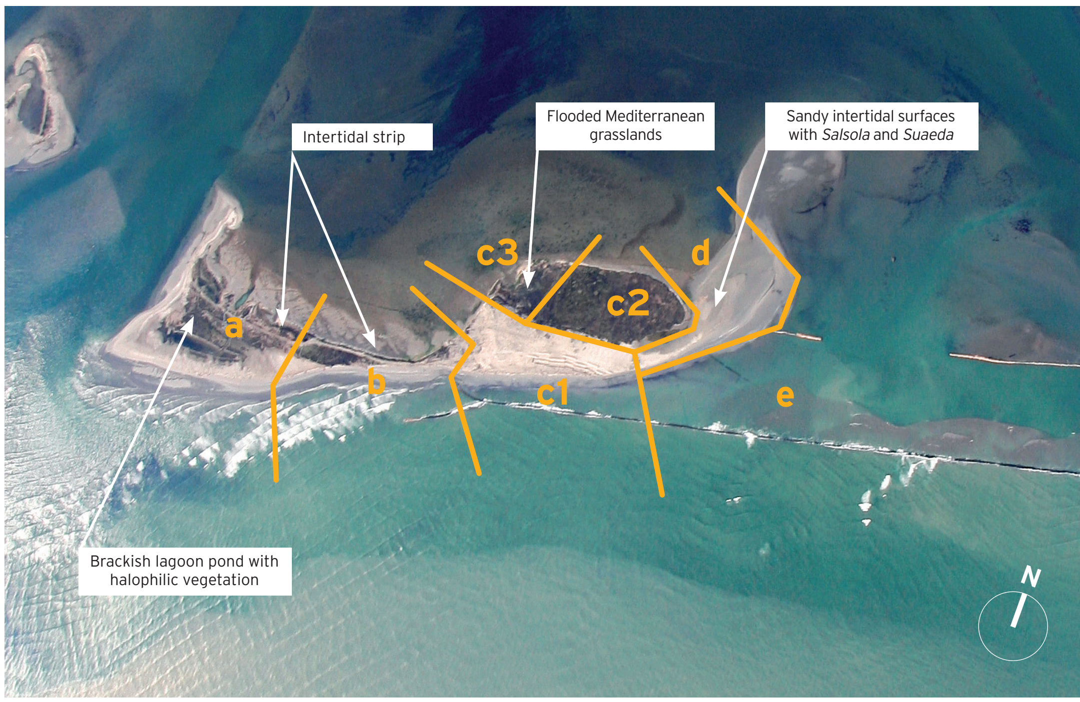
Recent remodeling of the waterfront embankment has highlighted important corrective potential that can be activated through quota reductions, sediment movement, and the introduction of light structures associated with dune plants that trigger typical constructive processes. Behind the sand embankment bordering the lagoon there is a wide slightly lower area dominated by nitrophilous and reed vegetation (Figure 3, c2); that degrades sharply in the western corner, reaching intertidal quotas on which a precious halophilous site has developed (Figure 3, c3).

The surface of the sandbar terminates in low quota sandy surfaces and with intertidal stretches towards the Sacca (Figure 3, Sector d) at the eastern end. The pioneer vegetation is restricted to these areas with *Cakile* and *Phragmites*, replaced on the lagoon facing side by Suaeda and Salsola Halo-nitrophilous scrub populations. It is to be noted how the orientation of the area foresees, in the near future, once the intended surface towards the sea is entirely flooded, considerable depth of the sandbar corresponding to this section, which could allow for an orientation of the ecological succession up to the interior habitats, starting from an almost natural current condition.

The final parallel and elongated section is currently under construction

[3] The situation described refers to 2009. Compared to which, at the end of 2012, the structure is similar to that observed in the first highlighted areas. Some changes involved: section a, further deposit of sandy materials; section b, a closed stone cell intervention and consequent important nourishment, which has significantly expanded the extension towards the sea and thus its stability, section e, is currently being filled, an operation which started in 2009. It's state will be monitored, taking into consideration the winter storms that periodically modify the situation and a comparison of the evolution of the transects will be made in the spring of 2013.

Figure 3: Zoning of the sandbar on the basis of different morphological characteristics (in orange) and identification of halophilic surfaces examined in the text (Aerial photo: *Consorzio Bonifica Delta Po*, 2009).



(Figure 3, Sector e). It is made up of the area bordered by the two shore alignments, where there is currently ebb flow, which will cause the sandbar to take on the planned size and shape. Note how a settlement consistent with the character of natural sand, having ebbed in late 2009 with largely silty sediments as a result of winter storms that washed out the fine components and leaving the grainy ones behind, has rapidly shown a colonization conforming to the characteristics of a natural beach, with a substantial *Cakile* presence.

The sandbar habitats on naturalistic maps

These different situations are reflected on the naturalistic maps. The regional habitat maps aimed at identifying the types defined in reference to Directive 92/43/EEC, clearly show that the values attributed to the directive are concentrated at the sandbank's extremes; however it does not classify the large areas of the central embankment, given the abnormalities that diminish the quality of the habitats and impede a qualification of the habitats under the Directive.

Instead the embankment is defined on the *Consorzio Delta Po*'s habitat map (Figure 5), which was prepared as part of the analysis of the ecological value of the lagoons (Pagnoni *et al,* 2009)[4]. In this work the deep sandy front and the rear surface (corresponding to sectors c1 and c2 in Figure 3) are defined as "non vegetated excavation sand " and "*nitrophilous anthropogenic grass community*".

One should always bear in mind that both natural and artificial sandy coastal environments are subject to rapid changes due to spontaneous or induced evolution. These have an effect on all the sandbar's habitats, but are particularly fast on muddy or sandy surfaces related to active depositional systems, which means that in order to safeguard the biocenoses worth protecting, rather than the preservation of specific locations derived from the maps, it is important that the factors and processes that enable the lagoon's habitat functionality, even at different times and locations, are guaranteed. In this evolutionary picture, the current situation, compared to that described in the two maps referred to, needs to be updated.

There is an evident variation to the embankment labeled as "non vegetat-

[4] In 2008, the Consorzio entrusted the assessment of naturality and quality of the Delta del Po habitats to the Consorzio Ferrara Ricerche. The work was consigned in 2009 and a summary was presented in the Quaderno Cà Vendramin Issue 0. More details are also available on the Delta mapping portal http://sil.deltapo.it/web/.

Figure 4: in the foreground one can clearly see the small earthy diaphragm, with its plastic film reinforcement introduced during construction separating the beach from the lagoon, covered with sparse ruderal vegetation. On the lagoon side (left), the presence of intertidal transition surfaces can be noted. This photo dates back to 2009; the sea facing artificial beach is now much larger as a result of recent ebb flow (photo: Bonometto 2009).

ed excavation sand" (Figure 3, Sector c1) on which, covering populations of *Cakile* and *Atriplex* have recently developed. Further significant changes can be seen in the complex of halophilic sites, in which the evolutionary processes have led to significant differentiations that tend to have structures conforming to natural habitats, as highlighted below.

The halophilic surface on the western extreme (Fig. 3, a), labeled *"annual Salicornia and other pioneer vegetation of the mud and sand areas"* on the regional map (the *Consorzio Delta Po Adige* map correctly describes a "brackish lagoon pool"), also currently has perennial psammophilic vegetation types making up eco-mosaic belts of vegetation further adding to the value, unlike on the eastern extreme where there is a thin surface shown on the regional map (Figure 3, d) that is labeled as the same type with the same annual characteristics, however without *Salicornia*, but *Suaeda* and *Salsola* halo-nitrophilous vegetation.The halophilic surfaces in Figure 3 (sector c3) labeled on the regional map as *"Mediterranean salt meadows (Juncetalia maritimi)"* (similar to the *Consorzio Delta Po Adige*'s definition), currently appears much more extensive than indicated on the maps, reaching the sandbar's lagoon banks in wide areas. The surfaces are currently home to an eco-mosaic complex, on altimetric discontinuity caused by artificial origin, which summarizes almost all high Adriatic halophilic habitats.

The incipient discontinuous intertidal zone on the lagoon side running from the western extreme to the concavity bordered by the bottleneck (Figure 3, sector a, b; Figure 4) is not highlighted on the regional map however, probably because it had not been identified at that time. This halophilic zone, identified however on the Consorzio map and an indicative of a positive process, has significant annual pioneer populations to the rear of the sandbar, covering considerable areas with pre-

KEY

- Mixed lagoon sediments emerging at low tide
- Non vegetated excavation sand
- Sandy marine sediments (sand>75%) emerging at low tide
- Sandy lagoon sediments (sand>75%) emerging at low tide
- Anthropogenic nitrophilous grass communities
- Annual mudflat or intertidal sand vegetation
- Annual marine deposit line vegetation
- Mediterranean meadows with pioneer Salicornia vegetation
- Annual Salicornia pioneer vegetation with muddy and sandy areas
- Junctus Mediterranean salt meadows *(Juncetalia maritimi)*
- Lagoon salt meadows

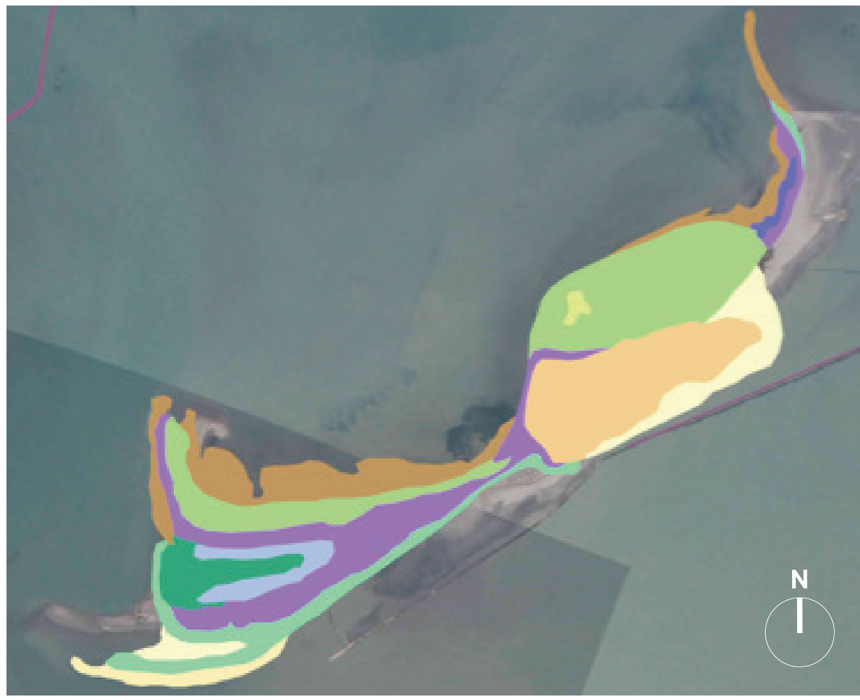


Figure 5: the Scardovari sandbar in the Charter of Habitat (Pagnoni et al, 2009).

cious silty bottoms and sandy material subject to tidal range. This situation, as described in 2010 (Gianoni *et al.*, 2010), has already undergone changes related to interventions and natural dynamics (the 2011 and 2012 winter storms in particular) that are currently being monitored to check stability and consistency.

However the sandbar's current situation confirms in essence, with some new elements, the analysis carried out in 2009. Observing changes over a short time reminds us that, in environments characterized by prominent evolutionary dynamics, the presence or absence of habitat value is mainly linked to the conditions that form basis of the evolutionary dynamics of these environmental systems. Therefore, due to erosion, a habitat can be here today and gone tomorrow, but the important thing is to verify the potential conditions for spontaneous reformation. It is therefore a case of overcoming a singular vision related to a habitat's presence / absence at a given time, and evaluating the potential over a wider temporal and geographic arc instead.

Sandbar stabilization

Regarding the issues of management and restoration of the sandbars and coastlines in general, the Italian experience is different to the international experience. For an example of a major restoration programs currently being carried out, one only has to look at that of the Barrier Islands along the Gulf of Mexico coastline, especially near the Mississippi Delta, which is a strategic component in the defense of the entire estuarine system (Khalil, 2008; Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority, 1998). In the restoration of coastal environments, a now widely shared approach is that of looking for solutions that integrate with the natural dynamics, favoring and channeling morphogenetic processes in order to maximize the environment's self conservation ability (homeorhesis), bringing a dynamic equilibrium between erosion and structural factors to the beach-dune system (Rose, 2009; Thompson, 2011). This type of restoration approach and management of coastal dune systems, aimed at ensuring flexibility and adaptability to changing environmental conditions, is of particular importance today in anticipating rising sea levels and the intensification of marine-related weather events associated with climate change.

The planning solutions envisaged for

Figure 6a: double row zigzag windbreak structures, Stone Harbor, New Jersey. (picture: www.flickr.com; Photo: Makz, 2006).

the *Scardovari* sandbar fit into this picture, aiming to favor and channel both present and future morphogenetic dynamics and ecology towards ever more resistant and resilient dynamic equilibrium conditions. In applying these criteria to the restoration of coastal systems one has to bear two important yet limiting factors in mind: the availability of natural sediment fills, resulting from coastal sediment transport and wind transport; and sufficient space for the ecological succession predicted (Nordstrom, 2008). The first factor is a critical issue, not only in Italy but also in most coastal environments in that the widespread interventions carried out in order to stabilize and manage hydrographic basins, and the removal of aggregates from waterways has drastically reduced downstream sediment transport (Simeoni et al., 2007). This often requires, in the restoration of coastal environments, beach nourishment through the application of sediment, with movements to orient the evolution of the profiles if need be. In the case of the *Sacca di Scardovari* the sediment available for beach nourishment is derived from the integrated management of the sandbar/ *sacca* system, which provides for the re-use of the material resulting from dredging carried

Figure 6b: brush windbreaks positioned at the foot of existing dunes to intercept the Bora wind transport blowing across the coastline (Alberoni, Venezia). (Photo: A. Bonometto, 2012).

Figure 6c: an example of a windbreak module and sand deposition (Photo: A Bonometto, 2012).

out in order to maintain the hydrodynamic efficiency of the mouths and the *sacca* in general.

These origins inevitably involve the use of different size sediments, that are at times very fine and may vary according to the localization and depth of dredging, creating high criticality and imposing, if tending towards the morphogenetic evolution conforming to the naturality and functionality of the dunes, the use of the same sediments according to the different localization and stratification criteria, favoring, where possible, classification processes and avoiding armoring or compaction phenomena that limit and possibly prevent wind transport (Nordstrom, 2008; Gianoni et al., 2010). The second limiting factor for the development of complete ecological succession on the Delta sandbars is the shallowness of the sandbars themselves, sometimes exacerbated by subtraction of space due to infrastructure and more generally the anthropic use of the territory; to which can be added, as in this case, very intense local natural erosion.

The establishing of a sufficiently evolved ecological succession, so as to

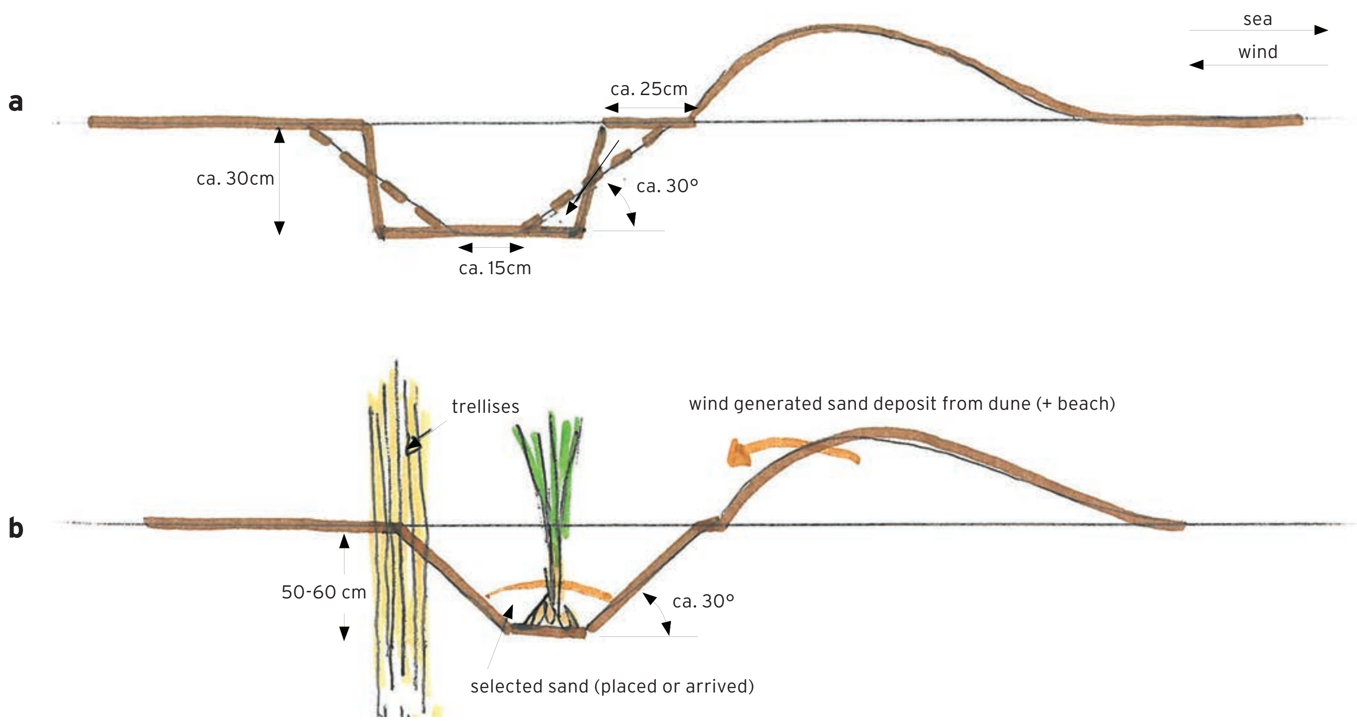


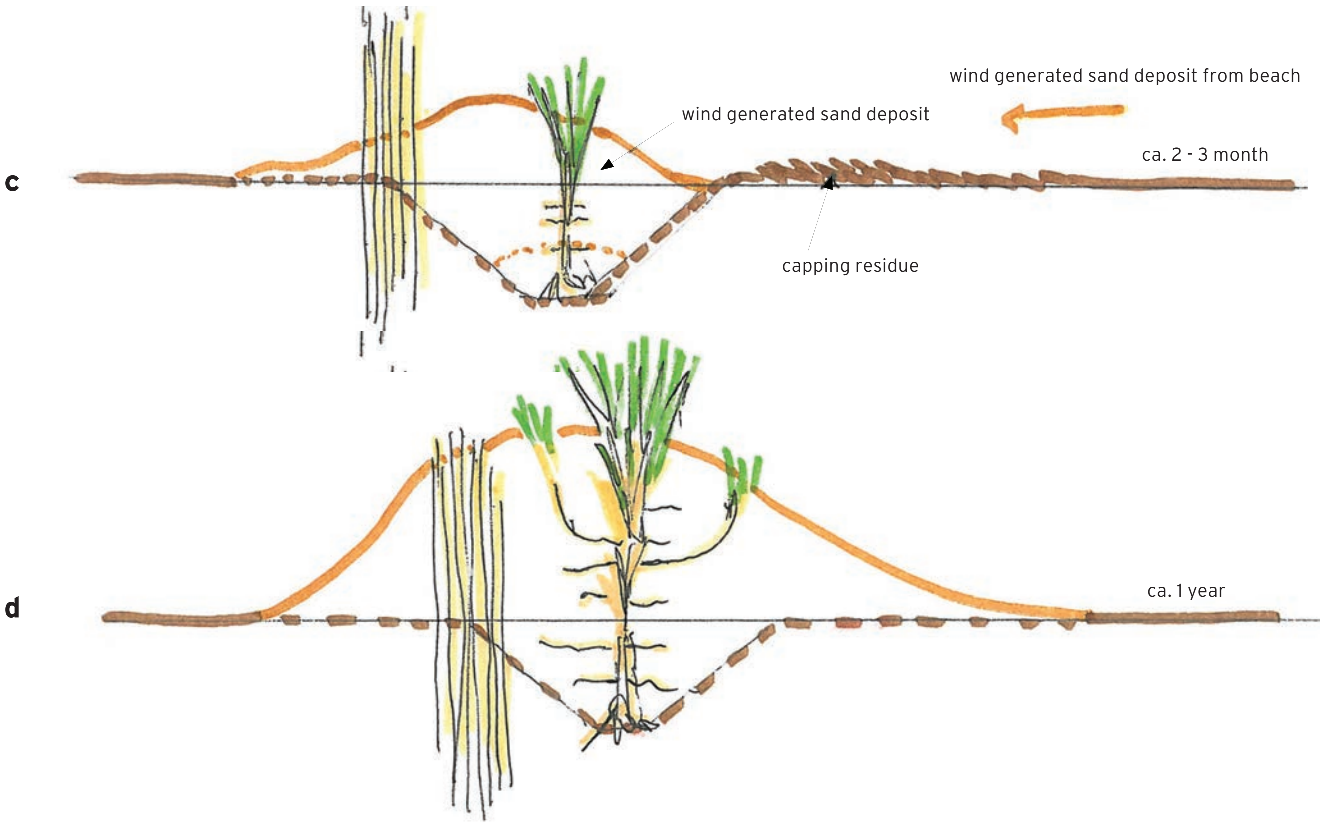
Figure 7: an upper beach *Ammophila* system. Planting phases (a, b) and foreseen developments (c,d). The dark brown lines represent the profile of the sand reflow present in the moment of planting; the light brown lines are profiles of the wind generated sand deposits.

ensure the functionality of the environment from an ecosystem point of view, is a fundamental prerequisite for the success of these interventions, at least in the sea-facing side where the formation of a proper active zone that stretches from the first pioneer groups to the "gray" dunes is of particularly importance from a morphological and functional point of view. It should be underlined how very important these dune environments are to morphological functionality, both for their ability to dissipate the temporary increase of wave energy during the more intense storm surges (Thompson, 2011) and for their role as a "sediment tank " in the exchange of sediments with the beach during nourishment and for the natural restoration of morphological quotas in exceptional marine weather erosion events. Furthermore, the presence of barriers of dunes on the sandbars restricts overwash phenomena, avoiding the consequent loss of sediment, instability and breaches.

Regarding the sandbars in general, different solutions should be planned and evaluated for the sea facing side, the internal surfaces and the lagoon facing side, depending on the different hydrodynamic and wind forces that induce and channel the evolutionary process. The main intervention criteria for the Scanno di Scardovari are as follows.

- On the sea-facing side, for the entire depth directly affected by the marine weather process and wind sand transport, after the implementation of the basic structures for the formation of the sandbar (shoreline and ebb flow), interventions should be aimed at orienting and favoring the morphogenetic constructive factors conforming to the natural ones. The final balance profile should therefore be achieved thanks to the spontaneous recharging processes induced by the said interventions.

- In the internal surfaces of the sandbar, which correspond to the zone occupied by the stabilized dunes, the actions will lead to almost finalized structures,



only leaving the settling of morphologies to the spontaneous dynamics (somewhat weakened by the absence of significant sand recharge).

-On the lagoon-facing side the transitional environments will be planned foreseeing works that will bring about morphological structures that are close to those expected, leaving remodeling functions, essentially those of improvement and expansion of intertidal surfaces, to the tidal lagoon dynamics.

Different methods of intervention should be adopted in relation to the current morphological and sedimentological features of the sandbar, arising from past interventions and the evolutionary processes induced (Figure 3). Specifically, the element that basically differentiates the sandbar from its interior, imposing appropriate intervention strategies, is the artificial heterogeneous embankment in the central part (Figure 3, C1), which requires specific, stretch-by-stretch evaluations in relation the following variables:

- distance between the various points of the embankment being examined and the sea (adequate, excessive or small);

- morphology (dimensions, depth, slope, etc.) and the dynamics of the embankment compared to natural conditions (it is important to assess whether they are similar to or far from natural equilibration dynamics);

- sedimentological characteristics of the sand (especially checking for selected sand, unselected sediment with silty, clayey or gravely elements);

- ongoing processes of erosion / removal, or the recharging of sand by the wind, on the different section fronts and surfaces.

These variables are of primary importance for the identification and adoption of intervention strategies in that they differentiate surfaces allowing one to identify areas that require only minor interventions, based on the principle of favoring eco-morphological processes that conform to the natural processes, and those in which more substantial interventions are necessary such as beach nourishment and / or sediment movement. Certain widespread and often synergistic types of intervention can be used to initiate the morphogenetic processes aimed at the formation of typical coastal environment ecological succession:

- input and movement of sediment, with modeling of surfaces;

- insertion of windbreak structures designed to interfere with the wind removal-transport–accumulation of sand;

- introduction of basic plant species in the activation of morphogenetic consolidation and construction processes.

As well as being used for beach nourishment, sediment input and the eventual movement thereof can be useful in accelerating the reconstruction process of the dune ridges. To this end the embankments are to be designed with heights that are possibly lower than those expected, so that the said heights are reached with the subsequent deposition of sand selected by the wind transport.

Rigid structures can be useful in protecting beach nourishment from more intense storm surges and intercepting sediment transport along the coast, but must be carefully planned and designed, taking into account the large scale effects so as not to interfere negatively, aggravating erosion problems downstream. Furthermore, the use of rigid structures may be necessary to limit and confine the mobility of sandbars according to specific needs: in the case of the Scardovari sandbar, to ensure the hydrodynamic efficiency of the mouths limiting burying.

Windbreak structure

To trigger and/or accelerate the morphogenetic processes related to wind energy, windbreaks structures able to "capture" and retain sand carried by the wind are both cheap and widely used. These structures reduce wind speed locally and cause small dissipative vortexes, favoring the deposition of sediments and the formation of dunes. In order for the dunes begin to form and develop at the expected increased quota, certain basic requirements must be met (Khalil, 2008):

- there must be a recharge area that is big enough for wind transport consisting of an either poorly or non-vegetated and unsaturated (usually dry) strip of beach;

- wind speed must exceed the threshold for periods of time that are long enough to move and transport sediment;

- the depth, angle and height of the beach must be such as to dissipate the incoming wave energy on the dunes in neo-formation. Conversely, beaches that are too high limit their interaction with the sea and marine hydrodynamic forces, reducing and at times impeding the continuous recharging of sand and the structuring of sediment, leading in some cases to the phenomena of beach armoring (Nordstrom, 2008).

There are numerous types of windbreak structures, their primary differences being the materials from which they are made (e.g. wooden palisades, reed lattice, strips of branches or Spartina versicolor etc.), their orientation (rectilinear, sloping, brush, zigzag, open or closed groups – see Figure 6), height (generally between 50 cm and 1.2 m) and by number of rows.

Their porosity is the only parameter in which there seems to be substantial concurrence, referred to as optimal in values ranging from 40 to 60% (Coastal Engineering Research Center (CERC), 1984; Khalil, 2008; Nordstrom, 2008; Florida Department of Environmental Protection, 2006; Grafals-Soto e Nordstrom, 2009). The following paragraphs propose, according to its site-specific needs and in comparison with the different techniques available, some possible solutions deemed suitable for the formation of dune systems in the *Scanno di Scardovari.*

The use of vegetation for morphogenetic purposes

The planting of psammophilic vegetation in the restoration of dunes, often associated with the insertion of windbreak structures, is carried out with two different objectives that are in most cases contextual and interdependent:

- to activate, support and accelerate the construction and stabilization processes of dune systems, mostly in the bands of embryonic and "white" dunes, favoring the capture of sand and the resulting consolidation ensured by the root systems;

- to have an anti erosion role protecting existing dunes, not only in the lower parts where the beach is not very deep (a condition that might favor the erosive and not constructive effects of the wind, or even cause the winter storms to reach the dunes), but also in the internal surfaces where the changing environmental conditions expose valuable environments and grey dunes to abnormal winds.

Morphogentically speaking, the two most important species on the Adriatic coasts are *Ammophlia littoralis* and *Elymus farctus* (Thompson, 2008; Speranza et al., 2009; Bonometto, 1992), thanks to their stabilizing and constructive functions. Important ecological and therefore technical differences can be seen in the localization and roles of the two species:

- Elymus farctus supsp. farctus (= *Agropyron junceum* = *Elytrigia juncea*) is a constructive species that plays a very important role in the initiation of colonization processes and the formation of embryonic dunes, starting from their initial dimensions and distances not reached by the usual storms. The species' position in front of the sea fa-

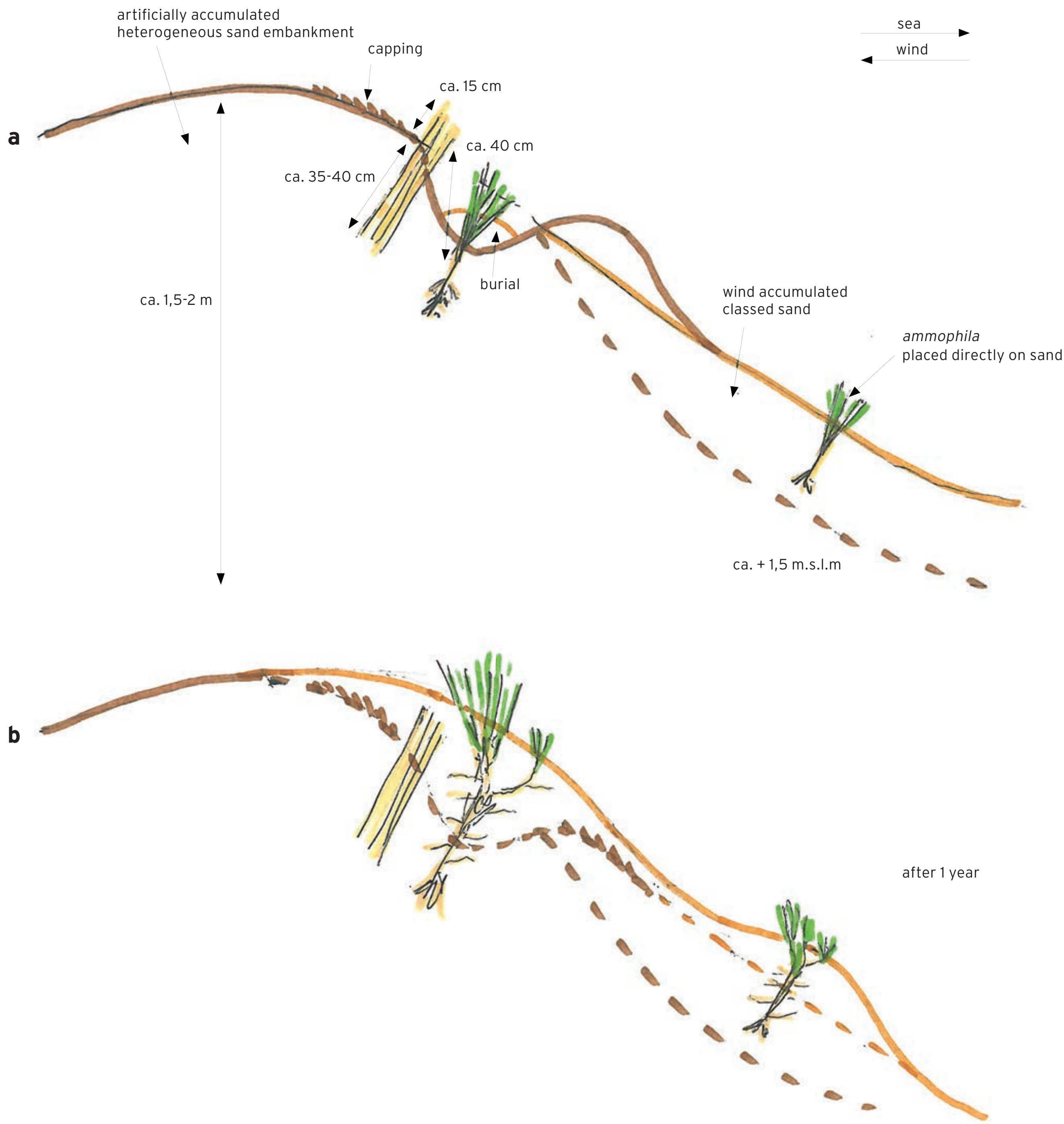


Figure 8: initial phase and the first year of evolution and of *Ammophila* plants on the artificial embankments. For sand colours see Figure 7.

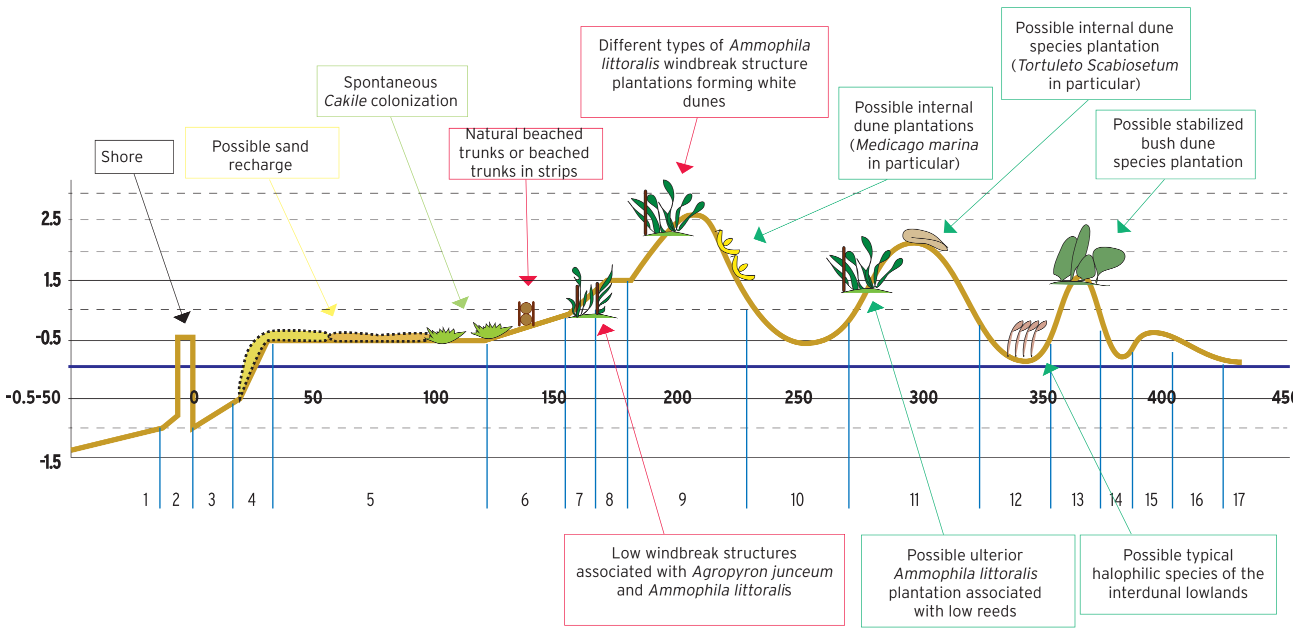


Figure 9: transect type, with scheme of initial morphology, extending where possible through reflow, remodeling, and subsequent interventions aimed obtaining (potentially at least) an ecological succession conforming to the natural one (own elaboration). The numbers in normal font refer in meters, on different scales, to the quotas of the average sea level and distance from the shore, while the numbers in italics refer to the sequence of the different elements or environments, according to the following sequence.

1: sea;
2: artificial reef;
3: submerged surface between the reef and beach;
4: foreshore (intertidal zone);
5: beach and initial colonization zone;
6: first embryonic dune;
7: Agropyron dominated embryonic dune;
8: embryonic dune with initial *Ammophila* growth;
9: white dune
10: initial interdunal lowland;
11: initial grey dune
12: wet interdunal lowland;
13: consolidated dune plantation;
14: halophilic lowland;
15: terminal undulation;
16: lagoon facing margin;
17: intertidal lagoon and watery surfaces.

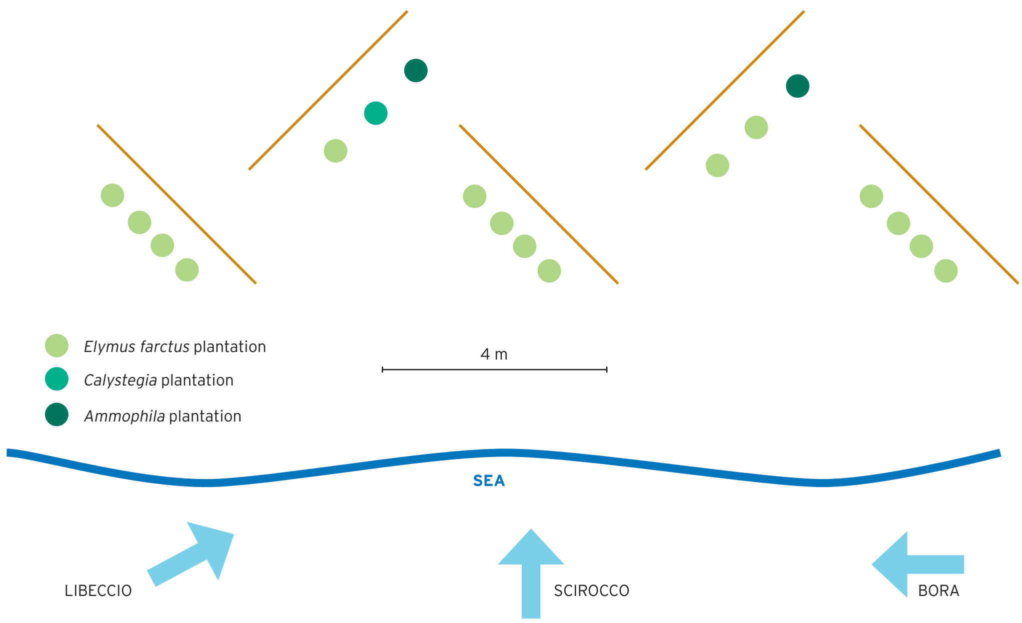
vors sea spray and eventual contact with salt water. An indicator species of *Sporobolo arenarii - Agropyretum juncei*, in addition to its high resistance to salt, requires less sand input than *Ammophila*, making it also suitable for the restoration of differing areas of the dune. *Elymus* is frequently associated with *Calystegia soldanella*, a species that creates ground covering surfaces on gentler slopes, which is not found on the sandbar.

- *Ammophlia arenaria subsp. australis* (= *Ammophila littoralis*) is the main constructive species, as well as dynamic equilibrium and evolutionary element between the sand, wind and vegetation that enables the natural construction and consolidation of the dunes. An indicator species of *Echinophoro spinosae - Ammophiletum arenariae*, at distances and quotas at which the direct effects of proximity to the sea normally weaken, it takes the place of *Elymus*.

The success of the system interventions is linked to the biological and ecological characteristics of the species, primarily for *Ammophila*'s need to be gradually planted in sand with a selected grain size in order to develop itself and consequently, the dune too. In fact, the growth of the plant is subject to the emission of secondary root systems by the stem nodes, more than that of rhizomes and stolons that allow the tillering that follows with the expansion of coverage. The formation of rooted nodes follows the planting of the plant, with a density (and therefore ability to "arm" the dune) related to the amount of the periodic submersion by the sand.

The granulometric homogeneity of the wind transported accumulations of sand is of particular importance to the species and its functions, giving the substrate its physical and chemical characteristics (permeability-drainage, porosity, oxygeneity) necessary for its proper development; in the absence of such characteristics there is a lack of

Figure 10: diagram showing the intervention configuration aimed at developing embryonic dunes with the use of 50 cm high windbreak structures and the planting of vegetation (the distance from the sea is not to scale) (own elaboration).



growth and anomalous phenomena or degenerative phenomena (silty-clayey elements which, when dry, appear in a powder form, retain moisture and in fact, block the interstices, hindering oxygenation by triggering processes of decay similar to those that can be seen in the older tufts in the internal areas) are established.

This has already occurred, also in significant areas in the upper-Adriatic, in systems of unselected refilled sand and/or surfaces without sufficient wind recharge. The expected widespread use of *Elymus* and *Ammophila*, to which *Calystegia* can be added, requires a suitable preparation of the specific nurseries, in order to ensure adequate availability of specimens without the need to resort to excessive extractions from the environment. At this point these areas can be organized for the production of the main species that in nature, synergistically accompany those outlined above, in order to revitalize the stabilizing dunes, the wooded dunes and the inter-dunal lowlands.

Sandbar system types

The interventions' adherence to the biological and ecological characteristics of *Ammophila*, in particular the fact that the species requires, in order ensure its constructive abilities, to be gradually planted in sand with a selected grain size, can be ensured during planting even through simple interventions; in these cases the inclination of the surface (beach or embankment slope) and the possible presence of sand that has already been selected by wind action are important variables in the site in question.

In order to enable the deep planting on selected sand surfaces, some simple preliminary operations are necessary for surfaces with heterogeneous sediment refill, consisting simply of the realization of holes or trenches with depths corresponding to or exceeding that of system, in which wind-blown sand can be deposited. Here follow some operational proposals (Figure 7 and Figure 8), which differ depending on whether one plants isolated tufts or rows, and the systems that appear on slightly inclined (the upper area), or very inclined surfaces (slopes of the artificial embankment). In any case, the requirements are the same: the digging of holes or trenches of a suitable depth and width; the upwind accumulation obtained by the input of removed sand; reed lattice elements (or similar) to trap the sand. In both examples one expects to plant in groups of three to five rooted trunks, preferably including the rhizome parts with multiple nodes, obtained by fanning out the tufts removed from the nurseries or the environment. The interventions should be adapted to suit the site-specific characteristics of the sandbar with solutions that can be adjusted however slightly each time according to the planting site and period.

Ammophila plantations and foreseen developments in the upper beach heterogeneous reflowed sand

In the upper beach area the planting of *Ammophila* (together with *Elymus* and possibly *Calystegia*) is carried out on very gently sloping surfaces, in order to activate the formation of a first line of embryonic dunes. The objective requires the use of light supporting structures, capable of starting the expected processes by quickly integrating itself, and conforming to what happens in nature, leads to the proposal of sparse planting schemes, with distanced single tufts or with short lines starting from a quota of considerably less than two meters; the subsequent growth of the plant/sand systems will determine the fusion of the tufts and will reach the height two meters, on a reinforced embryonic dune connected to deep layers due to the gradually buried parts of the plants.

Figure 7 shows the planting stages (a, b) and the schematization of foreseen developments (c, d). This example refers to the system of individual lines of *Ammophila*; similar solutions with double lines could be realized through the creation of a dual trench with reed lattice in the middle, so as to exploit the accumulations of sand that form on the trellises in front of the area that is exposed to the wind, as well as those to the rear caused by downwind vortexes, in order to form the first undulations.

Phase 1 (Figure 7, a): digging a hole (or trench if for a line of plants), with upwind accumulation (sea facing side) of removed sand (this accumulation is the first source of sand for the gradual filling of the hole due to wind transport). A depth of about 30 cm is required; regarding width, one should bear in mind that the section will be affected by rapid subsidence of the edges before settling at an inclination of approximately 30 ° ("natural slope" of the sand).

Phase 2 (Figure 7, b): an initial quantity of selected sand of 10 to 15 cm (taken from a nearby source or obtained by sieving), should be placed on the bottom (this step can be omitted if the pit has been realized in advance guaranteeing a sufficient amount of equal spontaneous accumulation due to the effect of wind transport; it may also be omitted if the plants are already in a biodegradable container filled with a fair amount of selected sand). The system is planted by covering it with the selected sand at the bottom, possibly supported by a single reed. Downwind, about 25-30 cm from the plant, a reed lattice is fixed vertically to act as a trap until the tuft is able to carry out this function by itself once it has grown. The reed lattice, between 100 and 120 cm tall, and adapted to the size of the hole or trench, is buried just over halfway, with 40 to 60 cm protruding (with single plants a concave towards the sea is preferred).

Phase 3 (Figure 7, c): About 2-3 months after planting (depending on the age of the plant, the weather and wind transport intensity) the process should be well under way. In fact, the hole or trench should already have been filled as a result of the sand blown by the wind coming from the adjacent accumulation and beach; an initial undulation on the trellises, in part covering the Ammophlia; a good entrenching of the plant, having got over the shock of its transplanting, and the beginning of secondary root formation processes are expected. (In correspondence with the accumulation there should only be one layer of unearthed

PRINCIPLES AND PURPOSES

1. To Guarantee the sandbar's presence at sea and hydrodnamism.

2. To protect and consolidate existing environmental value.

3. To recuperate ecological functions (transitional habitats, reticles, dynamisms).

4. To activate habitat diversification mechanisms and the formation of new habitats of quality.

INTERVENTION AREAS

A The consolidation and improvement of the structure and dynamics of the sandbars.

B The protection and encouraging of the neo-formative dynamics of salt marsh and transitional areas on the margins of the lagoon.

C The recuperation of habitats and transitional functions between water surfaces and land through structural interventions on banks both on the water-side (salt marshes, mudflats etc.) and on the land (woodlands, bushes, freshwater areas etc.).

D The creation of a freshwater biotype in the lagoon through the controlled intake of reclaimed waters and the creation of a submerged embankment.

E The improving and valuation of ecological connections with inland habitats.

F The guaranteeing and improving of hydrodynamism within the lagoon based on the ecological objectives for the two sub-lagoons.

G The reinforcing of sructural and functional separation / transition elements between the two lagoons (relating to D).

Figure 11: overview of recuperation interventions in the Sacca degli Scardovari (own elaboration).


E
F
C
D
G
C
F
A
B

shells remaining, the removal of which should be considered). It 's very important that what is expected is affirmed by the summer so that the plant, possibly planted in late winter-early spring, is able to cope with the combined effects of drought and summer temperatures.

Phase 4 (Figure 7, d): After about 1 year the dune will have grown significantly, almost completely covering the trellises as a result of winter wind deposition. The growth of *Ammophila*, which seemed to stop at the end of autumn, but actually continued growing and differentiating underground through the winter, will have permitted spring tillering and consequently, maximum growth. The embryonic dune should appear in summer having grown at least 60 cm, the trellises should be buried, so that the development that follows will be completely natural in character, the tuft of *Ammophila* should be wide and dense, with deep growths of rhizomes-stolons and the initial vegetative formation of collateral elements.

Ammophila plantations and foreseen developments in the artificial embankments on heterogeneous reflowed sand

In particular, this condition applies to the remodeled embankments with morphology that is closer to those of natural dunes, where there is a range of effects between the slope and the top, caused by wind. Many sections of the sandbar slope show a consistent deposition of sand transported and deposited by the wind, thicker than 20 cm in places, thus permitting the direct planting of *Ammophila* (Figure 8); on the contrary, the top of the slope shows effects of wind erosion towards the sea, with exposure of sediment deposits and local effects of armoring that blocks morphogenetic dynamics. Below these tops there is an *Ammophila* plantation that is particularly useful in triggering the deposition of sand on the top, and the consequent growth of the dune. The principle behind achieving good entrenchment and growth of the tufts is similar to that considered in the previous type, with some differences due to inclination and altitude. It is a case of digging holes just below the ridge (not trenches, so as not to trigger land sliding effects) in the areas marked by erosion (Figure 8, a), that are deeper than the previous types, having to compensate for more dehydration due to exposure to the wind and more drainage due to altitude and inclination.

The excavation takes place on an angle and this provokes more extreme verticality of the slope upstream, the giving way of which must be prevented by means of piling before the excavation of the inclined trellises. The same plants are planted with the submerged part at an angle (Figure 8, a), to improve stability and ensure larger distances from the surface roots exposed to wind dehydration and high temperatures (highest in the south-facing slopes).

The high drainage of the slope sand calls for a deep trench of about 25-30 cm, revealing only the tops of the plants in order to maximize the rooting and anchorage functions of the submerged parts. Apart from this, the method is the same as the previous type; it is clear that by placing tufts in individual holes, one will initially get fragmented lines and wavy ridges (Figure 8, b), so it would be better to use plants with slightly differing heights, which require at least a couple of years to create a compact front.

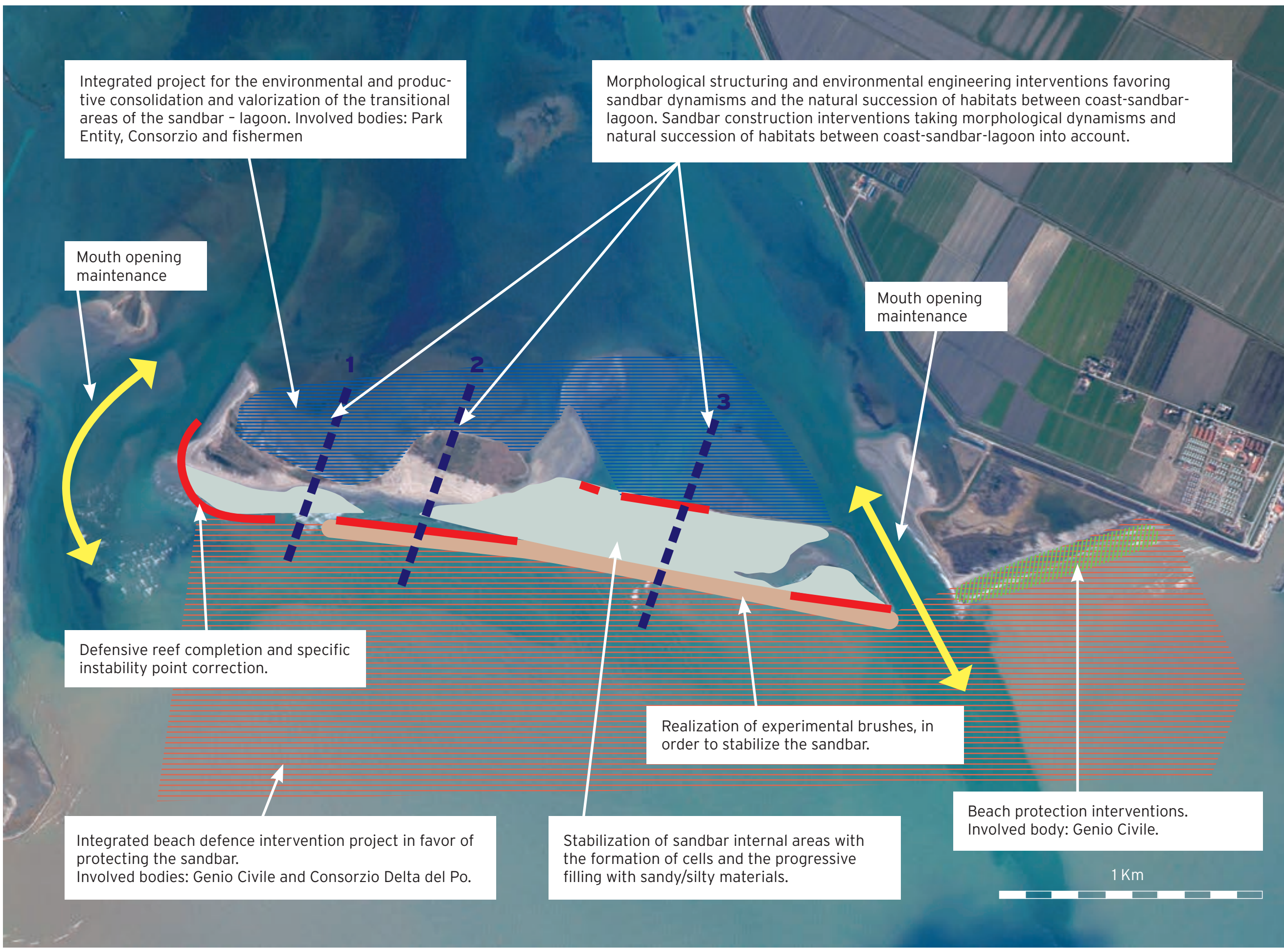
Phase 1 (Figure 8, a): Schematic planting profile. Consisting of: the original profile of the artificial embankment (brown dashes) and that following the spontaneous deposition of selected sand (beige line); the digging of a hole and its filling with sediment downstream just below the ridge subject to wind erosion, with reed lattice protection; the *Ammophila* planting method with that placed inside the hole being buried.

Phase 2 (Figure 8, b): Expected results after the first year, with remodeling of the surfaces due to the accumulation of sorted sand (in beige), covering the top, and expected *Ammophila* development with secondary root platforms.

Sandbar stabilization intervention proposals

The criteria and types of intervention defined can be put into practice according to a general scheme defined by the "transect type" (Figure 9), which summarizes possible types of restoration actions according to detectable and/or actionable ecological succession in general on the sandbar. This scheme represents a basic reference for the executive planning phases, showing a general indication of the interventions planned for each area. It is important to note that environmental groups 1-4, the natural forces and morphogenetic processes subsequent to refilling and remodeling are exclusively due to marine factors; in groups 5-9 they are due to the prevailing wind dynamics; and in 10 to 17 due to attenuating and stabilizing adjustment processes.

The diagram in Figure 9 represents ideal conditions that are only possible in some areas of the *Scanno* di *Sacca Scardovari*. Actually, a factor that widely affects redevelopment projects inherent to environmental protection purposes is the shallowness of the sandbar (also common to natural sandbars), which limits its



possible development towards the inside typical of coastal ecological successions thus limiting, in large parts, distances that favor more mature internal stabilized dune habitats. One should note that site-specificity and certain experimental characteristics of these interventions favor the gradual implementation of interventions and constant monitoring in order to evaluate their effectiveness and make appropriate changes if necessary over the course of the work. Furthermore, different solutions can be experimented with in the initial phase on a first portion of interventions, in order to select and fine-tune those that are more efficient and that could be applied to the entire sandbar.

Arrangement of windbreak structures and constructive species plantations

In the strip of embryonic dunes, in order to promote development, the planting of *Elymus* farctus and *Ammophila* littoralis is foreseen, with the possible addition of *Calystegia*, together with the implementation of low windbreak structures (about 50 cm). In relation to the transverse direction of the prevailing winds characterizing the sandbar (*Bora* and *Libeccio*), the positioning, as an experiment, of the trellises in two rows in modules of about 4-5 m diagonally to the

Figure 12: morphological structuring, protection and environmental engineering intervention guidelines for the sandbar and adjacent areas (own elaboration).

coast (Figure 10), with the second row oriented perpendicular to the first, in order to increase its ability to capture sand (Nordstrom, 2008, Grafals-Soto and Nordstrom, 2009), is considered favorable.

The two rows of trellises must be close enough to create embryonic dunes intended to coalesce into a single system over a width of about 10-15 meters (Figure 9, zones 7 and 8), bearing in mind that, as reported, the expected inclination of the growing dune system will be about 1:4-1:7 (Coastal Engineering Research Center (CERC), 1984). An indicative scheme of the configuration of the intervention aimed at developing embryonic dunes with oriented modules in relation to the prevailing winds is shown in Figure 10. The different inclination of the modules of the two rows of windbreak structures is for maximizing the interception of wind transport generated by the two prevailing winds blowing obliquely across the coastline (*Bora* and *Libeccio*). Furthermore, it helps to limit the formation of currents flowing parallel to the structures and the consequent removal of sand in the event of sea storms reaching the edges of the embryonic dunes.

The previous examined examples refered to area of the sandbar that had already been refilled and that were characterized by artificial embankments, as opposed to the refill on areas that tend to be flat (most importantly, zone "e" in Figure 3). In these, in the zone corresponding with the first row of dunes (zone 9 of the transept "type" in Figure 9), the positioning of high windbreak structures (1-1.2 m) should be carried out in one or two rows, depending on the slope of the embankment caused by sediment movement and the width of the dune required. In cases in which there are two rows, an optimal distance between them of 4 times their height (about 4-5 meters) is recommended (e.g. Khalil, 2008). The arrangement of the structures can be both diagonal modules (of approximately 10 meters in length), or "zigzagging" rows (Figure 6a, 6b, 6c), but both are solutions used for prevailing winds blowing diagonally to the coastline that lead to a more natural morphology (Nordstrom, 2008).

The planting of *Ammophila* in front of and/or to the rear of the windbreak is foreseen with the installation of the structures (Figure 7). Also in the first zone of dunes, but in particular near the already existing embankment, *Ammophila* will be planted at the base and on top of the sea facing slope, in ditches formed on oblique surfaces, with supporting low reed lattice trellises (about 50 cm in height) of limited length (approximately 2 m) to the rear, in order to reinforce the upper margin of the ditch (Figure 8).

As in nature, sparse *Ammophila* plantation schemes of individually spaced tufts or short rows are foreseen: it is the subsequent growth of plant/sand systems that will determine the enlargement of the base, the consequent fusion with those nearby, and the eventual formation of ridges of dunes.

Maximum distance between the plants is about 0.75 cm - 1 m, which would require about 2-3 years for a continuous ridge to form. Ammophlia coverings are dominant in dunes that are higher than about two meters. This means that, similarly to that which occurs in nature, the plantations should be planned so as to start from a lower height, so that the height of two meters is achieved with dune growth and the continuous emergence of species from the accumulated sand, which will thus be reinforced and connected to the deep layers thanks to the gradually buried parts of the plant.

Conclusions

The stabilization of the *Scardovari* sandbar is of primary importance to the general scenario of valorization interventions in the *Sacca*, thanks to its determining role of maintaining the Sacca itself. Interventions on the sandbar form part of a comprehensive framework of action (Figure 11) aimed at, on the one

hand, ensuring ecosystem and production functions in the area, and on the other, at improving the *Sacca*'s overall ecosystem, with particular focus on recuperating ecosystem deficits.

The presence of the *Scanno di Scardovari*, and its permanence, are crucial to ensuring the morphological and hydrodynamic conditions of the lagoon, while maintaining the typical characteristics of the transitional water; followed by the stabilizing of the sandbar, at least in a fairly large central portion, is the essential medium-term objective for the conservation of the lagoon ecosystem as defined by its qualitative, functional and productive characteristics.

The study enabled us to confirm that

Figure 13: the central part of the sandbar, early environmental engineering works 2011 (photo: P. Gianoni).

the formation and management of the sandbar requires an approach based on an evolutionary concept that integrates anthropic intervention and natural dynamisms. From this viewpoint, the knowledge of the phenomena of the formation and erosion of sandbars and dune systems should be the basis of any intervention project that aims to ensure the medium-term presence of stable morphological complexes.

. The analyses enabled the verification of the dynamisms as a basis for the defining of the interventions aimed at orienting the morphological evolution of the sandbar towards a dynamic equilibrium capable of guaranteeing as much resistance and resilience, and hence more overall stability, as possible in the system. Here follow some key points of particular importance to the basis of the project and the carrying out of future interventions to be integrally applied:

- Knowledge of the types of sediments moved is essential in defining their relocation on the sandbar, both with respect to positioning, and possibly to the stratification of refill; and it is for this reason, further to the traditional preventive analysis measures and specific methods of contract procurement, that the flexible management of materials according to their characteristics and their final destinations is foreseen;

- Vegetation plays a key role in the construction and reinforcement of the sandbars; planting interventions should therefore be planned whilst taking into account the general and particular conditions of the Scanno and the medium-term objectives of the project;

- The orientation and maintenance of the planted vegetation must be carried out for several years (initially 5) in order to ensure, not only the correct engraftment of singular species, but the functioning of the system, and the carrying out of necessary corrective measures;

- Constant monitoring of the morphological evolution with assessment tools (lidar surveys), the monitoring of the evolution of the vegetation (by phytosociological surveys on relevant plots, and the documentation of the development and species coverage), fauna and landscape observations (with photographic documentation of the evolutionary phases) are all essential to good medium-term results;

- Because the planned solutions are aimed at encouraging, orienting and strengthening the morphogenetic and ecological dynamics present, they require different solutions for the sea-facing slope, the internal surfaces and the lagoon facing side.

In the coastal and lagoon habitats adjacent to the sandbar, interventions should be integrated into specific larger scale projects developed in collaboration with the relevant entities, aimed at limiting erosion phenomena of the coast and the valorization of the lagoon areas as a whole. In a dynamic environment such as the sandbars, it is essential to overcome the sectorization of skills and move towards a unified overall planning system. In terms of planning, the general approach, in line with the natural dynamisms involves defining a rapport that is coherent with the height/depth dimensions of the sandbar, and identifying the correct sediments to form structures at the different heights and distances from the sea.

For the most part this amounts to stopping the remodeling and environmental engineering interventions the moment there are pioneer species (no further than the "gray dunes"), providing the necessary support structures to activate natural processes; only in areas where the sandbar is deeper (250-300 m, see Figure 3 section d), the objective could be to take the ecological successions as far as the formation of vegetated dunes, possibly compressing the successions so that they fit into the available space.

Early planning indications and surveys revealed some encouraging results, which to large extent confirmed the commencement of the predicted evolutionary dynamics. However, given the precariousness of the situation, as a result of the failure factors considered above, it appears that the monitoring on different levels over the next few seasons is necessary in order to adapt and implement planning and executive measures based on the gradual evolution in act.

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_VARIOUS ACTIVITIES
THE FAO-IMOLA PROJECT

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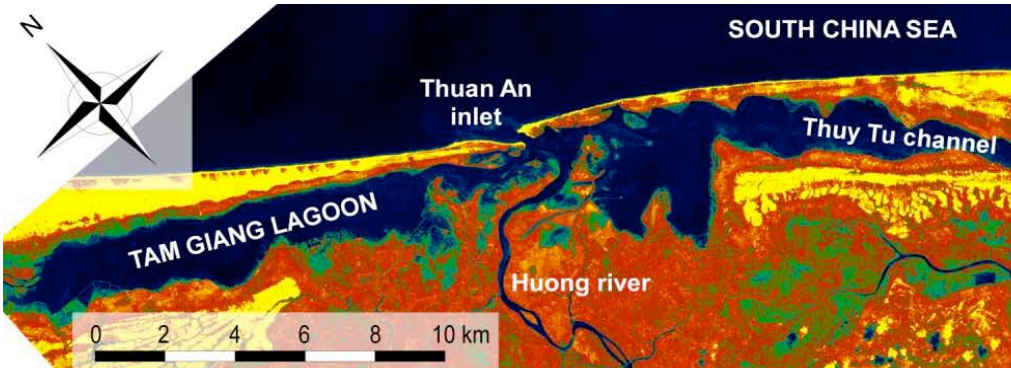
Consorzio di Bonifica Delta del Po

The general objective of the FAO IMOLA (Integrated Management of Lagoon Activities) project is to develop a plan for the sustainable management of the Tam Giang - Cau Hai (Hue, Vietnam) lagoon system's natural resources. Initiated in 2008, it is now in its second phase in which the *Regione Veneto,* through the *Consorzio di Bonifica Delta del Po,* has activated its *Progetto di Cooperazione Decentrata*.

This work concentrates on one of the priorities of the IMOLA project, which foresees the *establishing of a program for the environmental monitoring of the system and the hydrological modeling of the Tam Giang Cau Hai lagoon, to be implemented through automated environmental parameter detection methods and systematic lagoon morphology surveys*, that are essential to the design and monitoring of interventions within the lagoon environment aimed at the mitigation of ongoing environmental degradation.

In the light of experience gained in the coastal lagoons of the Po Delta in Italy, this paper aims to (i) broaden our knowledge of the mechanisms that can improve internal circulation of tidal currents and (ii) identify the areas of the lagoon that are characterized by lower water exchanges than others. The survey focused on the southern lagoon, from the Thuy Tu Channel to the Cau Hai lagoon, with particular focus on the Tu Hien sea inlet. The basic topographic and cartographic data were acquired from the GIS database made available by the IMOLA project technical office in Hue.

A partnership was established with the Hanoi Water Resources University, which has significant experience in the study areas, from which more specific data (bathymetric surveys, hydrological data and studies, tidal data) were acquired. Partnerships with local agencies were also established and data necessary for the compilation of a hydro-meteorological database containing chronological records of weather data and river water levels were obtained in order to characterize the system's seasonal regime. The most

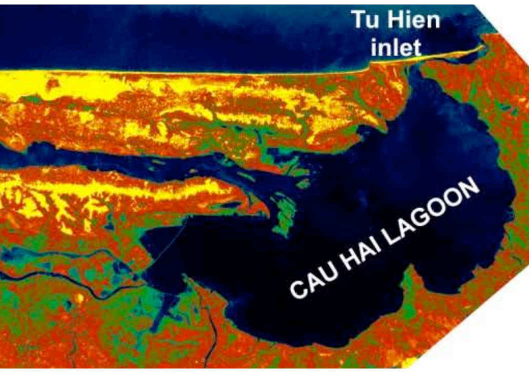


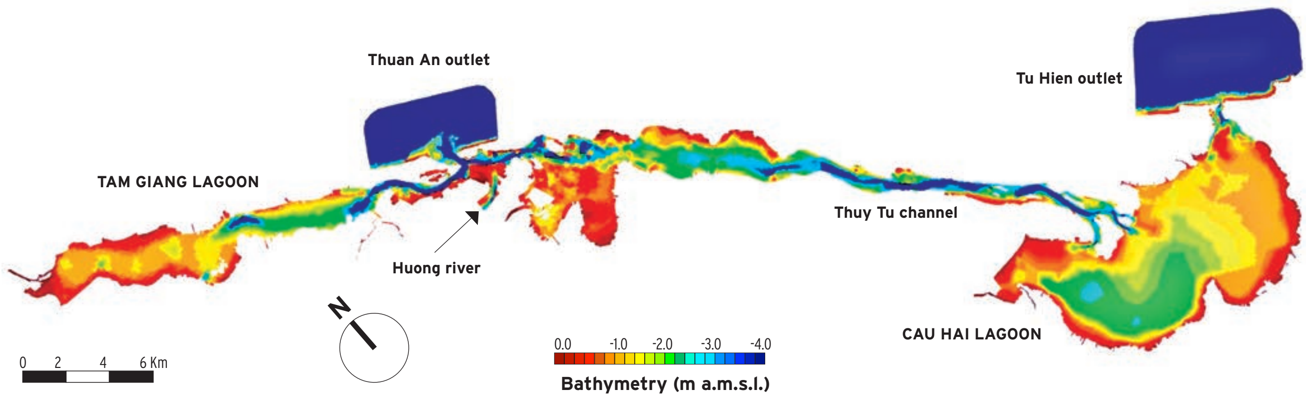
The Tam Giang - Cau Hai Lagoon.

relevant of the activities, however, consisted of carrying out field studies and the implementation of a mathematical hydrodynamic model of the lagoon.

The measurement campaigns, as well as being the first step in the IMOLA project's environmental monitoring program, are mainly for the collection of the data set required for the development and calibration of the mathematical model. The measurements focused on Cau Hai Lagoon, Tu Hien inlet and Thuy Tu Channel. Detailed bathymetric surveys, tide recordings, flow and current measurements at the inlet and along the main tidal pathways were conducted with an ADCP. CTD measurements were also conducted in order to map the distribution of temperature and salinity in the system.

The measurements were carried out by TE.MA. S.n.c. of Faenza, Italy from 15 to 22 April 2011, on behalf of the *Fondazione Ca' Vendramin* in collaboration with B. Matticchio and L. Stefanon as commissioned by the *Consorzio di Bonifica Delta del Po.*





Tam Giang - Cau Hai Lagoon hydrodynamic model computational domain.

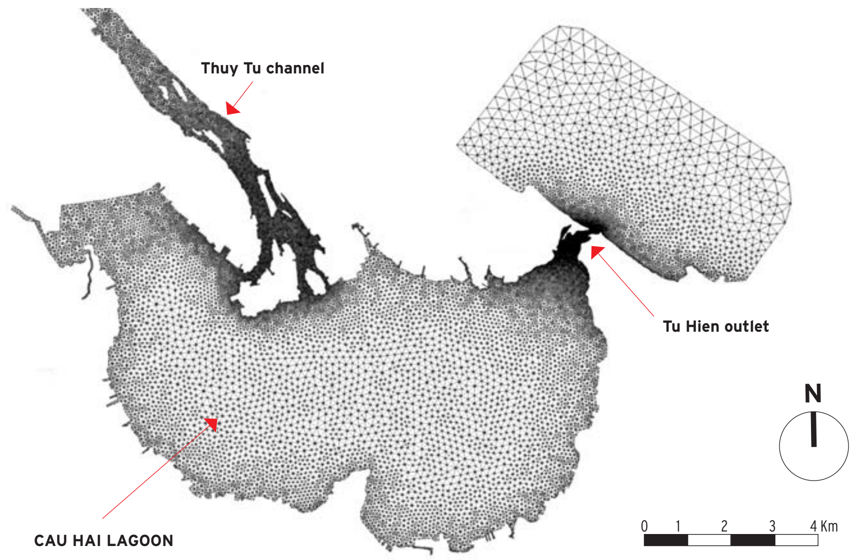
Logistic support and assistance was provided by the IMOLA team, which was coordinated by Prof. Massimo Sarti. Local operators provided the boats as well as directly participated in the survey (tide gauge measurements and salinity) after adequate training. The data collected, having been processed and validated according to the standards of the project, were made available in a GIS database.

Numerical modeling tools developed by the University of Padua, which consist of a series of modules based on a finite element formulation, and which allow the solving of different aspects regarding the hydrodynamics of the currents in shallow waters in a two-dimensional domain, including tidal levels and currents, dispersion of solutes and the movement of floating particles as well as sediment transport and wind generated waves, were used in the analysis.

A 3D baroclinic module was also employed to simulate the stratified currents pattern due to salinity differences. The model area was extended to the entire Tam Giang - Cau Hai Lagoon and portions of the ocean in front of Thuan An and Tu Hien inlets. The computational grid was constructed with cells of varying sizes in order to describe the morphology of the area of interest, i.e. Cau Hai Lagoon and Tu Hien inlet, in more detail.

The model was calibrated and verified mainly based on data collected in the April 2011 field campaign and other data collected in a previous campaign carried out by IMOLA in December 2010, in order to verify the tidal propagation results, the

Cau Hai Lagoon grid model.



magnitude of flow through the inlets and the Thuy Tu Channel, and the identification of the sub-basins pertaining to each of the two mouths. In order to identify the areas of the Cau Hai Lagoon most affected from a water exchange point of view, the mapping of the residence times was carried out, among other things.

The results identify an area next to the Tu Hien mouth (about 10 km^2) characterized by very low residence times (less than 6 days) and therefore has a considerable capacity for water exchange. Longer but still relatively short residence times (less than 30 days) characterize an area inside the lagoon of approximately 40 km^2.

In the remaining part of the Cau Hai Lagoon and along the Thuy Tu Channel, residence times are much longer (over 2 months), therefore these large portions of the lagoon basin are characterized by an almost complete absence of tidal action, thus water circulation and exchange is exclusively due to the much weaker and uncertain action of the wind.

The model was then used to analyze a series of scenarios involving different morphological configurations of the Thuy Tu mouth, including the possibility of proceeding with the dredging of the mouth. The results obtained can be useful in identifying possible interventions that may improve the quality and circulation of water inside the lagoon.

_VARIOUS ACTIVITIES
DELTA MED ASSOCIATION ACTIVITIES 2011-2012

LINO TOSINI
Director of the Fondazione Ca' Vendramin

The Delta Med Association, founded in 2002 by the General Comunidad de Regantes Derecha della Canal del Ebro and the *Consorzio di Bonifica Delta Po Adige di Taglio di P*o, and which today comprises representatives from nine different Delta and Mediterranean Wetland areas has, in line with its main objectives, continued to carry out its activities over the two year period 2011-2012.

Of the various activities undertaken, it is worth mentioning the constitution of the Delta Med General Assembly, which took place on 7 April 2011 at the General Comunidad de Regantes Derecha della Canal del Ebro headquarters and the Delta Med Association in Amposta (Tarragona), during which the activities carried out by the Association in 2009 and 2010 were preliminarily described, its economic management was accounted for and new member *Ente Parco Regionale Veneto Delta del Po*'s inclusion in the Delta Med Association was discussed. In particular, one should not forget that the 2010 Assembly that was due to be held in Alexandria, Egypt, was postponed due to political instability.

Among the particularly interesting topics discussed was that of Dr. Badawi Tantawi (Nile Delta) on the development of Delta Med rice varieties being carried out in the Egyptian research center in Sakha, where the selection of certain rice varieties is being studied in order to be presented as a joint project between Spanish, Italian and Egyptian representatives as soon as possible to enable rice to adapt to the issues of climate change and salt wedges.

On April 8 2011, the Delta Med Association organized a day of conferences on *"Futuro de la Agricultura en los deltas y zones humedes del Mediterraneo"* in which the following themes were dealt with:

- The issue of rice cultivation in the Mediterranean,
- The modernization of irrigation in Catalonia,
- The future of EU Agricultural Policy,
- The management of wetlands and deltas (in reference to the Po Delta),
- Water resources and agriculture in Egypt,
- Climate change impact and adaptation strategies in the Mediterranean deltas.

On this occasion Delta Med President Manuel Masià Marsà, presented Mr. Joan Maria Roig i Gran, the "Senador" of the Comunità Autonoma della Catalogna, with a document regarding the "Declaration of rice cultivation as an activity of special interest to the deltas and wetlands and of high ecological value to the Mediterranean Area", which had been signed by representatives of the various Delta Med regions in Valencia in 2003, in order for the aforementioned *Comunità Autonoma della Catalogna* to commit to submitting the said document to the relevant European Union department.

In August 2011, a delegation led by the President went to Cairo to observe the evolution of a new variety of Delta Med rice already in its last phase of development, and for which conclusive tests may later be carried out in order to define its behavior in Spain and Italy.

On December 5 2011, Delta Med, in collaboration with the Comunidad General de Regantes held a symposium at the 51st agricultural fair in Amposta in the Ebro delta. The topics covered were the evolution of the Spanish rice varieties in Egypt, with particular reference to those with higher yields and those that are more tolerant to extreme drought and high temperature conditions, as well as the development of irrigation techniques for the cultivation of rice and the efficient use of water in Egypt.

The engineer Lino Tosini, Delta Med representative in Italy, made a detailed presentation of the changes affecting the evolution of the Po delta and the problems of salt wedge ingress, in which Spanish participants were considerably interested in the proposed solutions and their connection with similar problems in the Ebro delta.

In 2012 Delta Med members were affected by the incumbent consequences of economic restrictions that all European Union countries encountered, thus resulting a reduction of intensity of the Association's activities. Nevertheless, its members continued in following the rice varieties' evolution in Egypt.

An interesting project developed in conjunction with schools and aimed at broadening knowledge of the environmental, morphological and productive reality of the Ebro Delta was also launched in collaboration with the Comunidad de Regantes de a Derecha del Ebro. This project's success means that in the future it will be extended to all the other Delta Med realities.

Delta Med general meeting at the head office of Comunidad General de Regantes del Canal de la Derecha del Ebro and the Delta Med Association in Amposta (Terragona).

_THESIS REVIEW
ON THE TIDALLY AVERAGED DIFFUSION IN THE VALLONA LAGOON (PO RIVER DELTA)

ANDREA DEFINA
Professor of Hydraulics at the Dipartimento di Ingegneria Civile, Edile e Ambientale (ICEA), Università di Padova

Graduate: **ALICE SGARABOTTOLO**
Civil Engineering Degree
2009 /2010 Academic Year

The thesis addresses the problem of hydrodynamic indicators, able to indicate the intensity of water renewal process effectiveness in shallow, micro-tidal basins. Up to now, residence time has been the most used hydrodynamic indicator; however, this time scale has not always proved to be significant in identifying critical conditions with reference to the problem of water renewal. This work proposes a different parameter, i.e., tidally averaged diffusion coefficient, which can, together with residence time, provide useful information on the state of a tidal basin and on the effectiveness of engineering works aimed at promoting lagoon-sea water exchange.
Andrea Defina

When planning tidal basin vivification works it is useful to have hydrodynamic indicators that are able to clearly show the effectiveness of the proposed works. To this aim, residence time (or, alternatively, water age) is by far the most commonly used indicator. High residence times are assumed to denote ineffective water renewal mechanisms that in turn indicate poor water quality. However, this relationship is not always respected, e.g., efficient exchange processes with the atmosphere can ensure good water quality even in the presence of relatively long residence times. In the thesis a different hydrodynamic indicator (i.e., not a time scale) is proposed: tidally averaged diffusion coefficient which measures the intensity, av-

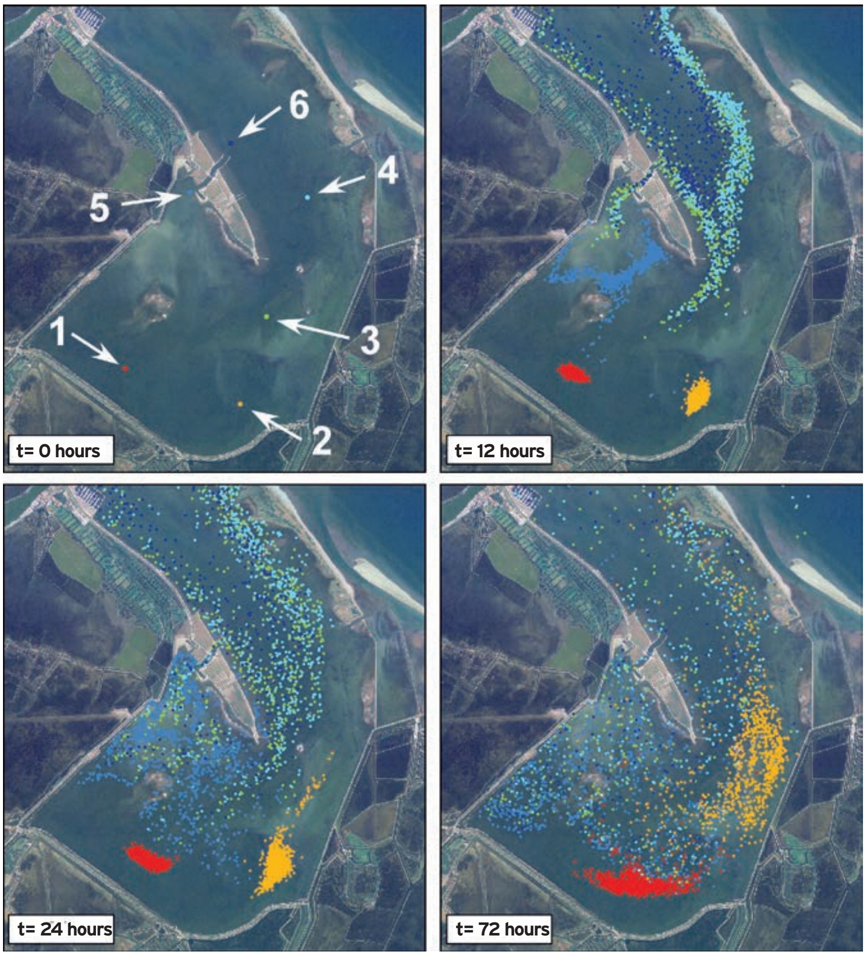


Figure 1: diffusive processes affecting six spots released in the Southern part of the *Vallona* lagoon.

eraged over a tidal period, of dispersion processes, hence the mixing efficiency of lagoon and seawaters. This indicator can profitably be used in conjunction with some time scales, such as residence time, to provide information on the state of a tidal basin and on the effectiveness of engineering works aimed at promoting lagoon-sea water exchange.The evaluation of the tidally averaged diffusion coefficient uses a Lagrangian particle tracking model coupled with a two-dimensional hydrodynamic model. With these models it is possible to reconstruct the transport and diffusion processes of clusters of particles, referred to as small spots, of a conservative tracer over a series of tidal cycles and, therefore, to assess the tidally averaged diffusion coefficient for each "spot", i.e., for each point where the spot was released.

Particles are transported by the average velocity provided by the hydrodynamic model and by a random fluctuating velocity whose intensity is related to the local and instantaneous diffusion coefficient; the latter is assumed to be equal to the eddy viscosity which is provided by the hydrodynamic model. A number of spots are released at different places within the lagoon, each spot being composed by a large number of particles; the trajectories of all particles of each spot are then reconstructed and the statistical analysis of particles displacement over a tidal cycle enables the estimation of the tidally averaged diffusion coefficient. This modeling procedure was applied to the Vallona lagoon as a case study. the Vallona lagoon, is one of the micro-tidal lagoon systems in the Po River Delta, intensively used for fishery activities. An example of the modeling results is given in Figure 1 where the different diffusion experienced by 6 spots released in the Southern part of the Vallona lagoon is shown.

The spots placed close to the mainland along the Southern edge of the lagoon (spots 1 and 2), experience relatively small displacements and a very weak diffusion: actually, these spots remain densely packed and their expansion, if compared with that of the other spots (in particular with spots 4 and 6) can be considered negligible. Intermediate diffusion characterizes spot 5 which, despite being released in a sheltered area, is affected by the current induced by the tide along the artificial channel that cut the *Santa Margherita* peninsula. The study analyzed the diffusive behavior of 550 spots, uniformly distributed within the lagoon and placed at four different moments during the tidal cycle, each delayed by 3 hours. The tidally averaged diffusion coefficient was computed for each spot, i.e., for each initial position of the spots, and for each instant of release; then it was averaged over the four moments of release. Once the mean diffusion coefficient was estimated for a large number of points within the lagoon, the map of Figure 2, showing the spatial distribution of the tidally averaged diffusion coefficient, was reconstructed by interpolation.

The results of this study confirm, even if only qualitatively, the capability of this parameter in identifying critical conditions with reference to the problem of water renewal (in the present case, very small tidally averaged diffusion coefficient is computed for the Southern area of the *Vallona* lagoon which is known to suffer low water quality). The next step is to determine, quantitatively, the effectiveness of this parameter through the estimation of any link between the tidally averaged diffusion coefficient and some bio-chemical water quality indicators (e.g., Chlorophyll a, dissolved oxygen, dissolved inorganic nitrogen), recorded in different lagoons of the upper Adriatic in particular.

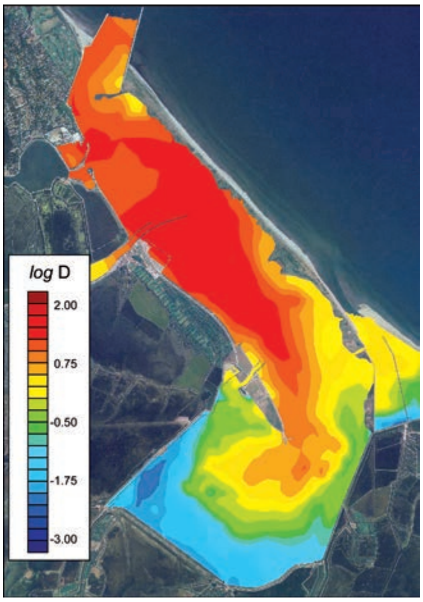


Figure 2: spatial distribution of the logarithm of the tidally averaged diffusion coefficient, D (m^2/s) for the *Vallona* lagoon.

_THESIS REVIEW
SALTWATER INTRUSION IN THE PO DELTA: PROBLEM OR OPPORTUNITY FOR THE TERRITORY? ADAPTATION PROPOSALS FOR AN INTERREGIONAL AREA

PIPPO GIANONI
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Graduate: **STEFANIA GIRARDI**
Doctor of Planning and Policies for the Environment - Università IUAV di Venezia

The thesis addresses the issue of salt intrusion and consequences associated with future climate change in a high risk area such as the Po delta via a systematic and multifunctional approach, comparing some similar situations in Europe and identifying specific directions in choosing coherent integrated defense measures, including adapting parameters and technical defense interventions. The consideration of defense as a single conservation act in the current state must be overcome with new integrated planning and design approaches also including the parameter of adaptation to the natural instability of the most vulnerable areas in policies and projects, while initiating new territorial management experiences based on more flexible and dynamic models.

The thesis was awarded the *Premio Speciale per la Salvaguardia del Territorio at the '13° Premio Ecologia Laura Conti – ICU 2012'* together with a scholarship for the thesis competition on Sustainable Development promoted by the *Associazione Gabriele Bortolozzo*.
Pippo Gianoni

The phenomenon of saltwater intrusion is particularly pertinent to the Po Delta due to the negative effects it causes in both natural and manmade areas. The will to study the issue and to understand whether it is possible to address the problem with an approach that is different from that of the past has led to the writing of a thesis that poses a fundamental question: should saline intrusion only be seen as a problem for the Delta, or could it be seen as an opportunity instead? So far a defensive approach to the phenomenon has prevailed through the insertion of anti-salt barriers in the estuarine areas. These structures are expensive both in terms of construction and maintenance, and are not fully effective.

One of the objectives of this thesis is therefore to establish if this is to be the main tool, or whether it should only be one of a range of proposals to be used synergistically against saline ingress phenomenon. Today, partly due to gradual changes resulting from climate change, an intervention with a different approach to that which exclusively counters ingress, and one that aims at adapting to the phenomenon is indispensable. The idea, however, is not to intervene only in this sense, but through the integration of different policies that can be more effective, given this phenomenon's close connection to other fields such as climate change, subsidence, anthropogenic interventions etc. The complexity of the delta, due to its contemporary characteristics of dynamicity and instability, should be also taken into account in adaption solutions both on a planning or single project level.

The area under consideration is that of the *delta polesano*, for which it was decided to use the NATREG[1] area as a point of reference, so that the proposals presented are for the most part applicable within the territory, and at the same time can serve as an example for similar contexts. The thesis was developed through the analysis of issues relating to salt intrusion, followed by a description of the delta and existing works or those still under construction, to limit the phenomenon analyzed. It goes on to discuss methods used in other areas, particularly in the Netherlands and Spain, which are considered key examples in the implementation of appropriate measures to reduce the phenomenon within the analyzed territory. Finally the thesis proposal, in which all indications concerning the adaptation to salt intrusion in the Po Delta are looked into, is described.

The achieving of the objectives of the thesis can be carried out along three main lines, starting from the development of the major risks threatening the delta: subsidence, salinization and landslides. The risk of subsidence was taken into consideration first and was then correlated to the risk of salinization[2]. This was followed by the preparation of a map of areas susceptible to salinity, taking the delta habitats and land-use into consideration. The intersection of these different maps led to the creation of a map of areas potentially at risk of salinization that, associated with the hydrogeological risk map and three different climate change scenarios, led to the identification of potential risk areas in the Delta del Po.

An adaptation map was created from the processed data obtained, which included actions aimed not only at adaptation and saline ingress but also at climate change (such actions can be seen in Figure 1). The proposals outlined on the map were also included in a fact sheet, designed to raise awareness of the phenomenon of saline ingress, the main risks to the delta and applicable solutions. This tool is aimed at both public and private administrators in order to promote widespread awareness.

The proposals made in the fact sheet refer to various themes, highlighting the existence of a wide range of possibilities that allow one to act on several fronts, all the while contributing to achieving the same objective. In order to define and get a better understanding of some issues, existing projects in progress in relation to various areas were considered in addition to innovative proposals. Among the more important proposals, the need to apply 'Continuous protocol ' in a practical way and for the effective control of the waters of the Po basin by higher-level authorities[3], was evident. The conversion of vegetation into crops that consume less water and are able to withstand higher levels of salinity as well as the realization of multifunctional basins throughout the territory is also encouraged. Further proposals both structural and not, relating to various themes have been associated with the aforementioned fact sheet.

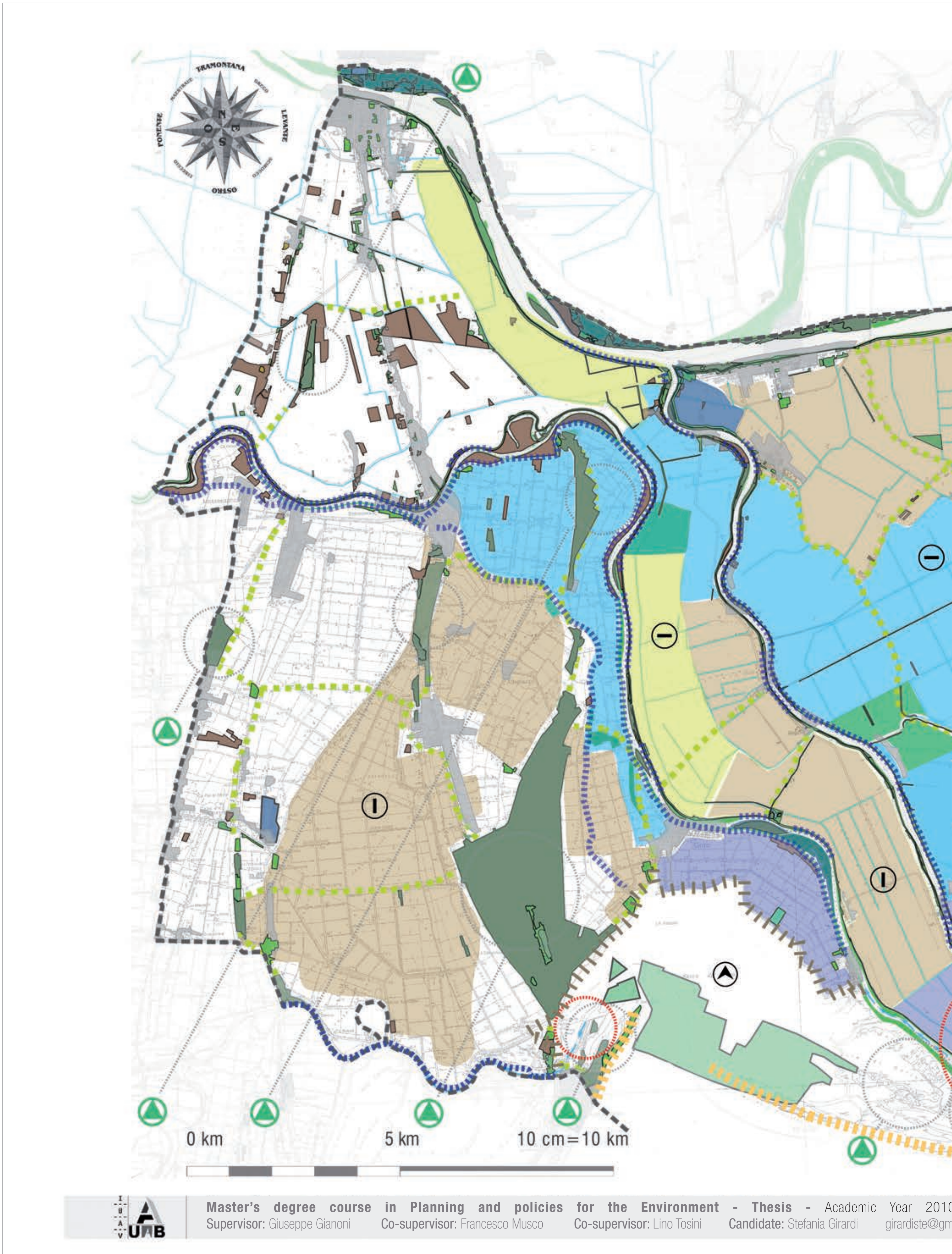
The definitive guidelines will be integrated with existing projects, such as saline barriers, bearing in mind that these works could be part of a more comprehensive proposal, incorporating solutions of different types, and also having an impact on the development of the territory. The decision not to consider a single area for the application for the various proposals is based on the need to deal with an environmental phenomenon as complex as salt intrusion on several fronts.

The multifunctionality of some of the proposed solutions, but above all the variety of themes, is aimed at covering as many geographical areas as possible

[1] The "Managing NATural Assets and Protected Areas as Sustainable REGional Development Opportunities" project aims to promote the inter-regional sustainable development of the area through the natural resources and protected areas' given potential.

[2] Constructed using innovative methods due to the lack of data.

[3] The proposal takes the realization of the *Autorità di Bacino del fiume Po*'s '*Piano del Bilancio Idrico*' into account.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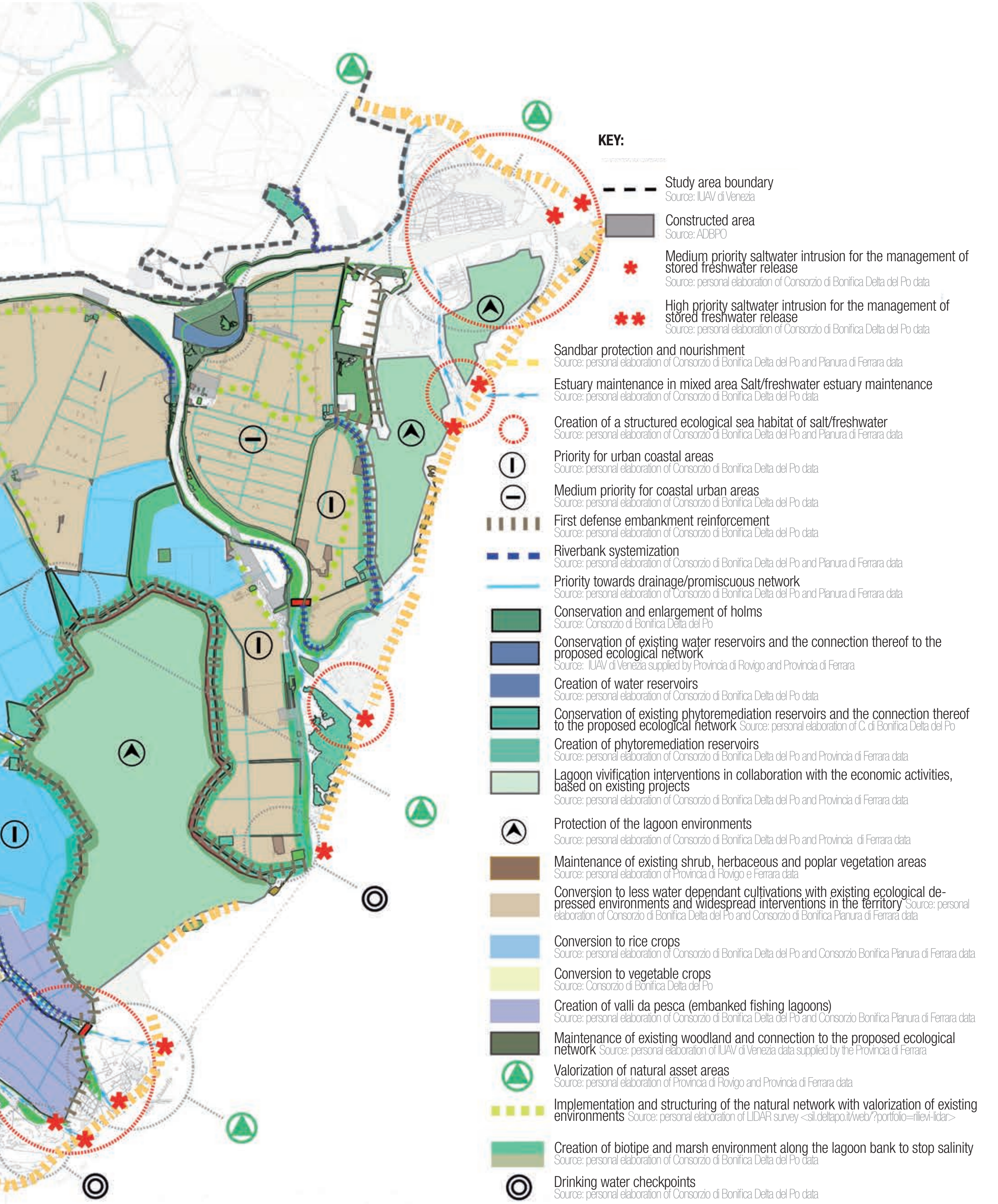
Master's degree course in Planning and policies for the Environment - Thesis - Academic Year 201
Supervisor: Giuseppe Gianoni Co-supervisor: Francesco Musco Co-supervisor: Lino Tosini Candidate: Stefania Girardi



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SALTWATER INTRUSION IN THE PO DELTA: PROBLEM OR OPPORTUNITY FOR THE DELTA?
Modification proposals for an inter-regional area

SALINITY AND CLIMATE CHANGE ADAPTATION MAP

and is therefore a problem that has no limits. Furthermore, the proposals cover both the basin as well as the local area, in order to consider affecting factors upstream of the delta and areas in which the phenomenon occurs. In the end, certain existing plans that could be useful in improving the area but lacking in aspects related to saltwater ingress, were considered in order to delineate the possible points of intervention and integration. One refers in particular to the *Piano Territoriale di Coordinamento provinciale di Rovig*o, the *Piano di Gestione della ZPS IT3270023 Delta del Po* and the *Piano di Gestione dell'area pilota nell'ambito del progetto NATREG*.

The aim of the thesis is to study an environmental issue that affects the territory and water, which in turn affects human life. The careful analysis of this process should allow for more observant planning in order to solve certain problems from the outset. It is necessary therefore to emphasize the need to ensure greater cohesion in the management of the territory. The will to make proposals that are useful to the area without constraints arising from administrative or bureaucratic limitations has made it possible to stretch out and to allow for an overall proposal that is not only different but also in-depth and innovative. In conclusion, the thesis subject matter is of great importance in that it would enable the territory to better address the problems caused by climate change, and the application of a different management approach would not only enable greater productivity and improve relationships with the agricultural and fishing sectors, but would also increase biodiversity.

The thesis has therefore enabled us to better our knowledge about salinization in the territory and bring together data from different sources corresponding to the inter-regional scope examined. Given the scarcity of studies relating to salinity in the delta area in question, the need for coordinated monitoring between different regions in relation to this theme should therefore highlighted. Among the results, it should also be noted how the theme of salt ingress provokes predominantly negative effects in different areas, however it must be pointed out that this phenomenon could also be the agent for new planning stimuli capable of increasing the development of the territory and at the same time achieving effective results regarding other problems. This theme should therefore be seen as an improvement opportunity for the delta from various points of view, which at the same time will allow for ecological, economic and social development.

'It is possible to build a new delta one step at a time.'

THE PO DELTA LAGOONS

By the Consorzio di Bonifica Delta del Po
October 2013

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