Adaptation Plan for Po River
PART A - Po River Delta - Veneto Region
Studies, methods, critical issues and strategies

Final Version of 30/11/2021

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1. Foreword

This document has been produced in the framework of the INTERREG Italy – Croatia CHANGE WE CARE Project. CHANGE WE CARE fosters concerted and coordinated climate adaptation actions at transboundary level, tested in specific and representative pilot sites, exploring climate risks faced by coastal and transitional areas contributing to a better understanding of the impact of climate variability and change on water regimes, salt intrusion, tourism, biodiversity and agro-ecosystems affecting the cooperation area. The main goal of the Project is to deliver integrated, ecosystem-based and shared planning options for different problems related to climate change (CC), together with adaptation measures for vulnerable areas, to decision makers and coastal communities. Additional information and updates on the CHANGE WE CARE can be found at https://www.italy-croatia.eu/web/changewecare.

2. Aims and content of the document

This document is the guideline for Adaptation plan in the Delta Po pilot Area and corresponds to the Deliverable 5.6.2 indicated in the Application Form. It represents the synthesis of adaptation/management Plans for the Pilot Sites, where the shared knowledge base on the present and expected dynamics of coastal systems in the cooperation area and Pilot sites, built in WP3 and WP4, is conveyed. The definition of such Plans is foreseen to be pursued by means of participatory processes (cf. Deliverable 5.6.1) determined in order to get all information available, shared decision and consensus by the stakeholders to make the Plan effectively implementable in a collaborative way by all subjects and decision makers involved. The Adaptation Plans will be developed taking into account outcomes of WP3, WP4 and of the Participatory process itself, including shared vision, objectives, measures/ actions/ interventions.

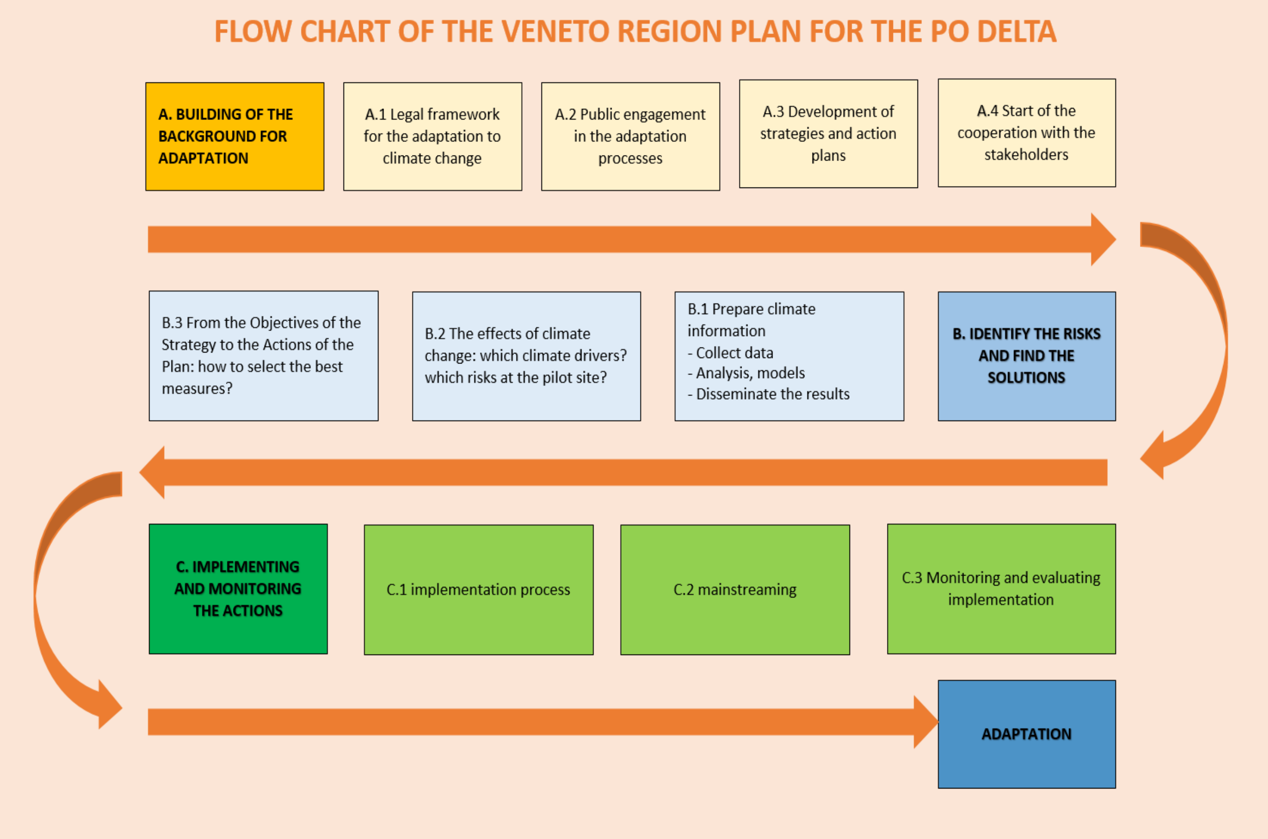
3. CHANGE WE CARE project and the objectives of WP5

The goal of WP5 is to develop a replicable method with the aim of creating a climate change adaptation plan for the coastal environment. In particular, the subject of the WP 5.6 report is the pilot site of the Po Delta coastal strip.

Various guidelines for the development of adaptation plans to climate change have been implemented in Italy at national (SNACC and its preliminary documents, PNACC in adoption), regional (MasterAdapt, Guidelines for Regions, etc.), and local level (Municipal PAESC). Some regional and municipal plans have been already implemented, while others are still in progress (e.g. Life ADAPT).

Area of interest of the plans is generally delimited by geopolitical boundaries. For the coastal area, and in particular for the Delta environment, there is still a lack of specific guidelines. The Integrated Management Plans of the Coastal Zone and the Planning of the Maritime Space report some governance aspects, however these instruments do not provide an integration with climate adaptation measures.

This report takes advantage of the toolkit provided by the CReIAMO PA Project ("Skills and networks for environmental integration and for the improvement of PA organizations") commissioned by MATTM - Directorate General for Sustainable Development. The toolkit, published in 2020, provides a methodological guide and the operational sheets for the definition of regional strategies and plans for adaptation to climate change in line with the PNACC. The methodology follows the steps depicted in Figure 1. Each phase will be explained in the following paragraphs.



STEP A.

A.1 integrate community and national strategies with the specific vision for the pilot site,

A.2 how to govern adaptation and who does what,

A.3 select the tools in which to define the objectives,

A.4 promote the participatory process among all the stakeholders and the different sectors; involvement of institutional and public stakeholders, establish roles, make their involvement more effective.

STEP B.

B.1 analysis of past climatic variability and evaluation of future scenarios in the pilot site,

B.2 assess climate risks, analyze the impacts and vulnerabilities in socio-economic and environmental sectors,

B.3 identify the various adaptation options in function of the risks and expected impacts.

STEP C.

C.1 establish how to implement the actions and how to bring them into existing plans,

C. 2 define a mainstreaming methodology of the adaptation in sector policies (already in planning and new measures),

C.3 develop a continuous process of monitoring, evaluating and reporting the effects of the strategy (process and result indicators).

Figure 1. Flow chart of the Veneto Region plan for the Po Delta.

4. Description of the Pilot Area, Knowledge Framework and Scenarios

4.1 Characteristics of the pilot area

4.1.1 General characteristics

The Po Delta is the final sub-basin subtending the entire Po catchment. The total area is 472.55 km^2 that is the 1.6 % of the entire catchment, and it is almost flat, (Management plan of the hydrographic district of Fiume Po, State of water resources, 2016).

In this area the Po river is made by five active branches: from north to South, *Po di Maestra*, *Po di Pila* (or *di Venezia*), with three different mouths (*Busa di Tramontana, Busa Dritta* and *Busa di Scirocco*); *Po di Tolle* (with the branches of *Bastimento, Bocca del Po* and *Tolle*); Po di Gnocca; and Po di Goro (Figure 2).

The area is recent and in continuous evolution due to the contribution of sediments from the Po River. The current morphology is the result of a long history of reclamation and hydraulic interventions. The territory is mostly below the mean sea level and is maintained emerged by various pumping stations. The embankments along the branches of the Po and the lagoon banks are the most important defense line against both floods of the Po and the effect of sea rising.

From an environmental point of view, the Po Delta represents an important environmental and ecological system because of the interconnections between aquatic and land habitats and the interactions between fresh and salt water (Table 1).

The Po Delta includes shallow coastal lagoons (most of them have 75% of their total volume in the first 1 to 1.5 m of depth) classified by average salinity between polyhaline to euryhaline and high trophic status. The main lagoons in the Po Delta area included in Veneto Region are *Caleri, Marinetta, Vallona, Barbamarco, Basson, Sacca del Canarin, Sacca di Scardovari* (from the north to the south). The lagoons represent the main production site of Manila clam (Ruditapes philippinarum) in Italy.

The pilot site is part of a social context typical of rural areas. The population density is quite low, with small urban villages, hamlets, and isolated houses.

The territory is not very industrialized. Anyway, it is affected by anthropic interventions, including: past gas extraction; presence of a thermo-electric power station (now disused); it is the terminal part of the most important water basin in Italy, which involves the arrival of water inflows with consequent polluting load deriving from upstream.

The most interesting developed areas are located in the coastal strip. Lagoons and beaches offer sites of anthropic and environmental interest. Fishing, fish farming and tourism are the main activities. The internal areas are purely agricultural with a prevalence of arable land. The territory remains emerged thanks to the hydraulic defenses and the pumping systems. The morphology of the area is mainly determined by artificial structures (embankments, fishing valleys, barriers) which, together with substantial reclamation works, preserve the environment from the most destructive natural dynamics and guarantee human activity. Furthermore, a large part of the area is subjected to environmental constraints caused by a high naturalistic value.

The Delta is an artificial environment affected by highly impacting human activities, continuous hydraulic management and maintenance of the defense structures. Despite this, the anthropic pressure does not impact its naturalistic value. Centuries of land management culture led to a harmonic coexistence of man and nature. Some damage was caused by the overexploitation of resources and land abandonment. The regulatory framework in the area is rather complex:

- the hierarchical levels are expressed integrally, from the municipal level to the European level;
- there are regulated environmental areas that include land, rivers, lagoons and the sea;
- the variety of resources caused issues and constraints of national and supranational interest: gas extraction, power plants and power lines (now disused), small ports, wetlands of environmental interest, presence of large farms (fishing, shellfish farming), etc.

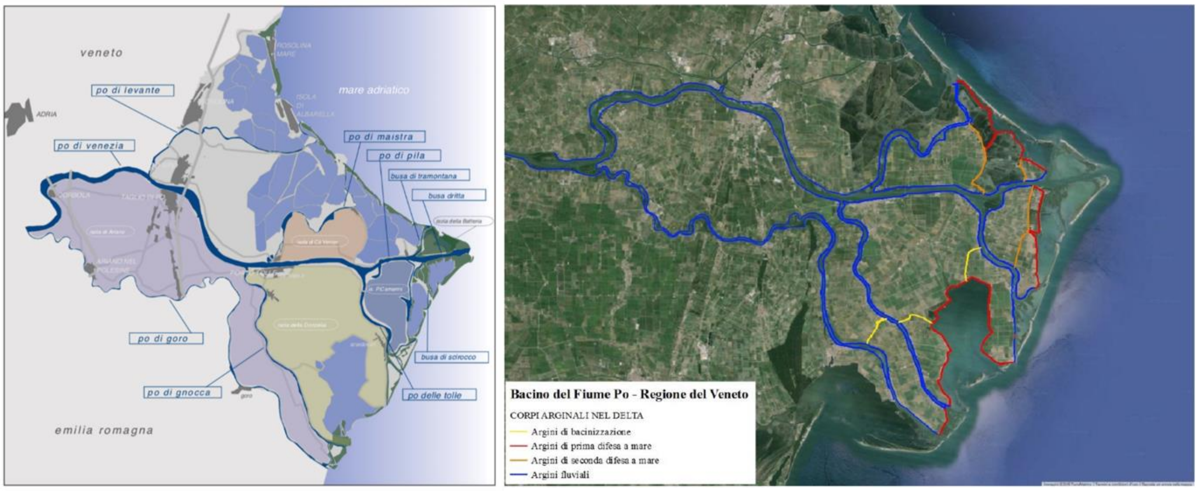


Figure 2. Po Delta (Veneto Region) with its branches and lagoons (Source: Atlante Delta del Parco); Veneto Po Delta embankments (Source: Piano per la valutazione e gestione del rischio alluvioni, 2016).

Agricultural and settlement lands:	42000 ha
Wetland areas:	18000 ha
7 lagoons:	8150 ha
Other wetlands:	1250 ha
24 fishing valleys:	8600 ha
Branches of the Po:	4000 ha
River and sea defense embankments:	400 Km

Table 1. The Delta territory (Source: Quaderni cà Vendramin n.0, ottobre 2009. Il valore della naturalità e la gestione degli interventi nelle lagune del Delta del Po).

4.1.2 Biodiversity

One of the main objectives of the Change We Care project is the biodiversity protection. The factors that determine the high naturalistic richness of the area are[1]:

- geographic location. The area is located between the temperate and Mediterranean regions and between the alpine and coastal areas;
- the floristic migrations from north and east occurred during different time periods in response to climatic fluctuations;
- the landscape heterogeneity, with the presence of many different environments (sandy, clayey, peaty, salty and fresh waters, with dune, hygrophilous, woody vegetation) despite the very limited altitudinal range of the territory;
- the important shaping activity of man;
- the moderate human presence.

According to the cartography of species distribution of the Veneto Region, the total number of species surveyed in the Delta (approved by D.G.R. n. 2200 of 27 November 2014) is 2212, of which 1793 animals and 219 plants.

Significant floristic entities from the phytogeographic point of view have been detected in the Delta endemic, Mediterranean, mountain relict (i.e. *Stachys recta, Teucrium Chamaedrys*), and oriental species. Other valuable species of the flora are listed in the endangered species with different degrees of threat. In particular, 25 taxa have been reported in the regional red lists of the flora and 9 in the national one. The contingent of allochthonous species (129 taxa) is very large and deserves particular attention for its potential invasiveness[1].

Regarding the fauna, there are numerous species of Amphibians and Reptiles, Fish, Birds listed in Annex I or Annex II of the Directive 92/43/EEC, some of which are priority species. The regional law n. 53/1974 (Norms for the protection of some species of fauna and lower flora) lists the protected species and for some of these the collection is forbidden.

4.1.3 Habitats according to Directive 92/43/EEC

Currently, the following sites of the Natura 2000 network are recognized in the area of the Po Delta:

- *IT3270017 "Delta del Po: tratto terminale e Delta veneto" (SIC);*
- *IT3270023 "Delta del Po", (ZPS) (*site largely overlapping the previous one*);*
- *IT3270024 "Vallona di Loreo";*
- *IT3270003 "Dune di Donada e Contarina";*
- *IT3270004 "Dune di Rosolina e Volto";*
- *IT3270005 "Dune Fossili di Ariano Polesine";*
- *IT327006 "Rotta di San Martino";*
- *S.I.C. IT3270025 "Adriatico Settentrionale Veneto - Delta del Po" (marine area).*

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[1] *Source: Management Plan of ZSP IT 3270023 33*

Figure 3. The Natura 2000 site IT3270017-IT32270023. The green areas are classified as Corine Land Cover, while the brown areas are classified with Habitat code.

The sites IT3270017 and IT3270023 cover almost all the Natura 2000 areas in the Delta. They largely overlap and extend along the Po River for several kilometers inland (Figure 3). The sites have a total area of approximately 28093 hectares and include 22 habitat types and some Corine Land Cover areas, e.g., fishing valleys (CLC 42150), reed beds (CLC 4111), river stretches (CLC 3116, 5111).

Other extensive aquatic habitats are Habitat n. 1150 "Coastal lagoons" and n.1130 "Estuaries" (river branches from the sea up to 30 km inland are also coded in this way) (Table 2). Among the areas where emerged vegetation is present, the majority is constituted by woods, especially alluvial (91E0), but also pine forests (2270) and strips of oak trees (9340) (Table 3).

The vegetation of the dunes and sandbanks, as well as the formations of the humid areas, is definitely less extensive but remarkable in terms of naturalistic value, as it includes species and associations now rare in Italy and extremely vulnerable.

Code	name	Ha	% on total site area
3270	*Rivers with muddy banks with Chenopodion rubri p.p e Bidention p.p.*	62.96	0.22
1140	*Mudflats and sandflats not covered by seawater at low tide*	70.88	0.25
9340	*Quercus ilex and Quercus rotundifolia forest*	74.45	0.27
1410	*Mediterranean salt meadows (Juncetalia maritimi)*	88.97	0.32
2270*	*Wooded dunes with Pinus pinea e/o Pinus pinaster*	145.16	0.52
91E0*	*Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)*	629.04	2.24
1130	*Estuaries*	2775.44	9.88
1150*	*Coastal lagoon*	6163.98	21.94

Table 2. Extension of the main Natura 2000 habitats in the site IT32270017-IT32270023 in terms of percent surface on the total protected area.

1210 Annual vegetation of drift lines
1310 Salicornia and other annuals colonizing mud and sand
1320 Spartina swards (Spartinion maritimae)
1410 Mediterranean salt meadows (Juncetalia maritimi)
1420 Mediterranean and thermo-Atlantic halophilous scrubs (Sarcocornetiea fruticosi)
2110 Embryonic shifting dunes
2120 Shifting dunes along the shoreline with Ammophila arenaria (white dunes)
2130* Fixed coastal dunes with herbaceous vegetation (grey dunes)
2160 Dunes with Hippophae rhamnoides
2230 Malcolmietalia dune grasslands
2250* Coastal dunes with Juniperus spp.
3150 Natural euthrophic lakes with Magnopotamion or Hydrocharition-type vegetation
3270 Rivers with muddy banks with Chenopodion rubri p.p. and Bidention p.p. vegetation
6210* Semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia)
6420 Mediterranean tall humid herb grasslands of the Molinio-Holoschoenion
7210* Calcareous fens with Cladium mariscus and species of the Caricion davallianae

Table 3. Habitat of sands and fresh-salt waters at the site IT32270017-IT32270023 (*priority habitats).

4.1.4 Delta Po migratory avifauna

The Po Delta is located in a Mediterranean belt and the climate is an intermediate between the cold northern European and Eurasian areas and the warm African territories. The temperate climate, that is also the result of climate change, favored the populations of some species to spend their entire life cycle in the Delta becoming sedentary.

In the Po Delta, regular annual censuses of wintering and nesting birds were conducted for decades. The counts are carried out by direct observations in January where birds aggregate in colonies. The migration trajectories are followed with the technique of ringing and recapture.

The graph of the total number of individuals surveyed in the provincial territory of Rovigo, whose main sites are in the Po Delta, shows an annual fluctuation with a constant increase (Figure 4).

The four sites with the greatest presence of aquatic avifauna are three valley basins (the Ca' Zuliani, Ca' Pasta, Ripiego and S. Leonardo Valleys), followed by the Sacca di Scardovari.

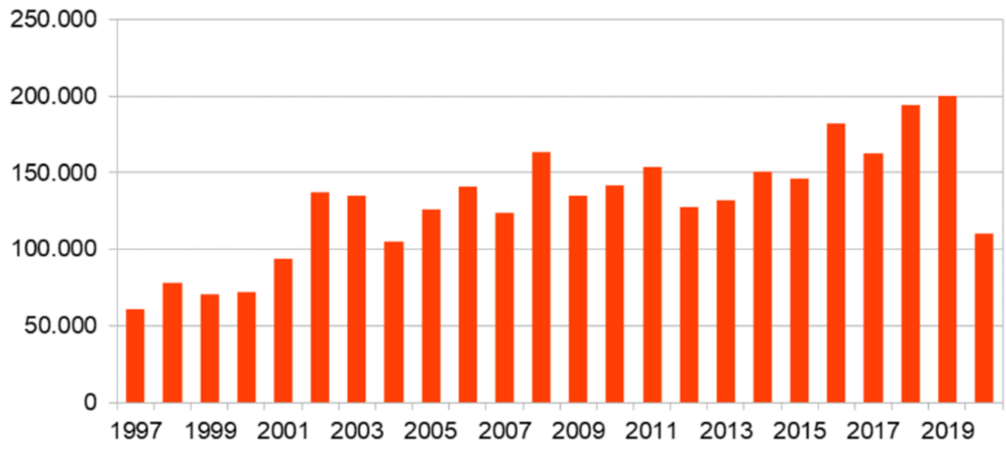


Figure 4. Mid January census of Rovigo Province (Censimento degli uccelli acquatici svernanti in Provincia di Rovigo-Anno 2020, Ass. Cult. Nat. Sagittaria).

All the European species of Ardeidae are present in the Delta, some of which can be seen all year round, while others during some periods only (summer or winter periods depending on the species).

The most important heronry (breeding area) and the most important post-reproductive nocturnal roost in the Po Delta, are located near the river branch of the Po di Maistra and of national and European importance (Figure 5).

Some heron species can be found also in agricultural environments, rice fields and lagoons where they feed mainly on small fish, amphibians, insects, spiders and shrimps. The management of perilaguna and estuarine reedbeds is a key factor in the conservation of the species (Table 4).

The herons are accompanied by other important species of birds: the Cormorant (*Phalacrocorax carbo*) and Lesser Cormorant (*Phalacrocorax pygmeus*); the Marsh Harrier (*Circus aeruginosus*); the Sacred Ibis (*Threskiornis aethiopicus*); the Spoonbill (*Platalea leucorodia*).

	Specie	**Habitat**
	Airone cenerino (Ardea cinerea Linnaeus, 1758)	freshwater, brackish and saltwater wetlands, drainage canals, fishing valleys, lagoon and coastal areas, rivers, rice paddies and other types of crops
	Airone rosso (Ardea purpurea Linnaeus, 1766)	nests in the reeds, feeds in the valleys, feeds in particular on amphibians
	Airone bianco maggiore (Ardea alba Linnaeus, 1758)	wetlands, both coastal and inland. It nests in areas with the presence of thick reeds and scattered bushes, but also in more mature hygrophilous forests, with formations of Salix sp.
	Garzetta (Egretta garzetta Linnaeus, 1766)	aquatic environments of different types, even saline, near lakes, coastal lagoons, drainage and irrigation canals.
	Sgarza ciuffetto (Ardeola ralloides Scopoli, 1769)	freshwater wetlands, along the canals, in the rice fields (in particular Isola della Donzella) and especially above the prairies of floating aquatic plants, preferably Water Chestnut.
	Airone guardabuoi (Bubulcus ibis Linnaeus, 1758)	mainly plains and inland wetlands with fresh water. It forages at alfalfa fields and fallow lands, or while following tractors or other vehicles to work.

	Nitticora (Nycticorax nycticorax Linnaeus, 1758)	It is a species linked to river environments with abundant aquatic vegetation and banks. It feeds near rice fields, slow-water ponds, drainage canals with a good tree and shrub cover..
	Tarabusino (Ixobrychus minutus L., 1766)	freshwater bodies of water, even artificial, with abundant bank vegetation of elophyte plants, especially Phragmites australis, and formations of floating aquatic grasses.
	Tarabuso (Botaurus stellaris (Linnaeus, 1758)	reeds of variable structure, in association with other elophyte grasses, present near the river branches and in some valley surfaces, freshwater or slightly brackish environments

Table 4. Ardeidae in the Po Delta. The species that are protected by the Birds Directive are highlighted by the red feather, while the blue one represents the protected species[2].

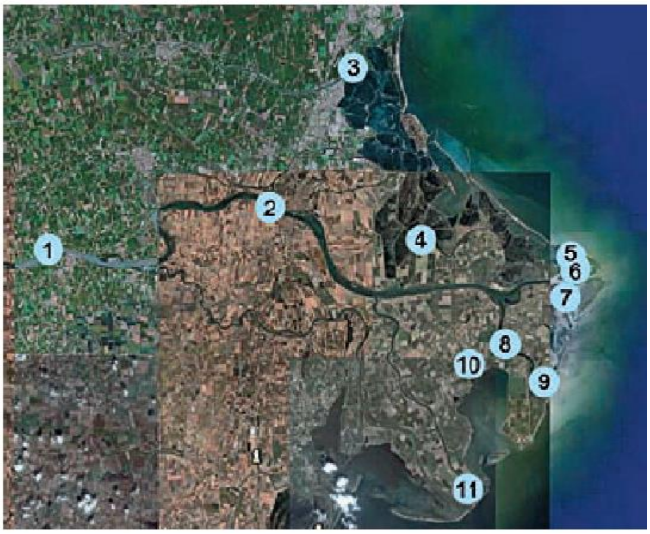


Figure 5. Location of the eastern Polesine heronry, years 2006-2008. 1-Canalnovo, 2- Ca' Zen, 3-Valle Morosina, 4- Po di Maistra, 5 Panarin (Busa di Tramontana), 6-Busa Dritta (Isola della Batteria), 7-Girotto-Pezze, 8-Giarette, 9-Busa del Bastimento, 10-Oasi di Ca' Mello, 11-Bacucco (foci del Po di Gnocca), 12-Scolo Ceresolo, 13-Gorghi di Trecenta (2)

4.1.5 Coastal dune systems (beaches, sandbars and dunes)

Sandy littoral environments are the result of a dynamic balance between fluvial inputs, wave motion, marine currents, and wind action, and are in constant motion[3]. Excesses or reductions in solid inputs result in shoreline advances or retreats, respectively (Figure 6).

Dunes form inland when the supply of loose sands is conspicuous and when steady winds from the sea tend to push the sands inland. Sand accumulation can start from any obstacle and continues until a state of equilibrium is reached. The equilibrium determines the height of the dune and depends on wind

[2] *Verza E., Trombin D. (a cura di), 2008. Gli Aironi del Delta del Po. Monitoraggio degli Ardeidi del Delta del Po e della provincia di Rovigo. Ente Parco Regionale Veneto del Delta del Po. Ass. Cult. Nat. Sagittaria*

[3] *Occhipinti A., Sacchi C.F. - 2. Ambienti marini costieri. In: Roberto Marchetti (a cura di) Ecologia Applicata, Città Studi, 1993*

speed and sand grain size. The perennial motion of the sediments of the first dune is strongly limited by the presence of some particular plant species that trap the sand grains with their roots or aerial parts.

In the final stretch of the Veneto Delta of the Po River, most of the coast coincide with the "scanni" or "defense bars" located at the mouths of the river branches, subparallel to the coastline and at a short distance from it. They are sandy bodies with small dunes and a limited transversal extension, always emerged. They still conserve natural characteristics in the Po Delta area, although they suffer from the direct disturbance of bathing tourism.

The dunes present extreme conditions that limit the survival of living organisms. These conditions mainly result from the dryness and the high temperature of the environment, and partially from the salinity. Sand particles are unable to hold water, can reach high temperatures when exposed to the sunlight, and are washed away by rain that removes the salt carried by the marine aerosol.

In the design of nourishment and stabilization of the defense bars, the environmental stressors and the adaptation strategies of the plants are taken into consideration (Table 5).

Stressors	***Plant adaptations***
Movable substrate	**Leathery leaves with few stomata, limiting transpiration;**
Aridity related to the inability of sand grains to retain water	**Succulence, to store water;**
Nutrient scarcity	**Hairiness, to limit perspiration;**
Salt, both in circulating water and in the atmosphere	**Creeping rhizomes under sand and basal sleeve of dry leaf sheaths to protect against heat;**
High insolation and low heat capacity	**Annuity, precocity and shortness of cycle**
High windiness	
Exposure to storm surges	
Habitat fragmentation, natural and human-induced	

Table 5. Elements to consider when designing sandbanks.

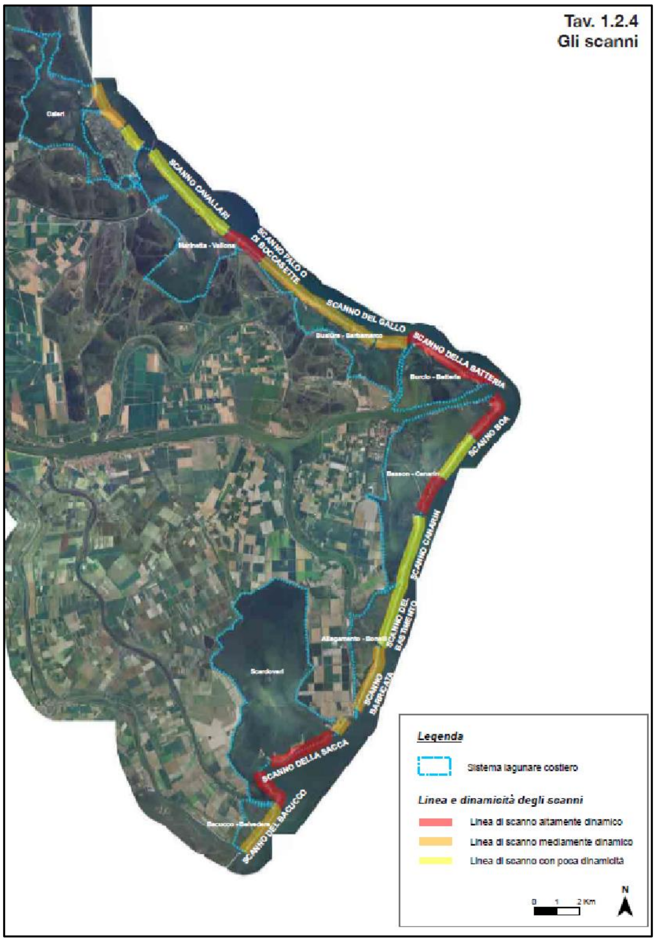


Figure 6. The sandbars of the Po Delta, classified on the basis of their dynamism. Red: highly dynamic; Orange: medium dynamic; Yellow: low dynamic (Source: Emiliano Verza, Luisa Cattozzo, Atlante lagunare costiero del Delta del Po - Regione Veneto, Consorzio di Bonifica Delta del Po, Associazione Culturale Naturalistica Sagittaria).

A sequence of vegetation is recognizable for inland dunes and sandbars, starting from the shoreline and evolving in the opposite direction[4] (Figure 7, Figure 8).

Starting from the first dune of the beach, the salinity, the wind, the motility of the substrate are maximum. Progressively, towards the interior, they are attenuated while there is a progressive accumulation of fine soil (silt and clay) that retains an increasing amount of water.

The sandbars are nesting sites for numerous bird species (Figure 9). Coastal sandy environments are extremely fragile because they are subject to numerous natural and anthropogenic disturbances. Climatic hazards include sea level rise, temperature peaks, erosion from storm surges and storms. Impacting anthropogenic actions are numerous: coastal building works; coastal roads and vehicular traffic; beach accesses; the bathing activities, which lead to the dispersion of waste, the trampling of vegetation and nests, the removal of wildlife.

[4] *AA. VV. Atlante del territorio costiero, lagunare e vallivo del Delta del Po. Parco Regionale del Delta del Po. 80 pp.*

Figure 7. View of the Scanno Barricata (Landsat 4/3/2020 from Google earth). *Amorpha fruticosa, Ammophila arenaria, Agropyron junceum, Cakile maritima,* images from Acta Plantarum.

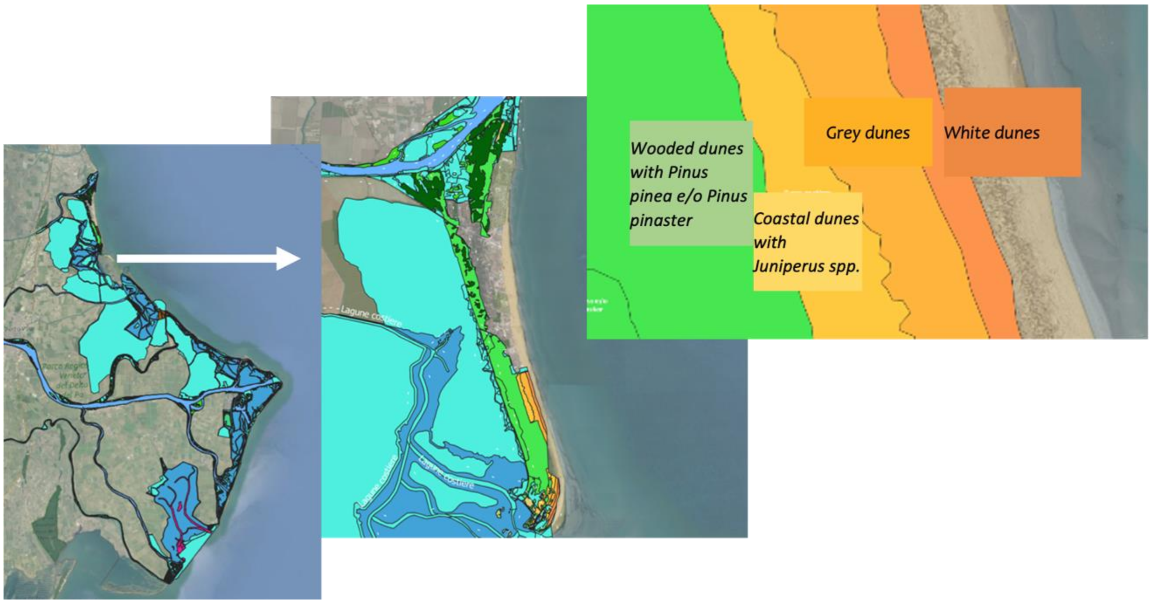
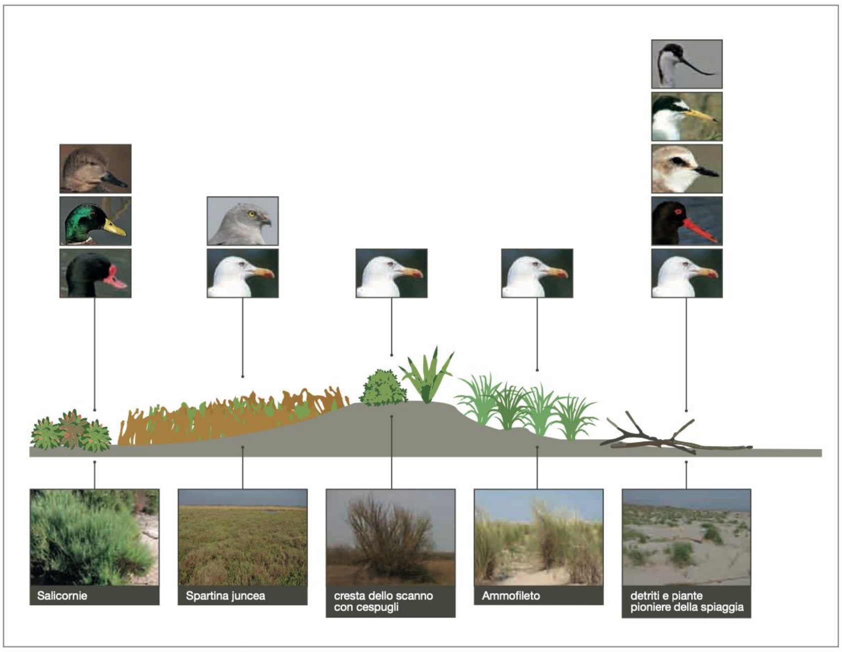


Figure 8. Habitat of the dune systems near Rosolina.



Sezione dello scanno con ubicazione specie nidificanti

Figure 9. Distribution on the sandbar of (from right-high) *Recurvirostra avosetta*, *Sternula albifrons*, *Charadrius alexandrinus*, *Haematopus ostralegus*, *Larus michahellis*, *Circus pygargus*, *Tadorna tadorna*, *Anas plathyrhynchos*, *Anas strepera* (Source: Emiliano Verza, Luisa Cattozzo, Atlante lagunare costiero del Delta del Po - Regione Veneto, Consorzio di Bonifica Delta del Po, Associazione Culturale Naturalistica Sagittaria).

4.1.6 Saltmarshes

The saltmarshes are intertidal lagoon areas that are crossed by small channels called Ghebi located above the average tidal level (Figure 10). They are constituted by silty-clayey soil deriving from fluvial or marine transport or from the same resuspension of the lagoon bottom. Sandbanks can form at river mouths, at the channel edges, and inside lagoons. As for the dunes, the vegetation contributes substantially to stabilize the sandbanks which are subjected to erosion due to wave motion generated by wind and boats. Velme (mudflats) differ from salt marshes as they emerge only at particular low tide conditions.

The salt marshes present a heavy, asphyctic, poorly permeable soil of silt-clay composition, with a high concentration of chlorides. They are marked by dense halophytic vegetation that developed several adaptations to salinity. The soil near the water is inconsistent, rich in organic matter, and hosts therophytic pioneer plants (salicornias) that are succeeded by perennial rhizomatous straws (Spartinae). *Tamarix gallica*, *Elaeagnus angustifolia* and *Amorpha fruticosa* were introduced by man for their resistance and consolidation characteristics and may be present in the higher rises. Generally, the Velme are colonized by marine phanerogams and the substrate (consisting mainly of mud and sand) provides shelter for polychaetes and mollusks during low tide.

Charadriformes are the most present birds in the salt marshes, even if during the breeding season they serve as a nesting site for the Herring Gull, the Montagu's Harrier and some Herons. Moreover, the passerines use the salt marshes during the migratory period while numerous Limicolae birds feed on invertebrates buried in the mud or on insects on the emerged muddy surface. During the last decade, 39 species of Limicolae have been recorded in the Veneto Delta among which 8 are breeding birds.

Figure 10. Salt marshes near Porto Caleri, Sacca del Canarin, Laguna Boccasette. Red = 1320 Spartina swards (Spartinion maritimae), blue = 1420 Mediterranean and thermo-atlantic halophilic grasslands and fruticeti (Sarcocornetea fruticosi), brown = 1410 Mediterranean flooded pastures (Juncetalia maritimi), yellow =1310 Pioneer annual vegetation with "Salicornia" and other species of muddy and sandy areas".

4.1.7 Reedbeds

The marsh cane *Phragmites australis* (Cav.) Trin. ex Steud. is a perennial herbaceous and rhizomatous species that is an ubiquitous plant of fresh or slightly brackish humid environments. It grows in shallow marshy waters as well as in running waters, and it forms belts up to 3-4 m high on the banks of rivers, canals and ditches. It penetrates the coastal dunes and forms extensive grasslands along the lagoon edges and near river mouths (Figure 11).

Figure 11. The reedbeds ("bonelli" of Bacucco) in satellite images from June 2017 and April 2020 (Code 4111 Corine Landscape and code 53.1 Corine Biotopes).

The reedbed effectively holds the debris carried by currents, stabilizing the soils subjected to tides. Moreover, it has a remarkable ecological importance for the following aspects:

- it contributes to phyto-purification (adsorption and proliferation of micro-organisms among the rhizomes, which carry oxygen);
- it is a site of refuge and feeding for the avifauna, especially Rallidae, Anatidae and Ardeidae, and for Passeriformes, in particular Silvidae, which use the compact formations of Phragmites to nest in spring or to stop during migration.

Among the fish mullets, eels (*Anguilla anguilla*), and carp (*Cyprinus carpio*) are the most typical.

4.1.8 Lagoons and fishing valleys

The lagoon system of the Po Delta includes 18000 ha of water surfaces of which 8150 ha are occupied by lagoons, 8600 ha by dammed fishing valleys and over 1250 ha by wetlands (Table 6). There are seven main lagoons, of which the largest (Sacca degli Scardovari) occupies an area of 3300 ha, and the smallest (Burcio) 100 ha[5].

The fishing valleys of Veneto derive from the closure of some coastal wetlands during a long historical period ranging from the Renaissance to the early twentieth century. These are areas managed by private individuals for fish production (extensive or semi-intensive fish farming) and the attraction of huntable wildlife (hunting farms) (Figure 12).

The hydraulic of the valleys is artificially managed by a system of communicating lakes, with different flow rates and elevations. The incoming, outcoming, and internal flow water is totally governed by siphons, pumps, pipes and channels. The management follows a seasonal and multi-year calendar marked by the productive cycles of the fauna and the weather and climate conditions.

Fresh and salt water is run through perimeter channels where it is clarified by deposition and purified by aquatic plants. Clean and oxygenated water is then introduced into the production lakes and expelled through sluice gates and water pumps.
To avoid summer hypoxia-anoxia phenomena or winter freezing, the water is kept in slow but constant motion. Salinity is imposed by fresh or saltwater inputs.

[5] *Lagune del Delta del Po, di Bruno Matticchio e Giancarlo Mantovani. Quaderni Cà Vendramin, n. 1. Novembre 2010.*

Figure 12. A typical Valley: 1 - Large lakes for fish and lake ducks; 2 - Ponds for hunting; 3 – "Vignùa" or main "Colauro"; 4 – "Peschiera"; 5 – "Casone"[6].

Vallive unit denomination	
Valli Boccavecchia	Valle Sacchetta
Valle Passarella	Valle Canocchione
Valle Spolverina	Valle Moraro
Valle Cannelle	Valle Cà Pisani
Valle Morosina	Valle Scanarello
Valle Segà	Valle Cà Pasta
Valle Capitania	Valle San Leonardo
Valle Pozzatini	Valle Chiusa o Palua
Valle Sagreda	Valle Ripiego
Valle Veniera	Valle Cà Zuliani
Valle Bagliona	Valle San Carlo o Valnova
Valle Baglioncina o Lago del Polesine	

Table 6. Delta fishing Valleys[6].

Plant biomass and sediments from the incoming water lead to rapid siltation of the channels, which must be dredged almost annually. The dredged sediments are used to raise the banks or to create new emerged structures: salt marshes, "ponsaùre", "tomboli", islands, and embankments. These structures favor the presence of Anatidae. Sediments are also deposited on existing sandbanks to allow a continuous regeneration of pioneer plants and the permanence of bare surfaces necessary for nesting. With the aim of improving the conditions of the lake's bottom, they are periodically harrowed and exposed to sunlight for up to a month. Hedges of tamarisk are planted on the most massive banks as

[6] *Verza E. (a cura di), 2019. "Le Valli da pesca e da caccia venete: straordinario esempio di gestione ambientale a sostegno della fauna e della biodiversità. Guida alla gestione delle Aziende faunistico venatorie vallive". Ente Produttori Selvaggina Sezione Veneta. Regione del Veneto.*

they are particularly resistant to salinity and heat and serve as protection from winds and shelter for wildlife (Figure 13).

The major limiting factor is the sudden rise in water level generated by intense weather phenomena, which causes submersions and hydraulic and qualitative alterations of water bodies.

The set of plants called "grisa" made by the aquatic phanerogams of the genera Zostera, Ruppia and Stuckenia are considered particularly beneficial. Besides being food for the diet of all anatids and coots, they maintain a good oxygenation in the water of lakes and canals where the flow is slow. The faunal community of the meadows consists of various species of invertebrates, including the Gray Shrimp, small fish that are essential for the food chain, and larger fish of commercial value. The group of "harmful" plants is mainly constituted by algae (Chlorophyta and Rhodophyta) that often generate rotting phenomena of the valley bottoms.

High-quality euryhaline fish are produced in the Valleys. The fish is traditionally "sown" in spring, using both farmed and wild fry; a small quota of them still enters in the valleys through the siphons.

The fishes live and grow in the wide lakes of the valley. When the temperature decreases, their migratory instinct pushes them to look for the sea. This attitude is exploited in order to bring them from the "vignùe" to the "colaùro" up to the "lavorieri" where they are caught with big nets, the "vòleghe". The bigger fishes are taken to the fish markets, while the undersized ones are stored in the winter fishponds where they spend the whole winter season. These operations are called "fraìma". The most fished species are the Bream, the Sea Bass, and the five species of mullets, while the production of the Eel is now very scarce. In addition, other marginal species that naturally reproduce in the Valley are fished.

The potential fish productivity strongly decreased in recent decades, from about 100 kg/ha per year to less than 50 kg/ha. The reduction is due to the increasing predation by ichthyophagous birds, in particular the Cormorant, to the general decrease in the market price, and the progressive abandonment of the activity. Many valleys have moved more toward wildlife management. This resulted in more freshwater, lower water levels, and a large amount of bare areas.

Figure 13. Small lakes in the valley [6].

From the point of view of protection, the Valleys are all Sites of Community Importance (SCI) and Special Protection Areas (SPA) according to the European legislation; moreover, about one third of the surface of each Valley is a protected oasis. Most of them are located in the Veneto Regional Park of the Po Delta.

4.1.9 Forests

Forests are the most extensive type of vegetation among the Natura 2000 protected habitats in the Delta. They are of three types: the oak forest, present exclusively along the coast of Rosolina and rarely on the internal fossil dunes; the pine forests of the sand dunes, typical of replanting, always in the same areas; the forests of the freshwater wetlands, made by strips along the river branches of the Po up to the limit of the saline waters. Despite their small areas, they are rare and important hotspots in the Veneto plain.

Forests are strongly threatened by freshwater salinization resulting from eustasy, sea level rise, coastal erosion, groundwater withdrawals, and increased drought.

4.1.10 Main threats

Like other major world Deltas, the site is highly threatened by Global Changes, with particular reference to the relative sea level rise (RSLR), mostly due to uneven subsidence rates ranging from a few mm/yr to more than 20 mm/yr (Lio and Tosi, 2019). Tectonics, sediment loading and sediment compaction are the main components driving natural subsidence rates, while the main anthropogenic cause of land subsidence is caused by methane extraction. Another major concern in the area is represented by the salt wedge intrusion (SWI), a phenomenon that covers a large portion of the Po Delta area, negatively affecting intensive and extensive agricultural activities locally carried out.

In recent decades, salt intrusion has assumed increasingly worrying proportions with a progressive intrusion in almost all the water bodies of the Po Delta, which has shown a tendency to increase salinity. The phenomenon, which in the 1930s was observed only for two or three kilometers from the river mouth, increased later extending to about twenty kilometers.

The effects of the salt intrusion can be summarized as follows:

- modification of the biological characteristics with changes in the trophic chain and consequent effects on the fish population with impacts on fishing activities;
- interruption of withdrawals for irrigation, with serious damages on agricultural activities;
- interruption of the water supply in the easternmost part of Polesine. The drinking water plants are not, in fact, able to desalinate the water;
- salinization of the aquifers;
- drying up of coastal areas and micro desertification processes.

The morphological and environmental features of the lagoons represent a peculiar aspect in the management objectives of these areas. In this respect, some crucial features can be highlighted:

- low depth (1-2 m);
- connection to the sea through one or more mouths, which regulate the exchange of marine water;
- important annual temperature variation;
- large salinity variation.

The main problems of the lagoons are connected to the intrinsic and highly variability of their environmental and morphological conditions, which tend to change quickly in response to the external factors. In particular:

- the salinity levels are extremely mutable and depend on the water exchanges with the sea and Po river (through floods);
- the oxygen content in the shallowest areas has a large impact on the production activities;
- the water quality is threatened by algae blooming and nutrients (phosphates and nitrates) coming from the fluvial waters;
- the infilling of the lagoons, due to sediment deposition, influence the internal circulation and consequently the fishing and shell-farming production;
- the continuous erosion of the external spits that usually protect the lagoons from the open sea threaten the existence of the lagoon areas.

One of the main challenges is the stabilization of the lagoon environment for the economic and development purposes, without deteriorating their value, especially considering the mutable conditions that the Climate Change will bring.

As for the Valle lagoons, one of the worst limiting factors is the sudden rise in the water level that can occur in the Valley, especially in May and June, caused by sudden weather events. The heavy showers, in fact, do not allow a sufficiently rapid emptying of the lakes by means of dewatering pumps or sewers. Every spring, a certain number of nests are lost due to the flooding of the salt marshes.

4.2 Status and trends of hydrological, geomorphological and biological process

4.2.1 Hydrological status and trend in Po Delta

Regarding the analysis of the current climatic condition, according to the fourth assessment report of the Intergovernmental Committee on Climate Change (IPCC, 2007; 2012), in the northern Adriatic the average annual surface temperature has increased by 0.5 °C in the last 35 years, but with increases of 1.1 °C in autumn (Conversi et al., 2010; Giani et al., 2012).

The IPCC study is the basis of the National Plan for Adaptation to Climate Change (PNACC). Starting from the analysis of current and future climate conditions, the PNACC identifies "homogeneous climate macroregions" for terrestrial and marine/coastal areas, for which data show similar climate conditions over the last thirty years. The EO Delta area is part of the "2 terrestrial macro-region" and the "1M" marine climate macro-region (Figure 14).

In the report 3.1 of Change We Care Project, the annual time series of temperature at 2 m and precipitation analysed, plus the wind rose, extracted for the area of Po River Delta site and coming from the AdriSC climate simulation (1987-2017). The analysis accompanies the modelled atmospheric fields described in Section 2.3.

Air temperatures (AdriSC model): clear temperature trend can be seen in the series, with the rate of approx. 0.2 °C per decade. The warming trend may be seen in all seasons, with winter mean temperatures ranging between 4 and 7 °C, while summer mean temperatures are ranging from 18 to 20 °C (Figure 15).

Precipitation: the precipitation rate is changing between 1 and 3 mm/day, i.e. between 400 and 1100 mm per year. The precipitation rate is maximal during autumn, when it might reach 6 mm/day, while the minimum precipitation rate is achieved during winter and spring, when it might go down to 0.4 mm/day, or about 40 mm per season (Figure 16).

Terrestrial macro-region:	MACROREGION 2
Average annual temperature (C°)	14,6 (±0,7)
Days of heavy rainfall	4 (+1)
Frost days	25 (±9)
Summer days	50 (±13)
Cumulative winter precipitation	148 (±55)
Cumulative summer rainfall	85 (±30)
95th percentile of precipitation	20
Consecutive dry days	40(±8)

marine climate macro-region:	Sea Surface Temperature (C°)	Sea Level (Sea Surface Heights) (m)
1M	18,2	-0,07
2M	19,6	-0,03
3M	20,3	0,05

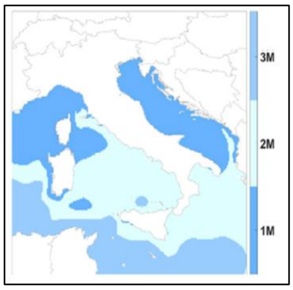
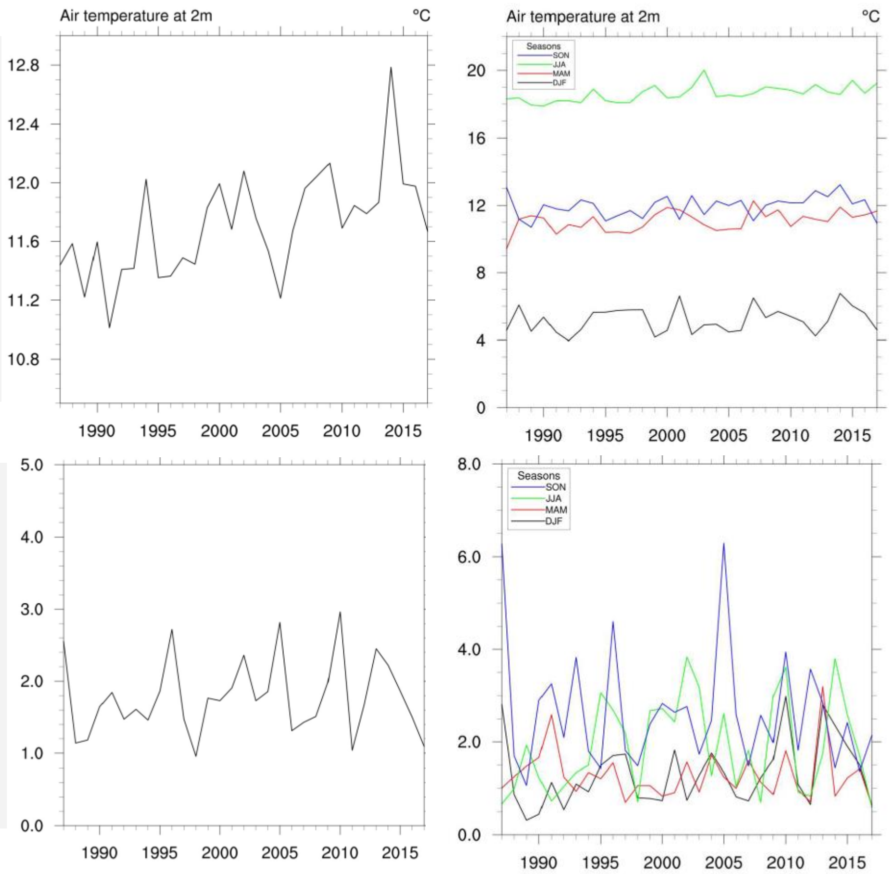


Figure 14. "Homogeneous climate macroregions" for terrestrial and marine/coastal areas (Source: PNACC).

The precipitation decrease is reflected in a decrease of the freshwater load to the Adriatic Sea, which is also important as bringing nutrients to the coastal regions. It is particularly relevant after 1970. With the reduction in the river supply, the sediment supply on the coasts decreases.

Annual air temperature at 2 m time series in the period 1987-2017 at the Po River Delta site as simulated by the AdriSC modelling suite.

Seasonal air temperature at 2 m time series in the period 1987-2017 at the Po River Delta site as simulated by the AdriSC modelling suite.



Annual air precipitation time series in the period 1987-2017 at the Po River Delta site as simulated by the AdriSC modelling suite.

Seasonal precipitation rate time series in the period 1987-2017 at the Po River Delta site as simulated by the AdriSC modelling suite.

Figure 15. Annual-seasonal temperature/precipitation time series (1987-2017) in Po Delta (AdriSC simulation).

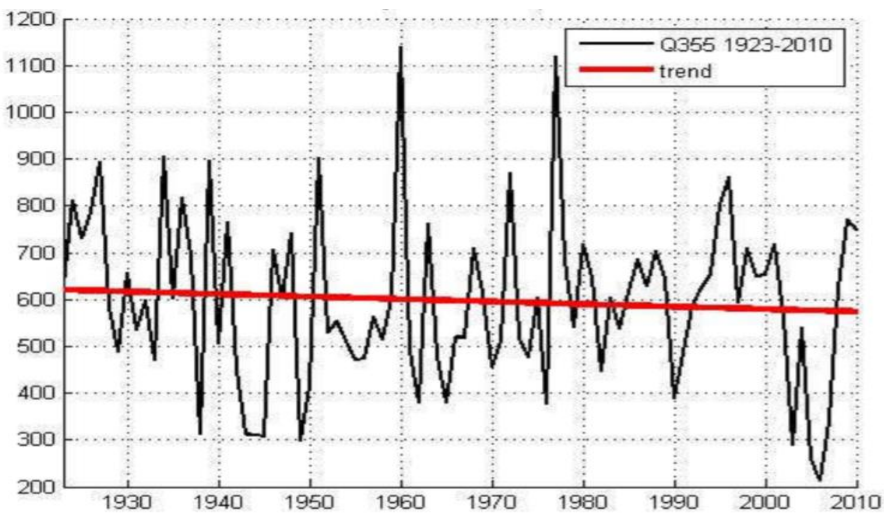


Figure 16. Flow rate with duration 355 days/year with its trend at Pontelagoscuro (Source: General report of Water Balance Plan for Po river district, Po River Basin Authority AdBPO, 2016).

Sea level: currently, the rate of rise is about 45-55 cm per century. This acceleration is reflected in the number of documented floods, particularly in its northern part as Venice (Figure 17).

According to the model AdriSC, Sea level constantly rose in the considered period, yet with quite strong interannual variability (Figure 18).

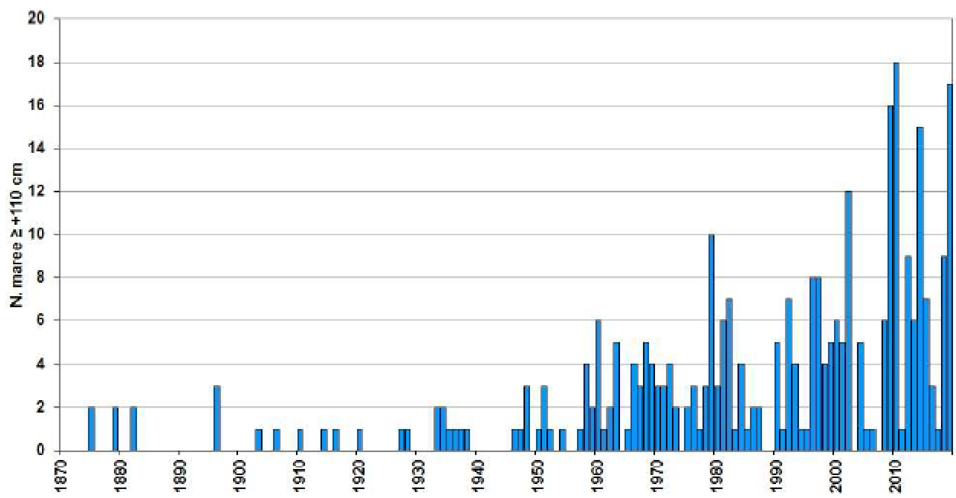
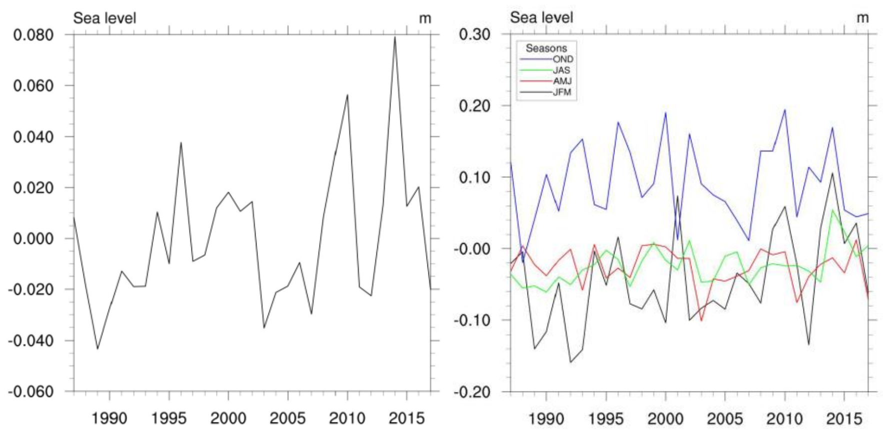


Figure 17. Number of extreme sea level heights (>110 cm) measured in Venice since 1872 (Source: www.comune.venezia.it).

Annual sea surface height time series in the period 1987-2017 at the Po River Delta site as simulated by the AdriSC modelling suite.



Seasonal sea surface height time series in the period 1987-2017 at the Po River Delta site as simulated by the AdriSC modelling suite.

Figure 18. Annual-seasonal sea surface height time series in the period 1987-2017 at the Po River Delta site as simulated by the AdriSC modelling suite.

Wind: The wind rose denotes the strongest winds from northeast, which are resembling bora conditions and the jet coming from the Golfo di Trieste. However, the most frequent, but weak, winds are blowing from west, along the Po Valley (Figure 19).

Sea surface temperature: Off the Po River Delta, the mean annual of sea surface temperature has values rising from 15.5 °C at the beginning of the AdriSC simulation to 16-17 °C at the end of the AdriSC simulation. The positive trends are strongest in spring and autumn periods (Figure 20).

Sea surface salinity: Off the Po River Delta sea surface salinity has strong interannual variability, ranging from 31 to 35, with lowest values in spring and highest in summer and autumn (Figure 21).

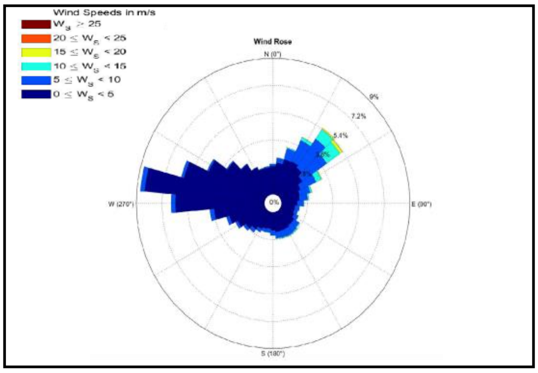
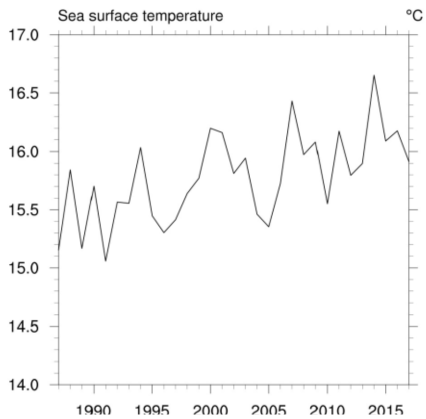
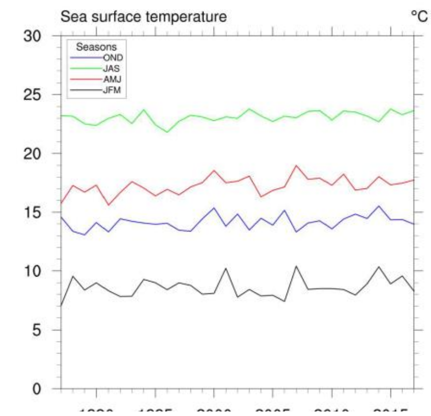


Figure 19. Wind rose at the Po River Delta site as simulated by the AdriSC modelling suite (1987-2017).

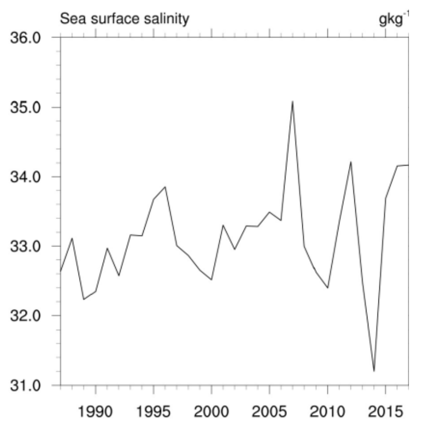
Annual sea surface temperature time series in the period 1987-2017 at the Po River Delta site as simulated by the AdriSC modelling suite.

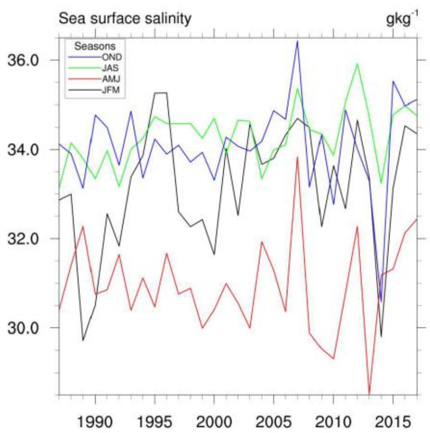




Seasonal sea surface temperature time series in the period 1987-2017 at the Po River Delta site as simulated by the AdriSC modelling suite.

Annual surface salinity time series in the period 1987-2017 at the Po River Delta site as simulated by the AdriSC modelling suite.





Seasonal sea surface salinity time series in the period 1987-2017 at the Po River Delta site as simulated by the AdriSC modelling suite.

Figure 20. Annual-seasonal sea surface temperature time series (1987-2017) in Po Delta (AdriSC simulation).

Figure 21. Annual-seasonal sea surface salinity time series (1987-2017) in Po Delta (AdriSC simulation).

Wave activity: Observations show an evident tendency towards a reduction of the wave activity in the Northern Adriatic Sea, in terms of intensity of the events, and a general increase in terms of frequency (50th and 75th characteristic percentiles). Of the two wind regimes, the decrease of intensity is mainly due to bora (particularly in the upper percentiles), while the increased storminess is associated with sirocco conditions.

4.2.2 Geomorphological status and trend in Po Delta

From a geological point of view, the Po Delta originates from the accumulation of the sediments transported by the Po River, whose discharge distributes through its branches, with Po di Pila delivering 61% of the total freshwater discharge and 74% of the total sediment load (Syvitzky, Correggiari 2005). Overall, the modern Po Delta shows sediment deposition rates of 2cm/year (over 100 year 0.5 cm/year) according to Palinkas et al. 2004, 2010. Nonetheless, it has undergone a steady regression phase in the last decades due to the reduction of sediment load. According to Nelson 1970, the composition of suspended sediments transported by the Po River comprises 7% clay, 70% silt and 23 % sand, as recorded at the section of Pontelagoscuro. The sand remains confined in the top set at the mouth bars of the Po Delta, while fine-grained deposits characterize the proDelta (Palinkas, Nottrouer, Wheatcroft Langone 2005).

From a lithological point of view, sand and silt are commonly observed in correspondence of fluvial ridges and ancient shorelines. Silt clay sediments, characterized by a high organic content, are mostly located in depressed areas that in the past were prone to swamping. Sometimes even peat can be detected in areas that are below the sea level. In the transitional regions, between elevated and depressed areas, sandy silts are prevalent (Figure 22).

The thickness of the deposits dating back to the Pliocene and Quaternary is remarkable, reaching sometimes 2000-2000 m, being dependent on the tectonic and subsidence processes occurred during the time. The material composing the quaternary deposits of the Delta derive from the crumbling of rocks transported from the Alps and Apennines to the sea (clay, fine sand with clay, black clay, fine sand). On the other hand, the Pliocene formation at the base of the Quaternary deposits is primarily composed of gray clays, with sand intercalations and bioclasts. Other distinct sedimentological successions can be recognized in the whole area, belonging to specific geological phases and comprising sand, clay, peat and sometimes conglomerate. The sedimentary deposits in the Po Delta region contain large aquifers of fresh water and an important amount of gas, which has been deeply exploited especially in the past.

A historical evolution of the Po Delta region is available from Correggiari et al. 2005, who also estimated the accretion rates and directions starting from 1600 until 1900:

- 1694 – 1750: the Po Delta grew mainly towards south at 86 km/year;
- 1750 – 1820: the Po di Goro – Gnocca moved towards south-east at 129 km/year;
- 1811– 1840: the Po di Maistra moved towards north at 60 m/year;
- 1840 – 1886: the fluvial lobes elongated, and Po di Tolle became; dominant growing at 60 m/year;
- from 1886 Po di Pila became the most dominant and grew at 47 m/year.

During the twentieth century, between the 1900 and 1996, the morphological evolution of the whole Po Delta coast followed three different phases as consequence of the changes in the sediment and water fluxes of the Po River (Simeoni et al. 2000):

1. a first period from 1900 to 1944, when the Po Delta area was influenced by the high amount of

sediments transported by the Po river. The average load of the suspended sediments between 1918 and 1944 was estimated equal to 15.5 Mt/year, with a minimum between 1942 and 1943. In this period there was a general progradation of the Po Delta;

2. a second period from 1945 to 1983, when there was a decrease of the sediment fluxes due to the excavation activities, which started in 1950, with a peak during the 80's. The sediment shortage accelerated the subsidence, which led also to the submergence of vast portions of the Po Delta;
3. a third period, from 1984 to 1996, when the sediment supply continued to decrease. However, since the subsidence rates were lower than the previous period thanks to a series of Government's intervention, the Po Delta did not exhibit relevant changes.

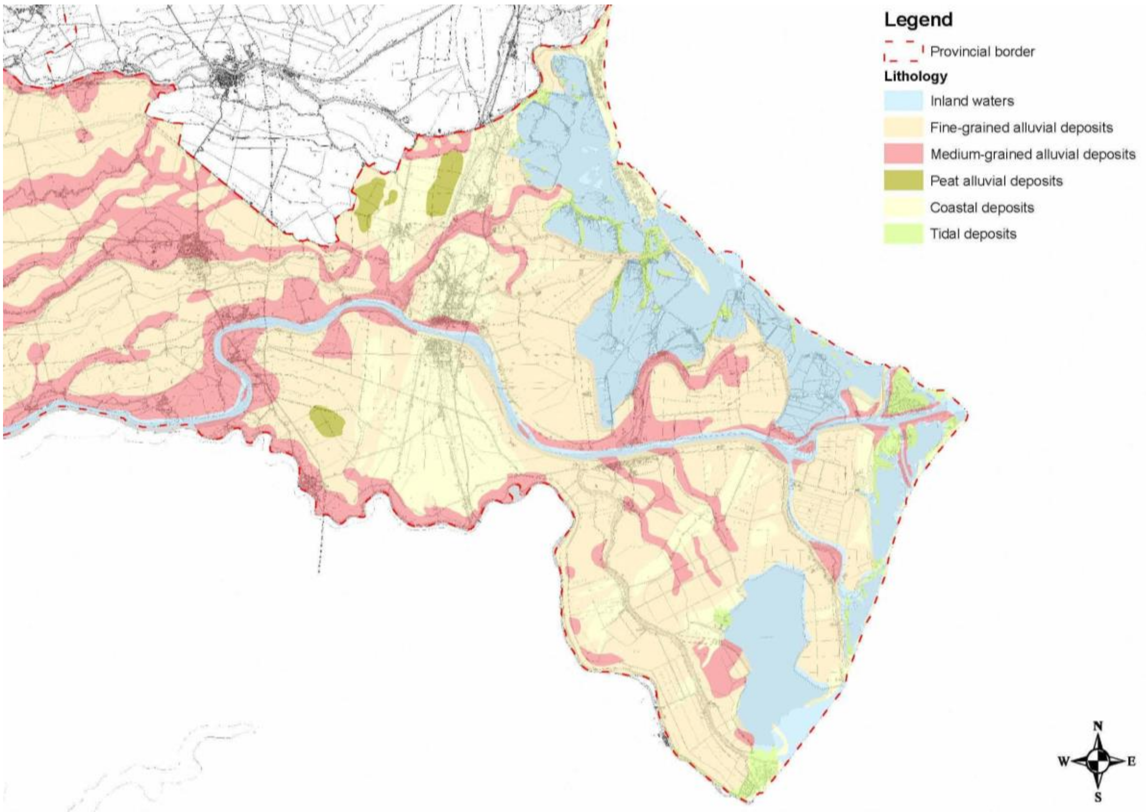


Figure 22. Lithology in the most part of the Po Delta Region (Source: IDT Veneto Region, https//idt2.regione.veneto.it/).

Therefore, until the beginning of 2000, due to the sediment shortage, part of the Po Delta was in a phase of erosion and it was dominated by the sea processes.

The changes in the Po Delta coast of the last 80 years can be derived and visualized clearly by the analysis of a multi-temporal aerial photogrammetric survey carried out from 1933 to 2018 on the Delta area (Figure 23).

The results were obtained by integrating the coastlines extracted by Fabris et al. (2012) with the elaborations of the 2018 lidar flight conducted by the Veneto Region. They show distinctly that the most relevant changes occurred between 1933-1977, when a large portion of territory was submerged as mentioned before. In that period vast areas of the Po Delta, including mainly valleys and lagoons, went underwater due the subsidence that reached its maximum intensity in the '60s. With the sinking of the ground's surface, many embankments were destroyed or damaged, while other defense works stopped working properly, exposing thus the littoral regions to the sea and fluvial waters.

In the last period (1977-2008), the emerged surfaces are comparable to the submerged ones and little changes occurred in the last 10 years (2009-2018). The most relevant variations have involved the frontal lobe, in correspondence with the Pila mouth, which has exhibited an accretion rate of almost 20 m/year according to Ruol et al. (2016).

A curved bar has also merged in front of this lobe (Ninfo et al. 2018), favoring its progradation and accretion. Regarding the other regions, the southern part of the Po Delta is more dynamic in comparison to the northern portion, where the touristic activities have imposed the implementation of diffusive measures to control the coastal evolution.

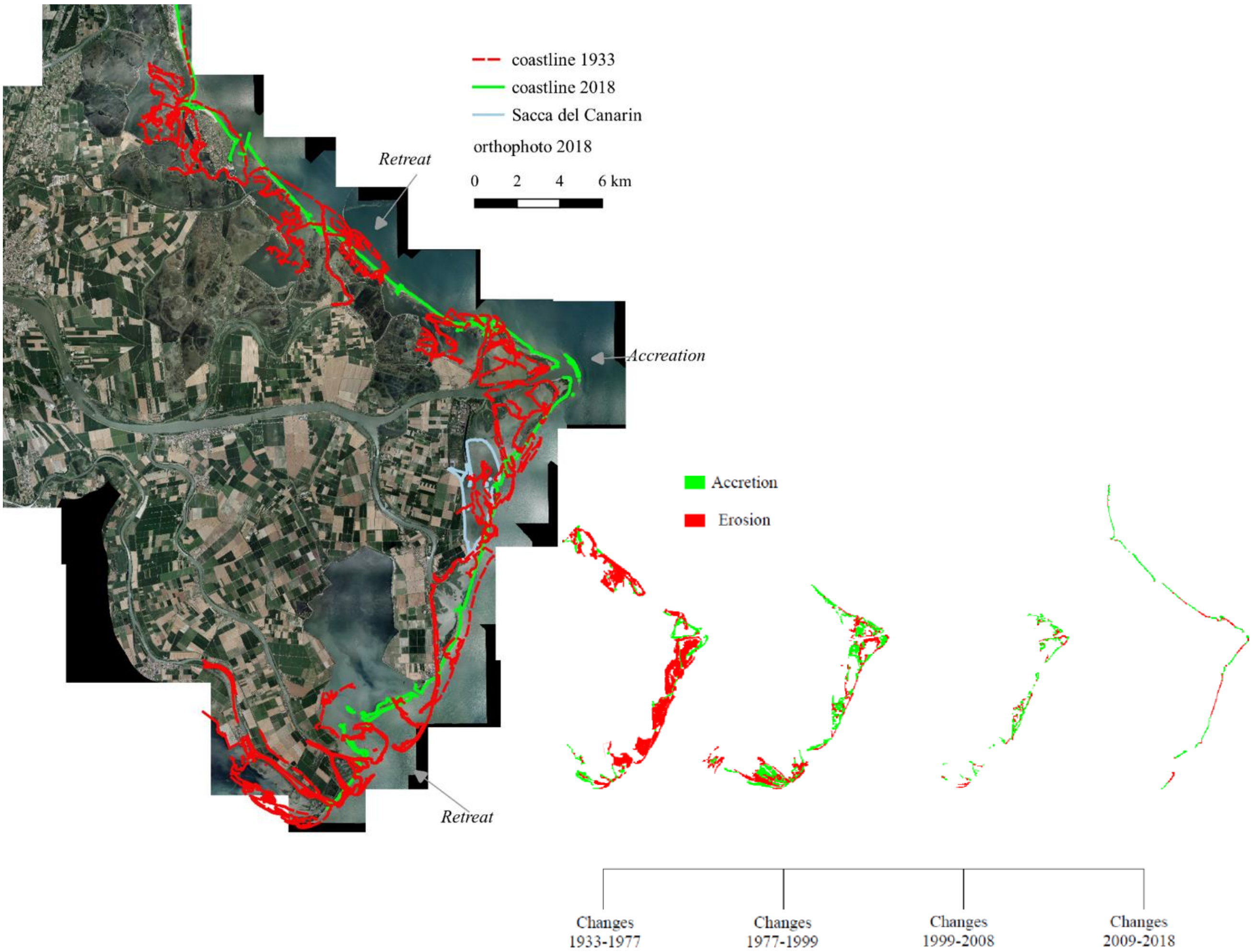


Figure 23: coastline evolution in the Po Delta area: 1933-2018 (left) and Po Delta coast changes from 1933 to 2018 (right).

The subsidence refers to a slow areal lowering of the ground surface, and its rate and distribution have been analysed in several works, such as the Monitor project, the paper of Tosi et al. (2016), as well as in the works of Bondesan et al. (2015) and Ruol et al. (2016).

According to these authors, natural causes induce a subsidence rate in the Po Delta region of approximately 5 mm/year and they are represented by:

- compaction, due to the presence of recent deposits constituting the Delta plain. They are subject to consolidation processes, with the expulsion of the interstitial water and grain compaction;
- deep tectonic;
- sea level rise (eustasy), occurring since the last glacial maximum and recent climate change.

Man induced subsidence has a higher rate and is due to:
- drained reclamation: the reclamation for agriculture purposes causes a compaction of the soils due to the expulsion of the water from the inter-granular voids;
- peat oxidation: especially in the areas subject to remediation, where the organic matter gets exposed to air and undergoes fast oxidation processes;
- fluid extraction (methane and water);
- lacking of new sedimentation due to dam construction and mining activities upward of the river mouths;
- artificial loads.

Regarding the closest areas to Sacca del Canarin, the most recent analysis carried out in Ruol et al. (2016) reported a subsidence between -2 mm/y and 0 in the internal part between Busa di Scirocco and Busa Storiona in the period 1992-2000, with a maximum rate of -5mm/y closer to Busa Storiona. The trend is confirmed and even reduced afterwards, between 2002-2010.

About sediment stocks, two sedimentary systems can be distinguished in a land-sea transition zone: one external represented by the sand spits, and one internal defined by the sacche and the lagoons. All the elements are influenced in different ways by the sea currents, the fluvial inflows and the meteorological variables (Figure 24).

Today the Po Delta protrudes in the sea for almost 25 km, bordered by a wide region occupied by a submerged proDelta, which extends for 6 km in the north and 10 km in the south (Biondani, 2008).

Two different types of depositional patterns are detectable from Very High Resolution (VHR) seismic lines recorded offshore: a) the Delta lobes fed by individual distributary mouths, onlap onto each other and reflect autocyclic processes, driven by discharge and sediment load variations, and human interference; and b) erosional features locally detactable close to individual distributary channels.

For an evaluation of the evolution of the Po Delta, DTM (250 m) of the bathymetry from the 1886 Ing. Stella map with data of 1877 survey and DTM of current bathymetry obtained by the integration of various singlebeam and multibeam data were compared. The differences vary between - 12m and about + 19m with areas of strong erosion off the mouths of the Po di Tolle and the Po di Maistra and a deposition area in front of the Po della Pila distribution channel (Figure 25).

Regarding current status on the sediment stocks in the coast and transition region, a sedimentological campaign carried out in 2006 by the Veneto Region led to the sedimentological characterization of the area around the Po Delta coast. The sedimentological distribution in the surface littoral area is strongly influenced by the sediment outflows coming from the Po River branches, which successively is mobilized and redistributed along the Delta by the sea currents.

Medium sand is concentrated in the proximity of the main Po River mouth (Po di Pila), where sediment transport is stronger, while fine sand sediments predominate close to the other mouths that deliver lower water and solid discharges. Far from the coast, silt deposits are prevalent, especially close to Sacca of Scardovari.

The overall analysis confirms that the Po Delta is still changing, especially as it concerns the coastal area, with some lobes of the Po Delta still prograding, some portions retreating, and other parts stabilized by human interventions. There is a general tendency of the lagoons to flatten, either by erosion of the tidal flats or through siltation of the channels, which in some cases have been filled completely (Antonioli et. al, 2017). Flattening of the submerged landforms are leading to a morphological simplification, which could result in lagoons that lose their typical shallow estuarine characteristics and change into marine embayments. External sand barriers are prone to erosion and quick changes as they are exposed to the shattering waves during storm surges.

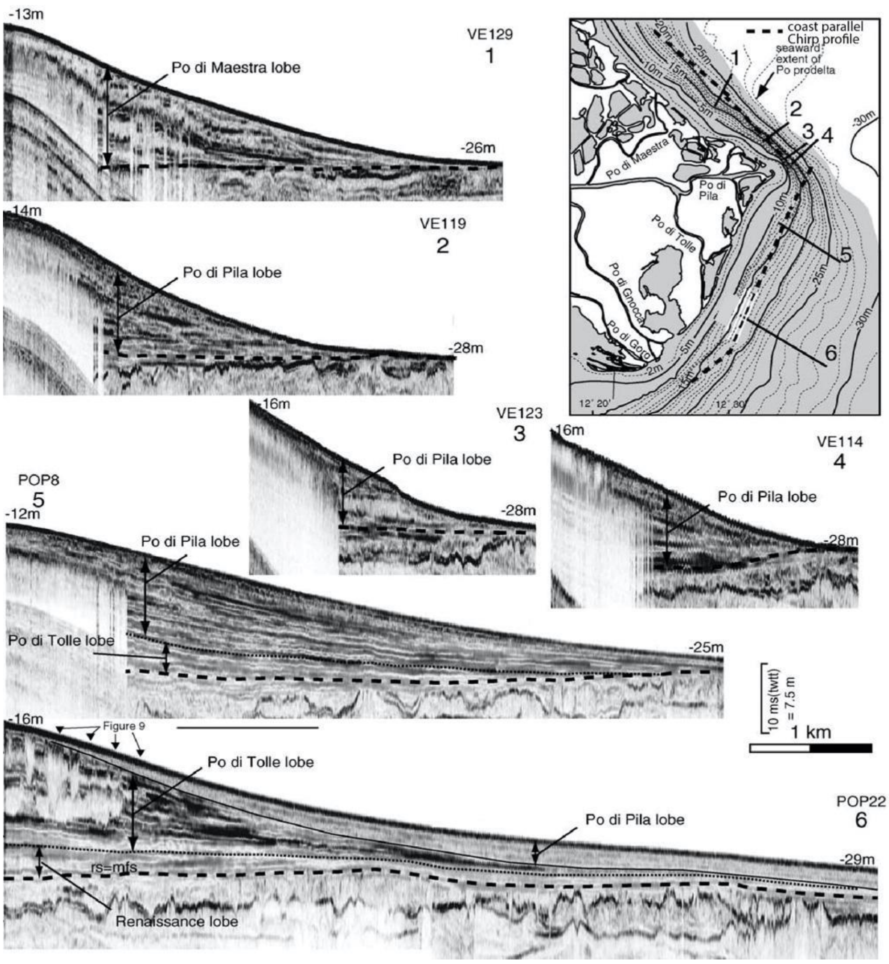


Figure 24. Chirp-sonar profiles perpendicular to the coastline illustrating the internal geometry of the Po proDelta lobes above the basal ravinement surface (rs), that corresponds also to the maximum flooding surface, mfs, see Correggiari et al. (2005). Each proDelta lobe is named after the river mouth of origin. The surfaces separating proDelta lobes are distinctive seismic reflectors that can be correlated laterally. The dashed line on the map shows the location of the composite profile parallel to the coast.

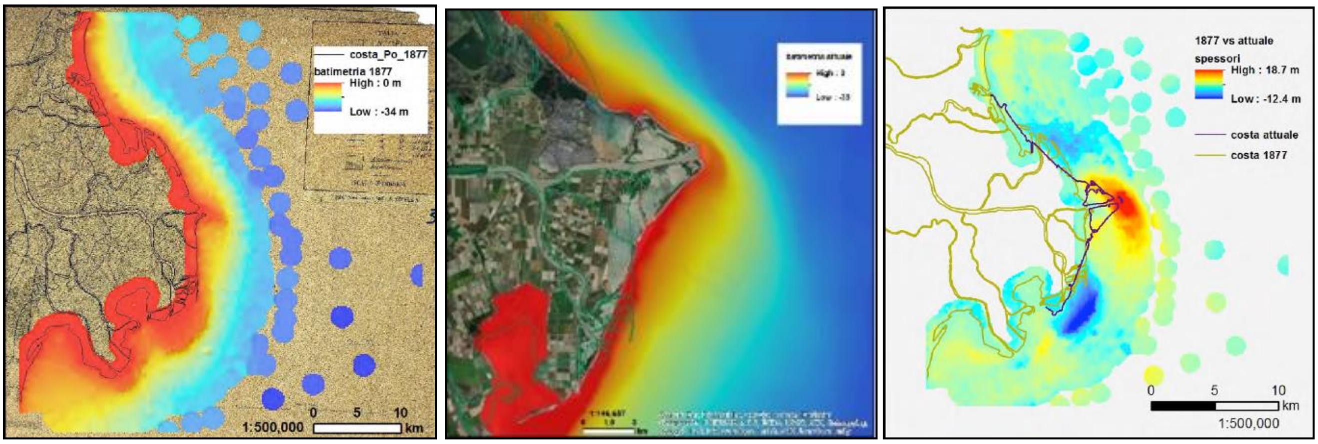


Figure 25. Left: DTM created on georeferenced Ing. Stella Map of 1886. Center: current bathymetry from singlebeam and multibeam data. Right: result from difference between modern and historical bathymetry.

Considering these elements, the expected sea level rise consequent to climate change is likely to worsen the problems that have been observed in the coastal areas.

From a morphological point of view, considering the lagoon environment, some particular elements can be recognized (according to Reclamation consortium Po Delta) (Figure 26):

- Sub-lagoon canals: they define a subaqueous network, connecting the lagoon to the mouths at the sea. At the beginning of the high tide (phase), the seawater starts flowing into the lagoon through these channels, with a velocity depending on the balance of forces between the lagoon waters and the sea variations. Water current in these canals is responsible for the erosion or deposition of important amounts of sediments, such as sand, silt and clay.
- Velme or tidal flat: they are submerged structures originated from the deposition of sediments along the sub-lagoon canals. They seldom emerge during the low tide phase.
- Barene or salt marsh: they are flat-marsh islands and they can be seen as consolidated velme, which become vegetated inducing a stronger process of sediment trapping and deposition. They tend to remain emerged, above the average level of the ordinary tides. They become stable during time thanks to the presence of vegetation.
- Ghebbi: waterways between velme and barene, connecting the internal areas to the channels
- Scanni: they are elongated structures, also called mouth bars. They are of primary importance to protect the lagoon from the intrusion of salty water. Their origin relies on the deposition of sediments from the river, and their reworking from the forces of the sea currents. For these reasons “scanni” are usually very mutable structures, sometimes showing parallel bars that testify the advancement of the line coast. They are usually located between the lagoon and the coast.

Figure 26. Satellite map abstract WorldView 2.0, anno 2011 (Source: Atlante lagunare costiero del Delta del Po).

Water and sediment fluxes are crucial factors in the evolution of estuarine regions, and the accretion and retreat of a Delta depend both on the amount of sediments reaching the river mouth from the hydrological catchments and on the erosive power of the sea processes. The occurrence of floods and surges in the area contributes to shape the Delta: a single exceptional flood is able to retain, transport and deposit large volumes of sediments towards the river outlets, while a single storm-surge can erode wide sectors of shores and destroy submerged bed-forms. Recently, two important events have affected the Po Delta, in November 2018 with the "Vaia" storm and at the beginning of November 2019. Due to their high intensity, they caused important changes in the littoral area of the Po Delta, with the removal of sand bars and deposits along the river channels and erosion of large coastal areas.

Satellite images offer a great opportunity to continuously observe the Po Delta area and to monitor some interesting aspects, such as changes in the emerged lands and sediment plumes during floods. The first satellite products have been available since the '70s with the Landsat mission 1 and 2, and the pool was augmented by the successive Copernicus Program that launched Sentinel-2 in 2015 and Sentinel 2-b in 2017.

Figure 27-28 shows turbidity plumes during normal and exceptional conditions and they come from elaborations of Sentinel-2 acquisitions (Trampe, 2016). The plumes coming from the northern tributaries spread at both sides of the emerged bar in front of the Pila mouth. At south a small plume enters into the sea through Po di Tolle and a denser, wider plume can be identified between Tolle and the spit at the southern end. The main branch of the Po River shows a higher turbidity in comparison to the others. The figure refers to the typical Sirocco plumes originating from the Po mouths.

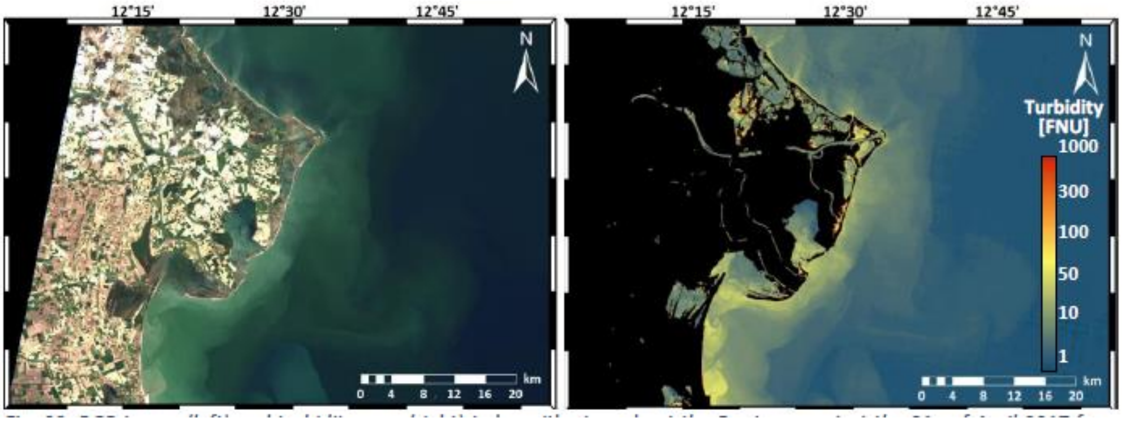


Figure 27. RGB image (left) and turbidity map (right) in logarithmic scale at the Po river coast in normal condition from Sentinel-2 acquisition (Trampe, 2016).

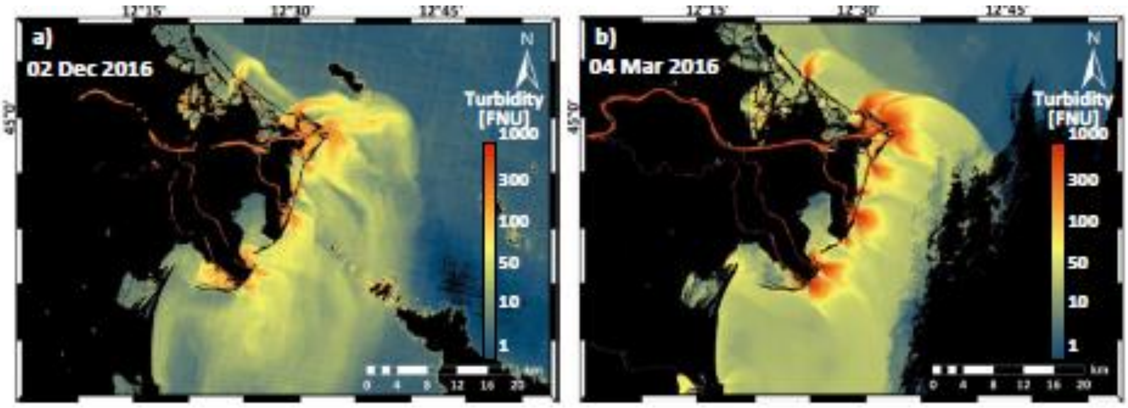


Figure 28.Turbidity maps (log scale) of typical Scirocco plumes: a) 02th of December 2016, b) 04th of March 2016 from Sentinel-2 acquisition (Trampe, 2016).

Generally speaking, the images display a strong connection between the fluvial flux, the sea-current and the turbidity plumes. In the north of the Pila mouth the sediments are transported near the coast while the plumes coming from the main Pila mouth and from the southern outlets are transported towards south and dispersed in a wider area offshore, where they settle down when their velocity starts reducing.

The sedimentation process is highly dependent on the strength of the sea currents and sediment fluxes coming from the river. The sediment particles dispersed in the plume settle down with different times and distances according to the prevailing forces acting on them. The correlation between the plume-spreading and the formation of subaqueous bedforms is not straightforward and is still a matter of research.

The satellite images confirm the observations carried out on the water and sediment fluxes partitioning. According to the measurements, the southern branches deliver more amount of freshwater and sediments with respect to the northern ones (Maestra 1%, Pila 74%, Tolle 7%, Gnocca 11% e Goro 8%).

A recent work shows the evolution of the Delta Po cusp starting from 1970 by comparing satellite images of different years (Figure 28).

The Sentinel-2 images acquired in 2017 clearly show the growth of a small bar in front of the main Pila mouth of the Po River. According to Ninfo et al (2018), its formation is connected to a series of floods occurred between 2013 and 2015. It was originally visible only during low tides, but then it grew quickly and became stabler during the years. In the same period, the satellite images display the creation of new half-moon spits in proximity of the secondary, northern mouth, where new deposits emerged clearly in the summer/winter 2016 and they were visible both at low and high tides. The trend seems continuing as shown by the Sentinel-2a images of May 2017.

Figure 28. Landsat satellite images: (a) L1MSS-12 August 1972 (60 m); (b) L5TM 8 May 1987 (30 m); (c) L5TM - 14 July 1994 (30 m); (d) L7ETM 23 April 2002 (30 m); (e) L5TM 17 April 1991 (30 m); (f) L8OLI 3 April 2015 - (30 m). (Ninfo et al. 2018).

The growing direction of the bars is N-NW, and it is very likely that it is influenced by the SE waves (Sirocco winds), which is the direction of the longshore sediment transport and it is opposite to the northern dominant wind (Bora). The same direction characterizes the main outlet of the channel and the bar of the subaqueous mouth.

In conclusion, the analysis of the data and studies confirms that the Po Delta is a sensitive and vulnerable area, as it develops at the closure section of the Po River, whose water and sediment fluxes are key factors at shaping the Delta morphology, but also at conveying pollutants and nutrients to the coastal areas. Moreover, transition environments such as lagoons and river mouths are delicate environments highly influenced by tides, river supplies, weather conditions and exchanges with the sea.

As regards water fluxes measured at the Po final section of Pontelagoscuro, the historical series available since the 1920s show that the monthly average and annual average flow of the Po River tend to decrease. However, the observed trends cannot be attributed only to the ongoing climate changes, since the water fluxes measured at the closure section are heavily affected by the withdrawals from the rivers in the Po catchment, occurring in the same period for drinking and irrigation purposes. Therefore, the observations can be taken with caution.

Concerning sediment transport, historical and recent studies have shown that solid discharge has dropped consistently over the time along the Po River. This trend is attributed to the construction of dams and hydraulic powerplants along the river course, which have trapped sediments preventing them from reaching the sea. Moreover, change of land use and excavation along the river bed have contributed to reduce the sediment fluxes.

Important measuring campaigns have regarded the Po branches in the Po Delta, with the aim of assessing the water and sediment flux partitioning and its evolution in time. The studies have confirmed the predominant role of the central Pila branch, which also shows the highest hydraulic capacity and consequently the highest growing rate.

4.2.2.1 Focus on the "Sacca del Canarin"

The "Sacca del Canarin" is the transition area on which the study focuses. It covers an area of about 6.5 square kilometers between the mouth of the Po "Busa di Scirocco", to the north, and the "Busa del Bastimento", to the south. The morphology of the lagoon bed is quite uniform, with an average depth of about 80 cm (Figure 29).

It extends over an area of about 6.5 square kilometers between the mouth of the Po "Busa di Scirocco", to the north, and "Busa del Bastimento", to the south. The morphology of the lagoon seabed is quite uniform, with an average depth of about 80 cm.

Hydrodynamic exchanges with the sea take place through a single mouth, the Bocca Nord, which opens in the northern part of the coastal strip, not far from the Busa di Scirocco. This conformation influences the quality of the water, in particular as regards the salinity.

In recent years, the "Sacca del Canarin" has undergone anthropic interventions, also to improve the hydraulic safety of the agricultural and settlement area behind it.

Figure 29. The main Pila mouth of the Po River and the inlet to Sacca del Canarin. On the background the Enel power station is visible (not working anymore). (https://emiliaromagna.cia.it/agrinsieme-ferrara-parco-nazionale-del-Delta-del-po-idea/).

The internal – natural- modifications concerned the closure of the second natural mouth of the lagoon, which was originally positioned on the south side of the same, near the mouth of the Busa del Bastimento of Po di Tolle. These interventions, together with the natural action, have produced a reduction in water supplies within the lagoon and an anomalous hydrobiological situation for a lagoon, which normally has two communication gates with the sea. The continuous accumulation of sediment over the years is causing a progressive burial of the "Sacca del Canarin" and the consequent decrease in depth reduces the circulation of water. A hydrodynamic reduction implies, from a biological point of view, a sure drop in the number and density of the life forms present and consequently of the animals that find suitable habitat there.[7]

The first picture of the Delta lagoon comes from the GAI flight in 1954, before the subsidence and the hydraulic works that were carried out in the area (Figure 30). In that period the sea water came only from an opening at the scanno, while the fresh water from the other two sides. Reeds were present on the river side. Nowadays, the morphological setting of “Sacca del Canarin” can be described by three main features:

1. an inlet to the sea, called Bocca del Canarin, from which the lagoon exchanges salt water with the sea. The mouth also constitutes the access for the sediments coming from the sea and the river (Busa di Scirocco). In the north it is protected by several small reefs that were built from the beginning of 2004 by the “Reclamation consortium Po Delta”, together with a sediment tank filled with the material dredged by the canals. On the other side, the south part is exposed to the action of the storm surges. The current depth of the bottom of Bocca del Canarin is 3-4 m b.s.l in the innermost part, while it decreases towards the sea. Here the DTM (2018) shows an elongated bar parallel to the coast with a depth of 1.0 b. s. l. This bar, which can be classified as an ebb tidal Delta, reduces the hydraulic exchange with the sea and holds the fresh water coming from Busa di Scirocco, both during moderate flows and floods;
2. the absence of a structured network of channels and morphological features such as barene and islands. Unlike other lagoon systems in the Po Delta region, in fact, Sacca del Canarin is characterized by a uniform and shallow bottom, with a mean depth of 0.85 m b.s.l (according to the most recent DTM of 2018). The only morphological features that can be recognized is the relict of an old littoral bar (Costà d’Avanzo) that develops parallel to the internal bank in the western part of the lagoon. According to Verza et al. (2015), here some barene emerge during low tide, when velme and oyster formation are well visible;
3. a “scanno” that protects the lagoon from the intrusion of saltwater between Busa di Scirocco and Busa Storiona.

The lagoon environment is a very dynamic system, controlled by the flux and reflux of the tides and river discharge, while quick changes derive by storm surges, events of very high tides and floods. Sediments and water interact constantly changing the lagoon setting (Figure 31).

[7] Source: “Sacca del Canarin vivification project” year 2007 - Doc. N. PO0 CA DA SVL 001. Generation and Energy Management Division Technical Area - Development and Realization of Engineering - Development - ENEL Plants.

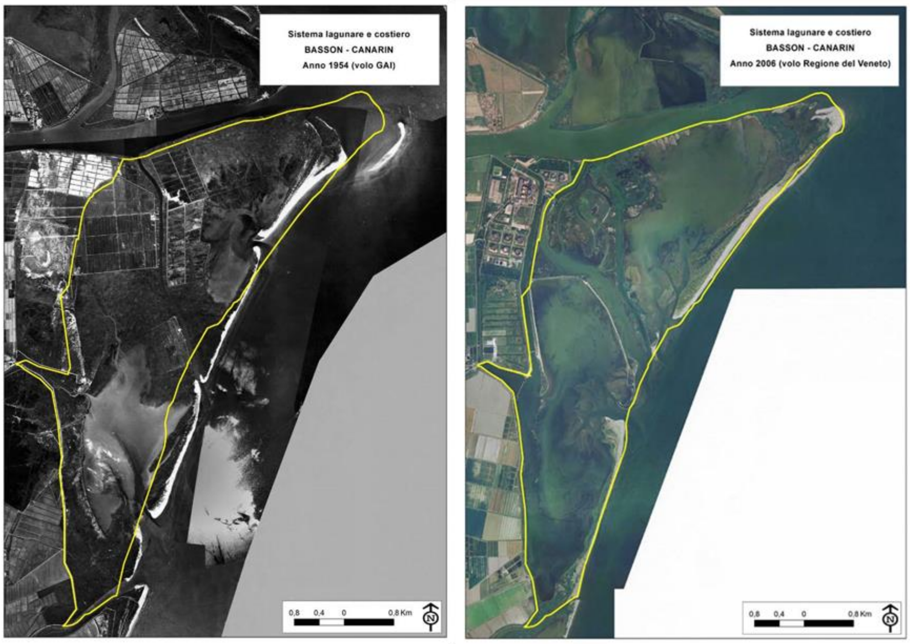


Figure 30. Views of the Basson-Canarin system of different years: 1954 on the left and 2006 on the right. Sacca del Canarin is located in the southern part of the system. (Source: Verza, E., & Cattozzo, L., 2015; Atlante lagunare costiero del Delta del Po).

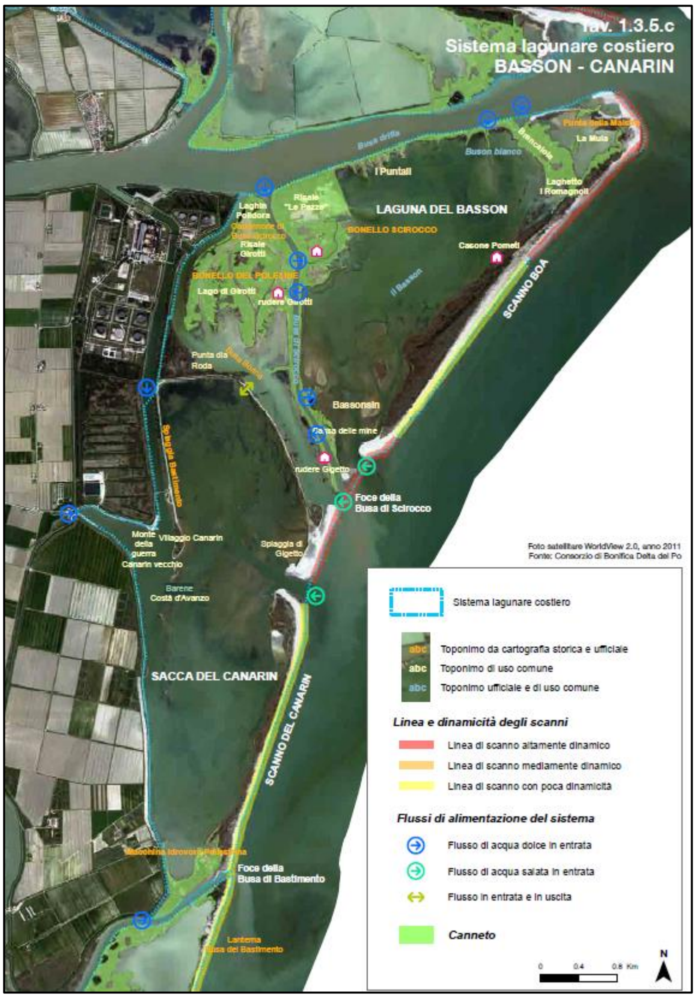


Figure 31. Bassona-Canarin system (Source: Atlante lagunare costiero del Delta del Po).

According to Verza et al. (2015), several interventions have been carried out at Sacca del Canarin:

- a stone ballast and a sediment tank have been recently built at the south part of the Basson, resulting in an increasing flux of salt water in that side. The ingression of fresh water from Busa di Scirocco has been furtherly limited by building a new ballast;
- deep canals have been dredged from the mouth to realize sediment tanks behind the scanno di Canarin and increase its stability. A fence was built at the border with the lagoon to dampen the sediment dispersion. The survey in 2014 showed that the area was slowly being vegetated and populated by birds;
- some of the dredged sediments have been used to nourish the velme;
- recently a stony groyne was built in the sea to limit the ingression of fresh water in the lagoon.

"Sacca del Canarin" is a shallow-water lagoon, whose economy relies deeply on fishing and touristic activities. In the past the lagoon experienced problems of eutrophication that were associated to the reduced hydraulic circulation within the water body. Currently, the recharging time of "Sacca del Canarin" (time spent to have a complete change of the water in the lagoon) is quite high and varies according to the vicinity to the river or to the sea. In fact, it is lower close to the mouths where the water exchange is strong, while it is high in the central part, where the circulation is practically null.

For this reason, important works of vivification of the lagoon are planned, and they are intended at reducing the freshwater flux from the river mouth and the pumping stations, while increasing the saline flux from the sea. They can be divided in three groups according to "Studio di fattibilità degli interventi per il riequilibrio morfologico ambientale della Sacca del Canarin":

A. short-term works: 1) maintenance of the inlet and adjacent channels; 2) reinforcement of the scanno in the north; 3) reinforcement of the northern embankment; 4) bounding of the discharge water from the Pellestrina pumping station;

B. medium-term works: 1) dredging of the internal channels and realization of barene; 2) reinforcement of the scanno in the south; 3) realization of a biotope/wet area in the discharge basin of the Boscolo pumping station; 4) reduction of the channel that connects the lagoon with Busa del Bastimento;

C. long-term works: 1) opening of a second mouth in the south; 2) dredging of the channel around the new mouth; 3) realization of barene and reinforcement of the scanno; 4) integration of the channels with the waterways in the coast.

Sedimentological maps and stratigraphic studies are still missing for Sacca del Canarin, but a general characterization of the lagoon can be drawn on the basis of samples and cores collected in the course of recent maintenance works. The samples, taken between May and June 2020 (Veneto Region, Patti, S., Selvi, G. Chiarion P., 2020 and Chiarion P., 2020), are located around the dredged canals, along the nourished beaches and on the external sand spit, providing valuable information on the area that is closer to the sea.

According to the analysis carried out on the sampled material, there is a progressive coarsening of the sediments seawards, with sandy deposits towards the lagoonal outlet, and silty sand in the channels closer to the sea. Moving inside the lagoon, the silty-clayey sediments prevail over the sandy accumulation, with few variations locally. The discrepancies between the surface layers (from the ground level to -0.5 m) and deeper deposits (to -1m) are negligible.

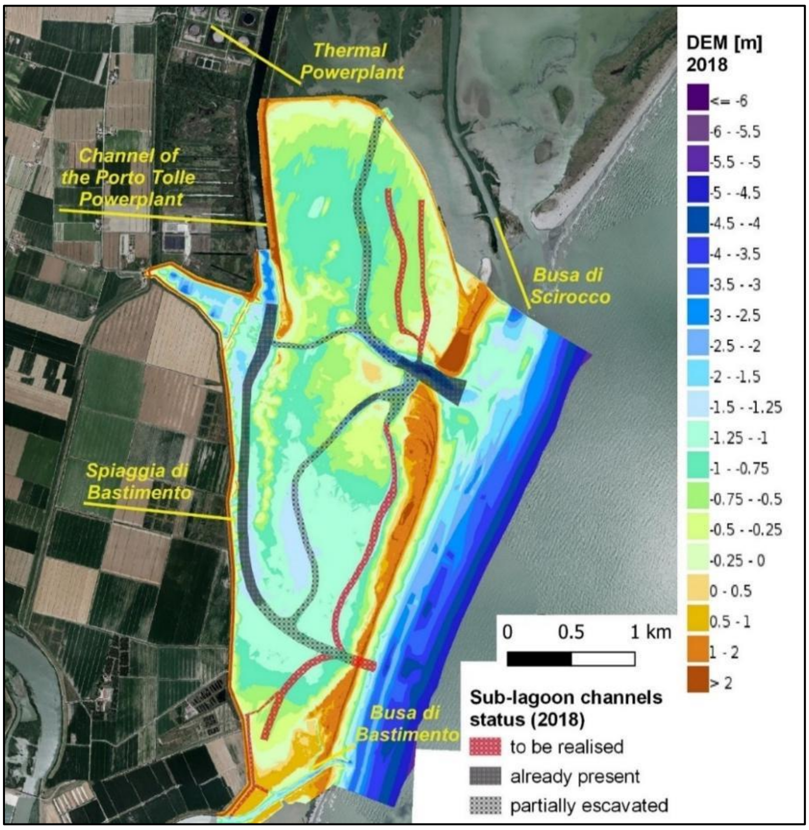
The emerged morphological features reflect the same sedimentological distribution of the lagoon bottom and the channels, with silty sand forming the external spit ("Scanno del Canarin") and silt with clay in the innermost part of the lagoon.

The sedimentological distribution results from the hydrodynamic circulation characterizing Sacca del Canarin (IPROS Ingegneria Ambientale S.r.l, 2018), which exchanges fresh and saltwater mostly through the outlet enclosed by the sand spit.

The main process affecting the ordinary circulation inside the lagoon is the tide range that usually is of ca. 50 cm, while the wind contribution often remains marginal and strongly aleatory. The tidal wave (for both the incoming and out-coming flux) reaches a maximum velocity of 0.5 m/s in the vicinity of the sea outlet, where it is capable of mobilizing and depositing sand sediments. In contrast to the external part of the lagoon, the velocity inside the lagoon drops to 0.10 m/s due to the high resistance exerted by the low bottom, and the conditions become unfavorable for the transport of coarse materials. Therefore, clay and silty deposits prevail in these regions. In the southern area of the lagoon the velocity is practically zero.

The channels represent the preferential direction for the flow, but they are exposed to infilling and sediment deposition processes (flood/ebb tidal Delta) that progressively limit the exchanges between the sea and the lagoon (*Figure 32*). Winds exacerbate the sea currents mostly in front of the lagoon with direct consequences on the sand spit, while their effects tend to diminish within the lagoon waters. Consequently, they do not alter the sediment distribution inside Sacca del Canarin.

The outlet at the sea is not only the main access to salt water but also to fresh water that comes from the River Po mouths located at south (Busa di Bastimento) and north (Busa di Scirocco) of Sacca del Canarin. In fact, during floods, most (.ca 66%) of the fresh water penetrates the lagoon through the



Bocca del Canarin after having saturated the surface layers in the frontal sea sector, while smaller quantities enter through a southern access near Busa del Bastimento (.ca 21%) and through a northern connection to the lagoon of Basson (.ca 11%).

Figure 32. Digital Elevation Model of Sacca del Canarin (2018).

The recent topo-bathymetric surveys confirm that the deepest regions are situated close to the sea outlet where the erosion/depositional processes are stronger, and in the proximity of the lagoon channels, characterized by a maximum depth of -3 m. The average depth of the lagoon is ca 80 cm below sea level. The sand spit has a maximum height of 2 m, and it shows a thinning trend caused by recurring storm-surges.

The sedimentological data retrieved for Canarin regard mostly the areas of the lagoon canals and the sand spit, and they refer to the most superficial layers. A homogeneous grid for a proper granulometric characterization is not available in the lagoon. On the other hand, LIDAR surveys and historical and recent aerial photos have proven to be useful to reconstruct the geomorphological evolution of the Sacca. They have confirmed the erosion of the external sand barrier delimiting the lagoon and the formation of a lens-shaped body at the mouth, which has been interpreted as an ebb-tidal Delta.

4.2.3 Physical and chemical status and trend in lagoons

The data concerning the quality of the lagoon waters were made available by the Regional Agencies for the Protection of the Environment of Veneto (ARPAV), and analyzed in the Report 3.4.1 by ISPRA. Data relating to the following physico-chemical parameters were acquired: temperature, pH, salinity, dissolved oxygen concentration (DO), total suspended solids (TSS), dissolved inorganic nitrogen (DIN), orthophosphate (P04).

The dataset covers the period 2008-2018. The data are available for 7 lagoons of the Veneto Region (Caleri, Marinetta, Vallona, Barbamarco, Basson, Canarin, Scardovari) (Figure 33).

Figure 33. Main lagoons in Po Delta area.

Further data collected within the same timeframe, resumed in the database of Pilot Site 5 Po Delta, not analyzed within this documents but reported in Deliverable 3.4.2, include:

- sediments data (granulometry, oxygenation, C, N and P compounds);
- water data collected in estuarine stations (final stretch of the Po branches).

According to the National implementation of WFD, each sampled lagoon corresponds to a separate water body.

A positive temperature trend has been detected both for yearly and seasonal data. In the former case it’s not possible to catch lagoon specific differences (i.e. the best model includes a common trend of about 0.058°C / year for all the lagoons), while in the latter there are lagoon-specific differences. The seasonal pattern describes a clear sinusoidal evolution during the year (Figure 34).

The best models for pH highlight the presence of site-specific trends both at yearly and seasonal scale, even if the range of values are relatively small. The seasonal term indicates that higher pH values are normally observed in late spring/early summer (Figure 35).

The estimated trend for salinity resulted to be lagoon-specific (both at yearly and seasonal scale), positive for most of the lagoons, negative for Barbamarco and Basson. For several lagoons, anyway, it is clear that the assumption of a linear pattern approximating the trend is not very adequate, as the salinity levels seem to be characterized by a high inter-annual variability. The seasonal smoother term shows a complex pattern with a strong peak in mid-summer (Figure 36).

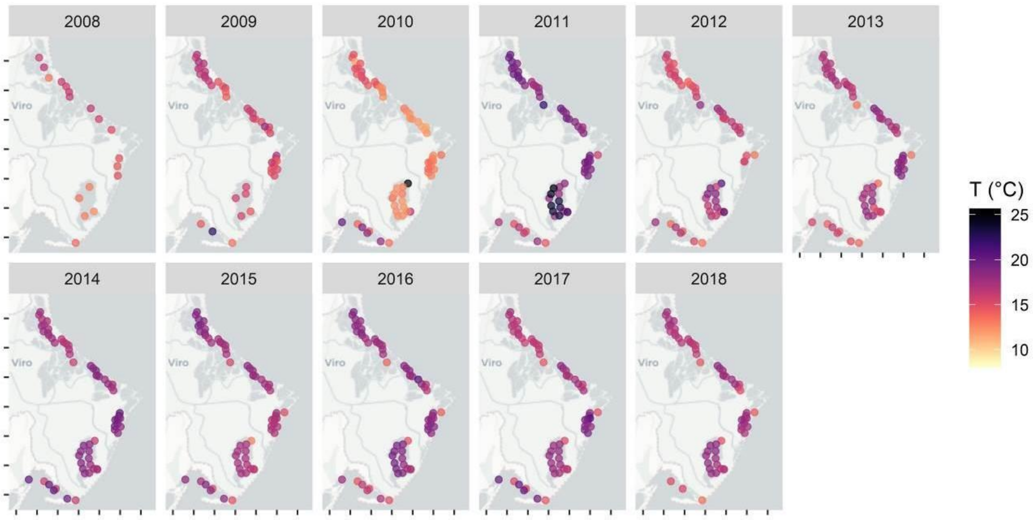


Figure 34. Average spring values of temperature for all collected data within the Po Delta case in the period 2008-2018 (yearly aggregations were not considered for temperature, as periodic sample is unevenly distributed in time in some lagoons, leading to biased average estimates).

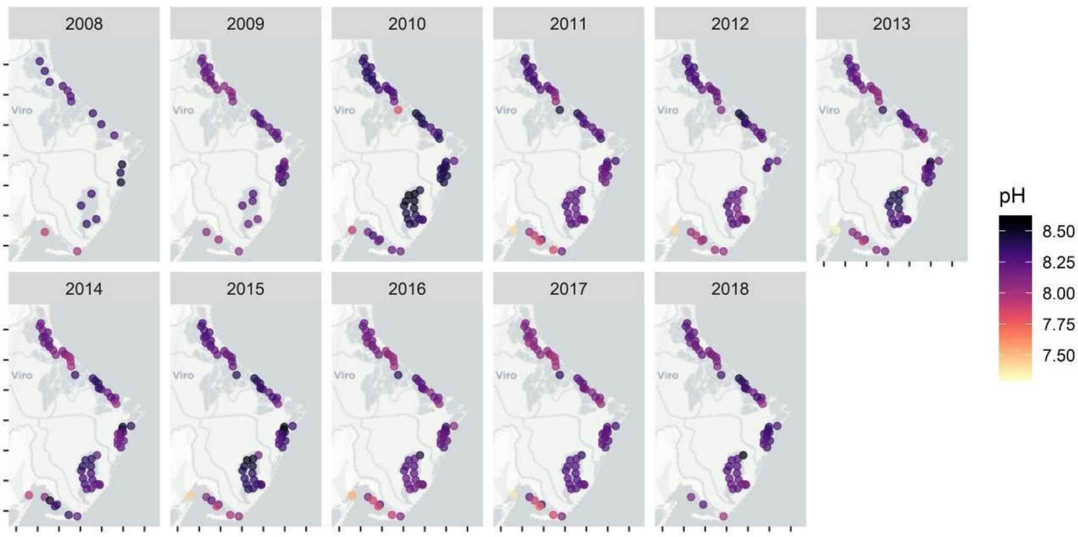


Figure 35. Yearly values (average) of pH for all collected data within the Po Delta case in the period 2008-2018.

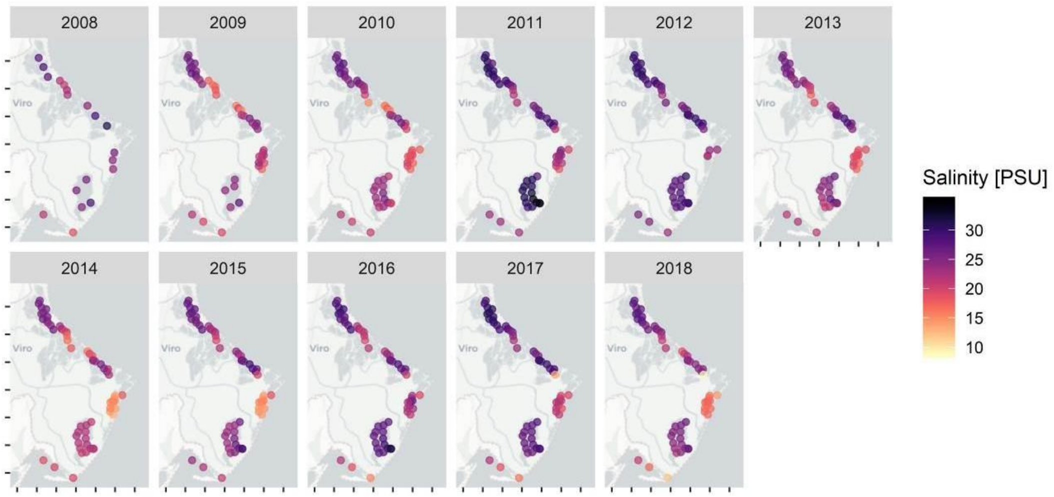


Figure 36: Yearly values (average) of salinity for all collected data within the Po Delta case in the period 2008-2018.

Also the estimated trend for dissolved oxygen is lagoon specific, even if, in general, it shows an increase in dissolved oxygen content over time. The seasonality term shows that lower values are expected in the second part of the summer (Figure 37).

Total suspended solid (TSS) values recorded in the Po Delta lagoon for the period 2009-2017 exhibited high variability, ranging from 0.5 to 205 mgL-1. Each lagoon evidenced fluctuations among and within the years but the observed pattern resulted similar. In the Po Delta lagoons the amount of TSS seems to decrease over the years. Considering the spatio-temporal evolution the highest values detected in 2012 and 2014, while any clear geographic pattern was observed over the years (Figure 38).

Marked lagoon specific trends have been detected at both yearly and seasonal temporal scale, with positive tendencies (with varying slopes) for the lagoons of the Veneto Region. Higher TSS values are expected in spring in all lagoons.

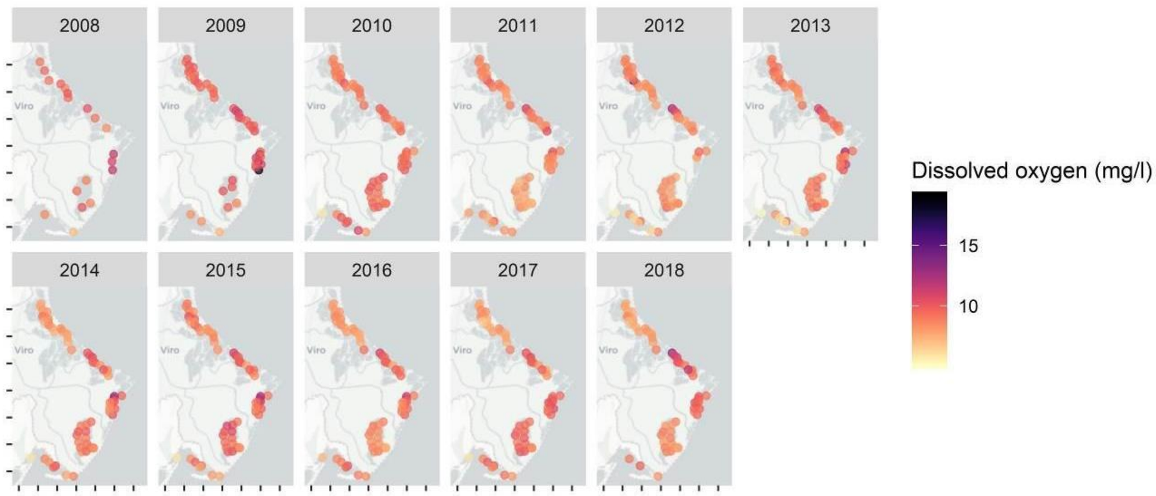


Figure 37: Yearly values (average) of dissolved oxygen for all collected data within the Po Delta case in the period 2008-2018.

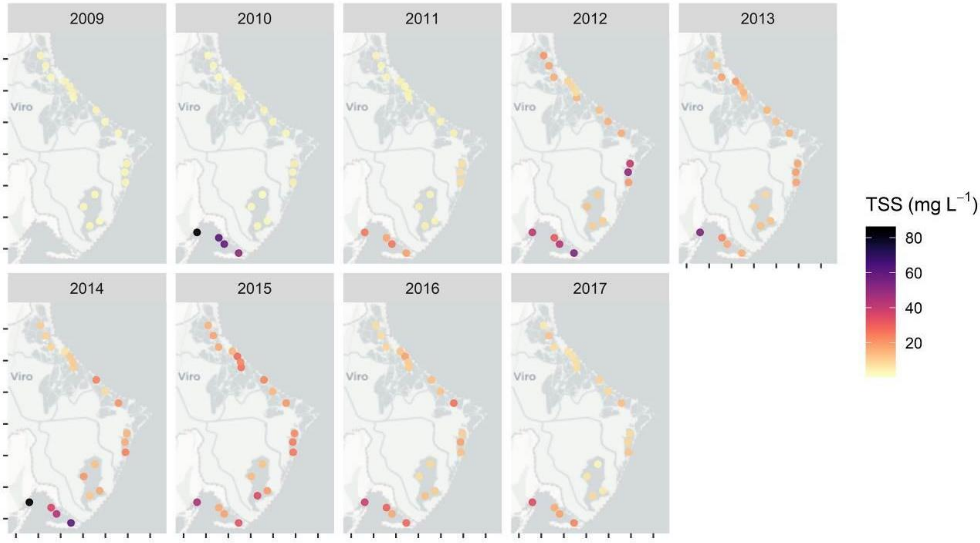


Figure 38. Yearly values (average) of sampled data for TSS for sampling stations within the Po Delta case in the period 2009-2017.

During the period 2009-2017 the Dissolved inorganic nitrogen (DIN) content in Delta Po lagoons exhibited some fluctuations both in spatial and in temporal terms. Marinetta and Vallona lagoons were characterized by the highest mean values (average value on the period > 1000 µgL-1), while Caleri and Scardovari exhibited the lowest mean contents (average value on the period < 500 µgL-1) (Figure 39).

In Transitional water assessment methods under the Water Framework Directive (WFD), the supporting physic-chemical quality elements include DIN and its reference boundary assigned by the national legislation (DM 260/2010) to declass ecological status from "good" to "moderate" is fixed at 420 µgL-1 for WB's with salinity < 30 and at 253 µgL-1 for WB's with salinity > 30 (data considered as annual mean values). During the investigated period these values were regularly trespassed in Marinetta and Vallona. However, annual mean values higher than the boundary limits are found also in the rest of the Po Delta lagoons. Taking into account the spatio-temporal evolution, higher DIN content was found in 2008, 2013 (for all lagoons) and Vallona lagoons, while any clear geographic pattern was detected. A positive annual trend has been detected. The trend is lagoon-specific, even if the inter-lagoon differences are relatively small. The same can be observed with seasonal data, with a relevant contribution of the quarterly period variable in the model, with larger observed DIN values in winter and autumn, and smaller in summer and spring.

During the period 2009-2017 the Orthophosphate content in Delta Po lagoons exhibited a common pattern among lagoons, with highest values recorded in 2009 and a consequent progressive decrease (Figure 40). Marinetta, Barbamarco and Vallona were characterized by a higher mean PO4 values (average value on the period > 20 µgL-1), while Caleri and Scardovari exhibited the lower mean contents (average value on the period 9.6 and 12.1 µgL-1, respectively). In Transitional water assessment methods under the Water Framework Directive (WFD) the supporting physic-chemical quality elements includes PO4 and its reference boundary assigned by the national legislation (DM 260/2010) to declass ecological status from good to moderate is fixed at 15 µgL-1 for WB's with salinity > 30 (data considered as annual mean values, no boundary available for WB's <30). During the investigated period these values were frequently trespassed in Vallona and Marinetta (≥80% of the samples), regularly trespassed in Barbamarco and Canarin (= 70% of the samples) and occasionally trespassed in Caleri and Scardovari (≤ 20% of the samples).

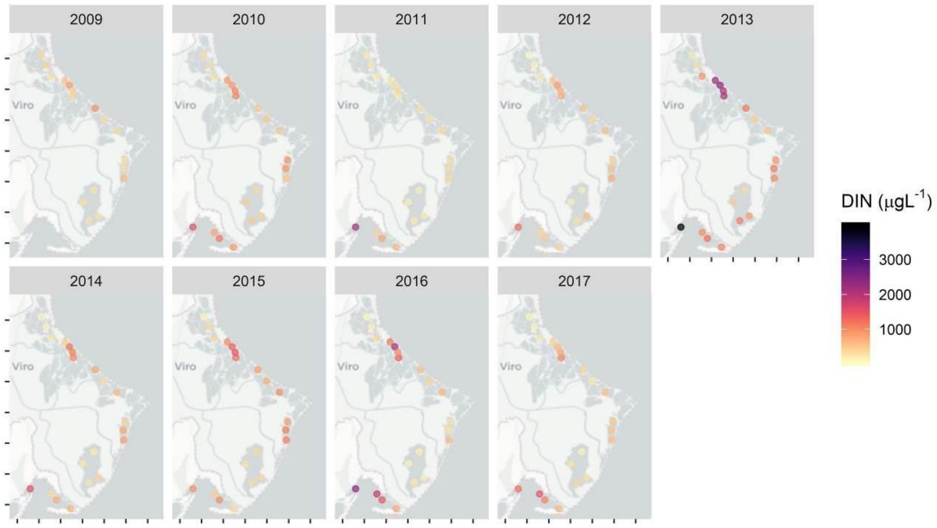


Figure 39: Yearly values (average) of sampled data for dissolved inorganic nitrogen for sampling stations within the Po Delta case in the period 2009-2017.

The DIN and PO4 data reflected a general condition of high trophic status in the waters of the Po Delta lagoons. Marked lagoon specific trends have been detected at both yearly and seasonal temporal scale, with a negative tendency (with varying slopes) for the lagoons of the Veneto Region. Lower PO4 values are expected in summer in all lagoons.

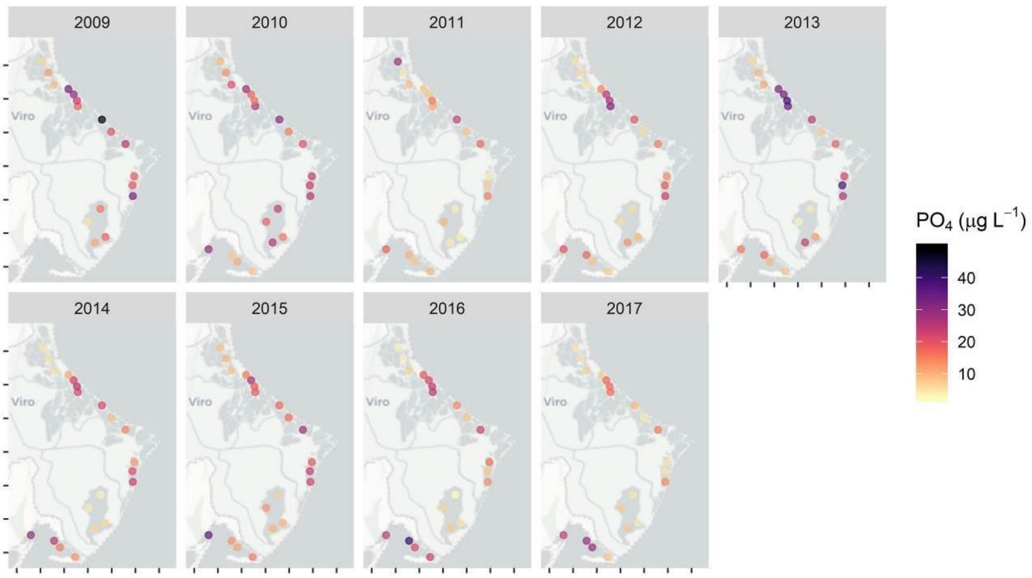


Figure 40: Yearly values (average) for sampled data of orthophosphate for sampling stations within the Po Delta case in the period 2009-2017.

4.2.4 Biological status and trend in lagoons

The biological status of the Delta was assessed based on indicators of the presence and abundance of phytoplankton, macrozoobenthos, and macrophytes, as well as production data for the manila clam.

Phytoplancton: in the period 2008-2018 annual mean Chlorophyll-a values ranged from 1.0 µg L-1 to 9.6 µg L-1. Considering the whole period, the highest chl-a content were found in Goro and Canarin lagoons (11.8 µg L-1 and 8.5 µg L-1, respectively), while the lowest content were found in Scardovari and Caleri lagoons (2.8 µg L-1 and 3.5 µg L-1, respectively). Considering the spatio-temporal evolution no clear geographical or temporal patterns resulted evident.

Macrozoobenthos: the ecological status of macrozoobenthic communities in the Po Delta lagoon has been assessed using the MAMBI index (Multivariate-AZTI's Marine Biotic Index). For the Po Delta lagoons belonging to Veneto region (Barbamarco, Caleri, Canarin, Marinetta, Scardovari, Vallona) available data include 2012 and 2014 (1 station sampled per lagoon). Differences over the two sampling years were detected, with some lagoons that increased their quality class (Barbamarco from “bad” to “good”, Canarin from “poor” to “moderate” and Scardovari from “bad” to “poor”), some others that decreased the quality class (Marinetta from “good” to “poor”, Vallona” from “moderate” to “poor”).

Macrophytes: the ecological status of macrophytic communities (macroalgae, aquatic angiosperms) in the Po Delta lagoons has been assessed using the MaQI index (Macrophyte quality index) (MaQI). For the Po Delta lagoons belonging to Veneto region (Barbamarco, Caleri, Canarin, Marinetta, Scardovari, Vallona) data were available for 2010 and 2014 (17 stations covering 6 lagoons). MAQI indicated a generalized “poor”status except for the stations 433 (Canarin) and 413 (Marinetta) 4 sampled in 2010, which indicated a “bad” quality status. These MaQI values indicate a very small presence of aquatic angiosperms, low macroalgal biodiversity and high occurrence of opportunistic macroalgal blooms (eg. Ulva sp.).

Manila clams: the Po Delta represents an optimal environment for the farming of bivalves, due to the shallow waters, high freshwater inputs rich in nutrients and high natural productivity, mainly driven by phytoplankton. The main farmed species is Manila clam (Ruditapes philippinarum), an allochthonous species which was introduced in the area in the early eighties and that rapidly colonized the Po Delta and Venice lagoons. The great suitability of these environments for Manila clam, both in terms of growth and natural reproduction, soon became evident, the species rapidly spread to all favorable sites, and Manila clam harvesting soon became the most economically important fishing activity. For the Po Delta lagoons of Veneto Region, a study carried out on the period 1986-2008 (Mistri, 2009) shows that the production and harvest of R. philippinarum in this area underwent through various stages. In the first part of the period (1986-1989) there was a rapid increase in the quantities, which was followed by a very strong increase in production (from 1800 tons in 1989 to 6100 in 1990). The production remained almost stable until 1997; after that phase a further subsequent increase (with a peak of 13600 tons in 1999) was observed, interrupted by a phase of production collapse in 2003 (4018 tons), then reabsorbed in the following years.

Successive studies carried out by the “Osservatorio Socio Economico della Pesca e dell'Acquacoltura” (OSEPA) of Veneto Region investigated the production of Manila clam in Po Delta lagoons during the period 2008-2018 (OSEPA, 2019 a and b), as shown in Figure 41.

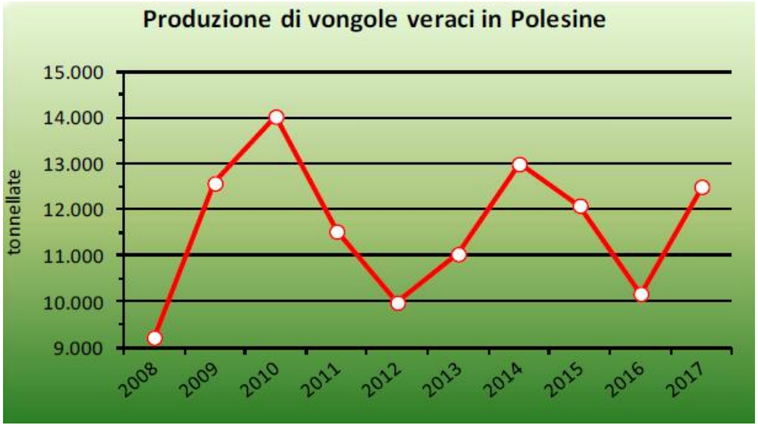


Figure 41. Production of Manila clam in the Po Delta lagoons of the Veneto during the period 2008-2017 (Source: Osservatorio Socio Economico della Pesca e dell'Acquacoltura, 2019).

During the ten-year comparison, a swinging production curve was observed, with maximum peaks of production observed in 2010 (approx. 14000 tons) and 2014 (approx. 13000 tons) followed by decreases to values around 10000 tons in the years 2012 and 2016. The production of clams estimated in 2017 was about 12,498 tons, while for 2018 the production decreased at 8363 tons (data not shown in the graph). The productive realities of the Po Delta lagoons can be divided into two large areas: the northern lagoons of Caleri and Marinetta-Vallona, and the southern lagoons of Scardovari, Canarin, Basson and Barbamarco, between the Po di Maistra and the Po di Goro.

A study carried out in 2010 (AA.VV., 2013) estimated for the Po Delta lagoons of Veneto Region an overall production area of 855 ha, mostly located in the lagoons of Caleri and Marinetta (44%) and Scardovari (34%) (Figure 42-43).

The same study indicates the clam production for each lagoon of the Po Delta and the harvest yield, estimated using data collected in the period 2006-2008. The incidence of the production areas goes from zero in the Basson to a maximum of 32% in Scardovari and 29 % in northern areas (Caleri and Marinetta).

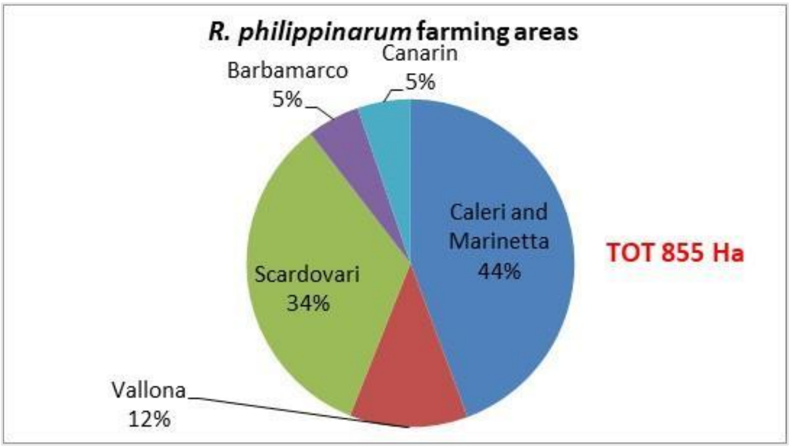


Figure 42. Farming areas for Manila clam production in 2010. Data expressed as a percentage of the total extension. Elaboration from AA.VV, 2013.

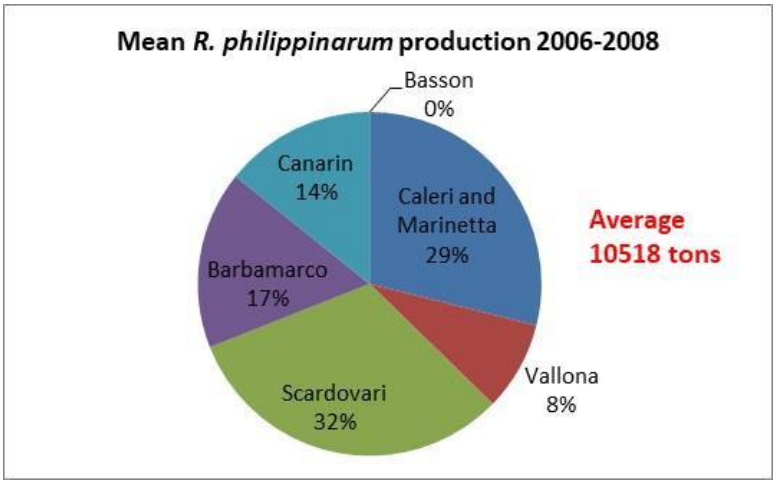


Figure 43. Mean Manila clam production in the period 2006-2008. Data expressed as percentage of the total production. Elaboration from AA.VV, 2013.

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 Ruditapes are fished only when there are no adequate operating conditions in the Canarin or Barbamarco (Figure 44).

The Clam Farming activity is sustained by Local Authorities for management purposes (Reclamation Consortium of Delta del Po, Genio Civile), through systematic lagoon vivification interventions.

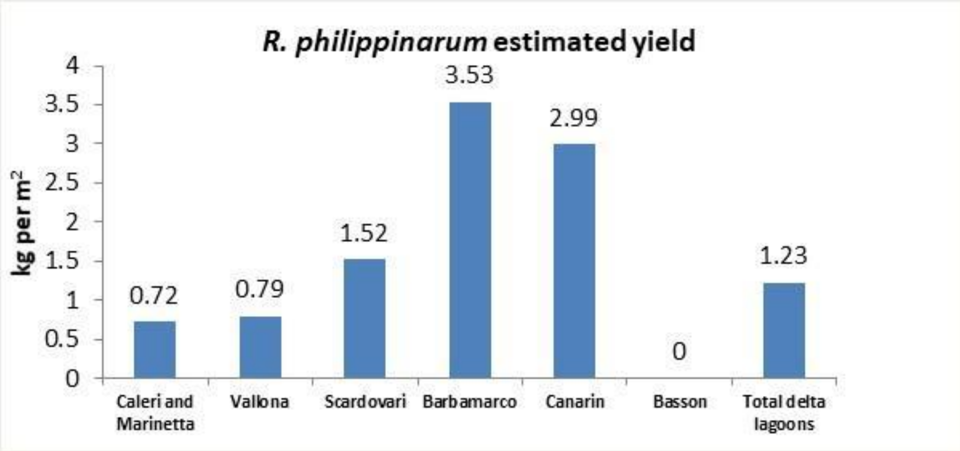


Figure 44. Mean Manila clam production in the period 2006-2008. Data expressed as percentage of the total production. Elaboration from AA.VV, 2013.

Reed beds: in the Po Delta area the *P. australis* forms different kinds of meadows (reedbeds):

- valley reedbed: Reedbed meadows are managed by the owner of the valley to host and protect bird fauna target for hunting activities;
- riverine reedbed: This kind of reedbed is mostly present in the Po di Maistra branch and in some sectors of the Po di Tolle branch - Reedbed of minor wetlands: it is located close to pond and ex mine areas or drainage canals. These reedbeds are generally of small dimensions but their role as nesting and foraging areas for bird fauna is relevant;
- lagoon or estuarine reedbed: it represents the main reedbed area in the Po Delta, with an almost monospecific presence of P. australis. This type of reedbed grows in intertidal areas subject to the tidal cycle. Its growth is limited to areas less affected by marine salinity, generally protected from marine influence by sandbanks.

The reedbed meadows are mostly found in the sheltered areas of the lagoons located in proximity of the main Po branches (Barbamarco, Basson, Burcio and Canarin), along the riverbanks and in the wetlands more influenced by freshwater (Allagamento Bonelli, Bacucco) (Figure 45).

Historically, the reedbed habitat covered larger surfaces in the Po Delta area but its presence has been greatly reduced by historic human interventions. Subsidence and the increase of the salt content in some areas, also obtained for productive purposes (shellfish farming), together with bathymetric and hydrodynamic changes, are the factors that have caused the decrease of reedbeds in the Delta. The analysis of the extension of the Bacucco reedbed, carried out on 7 sample years of the period 1977-2011, shows that in this period of time the surface of these reedbeds has decreased overall by 48% ("Atlante lagunare costiero del Delta del Po" - AA.VV., 2015). This contraction has developed primarily since the 1990s. Moreover, the structure of the reedbed has changed, initially appearing dense with the presence of some clearcuts and well-defined channels, and later with the presence of large disorganized spaces, especially inland. In 2006, after the breakup of the Bacucco reedbed in its median part, an acceleration in the disintegration was observed.

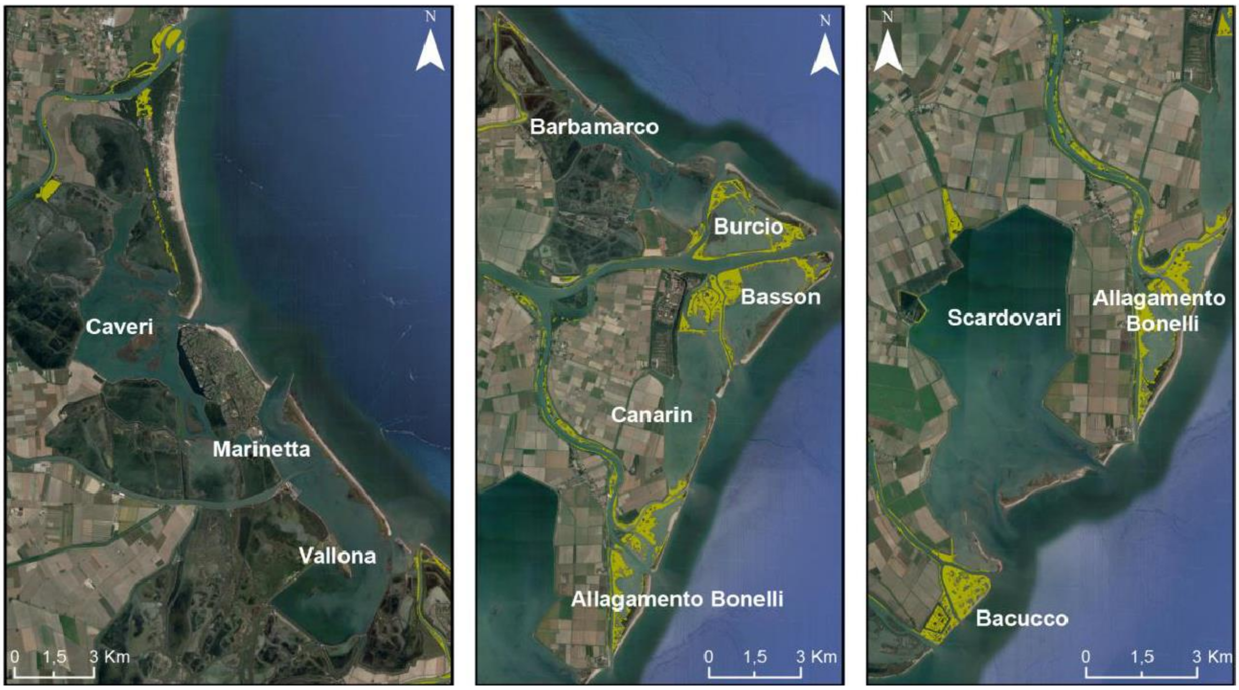


Figure 45. Maps of the reedbeds in the Po Delta lagoons of the Regione Veneto, year 2006 (Source: Parco Regionale Veneto del Delta del Po, 2015).

4.3 Evolution dynamics in the Pilot area under Climate Change

4.3.1 Hydrological evolution under climate change in Delta Po area

Regarding the analysis of the future climatic condition, for the terrestrial macro-regions, the climatic anomalies were calculated as the difference between the average values of the indicators in the future period 2021-2050 and the reference period 1981-2010 (IPCC, 2012).

Climate models predict that the effect of gasses will lead to an increase in air temperature of between 1.4 and 5.8 ° C by the end of this century (IPCC, 2012). Figures 46-47-48 illustrate the results of some climate simulations.

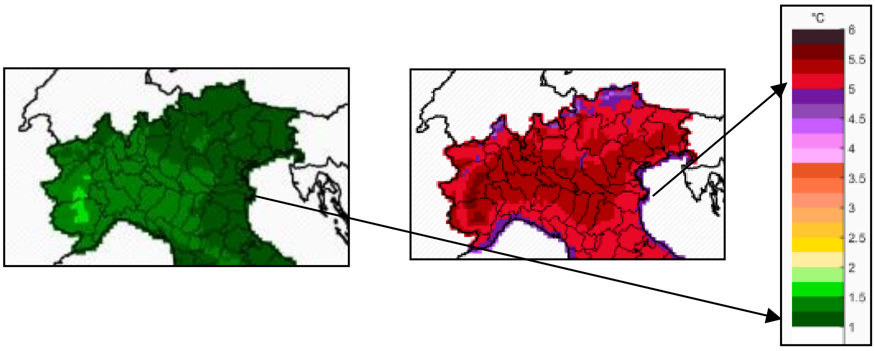


Figure 46. Average daily temperature increase (annual average) (T mean). Left: RCP 4.5 2021-2050; Right: RCP 8.5 2071-2100.

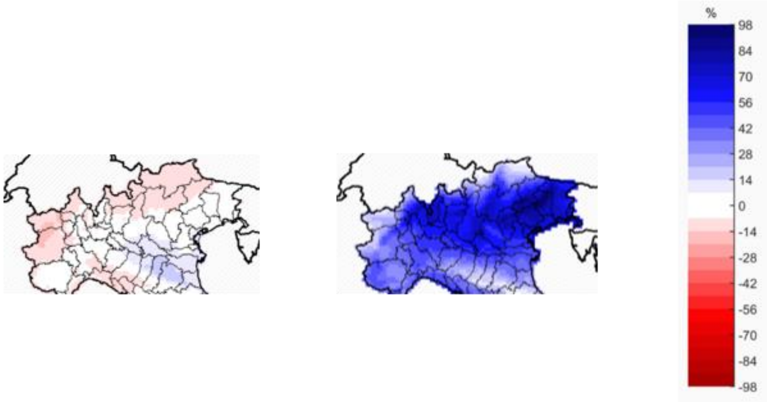


Figure 47. Winter Precipitation: Cumulated precipitation in the winter. Left: RCP 4.5 2021-2050; Right: RCP 8.5 2071-2100.

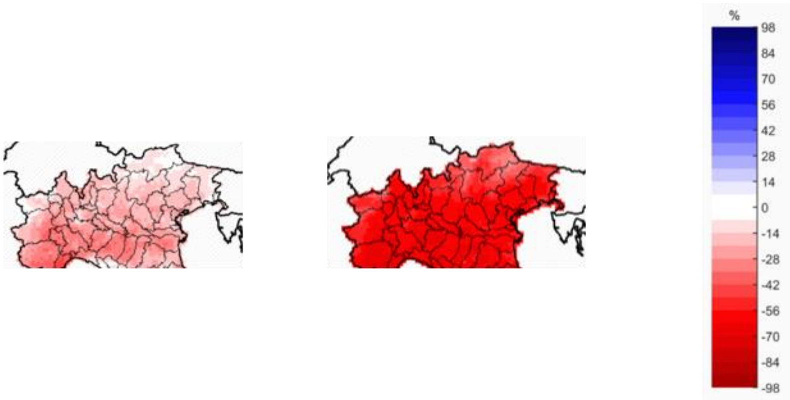


Figure 48. Summer rainfall: Cumulated rainfall in the summer months (June, July, August). Left: RCP 4.5 2021-2050; Right: RCP 8.5 2071-2100.

4.3.1.1 Adriatic sea

For the studies regard the effects of climate change on hydrological and hydrodynamic processes at the Adriatic basin scale and in Pilot Sites, it is used a modelling efforts were focused at characterising the intensity and variability of storm events in terms of wave parameters and surge, the modulation of freshwater runoff, and the implications of climate change for the main thermohaline dynamics of the basin, with some focus on the evolution of the main quantities at the Pilot Sites. Predictions for future periods in the 21st century are compared to 'present' (i.e. late 20th century) climate conditions under the IPCC RCP 2.6, 4.5 and 8.5 scenarios, in order to assess the climate change impact on the basin ocean properties.

Provision of climate parameters is intrinsic to the applied models and is set according to RCP climate scenarios 2.6, 4.5, 8.5.

In summary, the study focused on:

- wave height and period and storm surges;
- the thermohaline properties (temperature, salinity).

The projected changes of these variables are studied at the basin scale and within or offshore (in the case of waves) the five Pilot Sites. Derived variables taken into account are:

- frequency and intensity of Sirocco-induced storm surges (northern Adriatic);
- Ocean Heat Content, mixed-layer depth and BiOS (Adriatic-Ionian Bimodal Oscillating System).

The result of the analysis of past trends and long-term simulations indicates, together with the increase in air temperature, the following:

- a decrease in precipitation in most of the basin and particularly in northern Italy;
- an increase in the annual number of dry days in coastal areas;
- a negative trend in the freshwater balance in the Adriatic Sea (30% reduction in flow rates and nutrient reductions in recent decades);
- a more frequent occurrence of anticyclonic circulation in the northern Ionian Sea should favours the advection of less saline waters from the western Mediterranean into the Adriatic;
- the Adriatic is likely to become warmer and saltier; an increase in salinity, especially in coastal regions, due to a decrease in river input;
- deep convection is expected to be less frequent;
- a decrease in dissolved oxygen content in the deep layers of the Adriatic Sea;
- the acceleration of sea level rise in recent decades. Currently, the rate of rise is about 45-55 cm per century. This acceleration is reflected in the number of documented floods, particularly in its northern part such as Venice;
- a clear trend of decreasing wave activity in the northern Adriatic Sea, in terms of intensity of events, and a general increase in terms of frequency (50th and 75th percentile characteristic);
- the wave and storm surges induced by Bora are predicted to be less severe over the whole basin;
- the severity of those induced by Sirocco may be expected to decrease in the north and increase in the rest of the Adriatic Sea.

4.3.1.1 Po Delta

In order to investigate future changes through modelling activities, a scenario was defined. The present implementation took into account the worst case available from IPCC (RCP8.5, https://ar5-syr.ipcc.ch/topic_futurechanges.php) and evaluated the change trend corresponding to the last period simulated (2080-2100), to make clear the rate of change.

The model implemented is SHYFEM (Shallow Water Hydrodynamic Finite Element Model). Full description of the modelling tool can be found in Umgiesser et al. (2014) and the code is open source and freely downloadable at www.ismar.cnr.it/shyfem.
Setup is described in deliverable 4.1 § 5.1.1 (Table 7).

RCP8.5	Air Temperature [%]	Precipitation [%]	Salinity [%]	Water Level [m]	Water Temp [%]	River Discharge [%]	River Temperature [%]
Abs Var				+0.63			
January	49.42	18.71	1.65		32.86	41	39.66
February	50.45	18.09	1.51		38.61	43	42.80
March	42.37	5.51	1.56		38.81	41	44.02
April	30.78	-14.6	1.64		33.52	12	38.26
May	23.04	-4.57	1.72		25.82	-12	43.76
June	20.18	-17.97	1.81		20.36	-33	53.52
July	20.14	-32.41	1.88		18.58	-38	70.33
August	22.83	-31.31	1.91		19.03	-26	73.91
September	22.61	-12.95	1.92		18.91	-27	47.72
October	23.39	6.41	1.94		19.19	-8	38.62
November	30.93	11.94	1.92		21.66	15	35.12
December	39.07	17.18	1.84		26.21	11	35.23

Table 7. IPCC RCP8.5 scenario, rate of changes imposed, at the monthly and annual basys, for different forcings.

What concerns the dewatering pumps introduced in the Present State simulation, since it was not possible to do hypothesis on their discharge changes in the future, they were kept as in the present state. The hypothesis, given the lack of data on scenarios, is that there is no change in the land use and anthropic water use.

For reference on the Present State simulation and the full description of the setup, see Deliverable 3.3. The model implementation produced data, following the unstructured grid resolution, for the area of the Po Delta and its coastal shelf, for the following variables: water temperature, salinity, water level and currents. For the Po Delta Lagoons also the Water Residence Time (WRT) is computed.

In conclusion, monthly averages are presented for the two simulated years. These variables were computed in 3D and data is available not only for surface but for the whole water column, in NetCDF format and stored by the project.

Seasonal averages are presented for the two simulated years where computed considering the internal division as: January, February and March (Winter); April, May and June (Spring); July, August and September (Summer); and October, November and December (Fall).

The simulation results are very complex, as referred to in the report 4.1 paragraph 5.1.

4.3.2 Geomorphological evolution under climate change in Delta Po area

To identify coastal vulnerabilities and identify areas at risk, a study of past and recent coastal evolution was carried out, and the potential and real Coastal Vulnerability Index (short term) was assessed.

It was presented a detailed inundation map proposed in 2017 by Marsico et al., showing the present coastline of the Po Delta and its estimated future position due to the extension of land flooding for three different sea level rise scenarios.

An assessment of the morphological response of the Po River Delta to the future sea level rise was not possible within the activities of this project, considering the morphological complexity of the region, combined with the fragmentation of information on sediment fluxes, and the lack of a morphological model for the whole Delta. However, some general observations can be drawn on the basis of past studies and recent observed trends.

The relative sea level increase would presumably bring to a decline of salt marshes and tidal flats, and to a morphological simplification of the lagoons, deriving from the flattening of their bottom and the siltation of the channels. An anticipation of this trend has been observed before the 70's, when the Po Delta experienced high subsidence rates, sinking for several decimeters, and going under the water. During that period, a strong degradation of the coastal dunes and barriers was observed, together with the loss of tidal landforms.

The trend that was reduced thanks to a change of policy and several concrete interventions can become worse in the future, especially in case of erosion, submergence or overstepping of the barrier islands due to the sea level rise, which now provide a protective function to the lagoons. Finally, since the morphological response of the transitional system is strongly entangled with the sediment fluxes coming from the rivers, the natural resilience of the lagoons would depend deeply on the sediment availability.

<u>Potential vulnerability</u>

The potential vulnerability is defined as a linear combination of morphological and evolution variables, which measure the natural susceptibility of the coastal regions to erosion and overstepping. The presence of natural and rigid protections leads to a reduction of the potential vulnerability, resulting in what it is called real vulnerability.

Figure 49 shows an example of the procedure used to derive the morphometric and evolutionary information from the analyzed dataset and they refer to the barrier islands enclosing "Sacca del Canarin". The pictures describe the delineation of the cells in 4 temporal steps, the derived position of the coastline to assess the retreat and progradation of the coast, the bathymetric sections in front of the cells used to compute the sea-bed information, the centerlines from which the mean width has been calculated, and the DTM employed to derive the mean height.

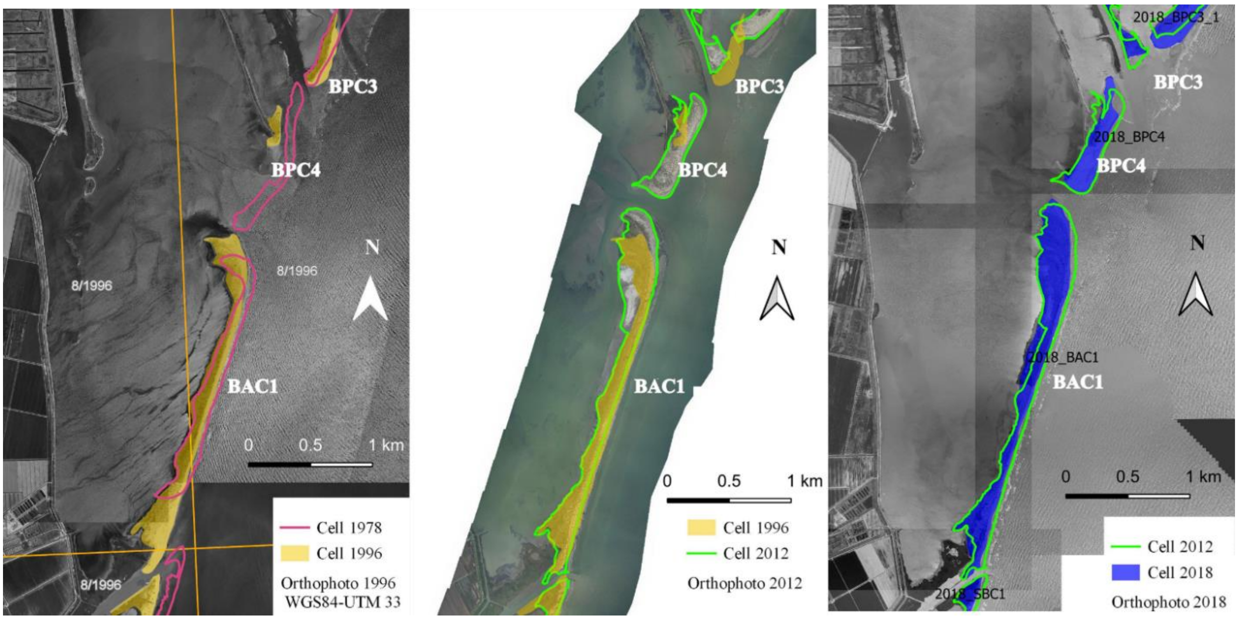


Figure 49. Temporal evolution of the barrier island of Sacca del Canarin 1978-2018.

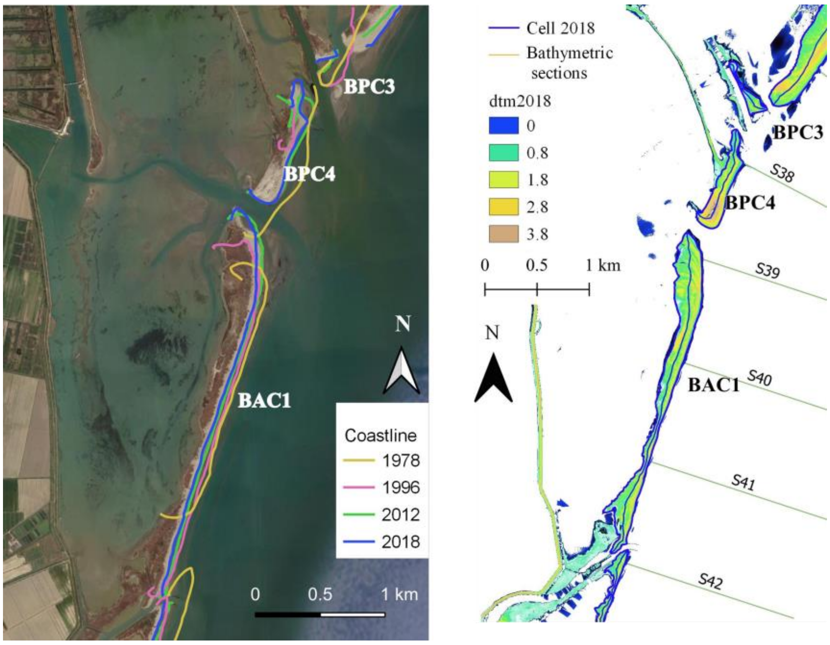
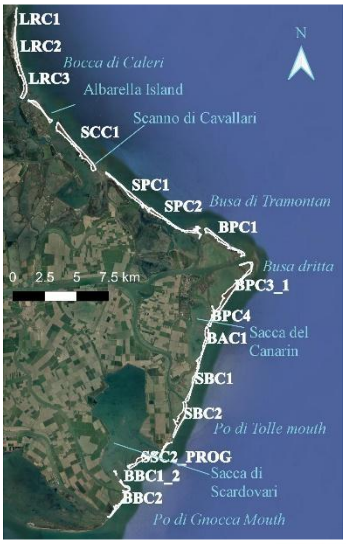


Figure 50. Left: coastline from 1978 to 2018. Right: DTM (2018) and bathymetric sections used for Sacca del Canarin.

As already highlighted, the morphological configuration of “Sacca del Canarin” has undergone profound changes in the period 1978-1996 and relatively lower variations later on, when the general setting has been influenced by several human interventions. For example, the presence of specific barriers has induced local sediment accumulations in proximity of the Enel channel (Cell BPC4), while the northern part of “Scanno del Canarin” (BAC1) has been subject to a series of recent nourishments that have contributed to increase the surface of the barrier island (Figure 50).

The next graphs (Table 8, Figures 51-52) give a brief overview of the historical and recent trends observed in the Po River Delta both in terms of shoreline variations and surface change of the barrier islands. As already pointed out, the data speak of a very dynamic system characterized by some regions stabler than others, while other regions shrinking because sediment is deprived. It is worth noting the nose of the Po River Delta, corresponding to Po di Pila, shows an extremely variable behavior, since it has always evolved naturally, without any stabilizing interventions or human modifications.

Cell 2018	Municipality	Definition	Type
LRC1	Rosolina	Litorale di Rosolina Mare	beach
LRC2	Rosolina	Litorale di Rosolina Mare	beach
LRC3	Rosolina	Litorale di Rosolina Mare	beach
IAC1	Rosolina	Isola di Albarella	beach
SCC1	Porto Viro	Scanno Cavallari	barrier island
SPC1	Porto Tolle	Litorale di Barbamarco	barrier island
SPC2	Porto Tolle	Litorale di Barbamarco	barrier island
SPC3_0	Porto Tolle	Litorale di Barbamarco	barrier island
BPC1	Porto Tolle	Bocche del Po della Pila	barrier island
BPC2_0	Porto Tolle	Bocche del Po della Pila	barrier island
BPC3_1	Porto Tolle	Bocche del Po della Pila	barrier island
BPC3	Porto Tolle	Bocche del Po della Pila	barrier island
BPC4	Porto Tolle	Bocche del Po della Pila	barrier island
BAC1	Porto Tolle	Canarin	barrier island
SBC1	Porto Tolle	Bonelli	barrier island
SBC2	Porto Tolle	Bonelli	barrier island
SSC1	Porto Tolle	Sacca di Scardovari	beach
SSC2_PROG	Porto Tolle	Sacca di Scardovari	barrier island
BBC1_2	Porto Tolle	Bonello Bacucco	barrier island



BBC2	Porto Tolle	Bonello Bacucco	barrier island
BBC3_1	Ariano nel Polesine	Bonello Bacucco	barrier island

Table 8. Identified cells along the Po River Delta. Overall, 21 cells have been identified along the Delta coastline, encompassing 16 barriers or similar to barrier islands and 5 linear shoreline parts. Tracking such temporal variations of the morphological units has been crucial to quantify the evolutionary trend of the coast.

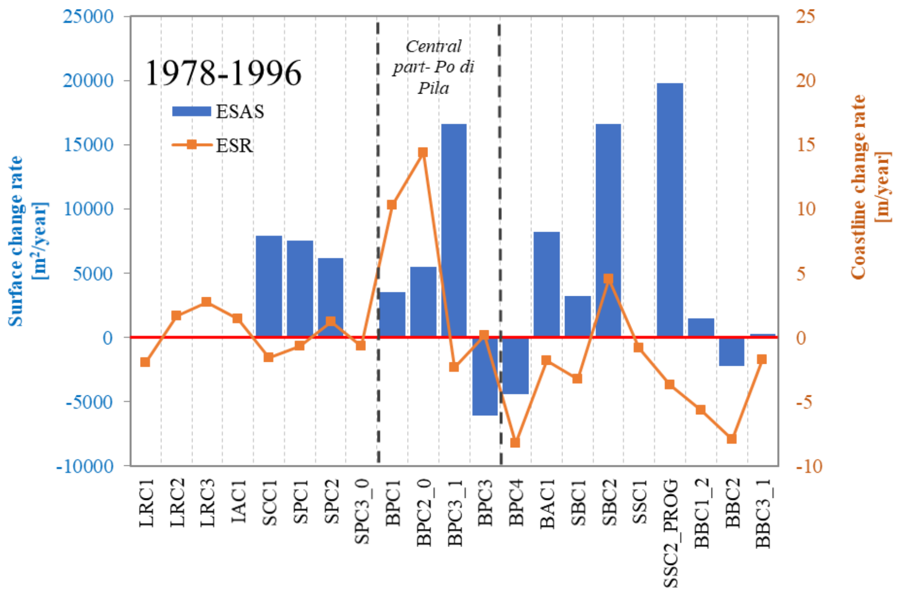


Figure 51. Historical evolution of the coastline (line) and the aerial extension of the barrier islands (bars). Rate of the variations. The cells are ordered from North (LRC1) to South (BBC3_1).

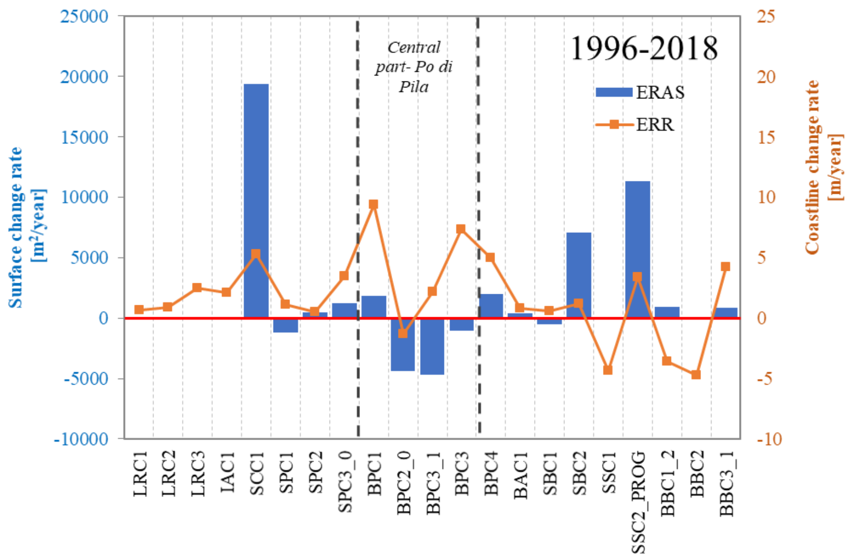


Figure 52. Recent evolution of the coastline (line) and the aerial extension of the barrier islands (bars). Rate of the variations. The cells are ordered from North (LRC1) to South (BBC3_1).

The extensive interventions realized in the northern part of the Delta to protect the touristic shoreline result in a more rigid configuration of some areas (e.g. Rosolina) and in the accretion of the neighboring islands, which have benefited from the protections put in place in the adjacent units. Similarly, continuous interventions have been carried out in the lagoon of Scardovari, whose island (SCC2_PROGR) is maintained in its specific location with periodic nourishments and reprofiling. Conversely, the Po Delta nose is subject to a high variability connected to the high sediment flux flowing through the main Po outlet Po di Pila. The southern part of the Delta has shown and continues to exhibit some criticalities due to high erosion rates.

The normalization has been carried out by using a linear interpolation of the measured values, assuming that the coastal susceptibility to erosion increases for low values of some morphological parameters, such as width and height of the barrier islands, while it decreases for higher values of such variables. The "worst" and "best" morphological conditions were based on the measurements obtained in the whole north Adriatic Sea to obtain results comparable to other locations (e.g. Friuli Venezia Giulia Region). The vegetation coverage was considered.

Four categories of vulnerability were considered, based on the classification proposed for the northern part of the Veneto coastline (master thesis Busetti, 2017):

- Low vulnerability: $V \leq 3.3$
- Moderate vulnerability: $3.3 < V \leq 6.6$
- High vulnerability $6.6 < V \leq 9.9$
- Very high vulnerability: $V > 9.9$

As visible from the map, most of the Po Delta Coast falls in the moderate class of vulnerability (between 3.3 and 6.6), some in the high class (between 6.6 and 9.9) and only few in the low class (<3.3) (Figure 53).

The methodology leads to a classification that reflects in large parts the critical areas highlighted also by the guidelines for the "Integrated coastal zone management of the Veneto Region" (Gestione integrate della zona costiera, Ruol et al. 2016), but it updates this assessment to the latest available surveys, providing at the same time a quantifiable index based on a larger set of geomorphological parameters.

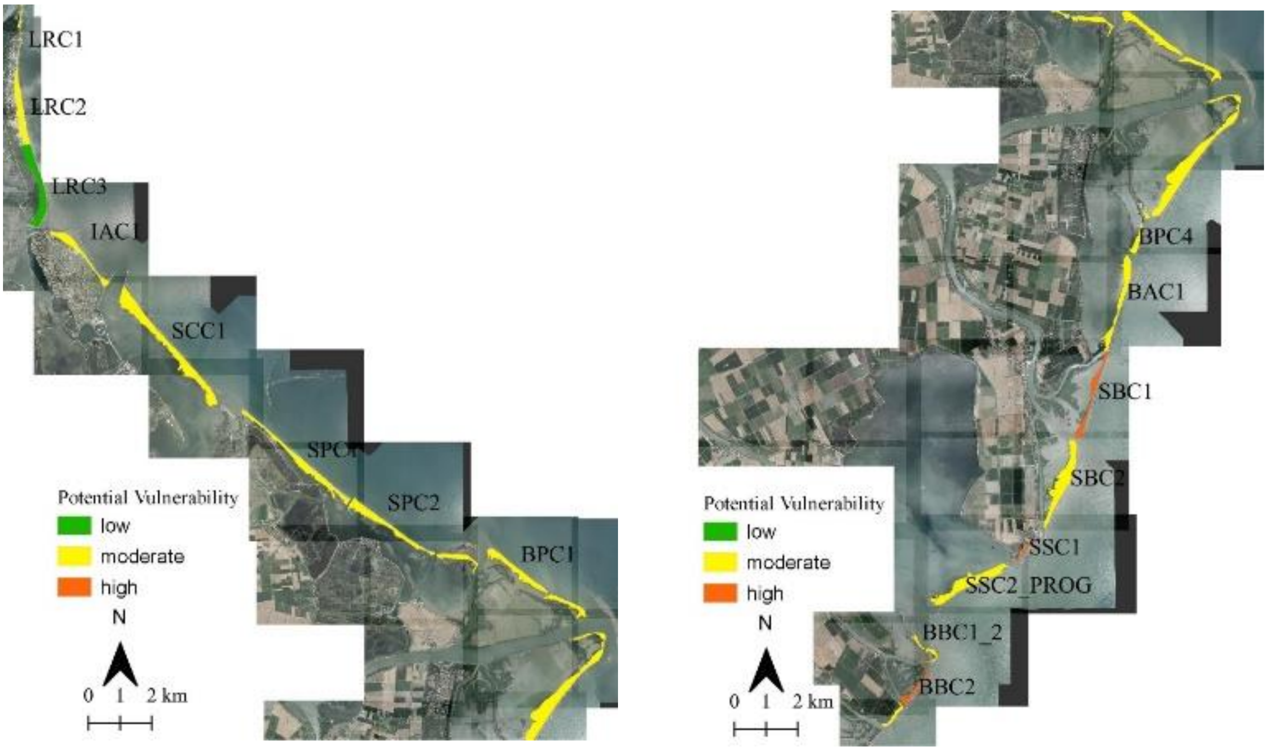


Figure 53. Potential vulnerability: northern part of the Po Delta (left) and southern.

<u>Real vulnerability</u>

Dunes and defense structures tend to reduce the potential vulnerability by offering reinforcement to the coast and protecting the land against potential ravages by storm waves from the sea. The real vulnerability is thus computed by subtracting the contribution of each element defending the coast from the potential vulnerability. Several parameters are contemplated to define the efficacy of these elements and to quantify their contribution to reducing vulnerability (Figure 54).

The factors used here to characterize the dunes are steepness (RIP), presence of small dunes (AvInc), vegetation coverage (Veg), and discontinuity (Open), in addition to the average height of the dunes (QN). Together these data define the grade of stability of the dunes and their ability to cope with severe events. For this work, the data were retrieved by the cadaster of dunes developed by Fontolan et al. 2014, and they were verified only through aerial photos and DTMs since field works were not possible due to the pandemic restrictions.

The contribution of each dune was then evaluated as the product of the efficacy, normalized height, and a constant that made the final value comparable to the potential vulnerability.

For sake of brevity here the normalized parameters pertaining to the dunes are presented considering only their aggregated value for each cell, computed as the average values of the total dunes falling in each morphological unit. Similarly, the contribution of rigid protection depends on their characteristics, such as location (sea protection, longshore protection, inland protection) and height.

The vulnerability is influenced by the stabilizing effect of the dunes and by the measures put in place along the coastline. Spiaggia di Barricata (SBC2, Figure 54) has a large system of dunes subject to constant maintenance works by the Region. As shown in the map, they contribute to the overall reduction of the cell vulnerability.

A more detailed analysis would require a further division of the cells in sub-units, to highlight the portions of islands or shorelines that are more exposed to erosion with respect to the others. Furthermore, a specific assessment of each construction is fundamental to understand its interactions with the local processes and its contribution to the protection of the coast. Some defense works, in fact, are effective as far as maintenance works are guaranteed, and their efficacy is deeply linked to the morphological system in which they are built (e.g. dykes that protect the shorelines).

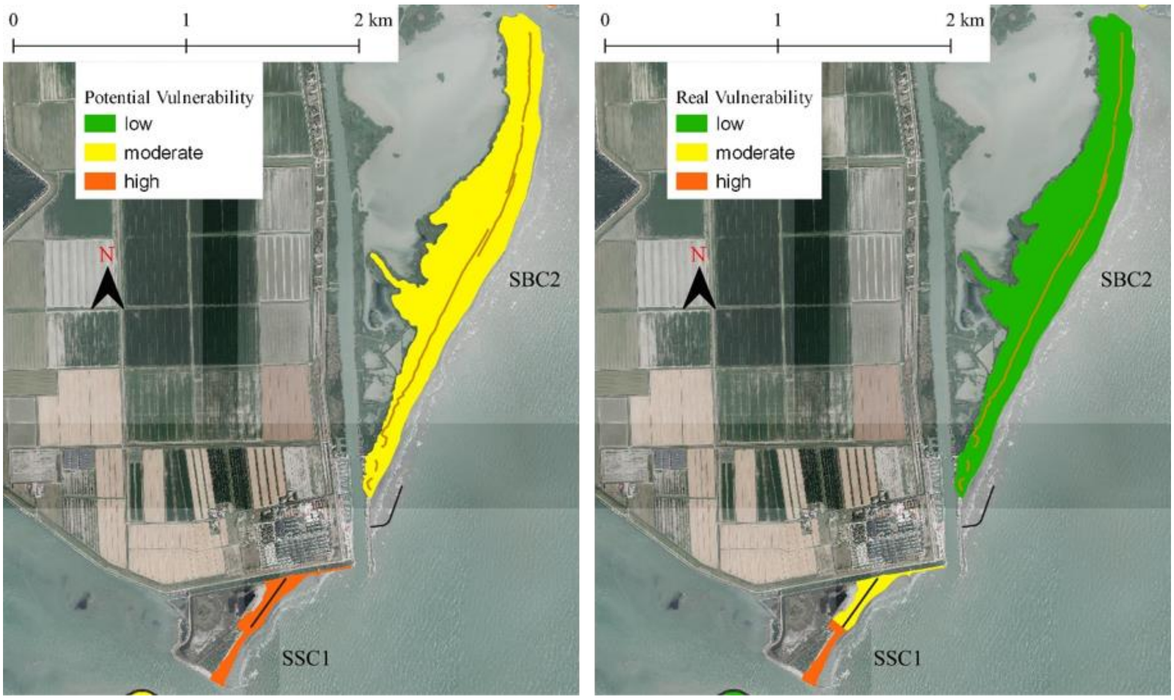


Figure 54. Left: Potential vulnerability, before considering the contribution of the defense structures and the dunes. Right: Real vulnerability, after taking into account the contribution due to defense structures and dunes. Spiaggia di Barricata (SBC2) and Spiaggia delle Conchiglie (SSC1).

Long-term vulnerability: flooding scenario for the Po Delta

The flooding map published in Marsico et al. (2017) represents the drowning lands for three different sea level scenarios. The authors used the worst IPCC projections (AR5 RCP 8.5 scenario) and the Rahmstorf (2007) model to account for the flooding expected in 2100. The IPCC scenario provides minimum and maximum values of the global sea level rise at 0.53 and 0.97 m, while the Rahmstorf (2007) scenario predicts an increase of 1.4 m. To evaluate the relative sea level rise along the Po Delta, the authors combined these three mean absolute values of the sea level rise with the vertical motions expected in the investigated area, thus encompassing the isostatic, tectonic, and eustatic-steric rates. A similar methodology has been used by Da Lio et al (2019), who computed the relative increase of the future sea level taking into account the subsidence rates predicted in the Po River Delta. Finally, the extension of the potentially flooded lands was derived by employing high-resolution Digital Terrain Models (DTM) at a spatial resolution of 1 × 1 m and a vertical accuracy ± 0.1 m.

The map reported here is an extract of the one published by Marsico et al. (2017).

The Po Plain, being already below the mean sea level, is foreseen to be almost completely flooded in the future. The inundated areas predicted for the three different flooding scenarios have similar extension, covering the flat region with its topographic depressions and stretching inland to the Rovigo town. The limit of the flooded land could represent the future coastline in 2100 as speculated by the authors, but also the extension of the potential areas that could be affected by extreme storm surges and high tides before 2100, considering the significant wave heights of episodic events in association to milder sea level scenarios (Figure 55).

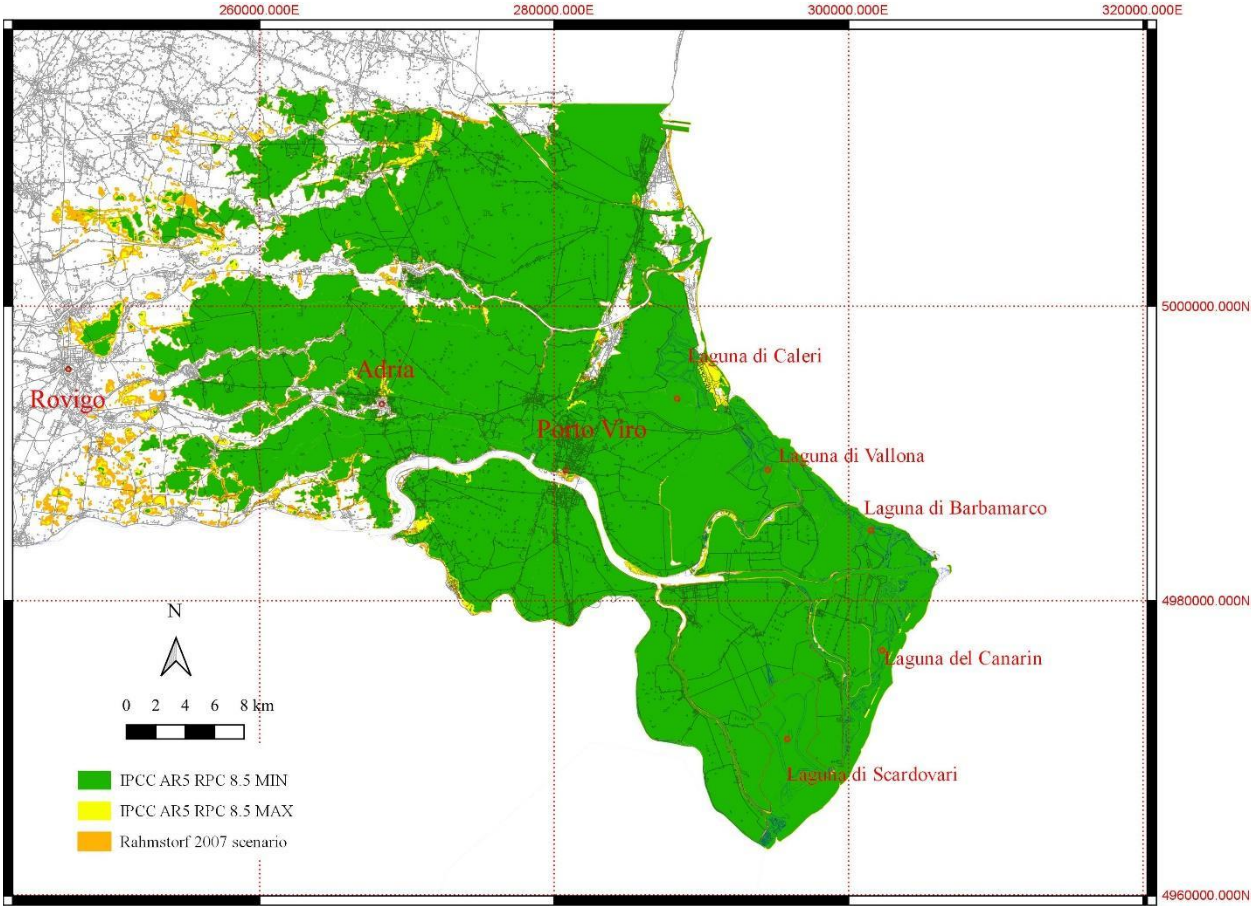


Figure 55. Flooding scenario for the Po Delta regions, extracted by the map published by Marsico et al. (2017) with permission of the authors.

Already today large portions of the Po Delta territory are reliant on a complex drainage system made up of several pumping stations, while coastal dykes are fundamental to prevent marine ingression in the transitional areas. Since low-lying areas will increase in the next 50 years, the number and the efficiency of the water pumps operating in the region need to be increased to guarantee the same conditions as today. Moreover, dyke elevation should presumably be enhanced to cope with the relative sea level rise.

The used DTM did not consider the almost 60 km of protection dykes (seawalls known as "first defense") that protect the inland region of the Po Delta, and that have an average height of about 4 m. An analysis of the efficacy of these dykes has been recently begun with the support of numerical simulations to assess the relative sea level rise in the lagoons.

4.3.3 Biological evolution under climate change in Delta Po area

The evolution of some Po Delta ecosystem characteristics was studied by means of Habitat Suitability Models (HSMs) for three habitats/species:

1. **Manila clam** (*Ruditapes philippinarum)* that is a species particularly relevant for the farming activities in several lagoons of the Delta. The species was introduced in Italy in the early 1980's. The species have high tolerance against variations of environmental parameters (salinity, temperature, dissolved oxygen), high adaptability to different substratum types, high fertility, etc., with respect to the native clam species *Ruditapes decussatus* (Table 9).

	Optimal range	Tolerated range
Salinity (psu)	20-35	15-45
Turbidity (mg L^{-1})	0-20	0-100
Temperature (°C)	15–25	0–32
Oxygen (% sat)	>80	>40
Hydrodinamisms (m s^{-1})	0.3–1	0.2–2
Phytoplankton (Chl *a*, µg L^{-1})	2–11	-
Sand (%)	>80	>20

Table 9. Resume table of optimal and tolerated ranges of the main biogeochemical and hydrodynamic parameters identified as essential for the Manila clam (Source: Boscolo et al., 2011 with elaborations of data collected by Breber, 1996; Paesanti e Pellizzato, 2000; Solidoro et al., 2003).

2. **Reedbeds** made by the common reed (*Phragmites australis*), a cosmopolitan perennial halophyte that lives in humid environments (drainage canals, river, valley). This plant is well adapted to grow in a wide range of environmental conditions, even if it tolerates only moderate salinity, up to 12-15 Psu. The emerged part is frequented by numerous species of birds of conservation interest for feeding, nesting, and night rest. The submerged part of the reedbed and the adjacent shallow waters are the breeding, nursery, and shelter habitats of various fish species. The reeds perform many ecological functions: constructed wetlands, oxygenation of sediments, defense from erosive processes, CO_2 sequestration, production of organic substrates. The presence of reedbeds in the Po Delta lagoon is generally limited to the areas that are protected from the marine influence by sandbanks. Its distribution already decreased in the past.

3. **Seagrasses** are aquatic angiosperms that developed adaptations to submerged life, hydrophilic reproduction, resistance to wave motion and, sometimes, tolerance to salinity. Aquatic angiosperms are fundamental elements of transitional ecosystems, are able to support high biodiversity and to increase the ecological quality of the habitat. Their presence characterize the good state of conservation of the habitat 1150* coastal lagoons. Meadow seagrasses provide numerous ecosystem services:
   - nursery, shelter and feeding for fish species of conservation and commercial interest, macrozoobenthic communities;
   - breeding and feeding for birds;
   - removal of suspended particulate matter with increase of water column transparence;
   - removal of nutrients from water and sediments, sediment oxygenation and mineralization;
   - defense of bottom surfaces from erosion;

- carbon sequestration.

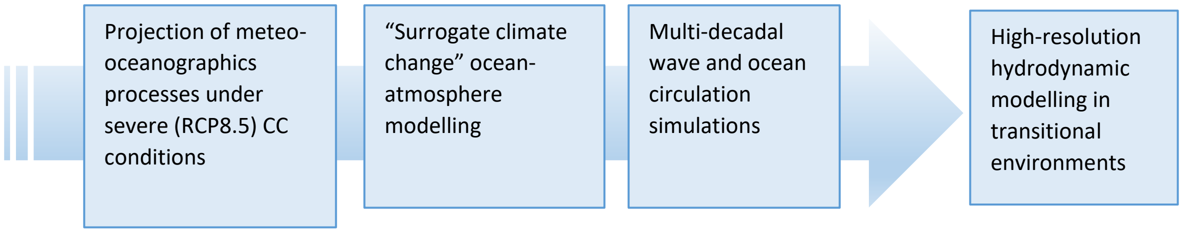
Even if seagrasses were quite widespread in the 1960s, they currently have a limited distribution, with meadows of *Zostera noltei* and *Ruppia spp.* mainly present in fish farms and canals. *Zostera noltei* was considered an indicator species to represent habitat suitability in the Po Delta.

A HSM with theoretically derived curves based on the implementation of the model proposed by Vincenzi et al. (2006) was used for Manila clam, while statistical models relating presence/absence to environmental conditions were used for reedbeds and seagrass meadows. In both cases the model outputs were assumed as estimations of the suitability of the environmental conditions for the specific target (Table 10).

Manila clams	- fraction of sand in the upper sediment layer; - dissolved oxygen of the water; - water salinity; - water hydrodynamics; - chlorophyll “a”; - bathymetry.
Reedbeds	- percentage of time with salinity values over the threshold of 15 PSU estimated on a yearly basis (% S < 15 PSU) - sand in the upper sediment of the bottom (% sand); - hydrodynamics (current speed); - percentage of time of exposure to the air estimated on a yearly basis (% submerged year); - slope; - median time of exposure to the air estimated for summer (t submerged summer).
Zostera Noltii	- fraction of time of air exposure of the bottom; - sand content in the bottom; - average salinity (polynomial form); - slope of the bottom; - water residence time (WRT); - total suspended solids; - hydrodynamics (polynomial form), - water depth (WD)

Table 10. Variable included in models.

The environmental variables related to the water dynamics in the Delta system (e.g., water temperature, salinity, water level, current speed, water residence time -WRT, etc.) were simulated by ISMAR-CNR with the 3D hydrodynamic model SHYFEM. The model was used to characterize the present state (period 2010-2011, Deliverable 3.3) and the Climate Change scenario (IPCC RCP8.5, 2080-2081, Deliverable 4.1; sea level + 0.63 m).



4.3.3.1 Climate scenarios results

Manila clam HSM (Figure 56):

A small reduction (-0.2 – 0.0) of suitability is reported at Delta large scale, while a slightly increase (0.0 - +0.2) of suitability is shown in the inner areas of Sacca di Goro, in Scardovari (south-west), north of Basson, and in the tidal flats close to Caleri inlets.

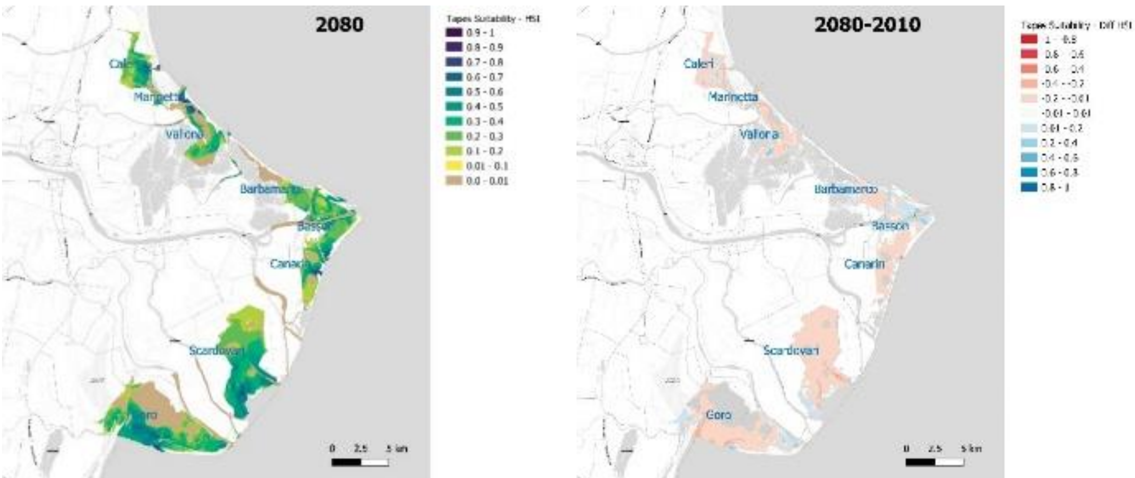


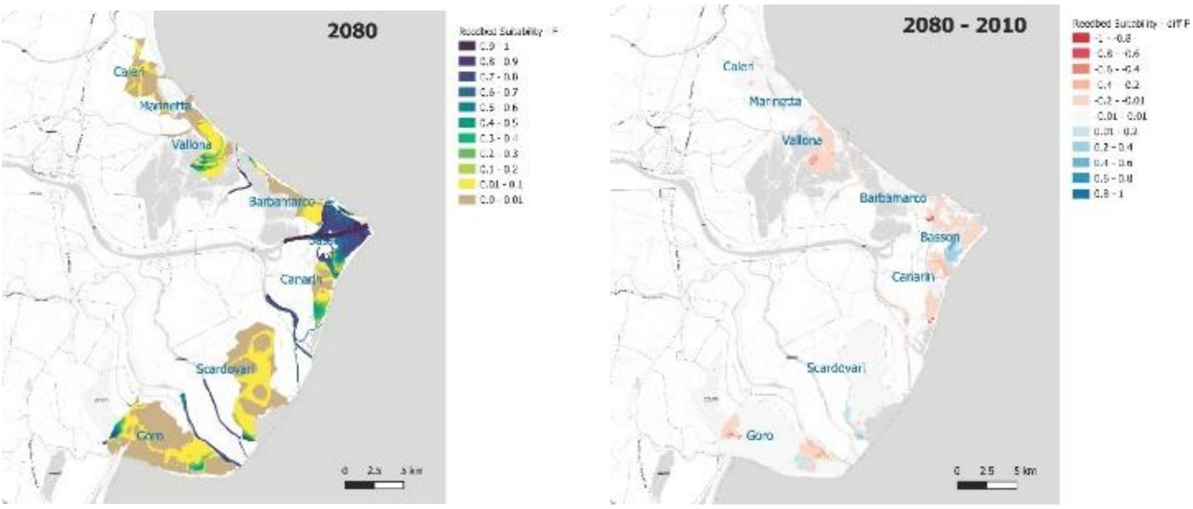
Figure 56. Left: Habitat Suitability (HSI) for Manila clam in CC scenario (2080-2081). Right: Differences of Habitat Suitability for Manila clam between CC scenario (2080-2081) and present state (2010-2011).

In general, the decrease in suitability is explained by the water depth parameter (i.e., bathymetry), even if the salinity variation is locally responsible in the Basson Sud area. The bathymetry and salinity of the water will be more favorable in future in some areas. Regarding the temperature (t), a reduction in suitability is expected with a temperature increase of 30 - 40% during the winter and 20% during the summer.

Reedbed HSM (Figure 57):

Generally, a reduction (-0.2 – 0.0) of suitability is reported at Delta scale with stronger reduction expected at local scale. On the contrary, a slight increase (0.0- +0.2) of suitability is shown in Scardovari (south-west) and in the south part of Basson (0.0 - +0.6).

Figure 57. Left: Habitat Suitability (HSI) for Reedbeds in CC scenario (2080-2081). Suitability is expressed in terms of Favourability (F). Right: Differences of Habitat Suitability (expressed in terms of Favourability- F) for Reedbeds between CC scenario (2080-2081) and present state (2010-2011).



Bathymetry and salinity are the most important parameters for the expected fitness changes, because:
- the time in which the reeds will be in a submerged condition will increase;
- the time in which the reed bed will be in conditions of salinity higher than 15 Psu will increase.

However, there will be an increase in suitability in the southern Basson area and in the southeastern Scardovari area affected by staying at salinity below 15 PSU.

Seagrass HSM (Figure 58):

A widespread decrease in the suitability of Posidonia is expected (-0.4 / -0.2), more marked (-0.6 - 0.4) in the south-west areas, attributed to the increase in the water level and the decrease in salinity. There was a slight increase in suitability (0.0 - 0.2 / 0.4) for areas located in the southern part of Barbamarco and in the northern part of Canarin, due to the increase in salinity.

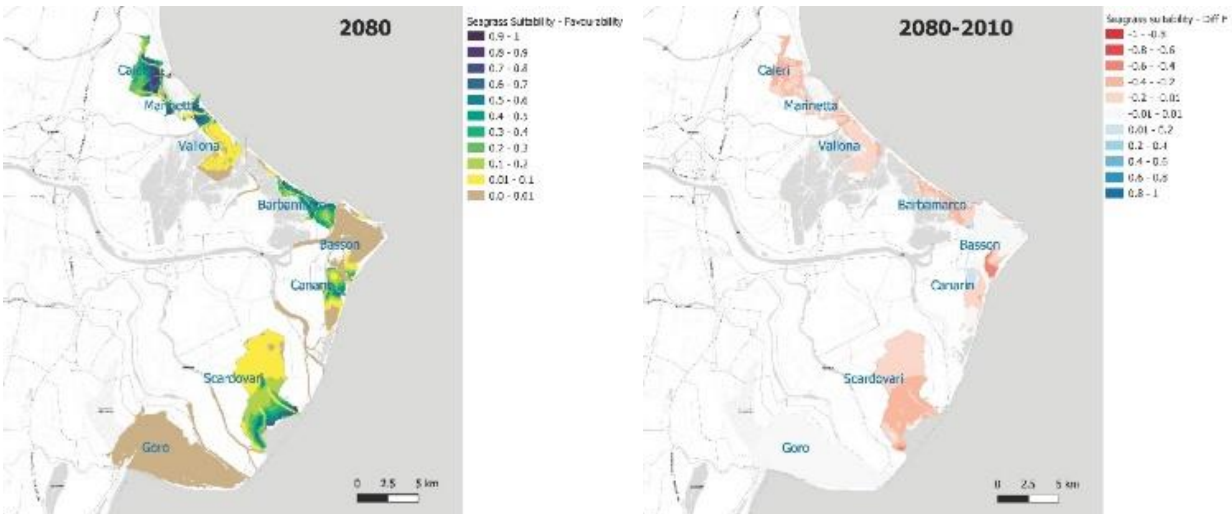


Figure 58. Left: Habitat Suitability (HSI) for seagrass in CC scenario (2080-2081). Suitability is expressed in terms of Favourability (F). Right: Differences of Habitat Suitability expressed in terms of Favourability (F) between CC scenario (2080-2081) and present state (2010-2011) for seagrass.

Among the parameters considered for the Habitat Suitability of seagrass in the CC (2080) scenario, salinity, TSS (a proxy for turbidity), and current velocity may be relevant limiting factors in future conditions.

In conclusion, the decrease in suitability is not particularly strong and it does not seem to preclude the presence of the studied species in the future. The water level rise within the Delta is the most detrimental variable, even if it plays different roles for the three targets.

4.4 Monitoring and information gap-filling strategies

The network dedicated to climate change includes a set of stations belonging to various measurement networks (meteorological, agro-meteorological, hydro-meteorological, etc.). It includes measurement stations for which long and continuous time series of data are available. It must guarantee the homogeneity of the spatial distribution and the density adequate to the representation of the climatic variables in the territory, ensure the development and constant updating of climate change data and trend indicators, ensure the adequacy and uniformity of the methods for calculating climate statistics, provide series of data, albeit from different sources, such as possibly to allow the calculation and use of climate indicators with semi-automatic procedures.

A monitoring system, specific for the Po Delta, will have to respect these principles. Furthermore, it must be integrated into the National System.

Furthermore, climate monitoring must allow:

1. immediately (hours or a few days), to alert the population in the event of catastrophic events, such as floods, storm surges, storms, etc.;
2. to plan the projects in the medium term (10-20 years) on the basis of the trends of selected climatic and environmental indicators;
3. to improve the performance of simulation models used to predict long-term climatic and environmental scenarios;
4. to control over time the consequences of the interventions implemented to counter the effect of climate change (planning).

The list of essential atmospheric variables EAV and climatic products derived in the atmosphere, at its surface, relevant for the Adriatic Sea includes the parameters in Table 11.

The list of ELV Essential land variables (ELVs) and the derived climate products on the land surface, being relevant for the Adriatic Sea includes the parameters in Table 12.

The essential ocean variables listed by the Global Ocean Observing System (GOOS, 2021) are summarized in Table 13.

ECV	Product
Precipitation	Estimates of liquid and solid precipitation
Pressure (surface)	Pressure
Surface Radiation Budget	Surface ERB longwave
	Surface ERB shortwave
Surface Wind Speed and direction	Surface wind speed and direction
Temperature (surface)	Temperature
	Daily maximum and minimum temperature
Water Vapour (surface)	Water vapour

Table 11. Essential climatic parameters for Adriatis Sea.

ELV	Product
Above-ground biomass	Maps of AGB
Albedo	Maps of DHR albedo for adaptation
	Maps of BHR albedo for adaptation
	Maps of DHR albedo for modelling
	Maps of BHR albedo for modelling
Anthropogenic Greenhouse Gas Fluxes	Emissions from fossil fuel use, industry, agriculture and waste sectors.
	Emissions/ removals by IPCC land categories
	Estimated fluxes by inversions of observed atmospheric composition - continental
	Estimated fluxes by inversions of observed atmospheric composition - national
	Hi-res CO2 column concentrations to monitor point sources
Anthropogenic Water Use	Volume of water per year
Fire	Burnt Areas
	Active fire maps
	Fire radiative power
Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)	Maps of FAPAR for modelling
	Maps of FAPAR for adaptation
Groundwater	Groundwater volume change
	Groundwater level
	Groundwater recharge
	Groundwater discharge

	Wellhead level
	Water quality
Lakes	Lake water level
	Water Extent
	Lake surface water temperature
	Lake ice thickness
	Lake Ice Cover
	Lake Colour (Lake Water Leaving Reflectance)
Land cover	Maps of land cover
	Maps of high resolution land cover
	Maps of key IPCC land use, related changes and land management types
Land Surface Temperature	Maps of land surface temperature
Latent and Sensible Heat fluxes	
Leaf Area Index (LAI)	Maps of LAI for modelling
	Maps of LAI for adaptation
River Discharge	River discharge
	Water Level
	Flow Velocity
	Cross-section
Snow	Area covered by snow
	Snow depth
	Snow water equivalent
Soil Carbon	%Carbon in soil
	Mineral soil bulk density to 30 cms and 1m
	Peatlands total depth of profile, area and location
Soil Moisture	Surface soil moisture
	Freeze/thaw
	Surface inundation
	Root-zone soil moisture

Table 12. Essential land variables (ELVs) and the derived climate products on the land surface, relevant for Adriatic Sea.

PHYSICS	BIOGEOCHEMISTRY	BIOLOGY AND ECOSYSTEMS
Sea state	Oxygen	Phytoplankton biomass and diversity
Ocean surface stress	Nutrients	Zooplankton biomass and diversity
Sea ice	Inorganic carbon	Fish abundance and distribution
Sea surface height	Transient tracers	Marine turtles, birds, mammals abundance and distribution
Sea surface temperature	Particulate matter	Hard coral cover and composition
Subsurface temperature	Nitrous oxide	Seagrass cover and composition
Surface currents	Stable carbon isotopes	Macroalgal canopy cover and composition
Subsurface currents	Dissolved organic carbon	Mangrove cover and composition
Sea surface salinity		Microbe biomass and diversity (*emerging)
Subsurface salinity		Invertebrate abundance and distribution (*emerging)
Ocean surface heat flux		
CROSS-DISCIPLINARY		
Ocean colour	Ocean Sound	

Table 13. Essential Ocean Variables (GOOS, 2021).

The regional monitoring network basically covers the needs. Not enough information was found for some parameters of the tables 11-12-13 such as: Albedo, Fire, Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), Latent and Sensible Heat fluxes, Leaf Area Index (LAI), Soil Moisture. Regarding the Essential Ocean Variables as listed by the Global Ocean Observing System (GOOS), most of the parameters are monitored by Research Institutes (CNR, ISPRA) in coordination with Regions and Ministries.

The study carried out for the project revealed a lack of data relating to bathymetry and continuous hydrography.

Sediment analysis, and in particular solid transport measurements and sediment stock assessment, are relatively scarce. The project included two surveys (bathymetric surveys on coastal and transitional zones) by PP1 (RER), the second of which was carried out in autumn 2021 so it was not possible to use the results of the surveys in this project.

The expansion of the existing monitoring network is expected / hoped for, with reference to the Delta area both inland and lagoon areas, in addition to the coastal strip and the overlooking marine area.

In this regard, the Regional Council, with resolution no. 1529 of 17/11/2020, adopted the Regional Plan for Recovery and Resilience (PRRR) of Veneto, which includes numerous project proposals including the "Strengthening, development and innovation of environmental monitoring and controls" project, in thematic area "Investments aimed at achieving European Green Deal objectives".

The priorities of the European Green Deal include:

- protect our biodiversity and ecosystems;
- reduce air, water and soil pollution;
- actions for a circular economy;
- improve waste management;
- ensure the sustainability of our blue economy and the fisheries sectors.

The proposal provides for the development, enhancement and innovation of environmental monitoring and controls, performed by ARPAV, with particular reference to ongoing emergencies including climatic ones. The project plans to develop a permanent monitoring system for species and habitats, in line with the envisaged objectives, aimed at obtaining “clean air and water, healthy soil and biodiversity”. This represents one of the challenges of the Green Deal. Implementation time 48 months, total financial requirement 21 million euros.

5 Elements of the participatory process for the Delta Po Pilot Area

5.1 Stakeholders involved

The purpose of the participatory process is to improve the perception of climate change and bring out the real environmental problems and socio-economic needs. The increase in knowledge of the territory, through the collaboration of the stakeholders, allows the actions and strategies to be defined correctly and specifically. The involvement of the various stakeholders helps to define the state and environmental conditions of the territory.

The participatory process aims to:

- involve all economic operators and public bodies working in the area;
- detect current problems related to climate effects;
- inform about the future effects of climate change on the environment;
- identify the vocations of the site;
- identify the needs of stakeholders;
- collect ideas on possible developments suitable for future climate scenarios, in particular - improve/maintain the productive conditions of the aquaculture sector;
- involve operators in the choice of projects aimed at preserving the natural environment and/or the anthropic activities of the site (e.g. the enhancement of habitats and protected species, the protection of mud flats and salt marshes, etc.).

The participatory process started with the selection of the stakeholders (cfr. STAKEHOLDER MAPPING - Activity 5.1). The most represented groups of stakeholders involved in the participatory process are those of economic operators in the fishing sector, and local administrators. As regards public administrations, both the mayors and the technical officials of the municipalities of the Delta area, and those of the Province of Rovigo were involved. All the school offices in the area, the territorial offices of the main environmental associations, some professional associations, university researchers, as well as all the sector bodies that in various capacities participate in the management of the territory were also contacted. Freelancers, regional officials from various sectors and other staff not directly contacted asked to participate in the workshops following the widespread publicity of the events through press releases (Figure 59, Table 14).

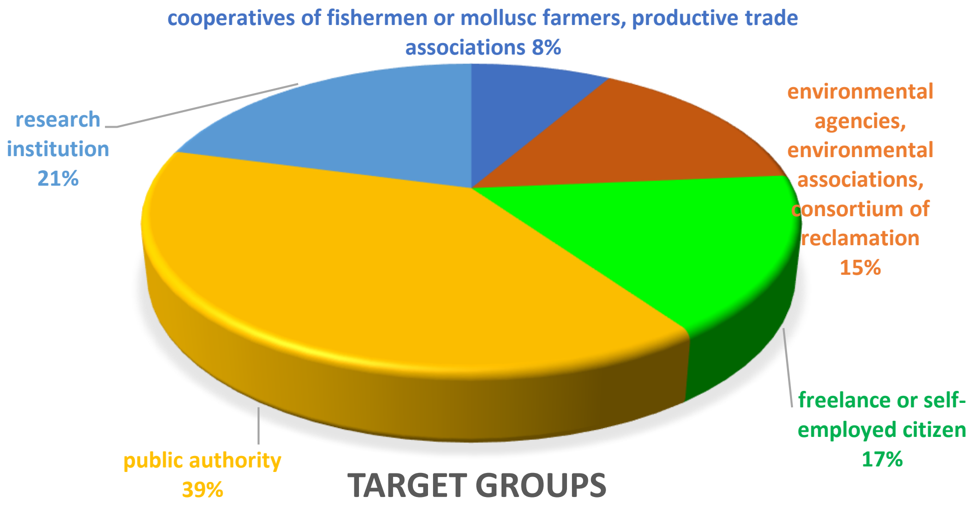


Figure 59. Target groups of Veneto Region.

Policymakers	**Veneto Region**
	Province of Rovigo
	Municipalities
Public administrations	Po District Basin Authority
	Reclamation Consortium of Delta Po
	Ministry of University and Research
	Ministry for Cultural Heritage, and for Tourism
	Superior Institute of Health
	Interregional Agency of Po River
	Regional Park Authority
Educationals	University (Ferrara and Padua)
	School Districts
	Museums
Researchers	National research council
	Italian Institute for Environmental Protection and Research
	Regional Agency of Environmental Protection
Associations	Professional association
	Italian bird protection league – Rovigo

	Legambiente - Rovigo
	World Wide Fund Rovigo
	Italian Association of Atmospheric Sciences and Meteorology
Economic trade associations	Coldiretti
	Confagricoltura
	Fishing and shellfishing consortium
	FLAG – GAC (Fisheries local action group – Chioggia and Po Delta), Coastal Action Group.
Fishing /shellfish farming Enterprise	Shellfishing farmers
	Fishermen
Other	Freelancers
	Companies
	Consulting firms
	Integrated water service managers
	Journalists

Table 14. Stakeholder groups in Veneto Region.

5.2 Design and implementation of the participatory process

In summary, the participatory process had two phases:

1. design of the Participatory Process, months 09/2019 – 05/2020: design /set up a dedicated participatory process in relation to the issues to be tackled, the nature and characteristics of the stakeholders, main local actors, citizens and associations;

2. implementation of the Participatory Process, months 09/2020 – 02/2021: implementation of the designed process along 6 months, including 3 Participatory Workshops in presence or via online support as Webinar, or other tools as indicated in the following page, and all other means designed/foreseen (as local coordination meetings, public meetings, online virtual squares, blogs, online consultations tools in general, etc.) following the developments of WP3 and WP4 and their specific outcomes for the Pilot Sites.

Six ways to contact people have been implemented: contact via institutional mail and personal mail, advertising on a specialized website, web meeting, telephone contact, press releases. The activities were implemented in the following ways:

- updates to the existing institutional website;
- 3 newsletters;
- 3 questionnaires (1 reconnaissance questionnaire and 2 satisfaction questionnaires);
- 2 press releases;
- 3 workshops as online meetings with google tools:

- "Climate change in coastal and transition areas: scenarios and impacts on the Po Delta" (23 April, 2021);
- “Climate change in the Po Delta: critical issues, proposals, priorities. Discussion with stakeholders " (June 17, 2021);
- “Climate change in the Po Delta: critical issues, proposals, priorities. Meeting with Public Bodies" (June 18, 2021).

The events were advertised on the project website, on the Region website, on the website of the Professional Order of Geologists and through the local press.

As part of the participatory process, together with the organization of the workshops, other stakeholder involvement activities were carried out:

- questionnaire on the perception of climate change;

- distribution of the presentations;

- publication of the material relating to the events on the regional institutional website and social network of the project;

- publication of articles on other relevant sites and local newspapers.

Stakeholders were contacted both by e-mail and by telephone before each workshop.

The first web meeting had a purely informative connotation, presenting, in addition to the general contents of the project and a general description of the pilot area, the results of some forecasting models applied to the specific territory.

In particular, the related problems were examined:

a) urban planning at the regional level (Regional Territorial Coordination Plan);

b) long-term local hydrodynamic scenarios, related to the impacts on the characteristics of the lagoons: temperature, salinity, hydro-phytic component;

c) coastal geomorphological vulnerability.

A survey was added to the invitation, carried out through an anonymous online questionnaire, aimed at collecting the opinions of the participants about the perception and knowledge on the issues of climate change and associated risk. The questionnaire, returned by 65 stakeholders, made it possible to identify some topics of interest to be developed during the second and third meetings.

72 people attended the web meeting, covering the entire competence panel described above. The responses to the feedback questionnaire on the event testified to the wide satisfaction of the participants, the desire for greater and synergistic involvement between the parties, and the need for further information on issues relating to climate change.

In continuity with the first workshop, specific stakeholders, belonging to different groups representing the main activities of the territory, were identified and invited to the 2nd and 3rd event.

The second meeting involved professional associations and freelancers, trade associations, employees of the fishing/shellfish sector, environmental associations, to which a discussion session was dedicated. In the third meeting, on the other hand, public bodies and institutions were invited with which a discussion table on technical, regulatory and managerial issues was shared.

25 people participated in the first meeting and 25 in the second meeting.

5.3 Outcomes of the participatory process

Criticalities and proposals that emerged from the participatory process mainly concern:

- conflict between European fisheries policies and local activities;
- conflict between tourist activities and environmental protection requirements;
- request for greater involvement of residents in the choices relating to the development of the area.

The common line that emerged during the discussion is to identify an adaptation strategy that follows natural tendencies of the area.

This is essential for the correct use of resources and for responsible and sustainable development. Above all, the need for more in-depth studies on coastal and marine natural dynamics emerged and a request for involvement and active participation.

The following results were obtained from the participatory process:

- increase of knowledge, among stakeholders, of the climatic effects and environmental scenarios in the Po Delta for the next decades;
- achieving awareness of the likely problems to be faced in the future;
- knowledge of the European and national tools put in place to start planning interventions for adaptation to climate change;
- the creation of a correlated series of relationships between the different actors;
- the collection of contributions, ideas, knowledge of the territory provided by local operators, relevant for the implementation of the subsequent planning phase.

During the second and third workshops, the interventions of the stakeholders identified the key aspects of the project and highlighted several concerns related to the pilot site, in particular:

- drilling in the sea, which could generate pollution effects and further problems (subsidence);
- the effects of the Mose of Venice on the hydrodynamics of the Po Delta;
- the tendency of lagoons to marinization;
- the constraints on fishing and aquaculture dictated by Europe and by the dynamics of the global market;
- damage to fish farms caused by extreme events;
- the changes taking place in fish populations (diffusion of blue fish eg Pomatomus saltatrix-pesce serra and Thunnus thynnus -bluefin tuna);
- the aspects related to the reduction of the fishing effort, which generated economic losses, but did not bring the expected effects in relation to the restocking and maintenance of fish communities;
- the lack of in-depth knowledge of the marine environment and awareness of climate-related issues;
- the need for continuous engineering interventions to guarantee the local economy, based on fishing, aquaculture and agriculture;
- plastic pollution;
- environmental damage caused by summer tourism.

PROPOSAL		FOCUS	TARGET GROUP	CRITICAL ISSUE
1	Elaborate an inter-sectoral "Delta lagoon plan", establishing a priori, at a strategic level, a long-term development objective, first of all defining whether to operate in order to keep the lagoons in their current conformation or to let them go towards natural evolution.	PLANNING	FISHERMEN	POOR COORDINATION OF INTERVENTIONS. LOSS OF SKILLS AND KNOWLEDGE
2	Coordinate the project choices that refer to different sources of funding.	BETTER EXPLOITATION OF AVAILABLE FUNDS	TRADE ASSOCIATIONS	DISSIPATION OF FUNDING
3	Develop a shared path - not only with all entrepreneurs and citizens of the Delta - but also with the District Authority of the Po river basin, and with the Interregional Agency of the Po river (AIPO) in order to manage the Po Delta area.	COLLABORATION BETWEEN RIVER, TERRESTRIAL, LAGOON, MARINE SKILLS	FISHERMEN	POOR COORDINATION
4	Develop scientific research on ecological dynamics in the North Adriatic to identify the real reasons for the reduction of the catch and the contraction of some fish species compared to the expansion of others	SCIENTIFIC RESEARCH	SCIENTIFIC RESEARCH	REDUCTION IN THE AMOUNT OF FISHING
5	Improve the information network and monitoring databases in the river-lagoon-sea context.	SHARING AND INTEGRATION OF ENVIRONMENTAL DATA	TRADE ASSOCIATIONS	LOW EFFICIENCY OF FORECAST MODELS
6	Organize dedicated dissemination events. (The need was noted for teachers and school representatives to access courses and events on the subject of CC. The availability of some representatives of associations and institutions to carry out educational activities was also noted).	ENVIRONMENTAL EDUCATION	TEACHERS	LOW KNOWLEDGE OF CLIMATE RELATED ISSUES
7	Focus the local economy on the short supply chain of the product and on conscious consumption.	ECONOMICS AND TOURISM	TRADE ASSOCIATIONS	LOW VALORISATION OF LOCAL PRODUCTS
8	Develop systems to reduce pollution from plastics resulting from farming and fishing activities (e.g alternative materials, energy recovery from plastics).	AQUATIC MACROFAUNA	FISHERMEN	MARINE LITTER
9	Develop prevention actions against damage from extreme events, at the level of civil protection, such as monitoring systems and warning systems.	CIVIL PROTECTION	PUBLIC BODIES	FLOODS AND STORMS
10	For the Sacca del Canarin, the goal is to reverse the dynamics of environmental degradation caused by poor hydrodynamics, anoxia, and alteration of the salt balance. Its vivification will improve fish production and may lead to local tourism development.	ENVIRONMENTAL QUALITY	FISHERMEN	DECAY OF CANARIN LAGOON

Table 15. Result from participatory process.

6 Adaptation Plan

6.1 Legal Framework for adaptation to climate change

ROAD MAP FOR THE ADAPTATION PLAN OF THE PO DELTA - VENETO REGION

A.1 Legal framework for adaptation to climate change

Knowledge of the environmental legal framework is essential for implementing climate change adaptation tools, strategies, or plans. It allows to identify a reference legal baseline to support the adaptation tools to be introduced at regional and local scale. The legal framework can be divided in three main levels: 1-international, 2-EU and 3-national.

A.1.1 The legal framework in the international dimension

The **United Nations Framework Convention on Climate Change (UNFCCC)** of 1992 (Rio de Janeiro) approved on 21 March 1994 is the first agreement adopted by the international community to deal with the problem of climate change. It is based on the work delivered by the Intergovernmental Panel on Climate Change (IPCC) established in 1988 by the World Meteorological Organization and the United Nations Environment Program. The main steps were the Kyoto Protocol adopted on 11 December 1997, and the Paris Agreement adopted by 196 parties at COP 21 on 12 December 2015 and entered into force on 4 November 2016. Its aim is to limit global warming to 1.5 degrees Celsius above pre-industrial levels. The countries communicate the actions they will take to reduce their greenhouse gas emissions in their Nationally Determined Contributions (NDCs). The Conference of the Parties - assembled as COP, CMP and CMA - has two main purposes: 1. Review the implementation of the Convention, the Kyoto Protocol and the Paris Agreement respectively; and 2. Make decisions to further develop and implement these three tools.

The **Convention on Wetlands** is the oldest among the modern global intergovernmental environmental agreements. The treaty was negotiated through the 1960s by countries and non-governmental organizations concerned about the increasing loss and degradation of the wetland habitat for migratory waterbirds. It was adopted in the Iranian city of Ramsar in 1971 and came into force in 1975. The mission of the Ramsar Convention is "the conservation and wise use of all wetlands through local and national action and international cooperation, as a contribution to the achievement of sustainable development throughout the world". The contracting parties approved the fourth strategic plan for 2016-2024 at COP12. It came into force in the national legislation with the DPR n. 448 of 03/13/1976, then amended with the Presidential Decree 11 February 1987.

Established in 1994, the **United Nations Convention to Combat Desertification (UNCCD)** is the only legally binding international agreement linking environment and development for a sustainable land management. The Convention 197 parties (including Italy, L. 170/1997) work together to improve the living conditions of people in drylands, to maintain and restore land and soil productivity, and to mitigate the effects of drought. The new UNCCD 2018-2030 Strategic Framework is the most comprehensive global commitment to achieve Land Degradation Neutrality (LDN).

The **Convention on Biological Diversity (CBD)** adopted in Nairobi on 22 May 22 1992 and entered into force on 29 December 1993. The three main objectives of the CBD are the conservation of biological diversity, the sustainable use of the components of biological diversity, and the fair and equitable sharing of the benefits arising from the use of genetic resources. The Conference of the Parties (COP) established seven thematic programs of work which correspond to some of the major biomes on the planet, including the “Marine and Coastal Biodiversity” program.

The **2030 Agenda for Sustainable Development** is a global action program that aims to eradicate poverty, protect the planet and ensure prosperity and peace. It was unanimously adopted by the 193 member countries of the United Nations with resolution 70/1 of 15 September 2015 entitled: "*Transforming our world. The Agenda for Sustainable Development*". Among the 17 goals, the objective no. 13 of the 2030 Agenda addresses the problem of climate change through mitigation and adaptation actions. Several other Goals face the theme of climate change and adaptation. The **Veneto Regional Council** adopted its strategy for sustainable development (SRSVS) on 12 May 2020 after a long process of discussion with the civil society and the stakeholders. The SRSVS takes a transversal approach to the various issues enhancing the specificities, capacities, and potentialities of the Venetian territories and communities. The document was approved by the **Veneto Regional Council** on 20 July 2020.

<u>Other international instruments related to the topic of climate change:</u>

- The **Barcelona Convention for the Protection of the Mediterranean** (UNEP / MAP) and its seven Protocols adopted under the Mediterranean Action Plan (MAP) constitute the main legally binding regional Multilateral Environmental Agreement (MEA) in the Mediterranean. One of the 7 protocols is the Integrated Coastal Zone Management (ICZM). The Convention was signed on 16 February 1976 by 16 governments, entered into force in 1978, and was ratified by Italy on 3 February 1979 with law no. 30.
- The Council of Europe’s Convention on the Conservation of European Wildlife and Natural Habitats (1979), or **Bern Convention**, was the first international treaty to protect both species and habitats and to bring countries together in deciding how to act for nature conservation. It was implemented in Italy with law no. 503 of 5 August 1981. The European Community adopted the Birds Directive in 1979 (later updated in Directive 2009/147 / EC) and the Habitats Directive in 1992 to make the Berne Convention operational.
- The **Convention on the Conservation of Migratory Species of Wild Animals (CMS)**. As an environmental treaty of the United Nations, the CMS provides a global platform for the conservation and sustainable use of migratory animals and their habitats. The CMS brings together the States crossed by migratory animals (i.e., the Range States) and defines the legal foundation for internationally coordinated conservation measures throughout a migratory range. It was adopted in 1979 in Bonn (Germany) and ratified in Italy in 1983 (Law no. 42 of 25 January 1983);
- The **Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)** is an international agreement between governments. Its aim is to ensure that the international trade in specimens of wild animals and plants does not threaten the survival of the species.
- United Nations Educational, Scientific and Cultural Organization (UNESCO): Declaration of Ethical Principles in relation to Climate Change, 2017.
- United Nations Educational, Scientific and Cultural Organization (UNESCO): **Convention concerning the protection of the world cultural and natural heritage** (Paris 1972). The Po Delta was recognized as a Biosphere Reserve under the UNESCO MaB Program in 2015.
- Food and Agriculture Organization (FAO) of the United Nations: FAO's strategy on climate change, 2017.
- **United Nations Office for Disaster Risk Reduction** (UNDRR) oversees the implementation of the Sendai Framework for Disaster Risk Reduction 2015-2030 supporting countries in its

implementation, monitoring and sharing of plans for the reduction of existing risks and preventing the creation of new ones.

•

A.1.2 The legal framework at the level of the European Union

Starting with the European Climate Change Program, the EU Emissions Trading System (EU-ETS), and the EU mechanism for monitoring and reporting emissions14, the EU wanted to support the achievement of the objectives set by the Kyoto Protocol and, since 2015, the Paris Agreement.

The **European Green Deal** will transform the EU into a modern, resource-efficient, and competitive economy, ensuring (i) no net emissions of greenhouse gases by 2050; (ii) economic growth decoupled from resource use; (iii) no person and no place left behind. The European Green Deal will improve the well-being and health of citizens and future generations. The actions of Green Deal are summarized in the scheme below. The core part of the European Green Deal named EU's biodiversity strategy for 2030 is a comprehensive, ambitious, and long-term plan to protect nature and reverse the degradation of ecosystems.

https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en#thematicareas

The European Commission adopted its new EU strategy on adaptation to climate change on 24 February 2021.

Brussels, 24.2.2021 SWD(2021) 25 final COMMISSION STAFF WORKING DOCUMENT **IMPACT ASSESSMENT REPORT Accompanying the document** COMMUNICATION ROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS **Forging a climate-resilient Europe - The new EU Strategy on Adaptation to Climate Change**

Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 **('European Climate Law'**)

Other European instruments related to climate change:

The European **Climate-ADAPT Platform** is an initiative of the European Commission created with the partnership of the European Environment Agency and launched on the web in 2012.

The EU **Covenant of Mayors for Climate & Energy** is an initiative of the European Commission launched in 2008 that brings together thousands of local governments voluntarily committed to implementing EU climate and energy objectives.

The **Integrated coastal zone management (ICZM) in the Mediterranean was** introduced in the European context with EU ICZM Recommendation 2002/413/EC. The ICZM Protocol was adopted in 2008 and entered into force in 2011. The Contracting Parties adopted in 2012 the Action Plan for the implementation of the ICZM Protocol. They also adopted the Common Regional Framework for ICZM in 2019. The Veneto Region deals with the programming and planning of interventions aimed at ensuring the defense of the coasts from erosion, the dredging of river mouths and the environmental requalification of the coastal strip in the context of ICZM.

The **Maritime Spatial Planning (MSP)** is the tool to manage the use of seas and oceans coherently and to ensure that human activities take place in an efficient, safe and sustainable way (Dir 2014/89/UE). The Directive was implemented in Italy through Legislative Decree 201/2016, the Decree of the President of the Council of Ministers of 1 December 2017, and the Guidelines containing the criteria for the preparation of maritime space management plans. The Guidelines also provide an indication of the geographic scope of the maritime plans, which must include marine areas up to the limit of national jurisdiction and coastal and transitional waters, if not already considered in urban or rural plans.

The **Marine Strategy Framework Directive (MSFD) 2008/56/EC** entered into force in 2008 and was implemented in Italy with the Legislative Decree no. 190/2010. It is applied to marine waters including seabed and subsoil over which the country exercises jurisdiction. In addition, it includes territorial waters, the territorial sea, the exclusive economic zone, the protected fishing areas, the continental shelf, and ecological protection zones. It constitutes the first binding regulatory framework for Member States that considers the marine environment from a systemic perspective. Each country must develop a strategy implementing the necessary measures to achieve (or maintain) a good environmental status with the aim of preventing ecosystem degradation and restoring the damaged ones.

The Marine Environment Strategy together with other European Directives (i.e., the *Habitat Directives* 92/43/EEC, *Wild Birds* 2009/147/EC, *Water framework directive* 2000/60/EC, the *Common Fisheries Policy*, EU Reg. 1380/2013), guarantees a robust political and legal framework for the fulfillment of international commitments related to the protection of marine biodiversity such as the Convention on Biological Diversity (CBD) and the Barcelona Convention for the Protection of the Mediterranean (UNEP / MAP).

A.1.3 The legal framework in Italy

1. **National Strategy for Adaptation to Climate Change *(Strategia Nazionale di Adattamento ai Cambiamenti Climatici* - SNAC**), approved by Ministry of Ecological Transition - DG Clime and Energy, DD 86/2015.

The **SNAC** provides a national strategic view on how to face the impacts of climate change and outlines possible sets of actions in order to reduce the impact of climate change on socio-economic sectors and natural systems.

2. **National Plan for Adaptation to Climate Change (Piano Nazionale di Adattamento ai Cambiamenti Climatici - PNACC)**, 2018 (adopted, pending approval).

   The drafting of the Plan was prepared by the Euro-Mediterranean Center on Climate Change (CMCC). The PNACC is the reference framework for the implementation of adaptation actions at national, regional and local level, which must take place in an integrated way through optimal combinations of measures in the various sectors, in the short and long term.
   In particular, the Plan defines at the national level:
   - climate scenarios of reference at the district / regional scale;
   - risk propensity;
   - sectoral impacts and vulnerabilities;
   - sectoral adaptation actions;
   - roles and coordination tools;
   - estimate of the necessary human and financial resources;
   - effectiveness indicators;
   - monitoring method.

   It is the main reference for the preparation of this report.

Other national instruments related to the climate change are:

- **National plan against hydrogeological instability** (Proteggi Italia 2019-2021) for the safety of the territory and for the risk prevention works, 27 February 27 2019.
- **Integrated National Energy and Climate Plan** (by Ministry of Economic Development, Ministry of the Environment and Protection of Natural Resources and the Sea, Ministry of Infrastructure and Transport) December, 2019, pursuant to the Regulations (UE) 2018/1999. The Plan Energy Climate 2030 marks an important change in our country's energy and environmental policy towards decarbonization.
- **National Sustainable Development Strategy** approved on 22 December 2017 by the CIPE, which is part of the 2030 Agenda.
- The **National Recovery and Resilience Plan** (PNRR "Italia Domani") is part of the Next Generation EU (NGEU) program, the 750 billion euro package, about half of which is made up of grants, agreed by the European Union in response to the pandemic crisis Covid19. The Plan is developed around three strategic axes shared at European level: digitization and innovation, ecological transition, social inclusion. The plan includes some actions and funds related to climate change.

Further rules related to the regional planning are mentioned in the next paragraph.

6.2 Mapping of the plans and programmes in force

ROAD MAP FOR THE PO DELTA - VENETO REGION - PLAN

C.1 implementation process

The identification of all actions already planned and directly or indirectly related to climate change impacts can be performed by mapping regional plans and programmes. Some measures and funding related to climate impacts may already be foreseen, even if not fully developed. Most importantly, the adaptation process needs new planning and programming models towards new strategies.

Urban planning

The main regional discipline on territorial governance consists of:

- Regional Law 11/2004, Rules for territorial governance and landscape matters (Norme per il **governo del territorio e** in materia di **paesaggio).**
- Regional Law 14/2019, Veneto 2050: policies for urban redevelopment and the renaturalization of the territory and amendments to Regional Law 11/2004 ("Veneto 2050: politiche per la riqualificazione urbana e la rinaturalizzazione del territorio e modifiche alla legge regionale 23 aprile 2004, n. 11 "Norme per il governo del territorio e in materia di paesaggio").
- Regional Law 14/2017, Containment of Land Consumption and amendments to Regional Law 11/2004 (Contenimento del consumo di suolo e modifiche alla LR 11/2004)
- Regional Law 61/1985, Rules for the planning and use of the territory (partly repealed).

The hierarchy of plans can be summarized as follows:

Regional Territorial Coordination Plan (Piano Territoriale Regionale di Coordinamento PTRC) of Veneto Region approved with Regional Council Resolution no. 62 of 30 June 2020. This plain does not have the value of a landscape plan pursuant to Legislative Decree 42/2004

↓

Area Plan of Po Delta (**Piano d'AREA**) (municipalities of: Rosolina, Donada, Taglio di Po, Porto Tolle, Corsola, Ariano del Polesine and a small part of the municipalities of Loreo and Papozze) approved with the Regional Council Provision n.1000 of 5 October 1994. The Area Plans assumed landscape value as a result of the L.R. 9/1986

↓

Territorial Coordination Plan of Rovigo Province (**Piano Territoriale Provinciale di Coordinamento** PTCP) of Rovigo Province approved with DGR n. 683 of 17.4.2012

↓

Territorial arrangement Plans (**Piani di Assetto del Territorio** PAT): city plans and related technical standards for implementation of Rosolina, Porto Viro, Ariano nel Polesine, Taglio di Po, Porto Tolle (coastal area municipalities).

↓

Municipal Intervention Plan (**Piano degli interventi** PI)

Cultural and landscape heritage

The Decree n.42 of 22 January 2004 named "Codice dei beni culturali e del paesaggio" lists the cultural and landscape heritage to be protected by the Landscape Plan.

Landscape plan (art. 143)

- ➔ PPRA (**Piano Paesaggistico Regionale d'Ambito**) Adriatic Coast Arch Venice Lagoon and Po Delta (in progress)

Constraints for: cultural heritage (Art. 10 – 11) landscape heritage (Art. 134), Real estate and areas of considerable public interest (Art. 136) Areas protected by law (Art. 142).

Fishing management

Regional Law 28 April 1998 n. 19 Rules for the protection of hydrobiological resources and fish fauna and for the regulation of fishing in inland and inland maritime waters of the Veneto Region

Regional Regulation 28 December 2018 n. 6. Regulation for fishing and aquaculture

Fishing regulation of Rovigo

Regional Fish Charter, adopted with DGR 1042/ 2021

European Maritime and Fisheries Fund (EMFF)

Protected areas – fauna management

As already mentioned, the European Community adopted the Birds Directive in 1979 (later updated in Directive 2009/147 / EC) and the Habitats Directive in 1992 to make the Berne Convention operational, and started the establishment of the European Natura 2000 network whose key regulation for Italy is DPR 357/97. The diagram below, which includes references to the rules for the protection of wildlife and the law on protected areas (parks), shows the essential tools set up by the Veneto Region for the protection of the natural environment in the Po Delta.

NATURA 2000: the site designed in Po Delta are described in paragraph 6.2 (8 sites).

With Regional Council Resolution DGR n. 786 of 27 May 2016, (modified by DGR 1331/2017) **the Conservation Measures of Special Areas of Conservation** (SACs) were approved.

The draft of the **Management Plan for the ZSP IT 3270023** Delta del Po has been already prepared.

Law 157/1992. Rules for the protection of homeothermic wildlife and for hunting. Transposes the European directive Wild Birds 2009/147/EC.

Regional hunting plan (2007-2012) in force: Regional Law 5 January 2007, n. 1

Regional Law 9 Dicember 1993, n. 50: "Rules for the protection of wildlife and for hunting ";

Proposal for a Regional Hunting Wildlife Plan (2021-2026) (in itere)

Law n. 394 del 1991 (updated to Law No. 426 of 9 December 1998 and Law No. 93 of 23 March 2001) "**Framework law on protected areas"**

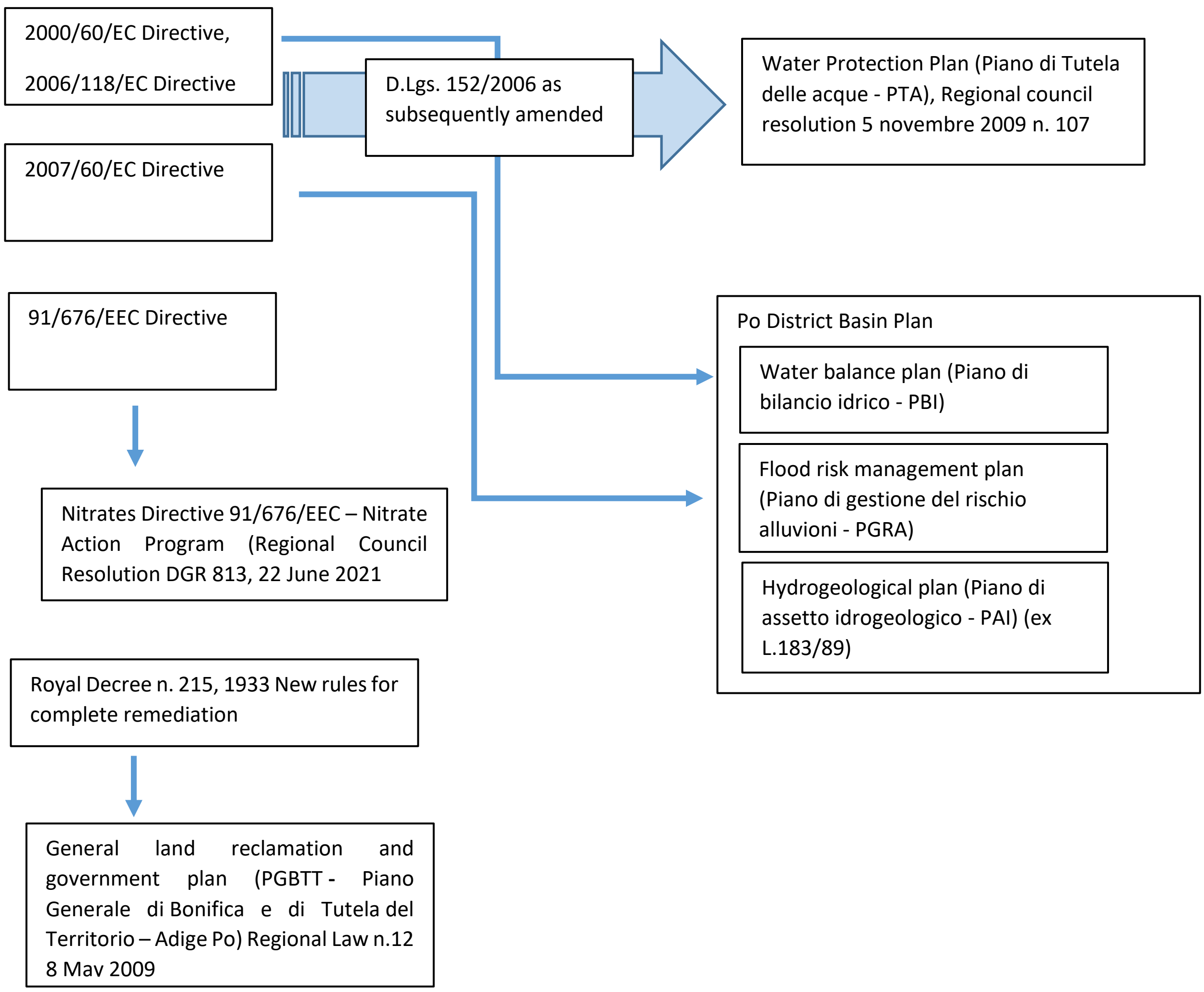
Regional Law 8 September 1997, n. 36 (B.U.R. 74/1997) **Rules for the establishment of the Po Delta Regional Park**

State or Regional Nature Reserves Bosco Nordio, Integral Nature Reserve D.M. 26/7/1971 (Veneto Agricoltura management)
Bocche di Po D.M. 13/07/1997 (Veneto Agricoltura management)

Regional Council Resolution n. 18 17/12/2012: **Adoption of the Po Delta Park Environmental Plan** (artt. 4 e ss. LR n. 36/97)

Park perimeter cartography LR n. 45, 17/12/2017 art. 58

Water management



6.2.1 Identification of the Delta Po Vision

A Vision for the Po Delta area was drawn up by the “Area Plan” approved with the Regional Council Provision n.1000 of 5 October 1994. The Area Plan is binding of all urban plans. This Plan gives considerable importance to the conservation and landscape interest of the area. However, it provides not only for protection but also for the use of ecosystem services by the local population, in order to avoid abandonment of the territory. Anthropic intervention to stem the damage generated by the climate trend will certainly be necessary given the partial artificiality of the places. The historical and current impact of human activities will need to be reconsidered, the hydraulic management and maintenance of the structures will be strengthened and made continuous. It will be important to develop an efficient monitoring system in assessing environmental responses to climate change to allow for sustainable management over time. The subsequent tools developed in response to European and national sector regulations, such as Flood Directive, Marine Strategy, ICZM & MSP) adaptation measures and instruments, as well as the Park Plan, do not deviate from this vision.

6.3 Action Plan for the Focus Area

ROAD MAP FOR THE PO DELTA - VENETO REGION - PLAN

B.2 the effects of climate change: wich climate drivers? what risk at the pilot site?	B.3 from the Objectives of the Strategy to the Actions of the Plan: how to select the best measures?

6.3.1 Foreword

The Po Delta is recognized as a site of great ecological importance (see paragraph 6.2) and considerable geomorphological vulnerability (see WP4). For this reason, the CWC project focuses on the climatic impacts on geomorphological and environmental aspects, also considering their effects on the socio-economic system.

The analysis of climate change effects follows these steps:

- identify the peculiarities, values and sensitive elements of the site;
- identify the indirect effects and threats;
- identify the responses and the possible short and long-term scenarios (interventions, measures);

This analysis is the prerequisite for drawing up the Action Plan for the Delta, which could be configured as an excerpt of the Area Plan, or be integrated into the SECAP (sustainable energy and climate action plan). The Action Plan requires:

- verification of the coherence of the actions and measures proposed with the legislation in force and with the actions foreseen in the PNRR (National Recovery and Resilience Plan);
- identify the measures already foreseen in the current planning and programming tools;
- assessing the level of risk;
- evaluation of the response feasibility in terms of technical aspects, cost, effectiveness;
- identification of the interactions between the proposed actions to eliminate the overlaps and amplify the convergences. Indeed, many measures are interdependent and have multi-sectoral effectiveness;
- development of an action plan and/or sector plan with assignment of roles and responsibilities, securing human and financial resources over the long term;
- monitoring of measures.

6.3.2 Tools used to identify impacts and measures

In addition to the specific knowledge about territory, climate change and their effects, the following reference documents were considered to draw up a guide for the development of the Po Delta Plan:

✓ Castellari S., Venturini S., Giordano F., Ballarin Denti A., Bigano A., Bindi M., Bosello F., Carrera L., Chiriacò M.V., Danovaro R., Desiato F., Filpa A., Fusani S., Gatto M., Gaudioso D., Giovanardi O., Giupponi C., Gualdi S., Guzzetti F., Lapi M., Luise A., Marino G., Mysiak J., Montanari A.,

Pasella D., Pierantonelli L., Ricchiuti A., Rudari R., Sabbioni C., Sciortino M., Sinisi L., Valentini R., Viaroli P., Vurro M., Zavatarelli M. (2014). ***Elementi per una Strategia Nazionale di Adattamento ai Cambiamenti Climatici*[8]*.*** Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Roma.
(https://www.mite.gov.it/sites/default/files/archivio/allegati/clima/snacc_2014_elementi.pdf)

- ✓ ***Strategia Nazionale di Adattamento ai Cambiamenti Climatici*[9] *(SNACC)*.** Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Roma. - § 3. Stato delle conoscenze degli impatti e delle vulnerabilità settoriali, - Allegato 3: proposte di azione. La SNAC (MATTM 2015) è stata approvata con decreto direttoriale n. 86 del 16 giugno 2015. https://pdc.minambiente.it/sites/default/files/allegati/Strategia_nazionale_adattamento_cambiamenti_climatici.pdf

- ✓ ***Piano Nazionale di Adattamento ai Cambiamenti Climatici*[10] *(PNACC)*****–** *Versione giugno 2018.* The Plan is defined from Direzione Generale per il Clima e l'Energia del Ministero dell'Ambiente e della Tutela del Territorio e del Mare with technical-specialist support of CMCC - Centro Euro-Mediterraneo sui Cambiamenti Climatici. - Allegato 3 - Impatti e vulnerabilità settoriali. - Allegato 4 - Azioni di adattamento settoriali. - Allegato 5 - Database delle azioni di adattamento. https://www.mite.gov.it/pagina/piano-nazionale-di-adattamento-ai-cambiamenti-climatici

- ✓ ***Climate-ADAPT platform****,* European Adaptation Platform created by European Commission and currently managed by the European Environment Agency (EEA) https://climate-adapt.eea.europa.eu/

- ✓ ***Progetto Competenze e Reti per l'Integrazione Ambientale e per il Miglioramento delle Organizzazioni della PA*[11]** *(CReIAMO PA)* Sezione toolkit – L5: Rafforzamento della capacità amministrativa per l'adattamento ai cambiamenti climatici, A5.1 - Metodologie per la definizione di strategie e piani regionali di adattamento ai cambiamenti climatici, - Schede operative per la definizione di strategie e piani regionali di adattamento ai cambiamenti climatici.

Furthermore, the identification of the effects of climatic impacts on the Delta coastal area and of associated threats was carried out considering:

- ✓ the specific work packages of "Change we care" carried out along the path of knowledge of the territory and of the climate changes in progress and foreseen;
- ✓ the instruction of the CMCC and the IPCC;
- ✓ some adaptation design experiences in Italy;
- ✓ the results of the public consultation.

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[8] Elements for a National Climate Change Adaptation Strategy.

[9] National Strategy for Adaptation to Climate Change. State of knowledge of sectoral impacts and vulnerabilities, - Attachment 3: Proposed actions.

[10] National Plan for Adaptation to Climate Change. Annex 3 - Sectoral Impacts and Vulnerabilities. - Annex 4 - Sectoral Adaptation Actions. - Annex 5 - Database of adaptation actions.

[11] Project Skills and Networks for Environmental Integration and Improvement of Public Administration Organizations. - L5: Strengthening Administrative Capacity for Climate Change Adaptation, A5.1 - Methodologies for Defining Regional Climate Change Adaptation Strategies and Plans, - Worksheets for Defining Regional CC Adaptation Strategies and Plans.

6.3.3 Impact chain and threat identification

The first phase of analysis concerns the reconstruction of a chain of impacts, peculiar to the pilot site. The relationships between elements are numerous and complex.

In Figure 60 a network is constructed for the Delta following the Impact Chains in coastal systems of the IPCC 2014 report. Another example is represented in Figure 61 that shows a network between the greenhouse effect and the suitability of the habitat in the lagoon environment.

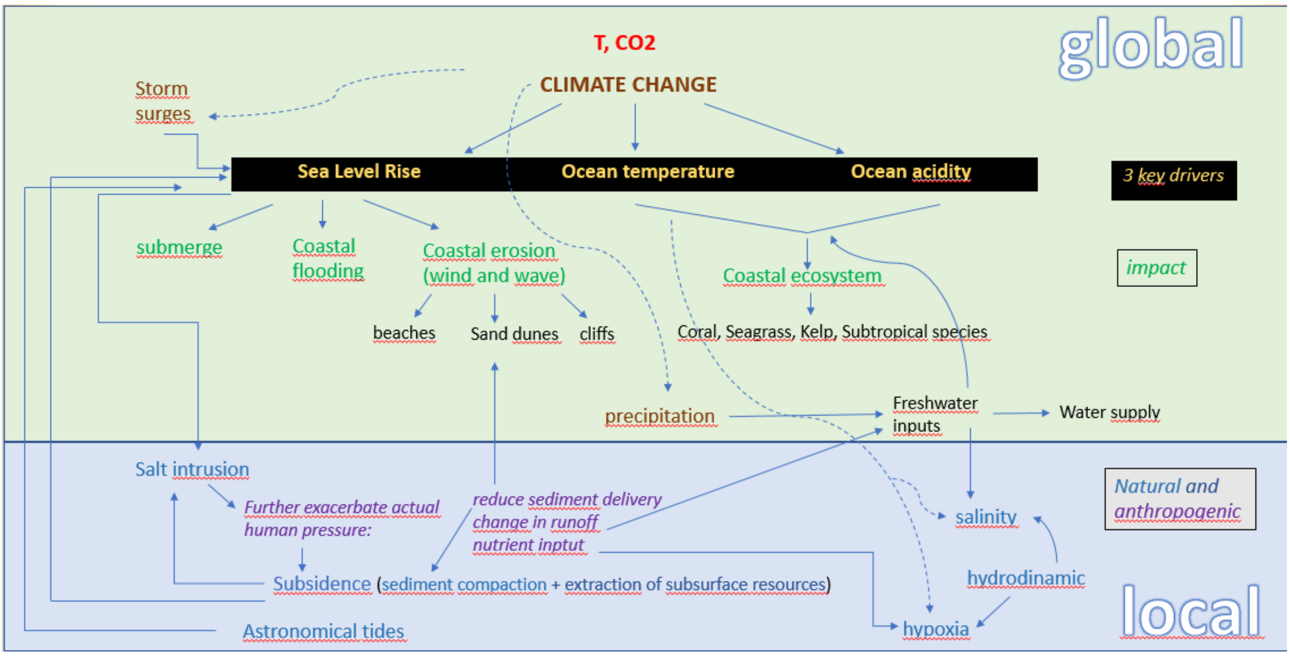


Figure 60. Three key drivers and chains of impacts in coastal systems (remaking by **IPCC**, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A).

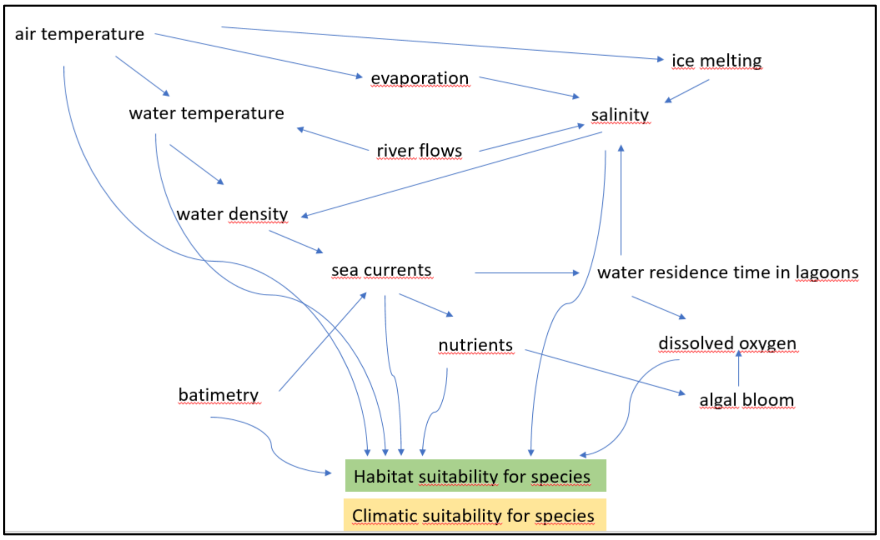


Figure 61. Concatenation of the climatic effects on the coastal biotic communities in lagoon waters.

The complete diagram from greenhouse effect to threats in the Po Delta territory is represented in the following tables, according to the scheme:

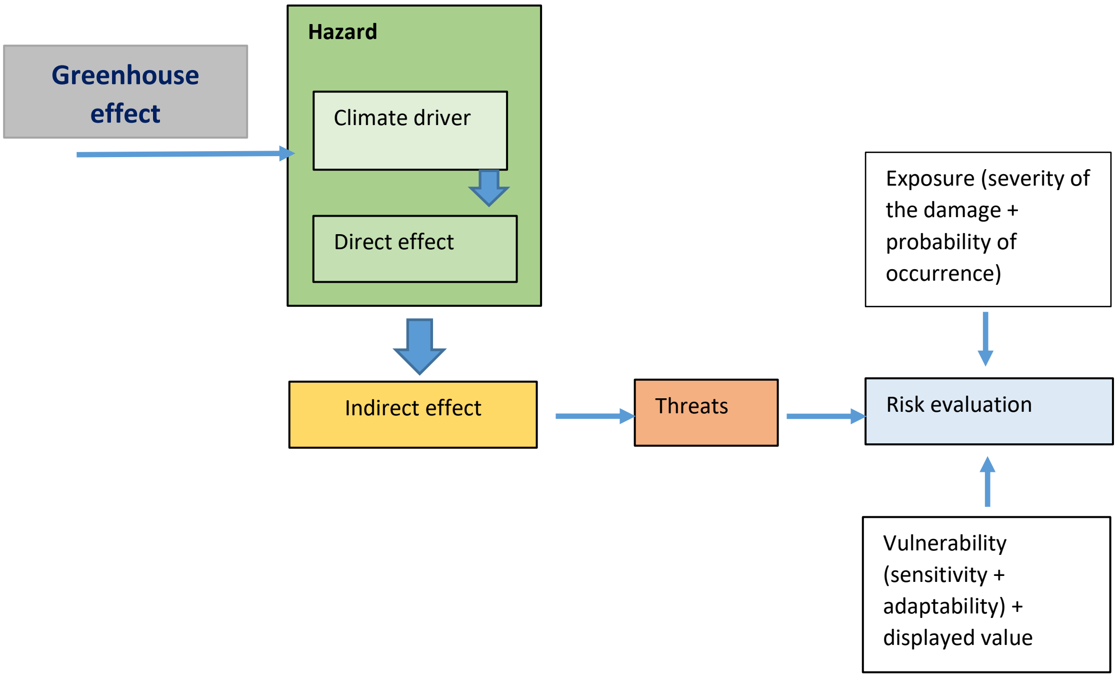
Greenhouse effects ->

Hazard = primary source of danger that includes climate signals and their potential direct effects) ->

Indirect effects = potential hypothetical effects ->

Threats = potential negative consequences for human or ecological systems.

The risk analysis is not addressed in this project.



Adaptation actions cannot mitigate climate signals and direct effects. Instead, they can control intermediate effects and threats by acting on limiting impacts and various risk factors (exposure, sensitivity, etc.)[12].

Regarding Greenhouse effect, general actions aimed at reducing CO2 are already present in national and regional policies (energy saving, management of green areas, use of alternative energies, etc.).

The assessment of the intervention priorities requires a risk analysis and a cost analysis that are not planned in this project.

[12] Masteradapt project

The *Special Report on the Ocean and Cryosphere in a Changing Climate - IPCC 2019 - Chapter 4 Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities,* says:

"Rising mean and increasingly extreme sea level threaten coastal zones through a range of coastal hazards including (i) the permanent submergence of land by higher mean sea levels or mean high tides; (ii) more frequent or intense coastal flooding; (iii) enhanced coastal erosion; (iv) loss and change of coastal ecosystems; (v) salinization of soils, ground and surface water; and (vi) impeded drainage. At the century scale and without adaptation, the vast majority of low-lying islands, coasts and communities face substantial risk from these coastal hazards, whether they are urban or rural, continental or island, at any latitude, and irrespective of their level."

"Coastal ecosystems are already impacted by the combination of SLR, other climate-related ocean changes, and adverse effects from human activities on ocean and land (high confidence). Attributing such impacts to SLR, however, remains challenging due to the influence of other climate-related and non-climatic drivers such as infrastructure development and human-induced habitat degradation (high confidence). Coastal ecosystems, including saltmarshes, mangroves, vegetated dunes and sandy beaches, can build vertically and expand laterally in response to SLR, though this capacity varies across sites. These ecosystems provide important services that include coastal protection and habitat for diverse biota. However, as a consequence of human actions that fragment wetland habitats and restrict landward migration, coastal ecosystems progressively lose their ability to adapt to climate-induced changes and provide ecosystem services, including acting as protective barriers."

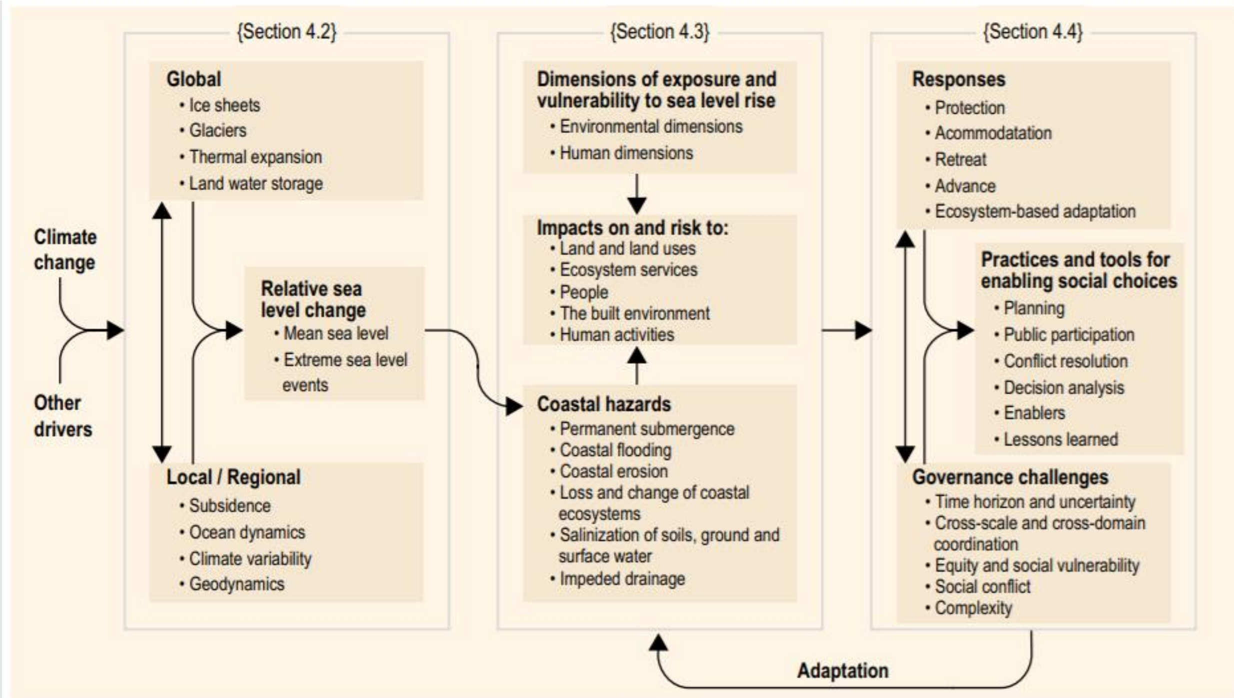


Figure 4.1 | Schematic illustration of the interconnection of Chapter 4 themes, including drivers of sea level rise (SLR) and (extreme) sea level hazards (Section 4.2), exposure, vulnerability, impacts and risk related to SLR (Section 4.3), and responses, associated governance challenges and practises and tools for enabling social choices and addressing governance challenges (Section 4.4).

The following diagrams reconstruct the climatic driver - direct effect - indirect effect - threats sequence for the Po Delta.

Climatic driver
Cannot be countered
Increase of average daily temperature
Increase of summer days (T > 29,5°C)
Decrease of winter days (T < 0 °C)
Increase of days of intense rainfall
Increase of consecutive drought days
Increase of winter rains
Decrease of summer rains
Wind direction and speed, humidity, insolation, cloudiness (unpredictable)

Direct effects
Cannot be countered
Sea level rise (IPCC)
Increase of sea temperature (IPCC)
Increase of sea acidity (IPCC)
Hydrological/hydraulic imbalance
change of sea currents
Increase in storm and storm surges
Evaporation
Mists, hail
Phenological mismatch in trophic interactions among Plants, Insects, and Vertebrates (interacting species change the timing of regularly repeated phases in their life cycles at different rates)
Asynchrony between life cycles (reproduction, migration, etc.) and favorable environmental conditions
Northward latitudinal shift of species
Extinction of rare species particularly sensitive to temperature, humidity, and salinity

Indirect effects

Can be countered

Climatic driver

Cannot be countered

Direct effects

Cannot be countered

Indirect effects

Can be countered

Water quality	Salt intrusion and water salinity increase
	Pollutants concentration increase (washout, poor dilution with low flow rates; lack of phytodepuration)
	Sediment transport decrease
Hydrological balance	Soil moisture imbalance
	Intermittence of freshwater flows
	Reduction of underground aquifer capacity
	Increased water residence time in lagoon
Hydrogeological imbalance	Submersion of the coast by the rising sea levels
	Floods caused by storm surges
	Floods caused by overflow of rivers
	Coastal erosion (beaches, sand banks, dunes) by wind, storms and storm surges
	Weakening and yielding of embankments due to seasonal variations of river flow
	Loss / displacement of submerged sandbanks due to variations in currents

	Destruction of coastal defense works
	Difficulty in rainwater disposing

Threats
Can be countered

The threats are grouped into sectors focused on the SNACC-PNACC line. Aquatic ecosystems are grouped because climate change impacts have similar effects on them. The most influencing factors are the morphology of the seabed, the morphology of the borders, water chemistry, horizontal and vertical exchange of matter-water-energy-heat between aquifers-rivers-lagoons-sea.

Threats
Can be countered

Aquatic ecosystems (transitional, fluvial, marine, marshes)	Alteration of the degree of connection between lagoons-sea-river-water table Alteration of organisms and materials exchanges between river-lagoons-sea
	Alteration of water column stratification; reduction in the connection between deep and coastal environments; alteration of the circulation of water masses
	Marinization or, conversely, stagnation of the lagoon due to protections from the sea
	Habitat changes: salinity, oxygenation, water turnover, temperature, bathymetry, grain size, pH Change in the distribution of lagoon organisms due to changing salinity and nutrient gradients Change in the structure and distribution of coastal planktonic and benthic communities
	Increase in mass deaths caused by heat waves
	Contraction of reed belts
	Regression/disappearance of intertidal habitats (mudflats, salt marshes)
	Increased nutrient loads (with nitrogen unbalance) due to flash-floods Increase of eutrophication phenomena Altered biogeochemical cycles and organic matter decomposition rates associated with altered microbial metabolism. Dystrophic crises caused by macroalgal biomass and temperature increase (anoxia, sulfide production) Increased acute effects of eutrophication (hypo-anoxic conditions) due to increased temperatures and planktonic blooms Increased acute effects of eutrophication during summer periods and Increased risk of anoxia
	Increased pollutants due to flash-floods Changes in the distribution and effects of contaminants and the impact of pollution

	Changing structure of primary producer communities: ● disappearance of seagrasses and associated algae ● replacement by phytoplankton and pleustophytes (floating) and later by picoplankton and cyanobacteria Increased presence of mucilage
	Development and increase of invasive/exotic/opportunistic and ubiquitous species, also favored by man for economic reasons
	Altered metabolism and growth rates of organisms; alteration of trophic networks Loss of nursery and lagoon breeding areas resulting in a decline in marine and riverine biodiversity Alteration of the dispersion of eggs and larvae
	Penetration of low-latitude species; extinction of T-sensitive species due to lack of northward expansion ranges
	Spread of parasites and pathogens; decrease of host species resistance Increase in epidemiological phenomena in wildlife
	Effects on migratory avifauna
	Erosion of sandbars, beaches, and coastal dunes due to erosion; Loss of habitat
	Loss / replacement of species (e.g. amphibians, birds)
	Seaside tourism

Aquaculture (extensive fish farming) and **Shellfish farming**	<u>Structural damage to fish/shellfish farms:</u> - morphological alterations of fishing valleys due to erosive phenomena and bathymetry increase in lagoons - difficulties in managing in-out water flows Infrastructure damage and loss of bred lots due to extreme weather events
	Change in production of fishery resources due to decreased benthic productivity and altered primary production
	Fishery profitability. Change in productivity (number of heads/head) of aquaculture and shellfish areas due to: - worsening of water quality (pollutants, oxygen, flash floods) - salinity and temperature variations - reduction of natural food resources - new relationships of competition or cooperation between "resident" and "non-native" species - possible reduction of natural taking of the seed and juveniles - alterations in metabolism and growth rates - phenological changes; alteration of the reproductive season of some species - widespread die-offs due to temperature rise, hypoxia, toxic microalgae, storms - adverse effect of decreasing pH of marine waters on larval stages of Bivalves and Gastropods (as well as early life stages of other organisms) - Biomass reduction of target species in fisheries and partial increase of new species Change in the structure of fish communities, with possible effects on the composition of the catch

	Loss of species of fishing interest that complete their life cycle in the lagoon
	Health risk from contamination: - spread of pathogens; contamination with pathogens risky for public health - presence of toxic fish in the catch - reduced resistance to pathogens Risk of disease outbreaks
	Modification of sites and optimal production periods; changing the distributional ranges of some target populations for fisheries

Drinking water resources	Reduction of the supply of drinking water
	Reduction of the quality of the water resource
	Increased supply costs
	Increased treatment costs

Agriculture	Agricultural yield variability
	Loss of productivity due to soil salinization
	Spread of new species of insects and weeds, with significant effects on agricultural production
	Adaptation of chemical and biological measures to control crop pests and diseases
	Increases in summer water requirements for intensive crops
	Reduction of irrigation water supply
	Reduction of irrigation water quality, salinization of both surface and underground resources
	Increased supply costs (irrigation, remediation, drainage)
	Soil degradation (aridification, loss of organic matter, erosion) caused by water stress, heat stress, heavy rainfall stress, run-off.
	Decrease in productivity of some species (maize, sunflower, alfalfa); Increase in productivity of some species (durum wheat, rice)
	Reduction in animal welfare with consequences on the quality and quantity of meat and milk

Terrestrial ecosystems	Loss of temperature and moisture sensitive habitats and species (fossil dunes, wet forests, amphibians, etc.)
	Changes in migration routes
	Establishment of allochthonous and opportunistic species
	Loss of terrestrial species due to phenological mismatch and disruption of the food chain
	Increaseing sclerophyllous evergreen vegetation
	Pine forest shrinkage
	Increasing fire risk

Tourism and cultural heritage	Damage to beaches and related services: restoration costs and decrease in tourist numbers
	Reduced periods of tourist influx due to water crisis, heat waves, storms
	Reduction in tourism for loss of environmental services

	Increased runoff from cultural heritage surfaces exposed outdoors during winter periods
	Maintenance costs of nature and cultural trails
	Changes in cultural heritage biodegradation processes
	Increased costs of maintenance and restoration of monuments, historic buildings, archaeological sites
	Increased costs for cultural landscape protection

Health	Increased risk of infectious diseases from insect vectors
	Increased risk of allergic and/or asthmatic crises due to a longer pollen season
	Risk of food contamination throughout the supply chain (from storage to distribution) due to high temperatures
	Hazards to outdoor workers (agriculture, construction, transportation) from exposure to elevated temperatures and storms
	Damage to the health of frail persons due to heat waves or wet or frozen pavements
	Health impacts caused by contamination and drinking water scarcity
	Physical risk from environmental disasters

Transport	Thermal expansions of structures (bridges/viaducts); Overheating and deformation of transport structures and infrastructures (asphalt, rails)
	Overheating of vehicle engines
	Interruption of goods supply, worker flow, fishing activities
	Flooding of rail and road transport infrastructure
	Increased risk of traffic accidents due to aquaplaning, hail, ice
	Risk of road accidents due to collapsing structures, reduced visibility, strong winds
	Damage to roads and rails structures, due to landslides, bridge failures, storms
	Increased tax costs
	Increase of insurance costs

Energy	Change in energy consumption due to: - increased summer air conditioning - increased water pumps use - decreased winter heating
	Blackout risk
	Difficulty in cooling power generation facilities due to rising temperatures and decreasing water resources.
	Increased resistance in transmission lines and consequent losses on the network

Dangerous industries and infrastructures	Risk of failure of infrastructure and major components of industrial activities (tanks, process equipment, piping, etc.) located in vulnerable settings

6.3.4 Fragility Elements - Vulnerability in the Po Delta

Impacts can be identified that will be amplified by the current fragility of the territory in the Delta. Some territorial characteristics must be kept in mind to identify possible mitigation actions. The critical points can be grouped on the basis of the most correlated impact, for example:

Disaster risk (destruction, submersion), with damage to people, properties, productive activities due to:

- sea level rise
- storm surges
- floods
- storms, whirlwinds
- Intensification of bora and sirocco winds

Critical issues that amplify the weather event:

- *Active subsidence, ground level lower than sea level*
- *Wide fluvial flow variations, complex, wide, dynamic catchment area*
- *Delta mouth in continuous geomorphologic and hydraulic evolution*
- *Territory bounded by three lines of embankments and drained with the use of pumping stations*
- *Shallow lagoon systems, mostly managed by fishing and shellfish farming in the valley*

Critical issues that amplify the damage to property and people:

- *Difficulty of alerting due to complexity of events and vastness of the territory*
- *Insufficiency of useful data for forecasting and monitoring floods and sea storms*
- *Difficulty of coordination between agencies*
- *Difficulty of rescue for isolation areas*

Loss of ecosystem services due to:

- sea level increase with coastline retreat and increase of lagoon bathymetry
- coastal erosion
- storms
- temperature increase

Critical issues that amplify loss of ecosystem services:

- *Modest sandbars to protect lagoons*
- *Vulnerable environments (dunes, salt marshes, wet forests, etc.).*
- *Rare protected species and migratory fauna linked to vulnerable environments*
- *Tourist beaches*
- *Unstructured urbanization*
- *Small ports with little protection*
- *Fragile structures serving ecotourism and fishing activities*
- *Imbalance in deposition processes - coastal erosion*
- *Vulnerability of the coastline, characterized by rigidity due to anthropogenic works, which counteract the natural displacement of the same*

Loss of productivity due to:

- bathymetry increase
- imbalance of flows and currents from land (fresh water) and sea (salt water)
- drought
- salt wedge
- loss of habitats suitability for shellfish and reed beds
- Increased water residence time

Critical issues that amplify the loss of productivity:

- *Economy based on fishing, fish farming and shellfish farming*
- *Developing eco-tourism*
- *Demographic fragility*
- *Diffusion of alien species*
- *Recurrent hypoxia phenomena*
- *Poor hydrodynamics*
- *Shallow waters, tendency to silting up*

6.3.5 The measures

The analysis of possible measures was carried out for the transitional ecosystems "coastal lagoons" only. These ecosystems assume significance for several reasons in the Delta (Figure 62):

- Coastal lagoons are, in the long term, the most vulnerable elements of the Delta and the least predictable; they have multiple interactions with their surroundings that result in their wide temporal and spatial variability.
- They are embanked on the land side and partially closed by dykes on the sea side; some lagoons are more stable because of the absence of mouths, while others are very unstable because of their recent formation (due to subsidence) or because of the influence of fluvial contributions.
- Lagoons are environments connected to the surrounding environments (terrestrial, fluvial and marine) by flows of matter and energy. Consequently, interventions on lagoon environments generate positive effects on other areas too.
- Lagoons include fragile emerged areas of considerable ecosystem value (e.g., sandbanks, salt marshes) in the inner and border zones.
- Even if some effects of climate change were already evident, most of all were ignored for decades and may become more severe. Some short-term measures are already in action or planned, but may be inadequate for future scenarios.

Interactions between lagoon waters and other ecosystem components are numerous:

- Interaction with the atmosphere: temperature, rain, wind; exchange of organisms (birds, insects, etc.).
- Interactions with the sea: tides; marine water quality (physical, chemical and biological parameters); exchange of organisms.
- Interactions with inland waters: freshwater flows; solid transport; transport of nutrients and pollutants; exchange of organisms; pumping of irrigation water.
- Interactions with terrestrial ecosystems: exchange of organisms; agricultural area run-off.
- Interactions with human activities: fishing; fish farming; tourism; navigation.

As illustrated by the study presented in WP 4.3, bathymetry, water temperature and salinity are the key determinants of the lagoon ecological aspects. Therefore, the key climatic impacts are sea level rise and changes in freshwater inputs.

Several possible scenarios were identified for coastal lagoons:

1. lagoons marinization and marine ingression into river branches if sea-side defenses will not be implemented and if land-side defenses will not be raised;
2. dystrophy if new defense barriers impede exchange with the sea;
3. maintaining current hydrodynamic conditions by managing in-out flows and implementing progressive morphological adjustment actions. The scenarios proposed by ISPRA (maintaining current morphologies) show that climate impacts to 2080 may be modest;
4. progressive retreat of the lagoons towards land driven by sea level rise. In this case, the sea defense lines should be remodeled inland to protect the area below sea level.

The geomorphologic and hydraulic interventions planned so far approached the third hypothesis, since they aimed to ensure the productive and touristic activity that was established in the last decades.

Moreover, the absence of morphodynamic models to support decision makers makes this option more suitable.

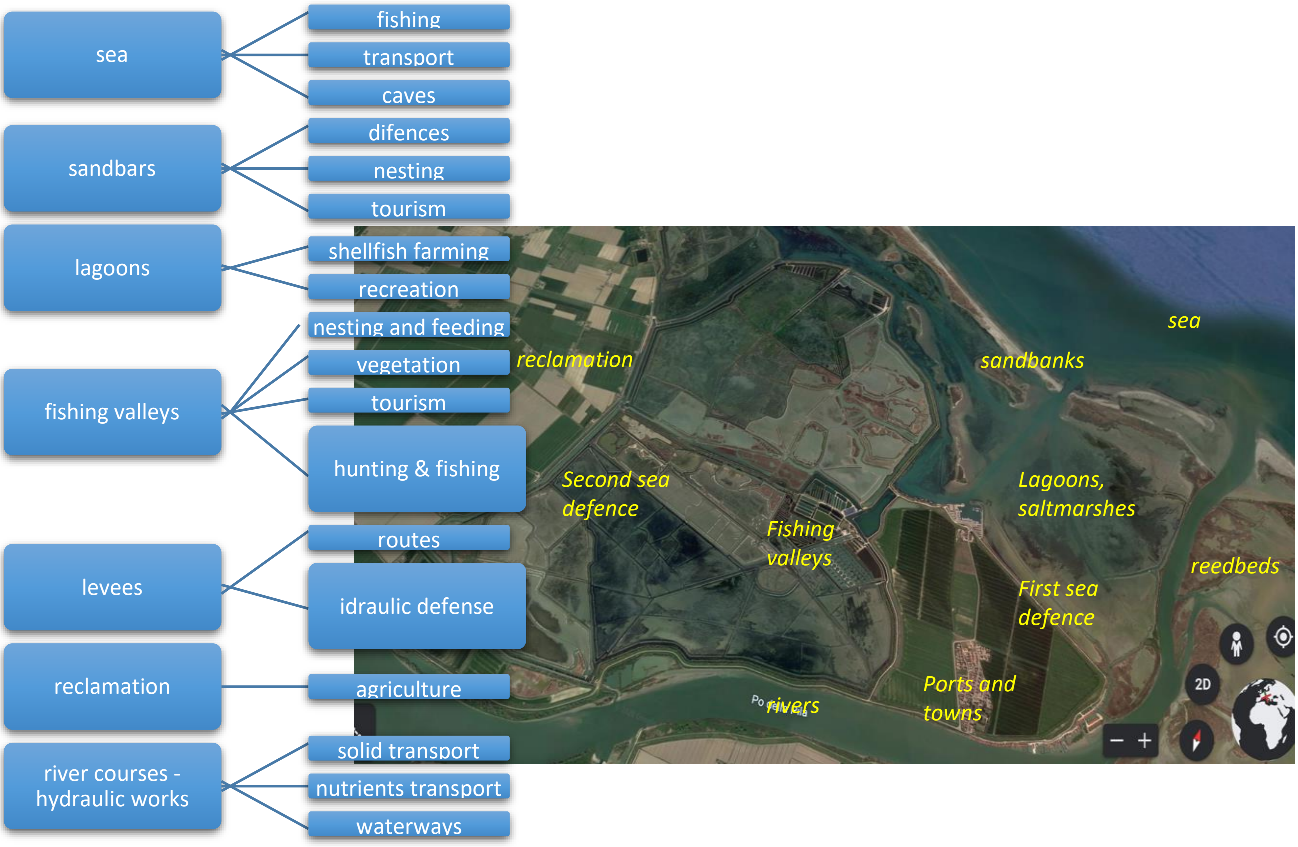


Figure 62. Delta elements and critical aspects.

Measures in transition ecosystems

Threats	Interventions
Alteration of the degree of connectivity between lagoons-sea-river-water table. Alteration of organisms and materials exchanges between river-lagoons-sea. Alteration of water column stratification; reduction in the connection between deep and coastal environments; alteration of the water masses circulation.	• Integrate drainage basin planning with coastal zone planning. • Ensure the rebalancing of the full saline gradient and an adequate supply of groundwater in damaged or threatened areas using modern techniques of naturalistic engineering and restoration ecology, to facilitate the restoration of connectivity with adjacent ecosystems. • Identify lagoon areas affected by high levels of habitat fragmentation and rebuild them, create buffer areas and ecological corridors, through ecological restoration works, increasing the chances of expansion for the evolution of the area.
Lagoon stagnation due to forced protection from high water or, conversely, marinization.	• Development of morphodynamic models of the Delta coastal strip. • Refine models for predicting the effects of mean sea level rise on lagoons and the Delta estuary and simulation models for resilience and adaptation scenarios. • Relocation of settlements and activities that are in subsiding and/or depressed areas. • Migration of wetlands inland (possible effect). • Violation of coastal defenses, allowing the creation of intertidal habitats (possible effect).
Habitat changes: salinity, oxygenation, water turnover, temperature, bathymetry, grain size, pH. Change in the distribution of lagoon organisms due to changing salinity and nutrient gradients. Change in the structure and distribution of coastal planktonic and benthic communities.	• Evaluate the feasibility of a guided process of forming new transition zones, with a balanced gradient of wetlands of varying salinity, where sustainable defenses to sea level rise cannot be implemented. • Apply knowledge of hydrodynamic management of fish valleys to transitional environments • Removal of defense works and non-strategic infrastructure and a more careful evaluation of the design of new infrastructure (e.g., river basining). • Monitoring of coastal alluvial aquifers where there is saline wedge upwelling.
Increase in mass deaths caused by heat waves.	• Ensure cold water circulation in shallow water areas. • Functional recovery of the secondary hydrographic network. • Develop a hedging strategy that can provide some form of insurance against economically damaging alterations in the provision of ecosystem services.
Contraction of reed belts.	• Restoration of the reedbed in lagoons with replanting techniques (or transplantation of organisms) and protection systems, ensuring suitable water and salinity levels. • Encourage the expansion of reedbeds (Phragmites australis) at the mouths of the Po River and at other wetlands in the Delta.
Regression/disappearance of intertidal habitats (mudflats, salt marshes).	• Progressive artificial reinforcement and reconstruction of mudflats and salt marshes using excavated soil from silted-up canals and green technologies. • Restoration and reconstruction of numerous sites in order to re-establish systems with suitable dimensions for the conservation of threatened and/or endangered species.

	● Develop assistance plans for the reproduction and adaptation of biological components that are more vulnerable to the effects of warming.
Increased nutrient loads (with an imbalance in favor of nitrogen) due to flash-floods. Increase in eutrophication phenomena. Altered biogeochemical cycles and organic matter decomposition rates associated with altered microbial metabolism. Dystrophic crises caused by macroalgal biomass and temperature increase (anoxia, sulfide production). Increased acute effects of eutrophication (hypo-anoxic conditions) due to increased temperatures and planktonic blooms. Increased acute effects of eutrophication during summer periods and increased risk of anoxia.	● Increase buffer strips along waterways in the basin. ● Functional recovery of the secondary hydrographic network. ● Reducing and controlling the input of nutrients from the various sources (agriculture, industry, urban centers, etc.). ● On-site improvement of water quality by enhancing and building natural filter-ecosystems.
Increased pollution due to flash-floods. Changes in the distribution and effects of contaminants and the impact of pollution.	● Water quality (e.g. saline intrusion, pollution): artificial hydraulic recharging, systems of infiltration wells, hydraulic barriers, anti-salt barriers in the terminal sections of the watercourse, management of river flows. ● Increase buffer strips along waterways in the basin. ● Reducing and controlling the input of contaminants from the various sources of generation (agriculture, industry, urban centers, etc.). ● On-site improvement of water quality by enhancing and building natural filter-ecosystems. ● Increased space for flood expansion. ● Activate practices for the removal of sources of pollution and alteration of coastal lagoon and marine environments, including plastic debris, in order to bring them to Good Environmental Status in accordance with the Marine Strategy Framework Directive. ● Develop systems to reduce pollution from plastics resulting from farming and fishing activities (e.g alternative materials, energy recovery from plastics). ● Increase discharge monitoring. ● Local interventions to manage the flows in some lagoons to decrease pollutant concentration. ● Redevelopment of river beds with careful design of outflow capacity and management of damming works.
Changing structure of primary producer communities: ● disappearance of seagrasses and associated algae; ● replacement by phytoplankton and pleustophytes (floating) and later by picoplankton and cyanobacteria; ● Increased presence of mucilage.	● Implementation of plans to assist reproduction and adaptation of the biological components most vulnerable to warming effects. ● Apply knowledge on hydrodynamic management of fish valleys to transitional environments. ● Restoration of aquatic vegetation in shallow waters: undertake the recolonization of the seabed of priority habitat 1150* with marine phanerogams (*Cymodocea nodosa*, *Zostera marina Linnaeus*, *Zostera noltei Hornemann*) or aquatic plants (*Ruppia cirrhosa*, *Petagna Grande*, *Potamogeton pectinatus*, etc.) to reduce erosion, nutrient and pollutant inputs, and restore ecological conditions in

	accordance with the objectives of the Water Framework Directive (2000/60/EC) (ecosystem restoration).
Development and increase of invasive/exotic/opportunistic and ubiquitous species, also favored by man for economic reasons.	● Removing invasive species and restoring native ones. ● Choice and selection of species/strains tolerant to climate change induced conditions.
Altered metabolism and growth rates of organisms; alteration of trophic networks. Loss of nursery and lagoon breeding areas resulting in a decline in marine and riverine biodiversity. Alteration of the dispersion of eggs and larvae.	● Deepen the understanding of climate change consequences on all biological components of the lagoon environment through observations, sampling, and measurements, and with the contribution of the local population.
Penetration of low-latitude species; extinction of T-sensitive species due to lack of northward expansion ranges.	● Preserve endangered species or encourage more suitable ones for the new conditions. ● Restoration and reconstruction of numerous sites in order to re-establish systems with suitable dimensions for the conservation of threatened and/or endangered species.
Spread of parasites and pathogens; decrease of host species resistance. Increase in epidemiological phenomena in wildlife.	● Catch or isolation of sick individuals/groups. ● Identify and disseminate organisms belonging to resistant genetic varieties.
Effects on migratory avifauna.	● Restoration of marginal areas and reconstruction of wetland microhabitats and vegetation belts. ● Protection of key habitats and species of recognized naturalistic value. ● Encourage new species that will stop or establish in the Delta in the future, which are better adapted to future climatic and environmental conditions.
Erosion of sandbars, beaches, and coastal dunes due to erosion; loss of habitat.	● Beach and dune nourishment; continuous protection and nourishment interventions. ● Strengthen or maintain existing lines of defense. ● Increase land reclamation, drainage with pumping. ● Promote coastal erosion mitigation actions by promoting and increasing vegetation conservation: - replanting systems and protective structures for dune restoration; planting of pioneer and shrub vegetation; - conservation and reconstruction of wetlands; - renaturation of rivers; - promote the expansion of reed vegetation (Phragmites australis) near the mouths of waterways. ● Proper planning of beach cleaning. ● Promote land use interventions in front of coastal marine ecosystems, in order to improve and make more sustainable the management of natural sedimentary inputs (e.g. through river basin management) and/or artificial (through modulation of coastal restoration or engineering).
Loss / replacement of species (e.g. amphibians, birds).	● Removing invasive and restoring native species. ● Partially mitigated by protecting current habitats (however the presence of new species can be an added value). ● Restoration of marginal areas and reconstruction of wetland microhabitats and vegetation belts. ● Protection of key habitats and species of recognized naturalistic value.
Seaside tourism.	● Appropriate management of tourist flows and routes, environmental education.

	• Interventions to maintain and restore the sites degraded by anthropogenic activities, preventing their use as illegal dumps, removing invasive plant and allochthonous species.

Measures in transition ecosystems – fishing, fish/shellfish farms

Threats	Interventions
Structural damage to fish/shellfish farms: - morphological alterations of fishing valleys due to erosive phenomena and bathymetry increase in lagoons; - difficulties in managing in-out water flows; - Infrastructure damage and loss of bred lots due to extreme weather events.	• Apply the extreme events vulnerability and risk analysis to the aquaculture sector (species, technologies, and production sectors) to develop multi-hazard maps in lagoons. • Assign CC-sensitive species "precautionary points" in management: incorporate additional precautionary factors in setting target values for fishing mortality (F) and biomass at sea (B); using the same criterion, adopt more permissive target values for F and B for species positively impacted by CC. • Study of the applicability of private insurance instruments for the management of environmental risks in fishing. • Feasibility study of an incentive system for fishing companies to promote the subscription of insurance policies for the damages caused by exceptional climatic events. • Strengthening of the services of vigilance, monitoring, and alert, performed by the Regional Agencies for the Protection of the Environment, the Civil Protection, and the Territorial Presidiums. • Relocation of settlements and activities (fisheries-related services) that are in subsiding and/or depressed areas. • Measures for the integrated management of the coastal strip (ICZM protocol) in relation to climate change to allow the development of aquaculture activities over time. • Strengthen and update existing early warning systems against climate change risks.
Change in production of fishery resources due to decreased benthic productivity and altered primary production.	• Reduction of fishing effort. • Use of selective fishing gear. • Improvement of cultivation techniques. • Selection of the most suitable varieties, implementation of appropriate tools. • Implementation of plans to assist reproduction and adaptation of the biological components most vulnerable to warming effects. • Apply the knowledge on hydrodynamic management of fish valleys to transitional environments. • Restoration of aquatic vegetation in shallow waters: undertake the recolonization of the seabed. • Develop a hedging strategy that can provide some form of insurance against economically damaging alterations in the provision of ecosystem services.
Fishery profitability. Change in productivity (number of heads/head) of aquaculture and shellfish areas due to: - worsening of water quality (pollutants, oxygen, flash floods); - salinity and temperature variations;	• On-site improvement of water quality by enhancing and building natural filter-ecosystems. • Adoption of systems of "quotas" of the annual catch attributed on an individual, group or individual boat basis, with the possibility of exchange on a special market.

- reduction of natural food resources; - new relationships of competition or cooperation between "resident" and "non-native" species; - possible reduction of natural taking of the seed and juveniles; - alterations in metabolism and growth rates; - phenological changes; alteration of the reproductive season of some species; - widespread die-offs due to temperature rise, hypoxia, toxic microalgae, storms; - Adverse effect of decreasing pH of marine waters on larval stages of Bivalves and Gastropods (as well as early life stages of other organisms); - Reduction of target species biomass in fisheries and partial increase of new species; - Change the structure of fish communities, with possible effects on the composition of the catch.	● Greater attention to the marketing and processing phase in order to obtain the maximum revenue from the catches obtained. ● Adjustment of the European rules on fishing to the peculiar characteristics of the Adriatic Sea and lagoon territory. ● Encourage the expansion of uncommon local species (es. Chamelea gallina) through the planning of fishing activities ("Carta Ittica"). ● Prevention of IUU fishing (Illegal, Unauthorized, Unmonitored) - development of information and monitoring systems. ● Valorization of the fished – certifications; development of production plans, product diversification and certification to increase added value. ● Introduction of new species to the market: communicate to the public the suitability for consumption and the qualities of any new fish species. ● Help reshape and reduce fishing activity, with possible declines in stock mortality; withdrawal of inadequate and obsolete vessels. ● Promote resilience of fishing enterprises through integration of marine fisheries and local tourism, environmental monitoring, removal of certain types of waste, and support for environmental outreach. ● Control and/or reduction of fishing waste. ● Reducing the environmental impact of catch - incentives to transition to more sustainable fishing systems: use of less impactful gear with a discrete/good target species spectrum and selectivity focused on discrete/good-sized fish. ● For the “Sacca del Canarin”, the goal is to reverse the dynamics of environmental degradation caused by poor hydrodynamics, anoxia, and alteration of the salt balance. Its vivification will improve fish production and may lead to local tourism development.
Loss of the interest on fishing species that complete their life cycle in the lagoon.	● Appropriate selection of sites and farming systems. ● Choice and selection of species/strains tolerant to climate change-induced conditions.
Health risk from contamination: - spread of pathogens; contamination with pathogens risky for public health; - Presence of toxic fish in the catch; - Reduced resistance to pathogens; - Risk of disease outbreaks.	● Programming the control of pollution and food contamination in the fishery production chain. ● Choice and selection of species/strains tolerant to climate change-induced conditions. ● Encourage production systems/practices with less impact on the environment (new technologies, energy efficiency, environmental certifications of companies).
Modification of sites and optimal production periods. Changing the distributional ranges of some target populations for fisheries.	● Prohibition of some forms of fishing in large tracts of sea (e.g. through Marine Protected Areas, No Take Area, Biological Protection Zones, etc.) extending in time and space an approach that so far in the Mediterranean has affected only areas of modest size. ● Choice and selection of species/strains tolerant to climate change-induced conditions. ● Space planning for aquaculture in relation to expected climate scenarios: integrating knowledge of evolving impacts for improved site selection for aquaculture; ongoing selection of suitable sites for shellfish production using models that account for evolving environmental changes.

GENERAL ACTIONS

It is essential to have an in-depth knowledge base that allows us to predict future territorial conditions in advance in order to develop a capacity for cultural / productive / technological adaptation. In any case, it will be necessary to continue to collect data on climatic and environmental components, also by implementing monitoring networks (WP4.4.1). To define further adaptation measures, it will be necessary to strengthen scientific research on the effects of climate change in marine and transitional environments, particularly in the Delta. Sharing experiences and programmatic choices with the local population is essential.
General actions identified are grouped in four sectors: education-participation, research, planning activity, monitoring activity.

LEARNING - PARTICIPATION

- Create a solid "capacity building" in the broader field of environmental management for decision makers and stakeholders; Raise the awareness of scientific knowledge is fundamental for decision support. Long-term ecological research programs are essential to address climate change; transferring skills to policy makers and stakeholders for the adaptive management of the environment and particularly of transitional ecosystems.
- Develop plans to disseminate and consolidate public awareness of the need to adapt lifestyles to the impacts of climate change on transitional ecosystems, particularly for workers in the fisheries, aquaculture, and tourism sectors.
- Dissemination and consolidation of public awareness regarding the need to adapt lifestyles as a result of climate change, particularly in the fisheries, aquaculture and coastal tourism sectors.
- Collect environmental and production data to create an information network on the impacts of climate change on aquaculture that will be available to those working in the sector.

RESEARCH

- Increase funding in ecological research to better understand the biophysical mechanisms underlying the provision of ecosystem services, aimed at greater prognostication and monitoring capabilities.
- Strengthen and orient scientific research on the response to projected climate change at the various hierarchical levels of marine ecosystem organization in order to predict possible ripple effects.
- Identify and predict the effects of mean sea level rise on transitional environments such as lagoons and estuaries as well as coastal environments and the goods and services they produce and/or provide.
- Extend knowledge about the effects of marine acidification on more exposed species such as calcifying species (such as ecosystem engineers), on the physiology and biological performance (e.g., reproduction) of non-calcifying species, on key ecosystem functions such as secondary production and biogeochemical cycling, and on community, habitat, and ecosystem structure.
- Identify possible consequences of changes in Adriatic circulation, stocks, and biodiversity of marine biotic resources, including those subject to exploitation.
- Increase the knowledge about the spread of allochthonous species, the consequences of possible invasions on biodiversity, the structure of trophic networks, and the functioning of coastal ecosystems.
- Identify and quantify the synergistic consequences of climate change and anthropogenic "multiple stressors" on biodiversity loss and subsequent alteration or impairment of key systemic functions.
- Identify spatiotemporal spread trajectories of autochthonous and allochthonous parasites and pathogens in relation to water warming synergistically with processes of unintentional spread of the same such as those mediated by sea farming or shipping.
- Research activities (e.g., physiological, zoogeographical, ecological studies) for a more precise identification of marine fisheries species that are most sensitive to CC impacts in order to define models that take into account the influence of climate on the population parameters of the various stocks considered, thus improving the scientific advice provided on fisheries.

- Study of the effects of climate change on farmed species (biology, ecology, genetics and health) through experimental tests, development of predictive models and specific indicators.
- Deepen the understanding of climate change consequences on primary production and trophic networks, which potentially affect fishing exploitation yields.
- Develop scientific research on ecological dynamics in the North Adriatic to identify the real reasons for the reduction of the catch and the contraction of some fish species compared to the expansion of others (proposal by stakeholder).

PLANNING

- Integrate sector plans and programs in order to achieve: sustainable use of water resources, reduction of natural and agricultural soil consumption, environmental restoration and enhancement of marginal areas in the agricultural system, conservation and restoration of the ecological integrity of riparian areas that function as buffers between aquatic and terrestrial ecosystems.
- Progressive integration of climate change adaptation actions into environmental policies.
- Adoption of management plans for natural areas (e.g. Natura 2000 network areas, parks, etc.) that are flexible and modulated on the basis of expected climatic variations.
- Integrate vulnerability assessment activities and adaptation measures into consolidated planning procedures (urban planning, water resources, coastal system protection, civil protection) at the municipal level.
- Development of Integrated Coastal Zone Management (ICZM) and Ecosystem Based Management (EBM) capable of dynamically responding to ongoing changes through the identification of ecologically coherent management units (ecosystem functioning units), promoting ecosystem-based (e.g., promoting coastal vegetation conservation) or infrastructure-based (e.g., through modulation of coastal restoration or engineering) coastal erosion mitigation actions.

MONITORING

- Consolidate long-term monitoring for understanding natural cycles and alterations induced by anthropogenic activities and climate change.
- Integration of extensive aquaculture in environmental monitoring and early warning plans in transitional and marine-coastal water production areas: chemical, physical and biological parameters, indicators of health risks, extreme events, alien species.
- Expand the monitoring of nutrient and suspended solid inputs to plan upstream or downstream actions of the water courses flowing into transitional systems.
- Expand the monitoring of indicators of trophic changes in lagoon waters: reactive phosphorus and nitrites in the water column, dominant macrophytes (type and biomass).
- Identify indicators and/or batteries of ecological indicators to anticipate, assess, or identify ongoing changes.
- Create "open access" and near-real-time consultation tools to assess the state of marine and transitional ecosystems using advanced GIS tools even in the underwater environment.
- Monitor the presence and distribution of alien species and those generating massive proliferations, such as toxic algae and jellyfish, whether native or non-native.
- Identify the possible spatio-temporal trajectories of diffusion of autochthonous and allochthonous parasites and pathogens and the possible consequences on the functioning of marine ecosystems in relation to water warming; consider synergistically the processes of involuntary diffusion of the same as those mediated by sea farming or maritime transport.

6.4 Monitoring plan

The monitoring of actions/measures can be done at two levels:

- ✓ In progress, monitoring the advancement of the measure;
- ✓ In the time following the implementation of the measure, monitoring its effectiveness with respect to the set objective.

The progress indicators may be quantitative (e.g., number of projects launched, number of parameters analyzed, etc.) or temporal (work progress stages to which authorization procedures and funding stages are associated: preliminary project - final project - construction site - start-up – testing).

The effectiveness indicators should inform about the degree to which the measure objective has been achieved.

Inspired by the 2018 version of the PNACC database, possible indicators to monitor some of the measures for transitional environments and fisheries/shellfish are proposed as examples in the following Figure. Actions were grouped by type (pink=monitoring, white=engineering interventions, green=study and research, blue=planning and management, yellow=data organization, gray=training) and by indicator similarity.

ACTION/MEASURE	PROGRESS INDICATORS	EFFECTIVENESS INDICATORS
- **Monitoring actions of trophic indicators** - **Identification of ecological indicators to assess changes in progress**	- Number of monitoring systems implemented - Number and types of parameters monitored in relation to climate change - Number of reports/publications	- Concentration of reactive phosphorus and nitrous nitrogen (nitrite) in the water column - Dominant macrophytes
- **Monitoring of the presence and distribution of alien species and species that give rise to massive proliferations, such as toxic algae and jellyfish, whether native or non-native**	- Number of monitoring systems implemented - Number and types of organisms monitored - Number of reports/publications	- Number of climate and environmental databases updated annually (observations) - Increased geographic extent of observation networks - Number of field-based land managers using climate data and models in their decision-making process
- **Integration of aquaculture into environmental monitoring and early warning plans in production areas of transitional and coastal environments**	- Number of monitoring systems implemented - Number and types of environmental parameters monitored in production areas	- Number of climate and environmental databases updated with aquaculture-related data - Improvement of the management of emergencies and criticalities
- **Standardization of basin observatory data collection methodologies**	- Establishment and updating of ecosystem inventories (mapping and status) for each major ecosystem/habitat type, and their biodiversity	- Improving the uniformity of climate and environmental databases - Improving the uniformity of available data
- **Restoration of shallow-water aquatic plant vegetation and reed vegetation barriers (Phragmites australis (Cav.) Trin. ex Steud) at the mouth of freshwater streams**	- Number of interventions - Area (ha or km2) of intervention	- Improving the ecological status of waters - Satisfactory conservation status (SCS) of coastal habitats and species; [13] - Effective consistency of aquatic plant meadows and reeds in the years following replanting - Interruption of erosive phenomena

[13] The satisfactory state of conservation (SCS) is defined in general terms in art. 1.e) (for habitats) and art.1.i) (for species) of Directive 92/43 / EEC (“Habitat”). In the context of monitoring, the adjective "favorable" is used as its synonym

- **Creation of buffer areas and ecological corridors to increase connectivity of coastal ecosystems**	- Number and progress of projects for the implementation of buffer areas and ecological corridors - Number of interventions in the field of ecosystem protection Extension of inaccessible coastal areas	- Use of ecological corridors by wildlife - Colonization of inaccessible areas by vulnerable species
- **Promote research on the impacts and responses of marine coastal ecosystems to climate change** - **Promote research on the effects of climate change on aquaculture species and production systems** - **Study the impacts of climate change on fish stocks and other renewable resources, in connection with harvesting techniques (synergy between overfishing, alien species, global change)** - **Promote research on the effects of marine acidification** - **Promote research on the impacts of climate change on marine currents** - **Promote research on the effects of sea level rise** - **Expand knowledge of the effects of climate change on the life cycles of marine species**	- Expenditure on research projects on climate change impacts and adaptation (Euro) (also considering different types of funds) - Number of studies and projects funded (national and international) - Number and type of partners involved in project consortia - Estimated economic (Euro) and environmental costs and benefits of various adaptation and inaction solutions	- Improvement of the knowledge (available data, information and knowledge) - Number of publications (peer and non-peer reviewed); - Impact of research activities - number of citations (in the first 3 years) - Increase in the number of administrations using scientific evidence to support decision and policy making - Improved catalog of cognitive instruments (decision support tools (DST), other tools, technologies, methodologies, etc.) to support adaptation
- **Development of methods/tools for risk and vulnerability analysis of production systems and technologies** - **Knowledge about the alterations of pollution and/or contamination phenomena and their ecological effects due to the amplification of climatic effects** - **Improved the knowledge about the marine species of fish most sensitive to climate change**	- Production of geographic information systems, smart-phone applications, and web applications for information gathering - Expenditure on research projects on climate change impacts and adaptation (Euro) (also considering different types of funds) - Number of studies and projects funded (national and international) - Number and type of partners involved in project consortia - Number of climate change vulnerability and risk assessment studies (by sector and region); - Risk and vulnerability maps developed for specific sectors and geographic areas	- Improved knowledge base (available data, information and knowledge) - Number of publications (peer and non-peer reviewed) - Impact of research activities - number of citations (in the first 3 years) - Increase in the number of administrations using scientific evidence to support decision-making and policy making - Increase in the number of companies / economic activities that assess risks and opportunities arising from climate change

- **Interventions to reduce the impacts on aquaculture and efficient use of resources**	- Number of plants with low environmental impact techniques; Number of plants with environmental and ecological certifications - Investment expenses for innovative production technologies with low environmental impact	- Improve the ecological status of production sites
- **Valorization of the fished - certifications**	- Number of beneficiaries (companies) receiving support; - National / international funding for adaptation to climate change - Number of environmental and social compatibility certificates (per year)	- Absolute (Euro) and relative (%) increase in the economic profitability of individual production activities
- **Development of production plans, product diversification and certification to increase added value**	- Number of studies and projects on the evaluation of environmental services provided by extensive aquaculture and shellfish farming activities in contrast with the effects of climate changes	- Increase of knowledge and tools for the management and conservation of natural environments and Natura 2000 sites through the maintenance of traditional farming activities
- **Improvement of resource management**	- Number of distinct stocks for which there are sectoral programs and plans that consider climate change adaptation (levels: inclusion, consistency, weighting, reporting)	- Decrease in habitat loss (ha and habitat types) - Trend in growth parameters of populations targeted by fisheries
- **Enhancement of the fish catch and improvement of business profitability - introduction of new species to the market**	- Expenditure (Euro) on outreach activities - Number of communication and dissemination actions/events per year - Number and types of stakeholders involved-participants (by type of activity or event) - Number of education programs established in schools - Territorial coverage of outreach events/education activities - Number of tools used for climate change dissemination - Number of public administrators who have received adaptation training	- Number of people involved in awareness campaigns - Increase in the number of trained people (certification of skills acquired) - Expansion of the network of actors and organizations involved in adaptation

- **Space planning for aquaculture in relation to the expected climate scenarios**	- Status of study tools for identifying areas for aquaculture development with low environmental and climate risk - Status of progress on regional planning for areas of aquaculture development	- Status of implementation of regional planning for areas designated for aquaculture development with low environmental and climate risk
- **Three-year experiment with a new minimum commercial size in the common clam fishery**	- Status of implementation of procedures	- Enterprise survival 5 years after implementation - Reduction in fishing mortality
- **Integration between fishing and local tourism or with other activities at lagoon/sea on an local scale**	- Number of beneficiaries (companies) receiving economic support - National/international funding for climate change adaptation received by companies - Number of financial mechanisms identified to support initiatives that consider climate change - Total expenditure in the form of economic incentives to support adaptation actions (Euro) - Number of fishery/livestock enterprise activity diversification projects	- Enterprise survival 5 years after implementation - Reduction in fishing mortality
- **Management and remodulation of fishing effort - adoption of catch ceilings for vessels**	- Number of studies and projects funded (national and international) - Number of fishing opportunity allocation plans adopted	- Enterprise survival 5 years after implementation - Reduction in fishing mortality
- **Withdrawal of boats (also obsolete)**	- Status of implementation of procedures - Number of vessels decommissioned	- Enterprise survival 5 years after implementation - Reduction in fishing mortality
- **Prevention of IUU fishing (Illegal, Unauthorized, Unmonitored)** - **IT and monitoring systems** - **Legislative and structural interventions**	- Production of geographic information systems, smart-phone applications and web applications for the gathering of information - Status of implementation of procedures under fisheries monitoring plans - Number of controls under the monitoring plans of fisheries	- Improved decision making by land managers (e.g., changes in vegetation type considering the ecological value of the species present) - Reduction in fishing mortality - Reduction in the number of IUU fishing events detected over time - Traceability of the supply of fish products - Disappearance of the sale of fish products during unauthorized periods

- **Monitoring and/or reduction of fishing waste**	- State of implementation of procedures - Reduction of undersized landings of the various species	- Reduction of fishing mortality
- **Reducing the environmental impact of catch - incentives for conversion to more sustainable fishing systems**	- Number of stocks for which there are sector programs and plans that consider climate change adaptation (levels: inclusion, consistency, weighting, reporting); - Reduction in the number of vessels	- Decrease in habitat loss due to climate change (ha and habitat types) - Reduction in fishing mortality
- **Application of private insurance instruments for the management of environmental risks in fisheries**	- Number of funded studies and projects on the applicability of private insurance (national and international) to the fisheries sector - Number of climate change vulnerability and risk assessment studies for the fisheries sector - Economic evaluation of damages not covered by insurance instruments.	- Number of businesses with risk management plans that consider aspects of climate change they may be affected by or adaptation options - Number of businesses with insurance for extreme events (per year) - Annual expenditure on claims (Euro)
- **Planning of assistance interventions for vulnerable species**	- Number and status of Protected Area Management and Integrated Coastal Zone Management Plans - Number of sector programs and plans that consider climate change adaptation (levels: inclusion, consistency, weighting, reporting)	- Status of implementation of Protected Area Management Plans and Integrated Coastal Zone Management Plans
- **Development of Integrated-Coastal Zone Management (ICZM) and Ecosystem Based Management (EBM) that dynamically respond to the ongoing changes through the identification of ecologically coherent management units**	- Number and status of Protected Area Management and Integrated Coastal Zone Management Plans - Number of sector programs and plans that consider climate change adaptation (levels: inclusion, consistency, weighting, reporting)	- Increase in the extent (ha) of protected areas - Improvement of the ecological status of water - Improved ecological coherence of coastal habitat networks
- **Organizing environmental data into a local-scale, open-source database to monitor the impacts of climate change on aquaculture**	- Number of databases, 'climate portals' and platforms that include aquaculture - Number of visitors to databases and websites	- Increased impact/value of the portal/platform as a source of information - Increased public availability of information and data

- **Creation of monitoring networks and databases on environmental conditions** - **Creation of tools for consulting "open" data on the state of marine/transitional ecosystems**	- Number of climate portals and platforms on adaptation - Number of visitors to adaptation website (monthly statistics) - Investment in the development of portals	- Increased impact/value of the portal/platform as a source of information - Increased public availability of information and data
- **Training, communication, and dissemination of knowledge about climate impacts to the population**	- Expenditure (Euros) on dissemination activities - Number of communication and dissemination actions/events per year - Number and types of stakeholders involved-participants (by type of activity or event) - Number of education programs established in schools - Materials developed for climate change dissemination - Number of public administrators trained on adaptation - Number of people involved in awareness campaigns	- Results of questionnaires after training and dissemination events - Number of environmental projects proposed by the population and local government
- **Raising fishermen's awareness of CC impacts - enhancing communication about it**	- Expenditure (Euros) on dissemination activities - Number of communication and dissemination actions/events per year - Number and types of stakeholders involved-participants (by type of activity or event) - Number of education programs established in schools - Territorial coverage of outreach events/education activities nationwide - Number of tools and materials used for climate change dissemination - Number of public administrators trained on adaptation.	- Number of people involved in awareness campaigns - Increase in the number of people trained (certification of skills acquired) - Expansion of the network of actors and organizations involved in adaptation - Increase in the number of vessels operating with low-impact gear