# Report on coastal and transitional aquatic ecosystems evolution at the multidecadal scale

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# Summary

## Abstract/Executive Summary

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.

## Introduction

This document reports the predictions of the evolution of biodiversity, and of coastal and transitional habitat and ecological quality elements in the different pilot sites considered in CHANGE WE CARE (Activity 4.3)based on the characterization of the expected evolution of the system forcing and on the outcomes of Activities A3.4, A3.5, A4.1 and A4.2. The habitat evolution was addressed by coupling the prediction of key hydrological and physical quantities and fluxes with morphological modification. Since biodiversity and ecological quality elements can be related to habitat attributes, dedicated models were framed by combining biotic and abiotic habitat descriptors. The prediction maps on Adriatic coastal area and on Pilot Sites was drawn up and was considered as part of the Knowledge Framework for the formulation of monitoring and Adaptation/management Plans (WP5).

A integration of geospatial database associated with this activity was also build and it is stored as a GIS, organized to mirror the structure of this document. The GIS will be available for the Project partners and will be present in D4.3.2.

This document is organized in three main chapters – beside this brief introduction- each reporting the information considered for each Pilot Site. The pilot sites (*Figure 1*) are:

1. Neretva River
2. Nature Park Vransko Jezero
3. Po River Delta


Figure 1. Overview of the Pilot Sites of CHANGE WE CARE

For each Pilot Site the information considered are the following: biodiversity, habitat and ecological quality target, the tool and approach used for the projection, the climatic scenarios considered and the future evolution of specific species and habitats.

With regard to the Jadro river and Kastela bay site, activities are ongoing and will be developed and reported in the WP5 documents.

Regarding Banco Mula di Muggia, his presence and the shallow seabed adjacent to the mouth of the Isonzo has as consequence that the real dynamic part of the coats profile is translated seaward and the seabed and the beach behind are protected from wave action. For this reason, their appearance is abnormal if compared to other Adriatic beaches: seabed are shallow and sediments has a significant fine component. The Banco Mula di Muggia survives and evolves migrating, occupying spaces now dedicated to seaside tourism. But this morphology constitutes an important sandy reservoir that should be understood as a strategic reserve for the conservation of our coasts, in consideration of the diffused erosive crisis of the coasts and the increment of the frequency of the extreme events. The available data on the Banco were limited; therefore it was decided to acquire original data within the CHANGE WE CARE project.

It was agreed to carry out the following field activities originally scheduled for spring 2020, but whose planning is now affected by the COVID19 emergency and needs to be rescheduled:

a) Sampling of phanerogams and sediment for granulometric analyses (rescheduled: autumn 2021) Phanerogams and sediment sampling stations will be located along two coastal transects offshore in order to overlap some transects already sampled by the FVG Region and the University of Trieste (see Deliverable A3.2). The sampling and analysis of the benthic invertebrates assemblages and fish fauna in the area of the Banco Mula di Muggia (Grado) according to Art.32 paragraph 14 of the Legislative Decree N.50 dated 18 April 2016 is done in spring 2021. Sampling and analysis of the benthic invertebrates and fish fauna is be carried out in 7 stations located in this pilot site (see Figure 2 benthic invertebrates red points, fish fauna green points).
b) Acquisition of bathymetric data with single beam echosounder and Side Scan Sonar through autonomous surface vehicle (OpenSWAP) (rescheduled: autumn 2020 and summer 2021). The study of the substrate of the Banco Mula di Muggia is important to understand the cubature of the sand deposit and the correlations with the extended portion of the beach that changed in the last 150 years. For this reason the research has been oriented towards a detailed knowledge of coastal deposits planning the sampling of 6 core and 7 penetrometries from Grado Pineta to Villaggio Primero and 3 cores in the portion of the sea around the banco itself (Figure 3). The results will lead to a better knowledge of the substrate and its geotechnical properties to project for the recovery and enhancement of peculiar environments also for the purposes of tourist enhancement.
c) Acquisition of geo-referenced images taken by a drone (rescheduled: autumn 2021)
d) Acquisition of pictures and videos through ROV (Remotely Operated underwater Vehicles) on the external and deeper zone of the Banco (rescheduled: autumn 2021) ROV pictures and videos will be acquired along the same transects already sampled by the FVG Region and the University of Trieste.


Figure 2: red dots represent stations sampled for benthic invertebrates and green dots represent stations sampled for fish fauna


Figure 3: red and yellow dots represent cores; light blue dots represent penetrometries.

# 1. Pilot Site Neretva River

## 1.1 Biodiversity, habitat and ecological quality target

In the Neretva River Delta, there are protected areas of nature according to Croatian Law of Nature Protection:

• ornithological special reserves: Kuti, Prud, Pod Gredom, Orepak, Modro oko and Lake Desne;

• ichthyological - ornithological special reserve: Ušće Neretve;

• significant landscape: Predolac – Šibenica.

Neretva River Delta is designated as internationally important wetland under the Convention on Wetlands (Ramsar, 1971). It contains a largest complex of wetlands in Croatian littoral with well-developed water-fringe vegetation (the largest reedbeds in the country that cover more than 3,000 ha, sedge communities, rush), floating and submerge vegetation around Neretva and its tributaries.

Also, it is a Natura 2000 site HR100031 Delta Neretva (SPA), HR5000031 Delta Neretva (SCI).

Neretva Delta is the most valuable wetland on eastern Adriatic coast and one of only few wetlands remained in Mediterranean region of Europe. The mouth of the river Neretva is characterized by wide lagoons, sandflats and saltmarshes. Though a large area of the wetland habitat has been transformed into agricultural lands, due to the branching network of channels, these areas are still important habitats for aquatic birds and a very important ichthyological area. Reclaimed land is covered by agricultural landscape with many irrigation channels. The Neretva Delta has many lagoons, shallow sandy bays, low sandy shores, sand flats, salt beaches, etc. The delta, lagoons and brackish waters are an exceptionally important habitat which creates room for the intensive growth of fry, which later spend their life cycle in the sea or fresh water. Furthermore, these areas are important for the migration of anadromous and catadromous fish species. Neretva Delta is important for breeding, migration and wintering of almost 200 regularly occurring bird species.

With a large number of endemic species and great diversity, the mouth of the Neretva River is one of the most interesting areas of Croatia.

The delta is surrounded with karst hills rich with underground water that supplies numerous springs, streams and lakes. More than 80 registered caves and other underground habitats in these karst surroundings are home for rich fauna with many threatened and endemic taxa.

SPA Neretva Delta is the Ramsar site with at least 313 registered bird species. Altogether there are around 193 regularly occurring species out of which around 89 are breeding birds (RIS Neretva Delta, 2012). The area is important stop-over place during migrations of birds from Middle and NE Europe to Africa, situated on the route of Central European (Black Sea/Mediterranean) Flyway. About 1/3 of registered species are wintering birds, accompanied with residents during the winter.

Neretva Delta is a part of the wider transboundary wetland with Hutovo Blato Ramsar site in Bosnia and Herzegovina. The same birds use both sites during migration, wintering and even breeding. Some species breed in Hutovo Blato and feed in Neretva Delta, like *Phalacrocorax pygmeus* and *Plegadis fascinellus*.

Neretva Delta regularly supports > 1% SE Europe/Turkey population of *Phalacrocorax pygmaeus.*

During the breeding season *Plegadis fascinellus* that breeds in Hutovo Blato in B&H (Ilić, HOD, pers. comm.) regularly feeds in Croatian part of Neretva Delta, depending on the phase of the breeding.

More than 10,000 waterbirds regularly winter in Neretva Delta (Ilić, HOD, pers.comm.), including several thousands of ducks, up to 3,000 Coots (*Fulica atra*), up to 2,000 ind. of Larus ridibundus, up to 2,000 ind. of *Larus michahellis*, cca 400 ind. of Phalacrocorax carbo and others. The most common are *Anas platyrhynchos* and *Fulica atra* but their numbers differ significantly from year to year, depending on weather conditions. During very cold winters, large numbers of geese stay in the estuary, mostly *Anser albifrons* and *Anser anser*. If we add wintering waterbirds of Hutovo Blato that has bigger numbers because of large open-water habitats the whole Lower Neretva area (transboundary Ramsar site) probably reaches the criterion of ≥20,000 waterbirds.

As Neretva Delta is situated on the Central European (Black Sea/Mediterranean) Flyway, this area is also important for migration of *Grus grus*. During February and March, flocks of cranes are flying over the delta and up to several hundred of birds per day have been registered (Ilić, HOD, pers.comm.). Although monitoring started only in 2011, data indicate that probably around 3,000 cranes migrate over Neretva Delta (threshold for the ‘bottleneck’ of European importance according to the BirdLife criteria). The river mouth with its shoals, sandbanks and saltmarshes is of greatest importance for migration of waders, representing one of the two most important coastal sites for waders, along with the SW Dalmatia and Pag. Bird monitoring on the river mouth during last several years indicates that Neretva Delta probably satisfies 1% level for Central and SE population of *Platalea leucorodia*. The river mouth represents the one of only two breeding sites of *Charadrius alexandrinus* in Croatia and one of only two coastal breeding sites of *Himantopus himantopus* – the other one being the SPA SW Dalmatia and Pag.

Reedbeds in Neretva Delta are especially important for breeding of *Botaurus stellaris* (50% of national population), *Porzana pusilla* (83% of national population), *Porzana parva* (25% of national population) and

*Porzana porzana* (17% of national population). It also holds 12.5% of Croatian population of *Ixobrychus minutus* as well as 17.5 of *Circus aeruginosus.*

The breeding of *Ardea purpurea* in Neretva Delta was confirmed for the first time in 2013 when the collony of 25-30 p. was found in reedbeds (Bariša Ilić, HOD, pers. comm.). Neretva Delta is the only breeding site for *Aythya nyroca* in Mediterranean region of Croatia. The breeding of *Acrocephalus melanopogon* was registered for the first time in Neretva Delta in 2011. Along with the SPA Cetina River, this is the only breeding site in Mediterranean region of Croatia for this species. Reedbeds of Neretva Delta represent the only breeding site in Mediterranean region of Croatia for *Panurus biarmicus* and for *Acrocephalus schoenobenus*. They are also important for migrating and wintering birds, especially for wintering populations of *Acrocephalus melanopogon, Porzana parva, Porzana porzana, Porzana pusilla* and *Rallus aquaticus.*

This area contains a high diversity of water habitats, the delta, lagoons, brackish waters, network of channels springs, streams with rheophilic characteristics and lakes that are inhabited with almost 20 fish species endemic to Adriatic basin. One of two important sites for endemic species *Squalius svallize.* Freshwater habitats with rheophilic characteristics are important for *Salmothymus (Salmo obtusirostris*). Freshwater habitats with rheophilic characteristics and oligotrophic lakes as the Lake Modro Oko are important for *Salmo marmoratus* with up to 60% of total Croatian population, this is only important site for that species. Brackish habitats of the site are important for *Pomatoschistus canestrinii* and *Knipowitschia panizzae*. One of two sites important for reproducing of *Petromyzon marinus*. One of two sites important for *Lampetra zanandraei*, endemic lamprey. One of three sites important for *Knipowitschia croatica*. Only important site for endemic species *Chondrostoma knerii* with the 100% of Croatian population. Only important site for *Alosa fallax*, important for reproduction. Only important site for endemic species *Alburnus neretvae* (syn. *Alburnus albidus*) with the 100% of Croatian population. Only important site for endemic species *Cobitis narentana* (*syn. C. taenia*) with the 100% of Croatian population. Baćina Lakes are important for *Cobitis illyrica* (*syn. C. taenia*), and *Delminichthys adspersus* inhabits them as well. Delta Neretva is important site for herpetofauna species *Elaphe quatuorlineata*, *Zamenis situla, Emys orbicularis, Mauremys rivulata* and *Testudo hermanii*. It is also southernmost site of distribution of *Lutra lutra.* Site is important for 8310 Caves not open to public - area important for *Congeria kusceri*, the only living underground bivalve in the world - species is found in altogether 7 localities in Delta Neretva site - two colonies (Jama u Predolcu hosting more than 72 000 individuals and Pukotina u tunelu polje Jezero - Peračko blato), one locality where only individual live specimens were found (Izvor špilja kod Kapelice) and four localities with only dead shells; five new underground taxa found and scientific described (*Cyphophthalmus neretvanus, Trichoniscus matulici, Emmericia narentana, Roncus narentae, Alpioniscus verhoeffi*); *Alpioniscus heroldi* known from seven localities of South Croatia, distribution area also in Herzegovina; *Saxurinator brandti* known from five localities of South Croatia.

This is one of on two sites important for the conservation of *Coenagrion ornatum* in the Mediterranean Biogeographical Region. Because of the large population (cca. 40% of the national population) the site is of great importance for the conservation of *Lindenia tetraphylla* in Croatia.

The largest *Miniopterus schreibersii* hibernation colony in the mediterranean biogeographical region in Croatia is in Delta Neretve. As well as one of the 34 underground sites with 10,000 or more bats recorded in Europe. Internationally important undergorund site for *Rhinolophus ferrumequinum* (nursery, migration), *Myotis emarginatus* (nursery, migration) and *Miniopterus schreibersii* (hibernation) and the southernmost known *Myotis capaccinii* nursery. Site is important for *Rhinolophus hipposideros* nursery and migration. Also, *Rhinolophus euryale* summer roost.

Important site for Mediterranean salt meadows (*Juncetalia maritimi*), as well for Mediterranean and thermo-Atlantic halophiles scrubs (*Sarcocornetea fruticosi*) and *Salicornia* and other annuals colonizing mud and sand; these two habitat types occur together on the site, with *Salicornia* represented in much smaller area. The area is considered to support a significant presence of Coastal lagoons. It is important site for 3130 habitat type, with some plant communities known only from this part of Croatia. Important site for habitat type 62A0 and 9320. One of the best areas for 92D0 Southern riparian galleries and thickets (*Nerio-Tamaricetea* and *Securinegion tinctoriae*) in Croatia. It is one of the most representative sites for Estuaries and important site for Mudflats and sandflats not covered by seawater at low tide.

According to the IUCN Red List of Threatened Species (IUCN, 2012), Neretva Delta with surrounding area supports significant number of globally threatened species in categories CR, EN, VU and NT*. They include: 1 VU and 2 NT mammals; 5 NT birds; 2 NT reptiles; 1 VU amphibian; 2 CR, 1 EN and 5 VU fishes; 1 VU mollusc. Neretva Delta is also important site for a number of species of European concern that are protected by the Birds Directive and the Habitats Directive as well as by the Convention on the conservation of European wildlife and natural habitats. European Red List species include: 3 NT vascular plants; 1 VU and 4 NT mammals; 2 NT reptiles; 1 VU amphibian; 2 CR, 1 EN and 5 VU fishes; 1 VU dragonfly and 1 VU mollusc. Regarding regularly occurring ornithofauna, Neretva Delta supports 80 birds under BirdLife categories of Species of European Concern (SPEC 2 and SPEC 3 – 8 vulnerable, 34 declining, 5 rare, 32 depleted and 1 localized) and 46 birds protected as the Annex I species of the Birds Directive. Neretva Delta is important for 60 Croatian Red List species (8 CR, 19 EN, 10 VU and 23 NT).

Maps of habitats trend and maps of ecological quality elements trend is available at web portal of the European Environment Agency (https://natura2000.eea.europa.eu/) as well as on the web portal of Nature Protection Information System – Bioportal (http://www.bioportal.hr/gis/).

## 1.2 Tool / approach used for the projection

Research and mapping will be performed by 30th of November 2021 in the scope of act. 5.2. It will be a combination of two methods: 1) multibeam sonar side scanning method and 2) diving visual method. It should provide a realistic view of bathymetry (depth map), which easily defines the tidal zones and habitat maps. As part of the service, it will be analysed coastal habitats and habitats of the tidal zone of the Neretva delta in the narrowest, front belt of the delta in direct contact with the sea, where there is a transition from fresh / brackish water to sea and where the influence of tides is noticeable (on a minimum area of about 8 km2). In addition, biodiversity will be explored by incidental recording.

As well, Mapping of all target fish species in the Delta Neretva Ecological Network NATURA 2000 (code: HR5000031) will be performed by 31st of October 2021 in the scope of act. 5.2 to gather additional data on the distribution and status of target species populations.

## 1.3 Climatic scenarios considered

Biodiversity is currently most threatened by habitat degradation and loss, unsustainable exploitation of natural resources and pollution. The most important climatic impacts in this sector are: changes in average air temperatures; reduction of quantities and changes in the spatial distribution of precipitation; occurrence of climatic extremes and warming, acidification and sea level rise. The most vulnerable ecosystems are freshwater, underground, high mountain and pre-natural grassland.

As a consequence, at the habitat level, it is expected:

• area reduction,

• change of share and disappearance of some habitats,

• increase in arid area,

• drainage of wet terrestrial habitats,

• flooding of coastal habitats, increasing salinity of terrestrial and freshwater habitats by the sea,

• fragmentation,

• changes in structure, processes, functions and services,

• changes in the composition of species communities.

The main expected climatic impacts that cause high species vulnerability have the following consequences:

• changes in phenology,

• cessation of flowering of plant cryophilic and stenothermic species with shortening of vegetation,

• changes in the number and distribution of species,

• expansion of the range of thermophilic species (which is both positive and negative) due to the increase in average temperature,

• drying and extinction of hygrophilous species due to reduced amounts and changes in precipitation distribution,

• expansion of the range of xerophilous species (which is both positive and negative) due to the reduction of quantities and changes in the distribution of precipitation,

• decrease in forest species populations due to frequent fires due to increase in average air temperature and decrease in precipitation,

• loss of species adapted to life in a narrow range of ecological conditions (especially endemic species of limited distribution),

• emergence and spread of invasive alien species and species that are adapted to life in a wide range of ecological conditions and suppression of native species, which consequently changes the structure and function of habitats,

• changes in interactions between species (positive and negative),

• changes in life cycles, changes in migration time,

• decrease playback performance,

• reduced resistance to disease or predation,

• reduction and extinction of freshwater species in the Adriatic basin due to salinization of coastal habitats due to rising sea levels,

• spread of marine species to the north and occurrence of thermophilic invasive alien marine species due to rising sea temperature,

• potential uncontrolled growth of populations of organisms causing diseases of shellfish, fish, etc.

The most vulnerable groups of species include the already endangered group of pollinators, which has a significant role in the ecosystem, as well as all species that are adapted to life in a narrow range of ecological conditions (especially endemic species of limited distribution). Soil is extremely important in adapting to climate change, with special emphasis on the importance of preserving soil biodiversity. The degree of research into ecosystems, habitats and wildlife is still insufficient to valorise their vulnerability to climate change and to develop predictive models, in order to be able to define all effective adaptation measures.

Sectors of particular importance for adapting biodiversity to climate change are water management, agriculture, forestry and spatial planning. Therefore, cross-sectoral measures to strengthen the resilience of biodiversity based on nature-based solutions, such as careful use of space, restoration, revitalization, measures related to traditional knowledge and agricultural practices, etc. are important.

## 1.4 Future evolution of specific species and habitats

Prediction of future of specific species and habitats in the Neretva delta can be based on the analysis of local trends in the last ten years, and the analysis of changes occurring in the southern areas of the Adriatic and Aegean Seas. Local trends in the 21st century show that some invasive thermophilic species are spreading rapidly along the Adriatic coast, and some have already established reproductive populations (examples of blue crab). In addition, some Adriatic species that prefer warmer temperature conditions, such as sea bream, have significantly increased their numbers in the waters of the Neretva delta. Some other species that were once numerous in the Neretva delta, such as the *Mugil cephalus*, are very rare today, although they were the main species in the former Neretva fisheries. Examples from similar areas of Greece, such as the lagoons of *Mesolonghi* and *Amvrakikos,* indicated significant changes in species composition and quantities, with certain species beginning to dominate (bluefish, blue crab, gilthead sea bream) and certain species of mullet, flatfish and other species declining.

# 2. Pilot Site Nature Park Vransko Jezero

## 2.1 Biodiversity, habitat and ecological quality target

Ecological quality of the lake ecosystem, depends highly on the inflow of freshwater to the lake and has an immense effect on the water level of the lake. Reduced inflows also result in lower water levels in the lake, and thus higher water salinization in the lake. Namely, according to the results of Rubinić's research (2014), the chloride content in water, in general, is inversely proportional to the water level in the lake (Figure 4.)

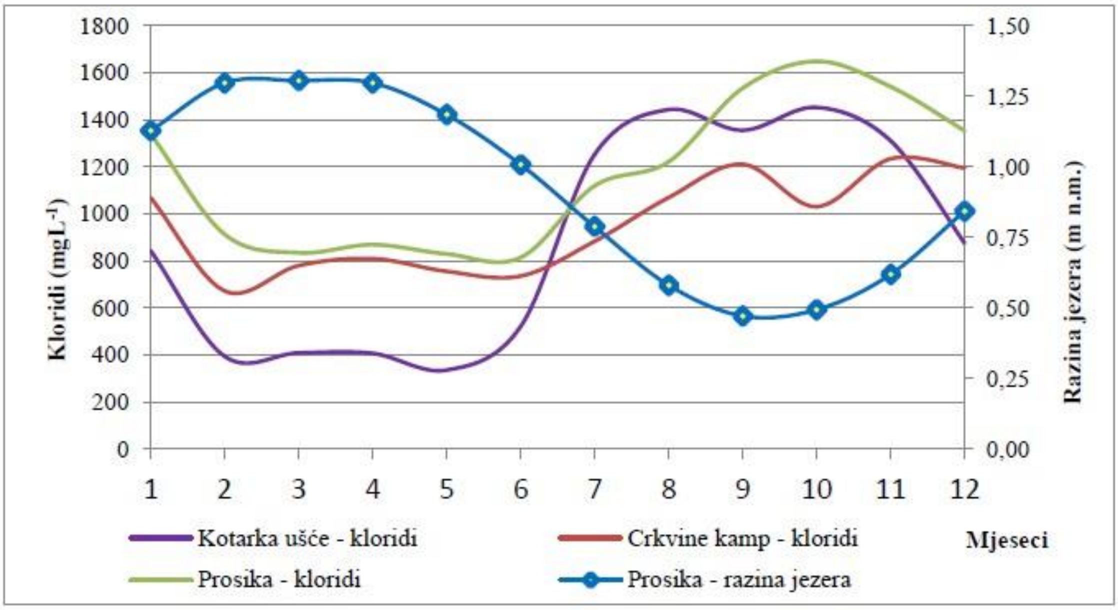



Figure 4. Comparative presentation of the intra-annual distribution of the average monthly chloride content in the water of VranskoLake at three locations and the average monthly water level in the lake (2000-2009) (Rubinić, 2014) y– axis (Klorides, mgL-1, x – axis – months, purple – Main Chanel Kotarka, red – Crkvine, green – Prosika, Blue – Prosika - waterlevel

**Communities of periodically flooded habitats near the ornithological reserve on Vransko Lake**

Along the north-eastern shore of Lake Vransko, several plant communities are developing due to periodic flooding as the dominant ecological factor (Alegro 2012.). The habitats are categorised as class *PHRAGMITI – MAGNOCARICETEA.* The length of water retention is also conditioned by micro-relief, so the communities are often mosaically distributed, conditioned by only a small difference in the depth of the terrain, ie water retention. The investigated communities on the north western shore of Lake Vransko are conditioned by different amounts of water and the duration of flooding. The current water regime does not provide sufficient water and sufficient flooding duration for the optimal development of the described communities. Evidence of this is the emergence of species that are not characteristic of these communities, but belong to arid habitats. Some of them are: *Althaea officinalis* (marshmallow, species of open, nitrophilous and slightly saline habitats), *Aster squamatus* (neophyte ruderal species), *Ambrosia artemisiifolia* (neophyte, invasive species, open dry habitats and weeds in agricultural crops), Dittrich species of ruderal, mostly dry habitats), *Cynodon dactylon* (weed species of dry habitats), *Cichorium intybus* (ruderal species of open, dry habitats) and some others. The habitats need conditions of raising the water level by about 30 cm and enabling water retention during the winter and spring months. These conditions foster the development and maintenance of these communities and would prevent the penetration of weed and ruderal species from surrounding habitats, especially agricultural areas.

**Macrophyte habitats**

State of clear water in shallow lakes are marked by the dominance of aquatic macrophytes (Popijač 2004). The constant "death" of algae from the *Characeae* family in the lake in 2012 is the result of a drastically increased salinity, as these are freshwater species that do not tolerate salinization of this magnitude. It can be seen that the species *Chara intermedia* is the only recorded species (Table 2, Figure 5), while other species completely disappeared from the lake in 2012 (Figure 5., Vuković et al. 2020).

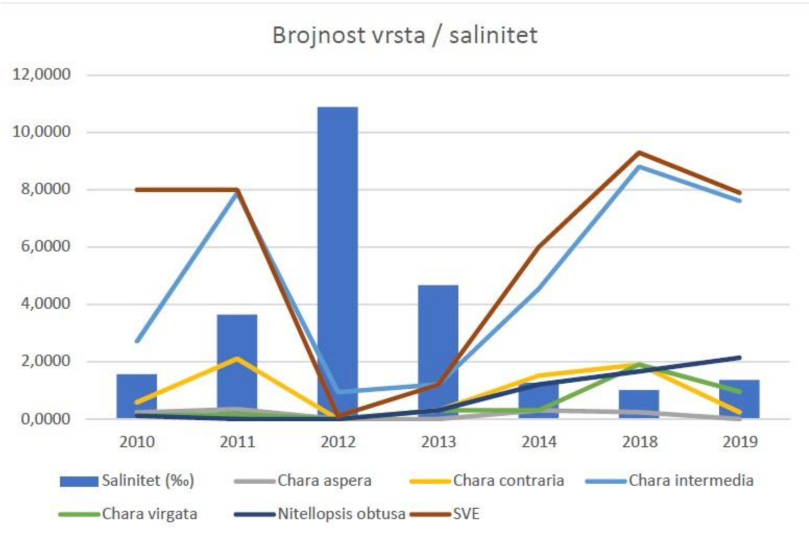



Figure 5. Average annual value of salinity and number of species in a given year sampling, including the total number of species (SVE). x-axis years, y-axis – number of species, blue column – salinity levels (‰) Vuković et al. 2020.

The increase in the amount of nutrients that leads to phytoplankton blooms and the increase in the number of suspended particles that reduce transparency certainly contributed to the bad situation, as these factors reduce the quality of the ecosystem in terms of macrophyte maintenance. Furthermore, the increase in salinity is such a dominant cause of charophyte death, that the contribution of other parameters is much smaller, if not negligible. The increase in the amount of nutrients is in principle related to the increase in salinity because in the background is the same process, a decrease in water levels, or a decrease lake volume and sea impact. In the absence of the influence of the sea, aid of this magnitude would very likely not occur, regardless of the increase in nutrient concentration and the associated phytoplankton blooms and a decrease in transparency. (Figure 6.)

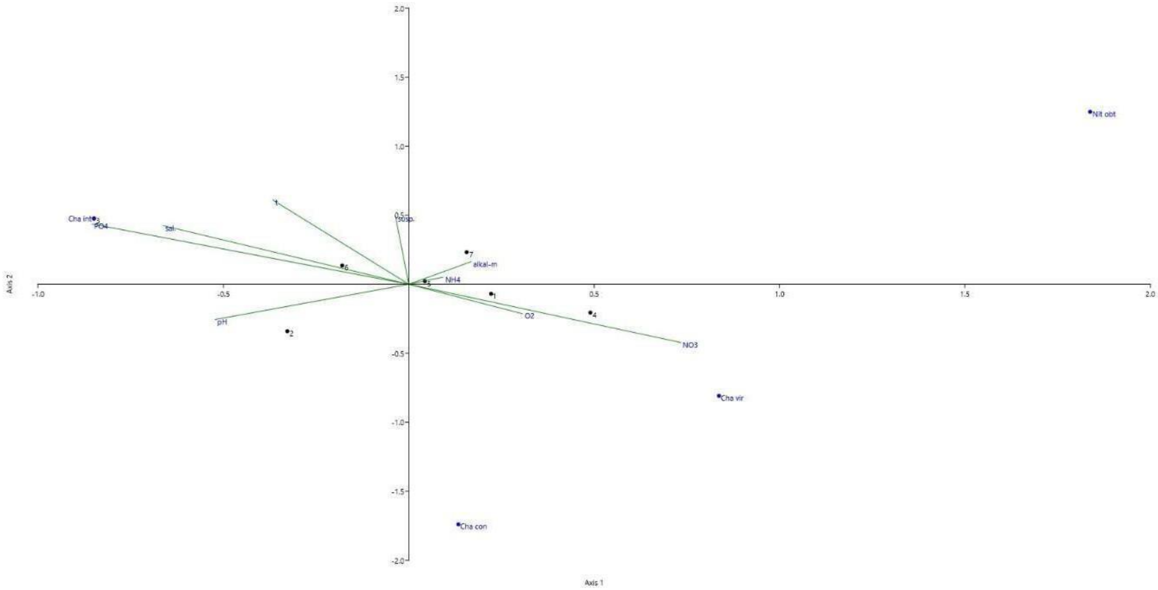



Figure 6. The result of CCA analysis showing the relationship of the analyzed physico-chemical parameters and recorded species in individual years. *Cha int - Chara intermedia, Cha con – Chara contraria, Cha vir - Chara virgata, Nit obt - Nitellopsis obtusa*. Years of algal sampling are numbered as follows: 1 - 2010, 2 - 2011, 3 - 2012, 4 - 2013, 5 - 2014, 6 - 2018, 7 – 2019 .(Vuković et. al. 2020)

Existing data on macrophytes of Vransko Lake are not sufficient for precise analysis of the influence of physicochemical parameters of water on their occurrence, but still provide insight into the structure and conditionality of macrophytic communities, and the basic processes that lead to their fluctuations. From individual years and there was generally no systematic measurement of the parameters so that their values could be related to the state of macrophyte populations. For this reason, we generally cite here general conclusions based on previous knowledge of the ecology and biology of macrophytes. It is known that the chemical composition of water strongly influences the floristic composition of macrophytes, but this influence is very difficult to quantify for several reasons. In addition to the chemistry of water is often variable, individual parameters are related to other parameters (for example, electrical conductivity may be high as a result of elevated values of various electrolytes), so it can be difficult to distinguish what impact works. In addition, water chemistry often has an indirect effect on aquatic plants, for example through an effect on algae, phytoplankton or zooplankton. Different species tolerate elevated or decreased values of individual parameters differently, but some regularities generally apply. Transparency can be a limiting factor for macrophyte development since plants in water are much harder to reach light than on land. The part of the light that reaches the surface is reflected, so the full amount does not reach the water, and by penetrating the water, different wavelengths are absorbed, with different wavelengths being absorbed differently, so some "disappear" before others. The transparency (and thus the available light) will be lower if an increased amount of suspended particles is found in the water, which can occur by inflow from the land or by sediment uplift due to strong winds. The amount of available light is reduced by the mass appearance of phytoplankton and cyanobacteria, which are in direct competition with macrophytes for light and nutrients and further increase water turbidity, and some species secrete toxins that are harmful to macrophytes. The more massive development of phytoplankton and cyanobacteria usually occurs due to the increased inflow of nutrients into the aquatic ecosystem, therefore eutrophication adversely affects the development of macrophytes.

**Fish population**

The zoning of important areas was made on the basis of observations during fish species research (Miočić-Stošić et al., 2010.) and reflects potential areas that should be paid special attention to in terms of preserving the favorable condition of ichthyofauna, with special emphasis on indigenous species. Three zones are identified: Zone I includes the main inflow Channel and coastal marsh and aquatic vegetation as the basic area of fish spawning and as such represent the basis for maintaining an ecologically favorable condition. These areas also introduce the richest feeding grounds as the richest habitat types with a very large production. The coastal area with the lake slope includes also bare rocky shores without vegetation; represented mainly on the coastal side of the lake and the coastal slope belt towards the muddy lake bottom also included in zone I. due to its importance for indigenous species (*Salaria fluviatilis*, *Knipowitschia caucasica* and *Anguilla anguilla*). Zone I also includes the locality Jugovir as a very important place for eel migration. In Zone II. Lateral canal and Prosika canal are included, which are important for fish migrations (especially Prosika for eel, mullet, bream, etc.). In zone III. Lake bottom is included, which covers the largest area (86%), but is a very monotonous habitat that is mostly used by non-native species (carp, catfish, baboon, etc.). The muddy bottom prevails here especially in the SE part of the lake. (Figure 7, Figure 8.)

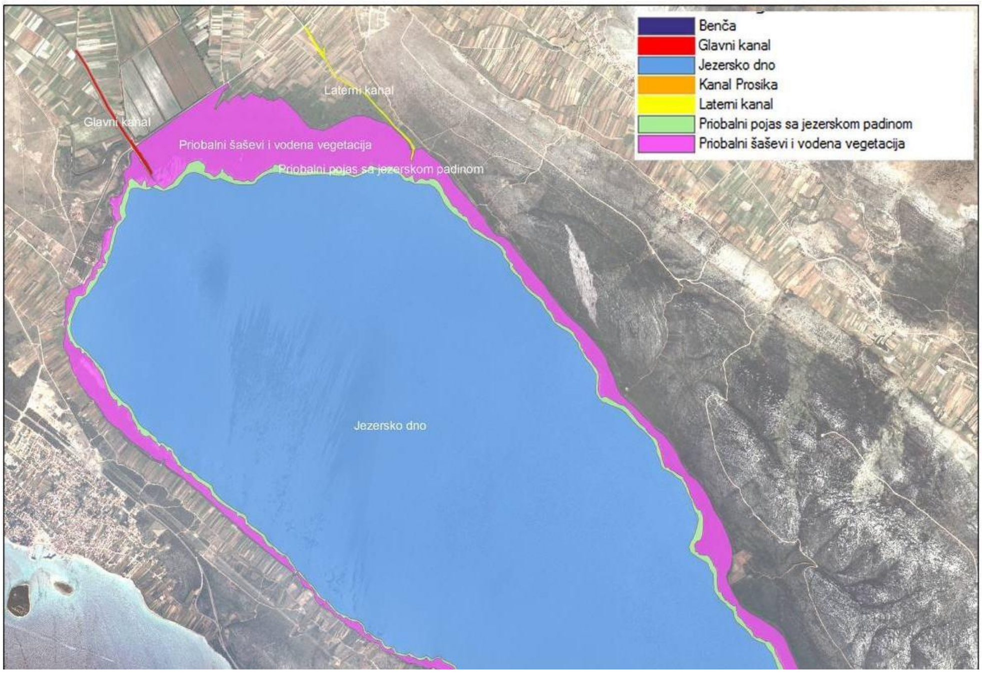



Figure 7. Division of lakes into areas (NW part) (Zone I -red, green, pink, zone II – orange, yellow, Zone III – dark blue an light blue)

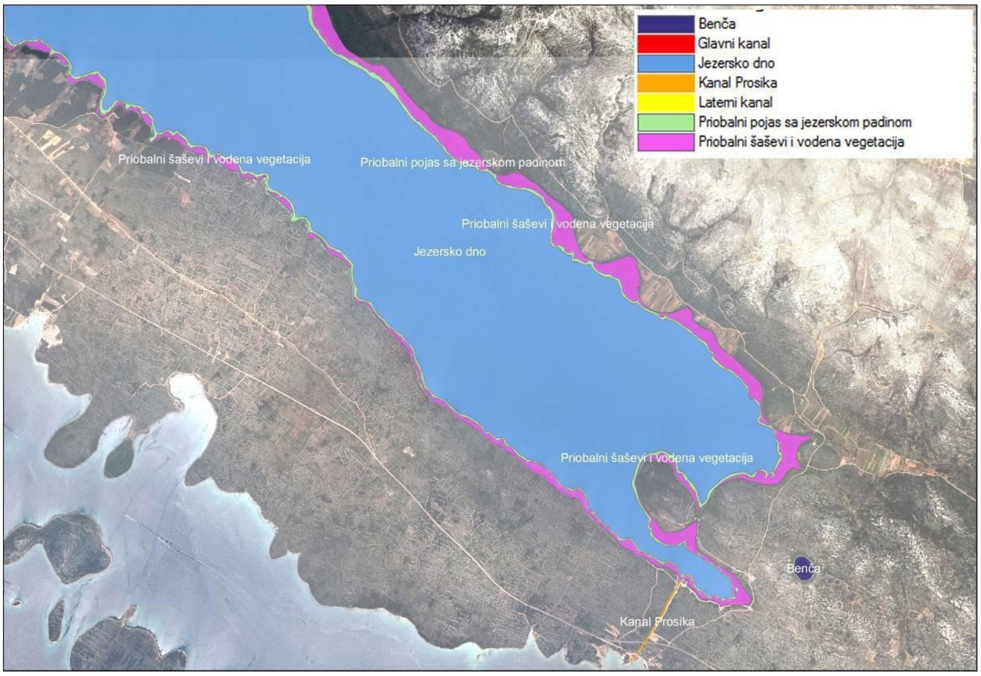


Figure 8. Division of the lake into areas (SE part) (Zone I -red, green, pink, zone II – orange, yellow, Zone III – dark blue an light blue)

According to Jelić (2012) the water level in the lake should be maintained in the best way to ensure the longest possible period of the year when water remains present in Zone I (which includes coastal marsh and the lake slope) because this area is used by fish for spawning and active feeding. A favourable regime would be if the water in Zone I would be retained even during the driest summer months. This zone is important for the growth of larvae and young fish because it provides appropriate nutritional and habitat conditions (shelter and protection). Adults fish also use the shallower parts of the lake as a good food source.

The water level in the lake needs to be maintained in the best way to ensure spring flooding of Zone I and the lower parts around the lake (coastal sedges) because the fish come here to spawn (March - April). These floodplains are extremely important for economically important species such as carp, Prussian carp, pike, etc. To ensure a favorable habitat for spawning, water must be retained in flooded areas long enough for the water to warm up to required spawning temperatures (16-24˚C, depending on the species). After spawning, the fish need some more time (2-4 weeks, depending on the egg-laying strategy) to hatch and during this period it is critical that the water does not withdraw and the microhabitats to dry out. It would be convenient to maintain a 30-40 cm water column in floodplain meadows during March, April and May.

Influence of water level on the most important bird species of Vransko Lake

Among 128 species related to aquatic habitats in Nature Park Vransko lake, there are 30 nesting birds, of which 12 species are present all year round. Populations of 75 species are migratory, and 47 species winter on the lake. The maintenance of high water levels, higher than 30 cm in the Ornithological reserve, during the nesting season provides conditions for nesting and feeding of herons, crows, ducks and other water birds (Kralj 2010). For successful nesting, many waterfowl need habitats with a certain amount of water available over a long period of time. A certain depth of water provides them with adequate feeding grounds and a nesting place safe from predators. During this time, they accumulate sufficient amounts of fat for the nesting season, build nests, lay eggs and incubate, and raise the young to independence. The accumulation of fatty substances can last up to two months before the start of nesting, so in migratory birds it takes place at least partially outside the nesting place. The length of the period encompassing nest building to the independence of the young depends on the species. In the case of herons, this period lasts about 3.5 months, so the flood period should be from at least 4 months (for migrants, on Vransko Lake it is, for example, the purple heron) to 6 months (for tenants, on Vransko Lake it is, for example, small crow). The nesting period for the most important species on Vransko Lake, as well as the total number of species nesting by decades is shown in Table 2. It can be seen that the nesting season lasts from early March to mid-August, with most species nesting from mid-May to late June. It is significant that of the six nesting species that are qualifying species for this area, nesting of three species lasts until mid-August. It is therefore necessary to provide high enough water during this period.

Since they represent the highest part of the flood zone in relief, wet meadows are the first to dry out at low waters. The Rails are extremely sensitive to changes in water levels during the nesting season and only a constant level in the critical period can enable their nesting. In terms of ecological range from wet meadows to open water, the order of species of the family *Rallidae* would be: (*Crex crex*) - (*Porzana porzana) - (Rallus aquaticus) -(Porzana pusilla) - (Porzana parva) - (Fulica atra*) (Cramp and Simmons 1980). Lawns covered with a few centimeters of deep water are also a rich breeding ground for many species of herons, glossy ibises, geese, ducks and other birds. In addition to flooded grasslands in the ornithological reserve, it is necessary to ensure the restoration of floodplain meadows in the area of Jasen, is their regular flooding. This area is an important feeding ground for nesting birds of Vransko Lake, as well as for birds that come during migration or winter.

Due to the microrelief of the shore, the water level in the reedbed decreases from the lake to the shore. Swimming birds, such as ducks, coots, grebes and hens, use the deepest parts of the reeds, while the shallower parts are home to the danguba heron and the wolf heron. The water depth can be roughly divided as follows (Robertson and Massenbauer 2005):

bare coast zone (0 cm deep)

wading zone (<25 cm depth)

shallow diving zone (> 20 cm depth)

deep diving zone (> 1 m depth)

Research shows that the greatest diversity of birds that feed is recorded in shallow waters, at depths less than 20-30 cm (Robertson and Massenbauer 2005). A study of the dependence of water habitat birds on the depth of water outside the nesting season, showed that the number and diversity of species is greatest in shallow wetlands (Colwell and Taft 2000). Therefore, when managing wetlands important as resting places for overflights, it is proposed to maintain wetlands with different water depths, but larger areas should have a depth of up to 20 cm. Given the importance of Lake Vransko for autumn migration, lowering the water level from August to October and the appearance of reefs would allow feeding different species of birds that feed in the area of the shore and gullies.

Due to the importance of reed beds for the ornithofauna of Lake Vransko, either as nesting grounds or as feeding and resting places, for a large number of bird species it is necessary that the dynamics of flooding correspond to their survival. In addition to herons and small crows, ducks, coots, reed warblers, and marsh bunting nest in reeds; for migrations they serve as resting places for large flocks of swallows and starlings, and are an important wintering habitat for Black-striped Reed Warblers, Marsh Buntings, Bearded Titmouses, etc. The hydrological requirements of reeds (Phragmites australis) were taken from Mesléard and Perennou (1996). During growth, in the spring, the reed requires water with a minimum depth of 10 cm, and it is optimal for it to be tens of centimeters deep. Outside the growing season (November to February) tolerates depths up to 1.5 m, and somewhere and larger (e.g. up to as much as 4-6 m in Greece). Annual droughts lasting 1-2 (maximum 3) months, favor the development of reeds, because it prevents the development of anaerobic conditions. The soil must not be completely dry, ie it must remain moist at a depth of 15-20 cm below the soil surface. The reed is relatively tolerant of the drying period, so it can be at any time, from July until winter. Given the needs of wetland birds and the distribution of precipitation in the Nature Park area, the most suitable period for soil drying would be during August and September before the onset of maximum precipitation in October. In addition to the amount of water, reeds are sensitive to water salinity, but tolerance varies by habitat. Reeds are generally considered to tolerate salinity of up to 10 g / l during the growing season, and higher for a shorter time outside (Mesléard and Perennou 1996). High waters in reeds in winter, before the beginning of the nesting season, on Vransko Lake would reduce the risk of accidental or intentional reed fires.

## 2.2 Tool / approach used for the projection

The assessment of the homogeneity of the results of historical data sets and data sets obtained using the mentioned climate models was performed by Wilcoxon's (1945) nonparametric test (ranking test), where the confidence level ± 0.05, ie the standard unit deviation U0≤|1.98 |. Testing was performed by comparing historical data sets from the period (1951-2011) and inflow data sets obtained by climate change modeling according to RegCM3 and Aladin models (2012-2100), both the original data sets and the modified data sets were examined. that the influence / magnitude of the reported trend for the period (1951-2100) is excluded from the members of the series.

Table 1. Examination of homogeneity of models of generated data series (2012-2100) with historical series data (1951-2011) (Rubinić, 2014)

| | Original data sets | Data sets with an exceptional trend |
|---|---|---|
| The historical sequence is continued by a series formed by the RegCM3 model | | |
| Standard unit deviation of the UO | 0,88 | -1,15 |
| Assessment of homogeneity | Homogeneous | Homogeneous |
| The historical series is continued by a series formed by the Aladdin model | | |

| | | |
|---|---|---|
| Standard unit deviation of the UO | 2,98 | -1,15 |
| Assessment of homogeneity | Inhomogeneous | Homogeneous |

The results of the performed homogeneity tests are shown in Table 1. It can be seen from this that, based on the RegCM3 modeling, the continued data sets are homogeneous to the historical data set for both the original string and the string from which the trend is excluded. When applying the Aladdin model, homogeneity was determined only in the case of trend exclusion, while the original data sets showed inhomogeneity. The reason for this is the more pronounced trend of declining values of average annual inflows. Given the present homogeneity in the case of excluding the influence of this trend, the implemented procedure of modeling and generating the value of annual inflows into the Vransko Lake basin until 2100 can be accepted. Based on these climate data and their predictions by the end of this century, modelling of mean annual inflows into Vransko Lake was carried out, using the conceptual model. For the implementation of further analyses - assessment of the impact of the obtained climatological changes on the hydrological characteristics (mean annual inflow), the results obtained by two models were selected: REG CM-3 and Aladin.

The obtained results - estimates of characteristic values of mean annual inflows for selected 30-year periods are shown in Figure 9 and Table 2. The value of the average annual inflow of the historical series (1961-1990) of 4.44 m3s-1 was determined as the average of thirty series of annual inflows generated on the basis of the mentioned method of application of the Langbein method (1962). It is also very close (difference of only 3.3%) to the value of the average annual inflow obtained from the map of the spatial distribution of precipitation and air temperature for the mentioned 30-year period of 4.30 m3 s-1.

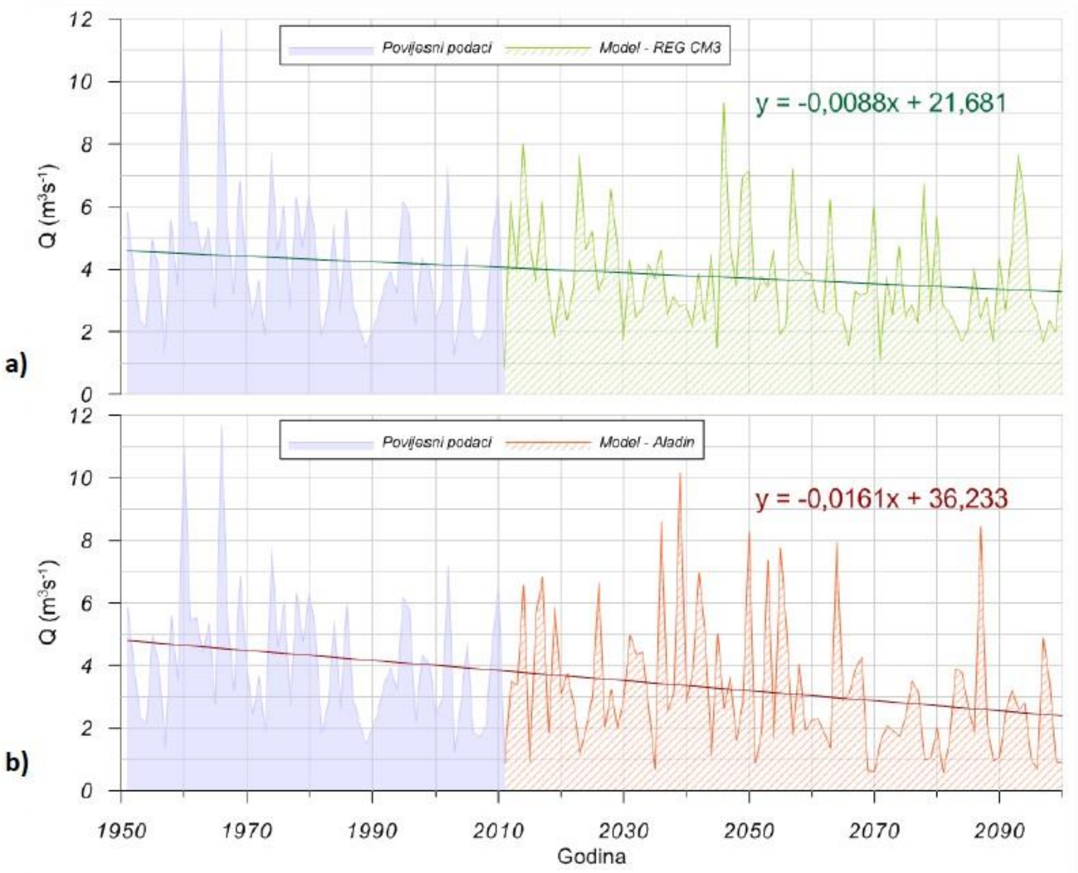



Figure 9. View historical data (1951-2011) and data generated by models (2012-2100) series of inflows into Vransko Lake with a corresponding trend for the entire analyzed period according to models: a) RegCM3 and b) Aladin (Rubinić, 2014)

It is evident from the given results that the recorded extremes had the character of very low probabilities of occurrence, below 2%, ie that the return period of their occurrence was less frequent than the 50-year return period. However, given the presence of a trend of increasing levels of the Adriatic Sea, and thus raising the level of water oscillations in the lake and its karst aquifer, it is expected that in the future such high levels, but also extreme droughts with low water levels in the lake, be even more frequent.

Table 2. Analysis of the probability of occurrence of maximum and maximum annual water levels in the lake at the hydrological station Pakoštanski most and maximum sea levels at the station Prosika-Adriatic Sea (Rubinić, Radišić 2020.)

| PROBABILITY (%) | TIME (YEAR) | Pakoštanski most – Vransko jezero (m n.m.) | | Prosika - Jadransko more (m n.m) |
|---|---|---|---|---|
| | | Maximum | Minimum | |
| 2 | 50 | 2,33 | -0,01 | 1,18 |
| 5 | 20 | 2,21 | 0,04 | 1,11 |
| 10 | 10 | 2,08 | 0,08 | 1,06 |
| 20 | 5 | 1,91 | 0,14 | 1,00 |
| 50 | 2 | 1,53 | 0,25 | 0,89 |
| Zabilježeni ekstrem | | 2,35 | -0,06 | 1,20 |

## 2.3 Climatic scenarios considered

The impact of climate change on Vransko Lake is already evident at the present time (Rubinić and Katalinić, 2014). It was researched for the first time in the work of Rubinić's dissertation (2014), from which the obtained results of the assessment of the possible effects of climatological changes on the flows, as well as on the chloride content, are transferred. Climatological bases of the State Hydrometeorological Institute (Gajić-Čapka et al., 2010, 2011) were developed within the EU project CCWaterS (Terzić et al., 2011, Rubinić et al., 2011). Within this project, based on the available set of measured data from the main climatological station Zadar from 1951 to 2009, an estimate of average annual air temperatures and precipitation for the period from 2010 to 2100 was conducted. Estimates were selected, ie time series of mean annual air temperature and annual precipitation obtained on the basis of two regional climate models - REGCM3 (Pal et al., 2007) and Aladdin (Bubnova et al., 1995).

The main climatological station Zadar was chosen because it has a reliable and continuous series of collected data for the entire analyzed period after 1951. It was selected as the basic station for the implementation of climate predictions, and is about 30 km away from VranskoLake and the boundaries of its basin only about ten miles. For the given locality, a comparison of time series data obtained by direct measurement and series from the E-OBS climatological database was performed, and an additional adjustment of the model to local measurements was performed. Climate change is defined as the difference between the future climate (period P1: 2021-2050 and the period P2: 2071-2100) and the reference current climate (period P0: 1961-1990). The results of both models indicate a pronounced increase in mean annual air temperature, while trends in annual precipitation show significantly greater variability in terms of possible sign and amount of change depending on the model and season (Gajić-Čapka et al., 2011). Figures 10 and 11 give a summary of historical and future generated series of mean annual air temperatures, as well as annual precipitation for the Zadar station for the period (1951-2100). In addition, a statement of the resulting trends for such time series is given, as well as characteristic indicators - mean values and standard deviation for selected characteristic 30-year periods P0, P1 and P2.

In doing so, during further processing, the calculated results of the generated series for 2010 and 2011 were replaced by their actually observed values. In addition to the common tendency of a general decrease in annual precipitation and an increase in mean annual temperatures, these results also have relatively significant differences. The resulting data from 30-year averages for the period (1961-1990) from the Zadar climatological station were compared with the average annual air temperature and the average annual rainfall in the Vransko Lake basin. These data were obtained via a digital map of their spatial distribution and were reduced to the basin itself by the coefficient of interrelation of the mentioned quantities.

The results of the conducted assessments (Gajić-Čapka et al., 2011) show, depending on the applied model, various possible changes in climatic conditions. According to the results obtained using the REG CM-3 model, the average annual air temperatures in the period (2021-2050) could increase compared to the temperatures during the period (1961-1990) by 8%, and during the period (2071- 2100) as much as 22% compared to the reference period. No significant changes (1-2% increase) are expected in the average annual precipitation amounts. The results of the mentioned estimates according to the Aladdin model show that average annual air temperatures during the period (2021-2050) could increase even more markedly compared to the reference period - by about 11%, while for the period (2071-2100) was obtained practically the same value of temperature increase of 22%. However, according to the Aladdin model, the amount of precipitation is expected to decrease compared to the average amount of precipitation during the reference period, by 2% in the period (2021-2050) and by 15% in the period (2071-

2100).

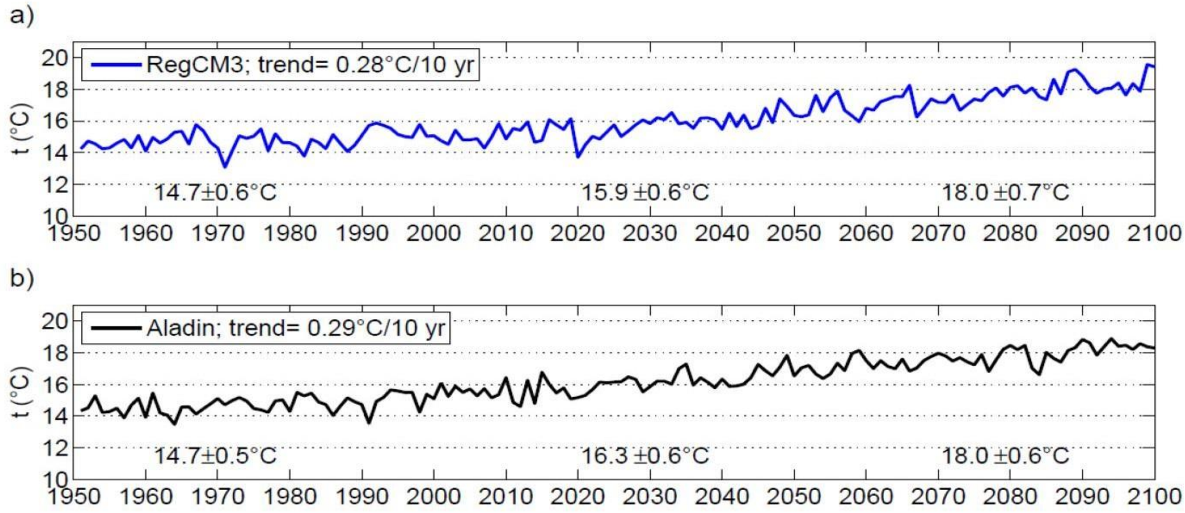



Figure 10. Mean annual air temperatures for Zadar station - extended with the model: a) RegCM3, b) Aladdin, with plotted values of average trend as well as average values and standard deviations for three reference 30-year periods P0, P1 and P2 - (Gajić- Čapka et al., 2010)

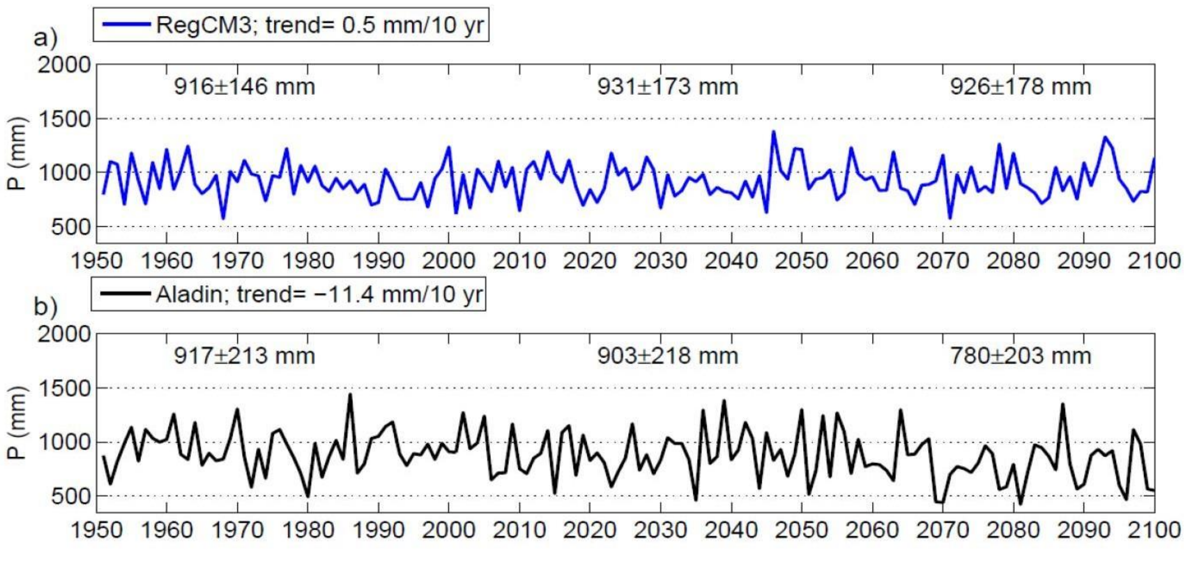



Figure 11. Annual precipitation amounts for Zadar station - extended with the model: a) RegCM3, b) Aladin, with plotted values of average trend as well as average values and standard deviations for three reference periods P0, P1 and P2 - (Gajić-Čapka et al., 2010 )

## 2.4 Future evolution of specific species and habitats

The condition of the lake is very variable - the change of favorable and unfavorable hydrological conditions have the tendency of increasing frequency of negative phenomena and processes. Salinity is increased by decreasing inflows, decreasing lake water levels and rising sea levels (highest mean sea levels most often during the summer dry season), increased evaporation and water abstraction for water supply and irrigation. All this also affects the rise in water temperature. Climate change models show that temperatures will rise further, precipitation will stagnate or fall slightly with more pronounced extremes, and flows will fall. Continued climate change will encourage the intensification of negative trends with the increased need for water for water supply and irrigation. The lake remembers the chloride content, so there are problems if dry periods last, and reduced water and sea water exchange is expected in terms of desalination. In addition to climate change, the cause of negative phenomena is also anthropogenic changes in water use (Prosika canal trench, water use in the basin). Water and sediment are connected, water comes surface from springs at the contact of carbonates and flysch on land, sweet and brackish springs in the lake and the influence of the sea through karst. The influence of sea water also changes sedimentation through the influence on production in the food chain. Ecologically, there are two alternative conditions in shallow lakes, including Vransko Lake. A shallow clear state dominated by macrophytes that stabilize sediment, draw nutrients from water, as a habitat allow optimal development of zooplankton and macrozoobenthos and affect greater biodiversity. Macrophytes inhibit the development of phytoplankton by competition for nutrients. The ideal condition of macrophytes in a lake is when the presence of *Characeae* and *Potamogeton pectinatus* species meadows on more than 50% of the lake surface. The number and biomass of zooplankton macrofilters are also important for a stable lake ecosystem, because they feed on phytoplankton and thus reduce their biomass. The relationship between macrophytes, zooplankton and fish, which are a significant predator of zooplankton, is very important. Therefore, it is necessary to look at all groups together: phytoplankton, zooplankton, macrophytes and fish and model the entire food network.

Of all natural lakes in Croatia, only the ecological condition of Lake Vransko was assessed as moderate due to the moderate condition of macrozoobenthos and fish, which can be attributed to foreign species that are also related to environmental factors. Measures need to be taken to improve the condition to good or very good status.

The Kotarka Canal and the Lateral Canal were rated very poorly / moderately due to elevated nitrogen and nitrate concentrations, which is a visible and expected impact of agriculture in the basin, and it is to be expected that this impact will be seen in the lake over time. The question is how macrophytes react to these existing phenomena. The lake is resistant to nitrate and phosphate intake precisely because of the abundantly developed macrophytes and reeds.

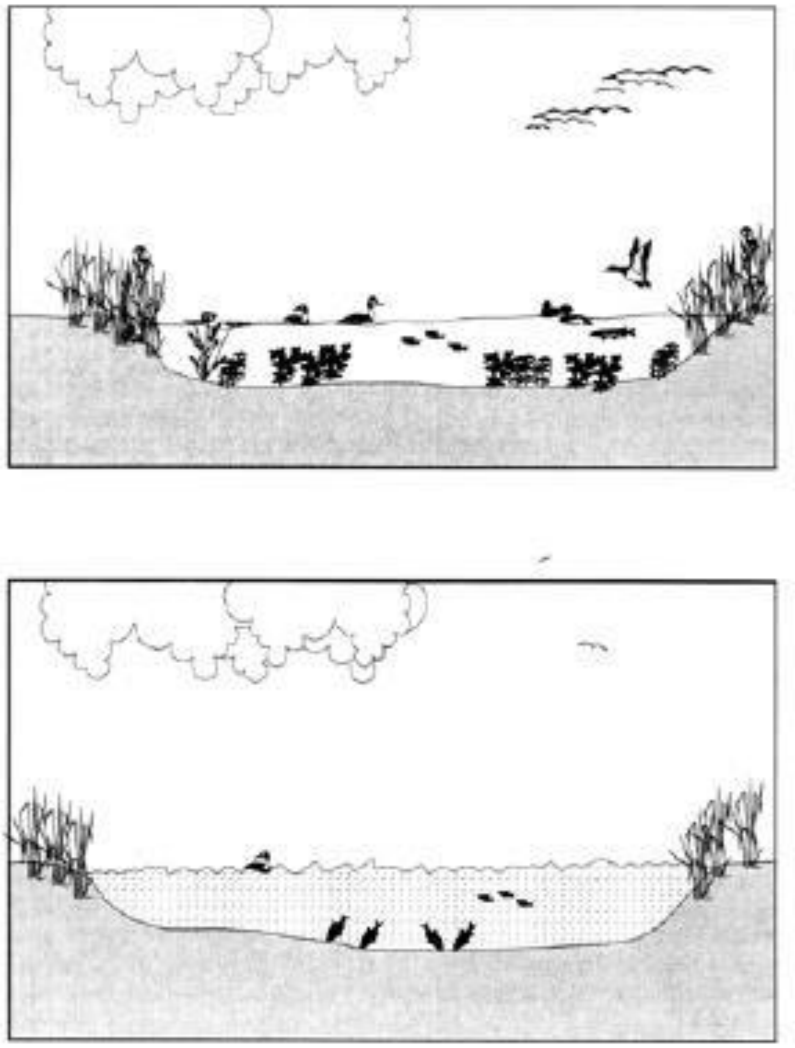


Figure 12. Schematic representation of a shallow lake in a state of clear water (a) with lush vegetation and in a state of turbid water (b) rich in phytoplankton, where underwater plants are mostly absent and benthic fish and waves stir sediment and turbid water. Taken from Scheffer (1998).

Due to pollution, decreasing water levels and / or increasing salinity, the lake ecosystem may become turbid. In the state of turbid water, macrophytes disappear, sediment is destabilized (which further reduces the transparency of the lake), the disappearance of habitats reduces the biomass of zooplankton and macrozoobenthos, and the dominance of phytoplankton and a significant reduction in biodiversity (Image. Also, the increase in temperature and salinity has a negative effect on zooplankton, while in macrozoobenthos there are spatial and temporal changes in the composition of communities, and biodiversity decreases with increasing salinity (the limit of maximum biodiversity is 2 (). Salinity changes in 2012 were first observed on benthos because salt water is in the lower layer. Large quantities of brackish or marine species of fouling algae develop that can rise in clusters under the influence of wind. They also prevent the development of macrophyte vegetation. Light is not a limiting factor for macrophyte development because it is the euphotic zone of the lake to the very bottom. It is necessary to determine what was the key mechanism for the non-development of macrophytes in 2020.

In 2020, the entire length of the canal in Vransko polje was cleaned, which is done regularly, but also 400 m of the main canal in the ornithological reserve, which is cleaned every 6-7 years. Evidence needs to be gathered if this intervention is really the cause of the recorded condition in the lake, so that more can be taken into account in the future.

The permanent state of turbid water is not easily reversible without undertaking significant management activities such as reducing nutrient inflows, fishing. The change to a permanent turbid state usually occurs gradually and takes some time.

It is assumed that there are cyclic changes that depend on the intensity of salinization which depends on the hydrological regime. The question is to what extent the lake system will be able to return to a state of clear water after such opportunities. Will these increasingly frequent occurrences have some cumulative impact that will no longer be reversible after some time? It is expected that the impact will be cumulatively increasing and it is not authoritative to look only at individual years but at the whole processes that occur in extreme conditions. The advantage of a closed shallow system is that, although they are brought to the limit values, macrophytic bottom species are not lost. Parishes have permanent stages and are pioneers of vegetation because as soon as favorable conditions are created, they can grow again. We assume that they tolerate salinity to some extent (which ones?). Also, due to the closed nature of the system, it is possible to influence nutrient intakes and adapt to climate change. Precisely because there are no large inflows of fresh water is subject to a higher degree of control.

# 3. Pilot Site Po River Delta

For the Po River Delta pilot site, the evolution of some characteristics of the ecosystem have been studied by means of the application of Habitat Suitability Models (HSMs). In particular, this approach was implemented for three habitats/species:

- Manila clam, *Ruditapes philippinarum*, a species particularly relevant for the farming activities in several lagoons of the Delta;
- reed beds of *Phragmites australis*, a habitat whose distribution already shrunk in the past, particular relevant for the ecological role in transitional water bodies and associated with several species of conservation concern;
- seagrass species, protected species characterizing the good state of conservation of the habitat 1150 * coastal lagoons, scarcely present in the Delta but showing positive trends in other Northern Adriatic transitional areas.

As regarding Manila clam, the suitability of the different lagoons was assessed using existing models (Vincenzi et al., 2006; 2007; 2011; 2014; Zucchetta, 2010).

As regarding Reed beds, the suitability of the different lagoons was assessed using a Habitat Suitability Model (HSM) developed within the project.

As regarding Seagrass distribution, the suitability of the different lagoons was assessed using a Habitat Suitability Model for *Zostera noltei* adapted within the project (originally developed for the Venice lagoon).

## 3.1 Biodiversity, habitat and ecological quality target

### *3.1.1 Manila clam*

*Ruditapes philippinarum* (Adams and Reeve, 185) is a dioecious bivalve, native from subtropical to low boreal part of western Pacific but, due to its high commercial value and its great adaptability and resistance to a wide range of environmental conditions and stressors, it has been introduced in several parts of the world, where it has become permanently established.

This species (Figure 13) lives in shallow waters buried in sandy, silty-sandy substrates at a depth of 15-20 cm and feeds by filtering phytoplankton and suspended organic particulate from the water through siphons. Reproduction is external and occurs mainly in the spring-summer season; sexual maturity is reached at a size of about 15 - 20 mm, which corresponds to the age of one year.

*Figure 13.Manila clam (*Ruditapes philippinarum*)*

In Italy the species was introduced in the early 1980's with the seeding in Venice lagoon of a batch of juveniles produced by artificial breeding in an Atlantic commercial hatchery. Here, the species found adequate environmental conditions for an extensive settling in many areas of the lagoon. In the following years, the species was introduced, using a similar approach, in other Northern Adriatic transitional systems (e.g. Sacca di Goro, Sacca del Canarin, Grado-Marano lagoon). The great suitability of these environments for Manila clam (high trophic status of water, shallows depths, hydrodynamic features adequate for the species) led to a rapid spread of Manila clam to all favorable sites and its harvesting soon became one of the prevailing employment and economic activities in Northern Adriatic transitional systems.

The success of Manila clam in the colonization of the Po delta areas could be explained taking into consideration different factors, such as its high tolerance against variations of environmental parameters (salinity, temperature, dissolved oxygen), its high capability to adapt to different substratum typologies and its higher fitness (early gonadic maturation, high fertility, long spawning period in which multiple spawning events are possible) with respect to the native clam species *Ruditapes decussatus.*

Clam production in Po delta area is currently based on farming of licensed areas managed by cooperatives of fishermen, under the control of regional and local authorities and it depends for a large part on natural recruitment of juveniles, collected in specific natural "nursery areas" and seeded in shallow areas managed by fishermen's cooperatives. Only a very small amount of spat is supplied by hatcheries. Duration and yield per surface area are highly variable, depending on several factors such as the initial size of spat at seeding and its density, the correct management of the farmed areas, the period of farming, the local biogeochemical and hydrodynamic conditions, which may fluctuate among and within the farmed sites (Table 3).

*Table 3. Resume table of optimal and tolerated ranges of the main biogeochemical and hydrodynamic parameters identified as essential for the Manila clam (Boscolo et al., 2011 with elaborations of data collected by Breber, 1996; Paesanti e Pellizzato, 2000; Solidoro et al., 2003).*

| | **Optimal range** | **Tolerated range** |
|---|---|---|
| Salinity | 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 |

The productive realities of the Po delta lagoons are mainly located in two areas: 1) Po delta lagoons of Veneto Region, including the northern lagoons of Caleri and Marinetta-Vallona and southern lagoons of Scardovari, Canarin, Basson and Barbamarco, with a mean estimated clam production of approx. 12.000 tons in the period 2009-2017; 2) the Sacca di Goro, which is one of the top European sites for mollusc rearing and the most productive lagoon in Italy, with a mean estimated clam production of approx. 13.000 tons in the period 2009-2017.

Data about local production of Manila clam in the Po delta and maps of the licensed areas are included in the Deliverable D.3.4.1 "Report on existing data and relative gaps".

### 3.1.2 Reedbeds

The common reed [*Phragmites australis* (Cav.) Trin. Ex Steud] is a cosmopolitan perennial halophyte that forms dense and wide meadows (reedbeds) in wetland environments (floodplains, waterlogged depressions, estuaries). It is a broad-leafed, about 1.5 to 5 meters tall, with feathery flower clusters and stiff, smooth stems. The leaves are stiff, lanceolate and 20-40 cm long and 1-4 cm wide (Figure 14).

*Figure 14. Common reed (*P. australis*) meadow in the Po delta area.*

Flowers occur between July and October and are arranged in spikelets, each containing 2-9 flowers. Rhizomes can be extremely developed and penetrate the soil up to 1 m deep forming a compact layer of sediments with a high content of organic material that remains in the sediments for centuries after the disappearance of the reed bed. This plant is well adapted to grow in a wide range of environmental conditions. It can be found also in areas where water surfaces are limited but it tolerates only moderate salinity, up to 12-15.

Reedbed supports an array of valuable and diversified provisioning and regulating ecosystem services, thereafter resumed in two main categories:

**Biodiversity and biomass support**:

- the reedbed is species habitat for many species of birds of conservation interest that use this environment for feeding, nesting, and night rest. The main bird species strictly connected to the reedbed in the Northern Adriatic area are the pygmy cormorant (*Microcarbo pygmeus*)*, the bittern *(Botaurus stellaris*)*, the purple heron *(Ardea purpurea)*, the little bittern *(Ixobrychus minutus)*, the marsh harrier (*Circus aeruginosus*), the hen harriers (*Circus cyaneus)* and the common kingfisher (*Alcedo atthis)*, along with a large number of passerines.
- The submerged part of the reedbed and the adjacent shallow waters are the breeding, nursery and shelter habitats of various species of fish, such as the black-spotted goby (*Ninnigobius canestrinii, included in* Annex II of 92/43/CEE Directive ), the seabass (*Dicentrarchus labrax*), the

eel (*Anguilla anguilla*), mullets (*Mugil cephalus*. *Chelon* spp.), as well as amphibians and invertebrates.

**Regulation and maintenance**

The reedbed and the associated microbial and bacterial communities play a key role in:

- regulation of water and sediment quality by favoring the phytodepuration processes and sequestering from the environment elements such as nutrients, heavy metals and other nuisance compounds;
- trigger of the oxygenation processes of soils and sediments, thanks to the action of the rhizomes that receive oxygen from the leaves and distribute it in the undeground, facilitating the mineralization processes;
- defense of the sediments from erosive processes, by attenuating the wave motion and by trapping suspended particulate;
- atmospheric composition and climate regulation, by sequestration and sink of $CO_2$ by plants and associated biotic communities;
- Creation and consolidation of habitat, the reedbed are able to produce organic substrates useful to increase the settlement areas, acting as an ecosystem builders.

Historically, the reedbed habitat covered larger surfaces in the Po delta area but its presence has been greatly reduced by historic human interventions.
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, Sacca di Goro), along the riverbanks and in the wetlands more influenced by freshwater (Allagamento Bonelli, Bacucco), channels and terminal riverine tracts.

In the Po delta, there are four different typologies of reedbed meadows:

- Valley reedbed. In some fishing valley characterized by low salinity there are wide reedbed meadows that are managed by the owner of the valleys to host and protect bird fauna target for hunting activities.

-Riverine reedbed: mainly found both in the riverbanks and in the slinky canals present in flood plain areas, where the flow is moderate. This kind of reedbed is mostly present in the Po di Maistra branch and in some sector 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: represents the main reedbed surface area in the Po delta, with a presence of *P. australis* almost monospecific. This kind of reedbed grows in intertidal area subjected to tidal cycle and, accordingly, its growth is limited to the areas less affected by marine salinity. The presence of reedbed in Po delta lagoon is generally limited to the areas protected by marine influence by sandbank.

Detailed distribution maps of the reedbed in the Po delta area are included in the Deliverable D.3.4.1 "Report on existing data and relative gaps".

### 3.1.3 Seagrass

Seagrasses are aquatic angiosperms, flowering plants consisting of roots, stem and leaves, which have developed adaptations to submerged life, hydrophilic reproduction, resistance to wave motion and, sometimes, tolerance to salinity. Fundamental element of transitional ecosystems, aquatic angiosperms are able to support high biodiversity and to increase the ecological quality of the habitat. Their presence is an element characterizing the good state of conservation of the habitat 1150 * coastal lagoons.

In transitional ecosystems, aquatic angiosperms provide numerous and diversified provisioning and regulating ecosystem services, thereafter resumed in two main categories:

**Biodiversity and biomass support**:

- nursery, shelter and feeding area for organisms that live in and around the meadows: fish species of conservation and commercial interest, macrozoobenthic communities;
- breeding and feeding area for bird species.

**Regulation and maintenance:**

- 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;
- atmospheric composition and climate regulation, by carbon sequestration and trapping by plants and associated microbial communities.

The transitional water systems of Northern Adriatic region include five species of Aquatic angiosperms (Figure 15), briefly described below:

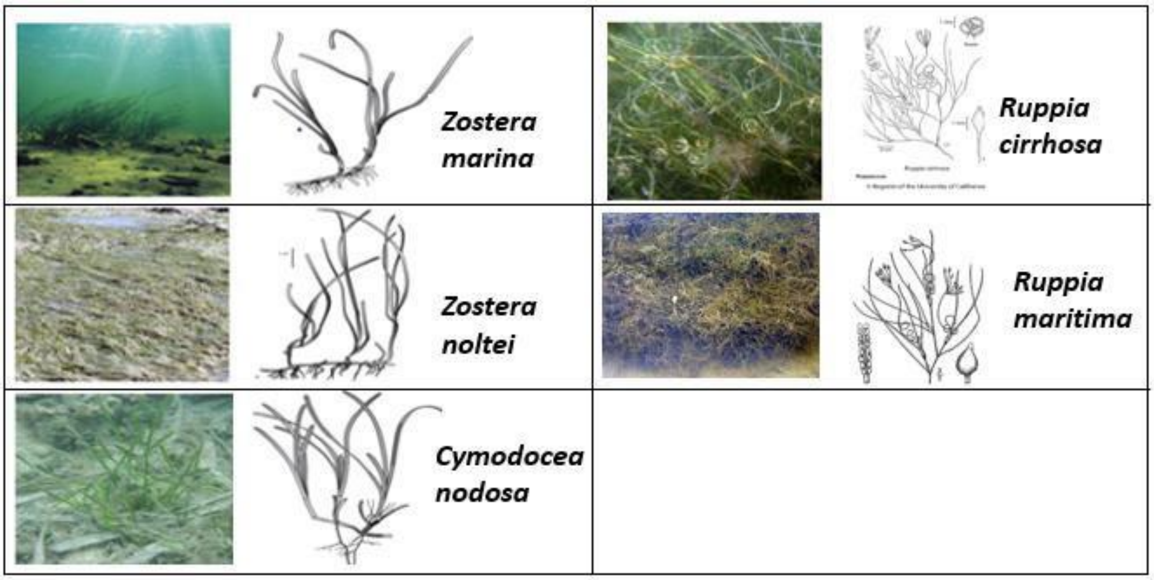



*Figure 15. Aquatic angiosperms species in transitional water systems of Northern Adriatic Region.*

*Cymodocea nodosa* (Ucria, 1870): a seagrass species that mainly colonize transitional areas characterized by marine salinity, sandy substrates and not emerged during low tides. The leaf bundles normally have from 2 to 4 (on average 3) leaves of different lengths (on average 100-120 cm) enclosed in a 5-15 cm long tubular and membranous leaf sheath. It grows in the period from May -December, as it is a species of subtropical origin. In winter only the rhizomes remain with the base of the leaf bundles and at most 1-2 short leaves. Taking into consideration its thermal requirements, in the Northern Adriatic area, the species hardly reproduces by seed, usually its diffusion occurs by growth and dispersion of the rhizomes.

*Zostera marina* (Linnaeus, 1753): a seagrass species that mainly colonizes shallow areas with salinity in the range 20-30 characterized by muddy or slightly sandy sediments. The leaf bundles normally have from 2 to 7 (on average 4) leaves of different lengths (up to 100 cm of height) enclosed in a 5-15 cm long tubular and membranous leaf sheath. It grows all year round, including the winter months, albeit much more slowly, and produces flowers, seeds and fruits between April and early June when it reaches the highest development.

*Zostera noltei* (Hornemann, 1832): a seagrass species that colonizes shallow brackish waters of habitat 1140 and 1150* and may tolerate frequent periods of emergence caused by tidal excursion. It prefers choked environments with protected fine sandy or muddy substrates and it is therefore often present in the mudflat areas surrounding the natural saltmarshes. The leaves are generally small and narrow and 10-20 cm long; several separate male and female flowers grow on a short, spear-shaped lateral stem flowering in July-September. The leaf bundles generally include 2-5 leaves and a well-developed meadows contain up to 15000 bundles per $m^2$.

*Ruppia cirrhosa* (Grande, 1918): aquatic angiosperm mainly found in areas characterized by low salinity, or high salinity fluctuation, and by muddy and partially anoxic sediments. The leaf bundles have packages of 3-5 small leaflets (15-17 cm). In well-developed grasslands, the leaf bundles reach 1 m in height and its density may reach over 30000 units per $m^2$. It grows all year round, including the winter months, although at low temperatures the growth effort barely compensates for the losses due to breathing. It produces flowers, seeds and fruits between July and August, period in which also reaches its maximum development. In consideration of the very high amount of produced seeds, if suitable conditions are met, the species may colonize large areas.

*Ruppia maritima* (Linnaeus, 1753): aquatic angiosperm very similar to *R. cirrhosa* but with minor dimensions, with a maximum height of 30.40 cm. It preferably colonizes oligo and mesohaline areas or shallow wetland ponds where temperature and salinity vary strongly. In the optimum conditions, the highest growth is in July and then it decreases with the increasing of temperature.

The decline of aquatic angiosperms in transitional environments is a phenomenon documented on a global scale and, in recent decades, attributable to various anthropogenic impacts (mainly loss of water quality and coastal development) and to climate change effects.

Historically, before the major reclamation works ended at the end of the 1960s, aquatic angiosperms were quite widespread in the wetlands of the Po Delta. Thereafter, a strong and constant decline was observed, mainly due to the increase of trophic load, with consequences on primary production shift, increase of turbidity, erosive phenomena.

Currently, the aquatic angiosperm distribution in the Delta area is quite reduced, with meadows mainly of *Z. noltei* and *Ruppia* spp., mostly present in the fishing valleys and in the canals, while in the lagoon areas they are limited to shallow areas with clear and non-stagnant water.

*Zostera noltei* was considered as an indicator species for representing the seagrass meadows habitat suitability in the Delta Po area, being one of the most typical species colonising transitional waters in the northern Adriatic.

## 3.2 Tool / approach used for the projection

For the projections of the suitable conditions of the three targets considered in Delta Po Pilot Site under present and future climate scenarios, a Habitat Suitability Modelling approach has been followed. Habitat Suitability Models (HSMs) are "*empirical methods that relate species' field observations or museum-type data to environmental predictor variables, based on a combination of statistically or theoretically derived* *response curves"* (Guisan et al., 2017). For Manila clam a HSM with theoretically derived curves based on the implementation of the model set up by Vincenzi et al. (2006) has been used, while for reedbeds and seagrass meadows statistical models relating presence/absence to environmental conditions have been used. In both cases the outputs of the model (*i.e.*, the spatial predictions resulting from the application of the model using maps of environmental variables described in the next paragraphs as inputs) have been interpreted as an estimation of the suitability of the environmental conditions for the specific target.

This activity has been developed in association with the hydrodynamic modelling activity, carried out by ISMAR-CNR within WP3.3 and WP4.1, and described in the relative deliverables (D3.3 and D4.1). The SHYFEM grid was used as spatial support for the development or application of the different Habitat Suitability Models, described in the following paragraphs.

### *3.2.1 Manila clam HSM*

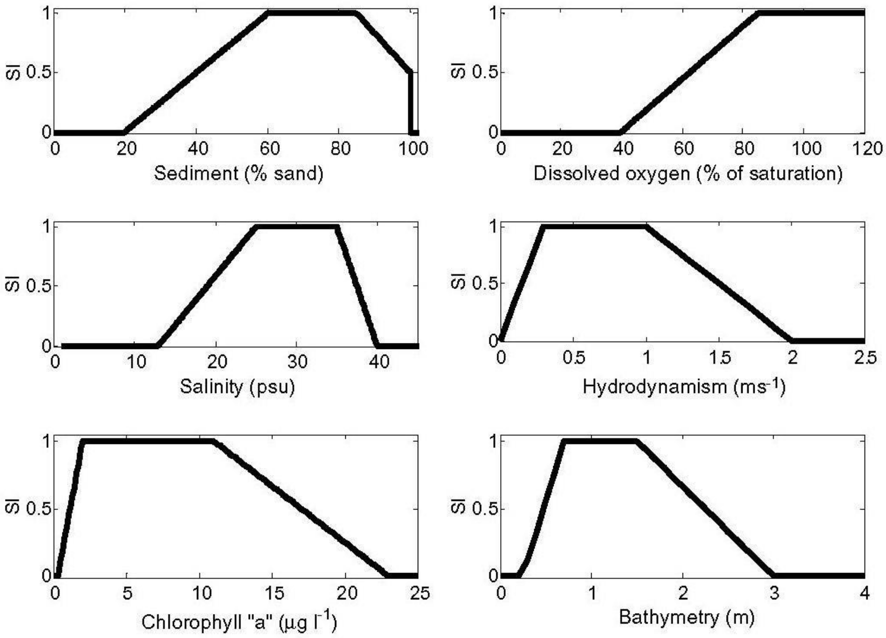
For the first target, Manila clam, the GIS-Based HSM developed by Vincenzi et al. (2006) has been used. This model was originally developed for estimating the potential clam yield in the Goro lagoon with theoretical or expert knowledge derived curves and weights, mostly based on Paesanti and Pellizzato (2000). The variables included in the model are:

- fraction of sand in the upper sediment layer;
- dissolved oxygen of the water;
- water salinity;
- water hydrodynamism;
- chlorophyll "*a*";
- bathymetry.

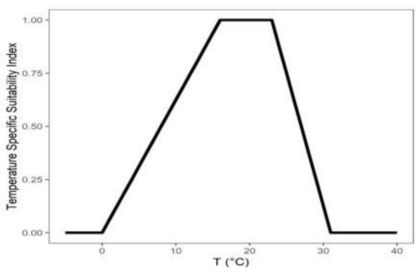
The shape for each response curve is reported in Figure 16a. For each site (each triangular element of the hydrodynamic model, SHYFEM grid), each curve allows to express suitability in terms of a Suitability Index (SI) defined on an arbitrary scale between 0 and 1, where 0 denotes a non-suitable habitat, while 1 a most suitable habitat (United States Fish and Wildlife Service, 1981). After the SI has been assessed for each variable, an overall suitability evaluation of a given site within the study area is computed as a weighted geometric mean of the different suitability indices. The weights used in Vincenzi et al. (2006) are: sand in the upper sediment, 5; dissolved oxygen, 1; water salinity, 1; water hydrodynamics, 10; chlorophyll "*a"*, 1; and bathymetry, 2.

Given the focus on the climate evolution of the Delta Po, an implemented version of the model has been applied to both present and future scenarios by including also water temperature among the suitability curves (Figure 16b). The profile of the temperature response curve was obtained from Paesanti and Pellizzato (2000).

As no data for the spatial distribution of Manila clam production were available within CHANGE WE CARE, it was not possible to evaluate the model predictive capabilities. However, the validation of the Manila clam HSM was originally performed on Goro (Vincenzi et al., 2006; 2007) and, for an updated version of the model, in the Caleri and Marinetta lagoons with production data collected in 2008 and 2009 (Vincenzi et al., 2014), showing a high predictive capability (adjusted $R^2$ of the observed-predicted relationship ranging from 0.86 to 0.87).




a




b

*Figure 16. Response curves used in the manila clam HSM (a; Vincenzi et al., 2006); Temperature Specific Suitability Index (b)*

### 3.2.2 Reedbeds HSM

For the second target, reedbed, a specific HSM has been developed within CHANGE WE CARE. Data of reedbed distribution were obtained from the map of Corine Land Cover (Typology 4.1.1.1) in the SIC IT3270017 (data from 2006) within the Po River Delta area of the Veneto Region (see Deliverables 3.4.1 and 3.4.2). The map of reedbeds distribution was overlayed with the grid of triangular elements of the SHYFEM model (see Deliverable 3.3.1), allowing to classify each element as being occupied (presence) or unoccupied (absence) by reedbeds. In this way it was possible to associate each presence/absence observation to the environmental conditions simulated for that element.

In particular, the following variables were considered:

- average salinity;
- hydrodynamics (current speed);
- $5^{th}$ and $95^{th}$ percentile of water temperature;
- the mean, median and maximum exposure time to the air of each element estimated for spring, summer, autumn, winter and on a yearly basis;
- percentage of time for each element exposed to the air estimated for spring, summer, autumn, winter and on a yearly basis;
- the mean, median and maximum cumulated time with salinity values over the threshold of 15 PSU estimated for spring, summer, autumn, winter and on a yearly basis;
- percentage of time for each element with salinity values over the threshold of 15 PSU estimated for spring, summer, autumn, winter and on a yearly basis;
- slope of the triangular element, computed from the bathymetry used in SHYFEM.

In addition to the variables obtained from the SHYFEM simulations, data on sand content (reported on Deliverables 3.4.1 and 3.4.2) were interpolated on the same spatial support (elements of the SHYFEM), Interpolations were carried out in R (version 4.0.3; R Core Team, 2020) using the 'gstat' package (Pebesma, 2004; Gräler et al., 2018).

Of the 69424 triangular elements of the SHYFEM model, 42366 were overlapped by the Corine Land Cover map, representing the dataset available for the development of the HSM. About 70% (n = 29103) of the observations were used for fitting the model, while the remaining were used for validation.

After a preliminary exploration, the number of candidate variables was firstly reduced by removing highly correlated variables. Following Fielding and Haworth (1995), a correlation analysis was conducted and variables with high correlation coefficient (Pearson r >0.7) were not considered for model calibration, in order to avoid multicollinearity.

The following candidate variables were considered for the inclusion of the HSM:

- average exposure to air;
- water resident time (WRT);
- sand in the upper sediment of the bottom;
- average salinity;
- slope;
- hydrodynamics;
- median time of exposure to the air estimated for summer;
- percentage of time of exposure to the air estimated on a yearly basis;
- percentage of time with salinity values over the threshold of 15 ppm estimated on a yearly basis.

A generalized additive models (GAMs; Hastie and Tibshirani, 1990) was used, following the approach to GAM as proposed by Wood (2006), using the 'mgcv' package (Wood, 2016) for R. Accounting for the importance of using different performance measure for habitat model (Zurell et al., 2009), we used several statistics to infer model predictive capabilities, chosen between the most appropriate to test a binomial model. These are: sensitivity (conditional probability that a presence is correctly classified); specificity (conditional probability that an absence is correctly classified); percent of correctly classified observations (PCC); and the area under the receiver operator curve (AUC) (Fielding and Bell, 1997).

Binomial GAMs were fitted considering different model formulations, corresponding to alternative hypothesis of reedbeds distribution/environmental variables association. The best model was chosen on the basis of an information-theoretical approach (Burnham and Anderson, 2002) and corresponds to the most reasonable hypothesis (i.e. better supported by the data).

The selected model included 6 variables:

- 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).

Average response curves are reported in Figure 17. The fitted model has a good predictive capability, as evaluated on the validation dataset (AUC: 0.941; PCC: 0.853; Sensitivity: 0.861; specificity: 0.853). The predictive application of the model was carried out expressing the outcomes in terms of favourability (Thuiller, 2008; Acevedo et al., 2010; Acevedo and Real., 2012).

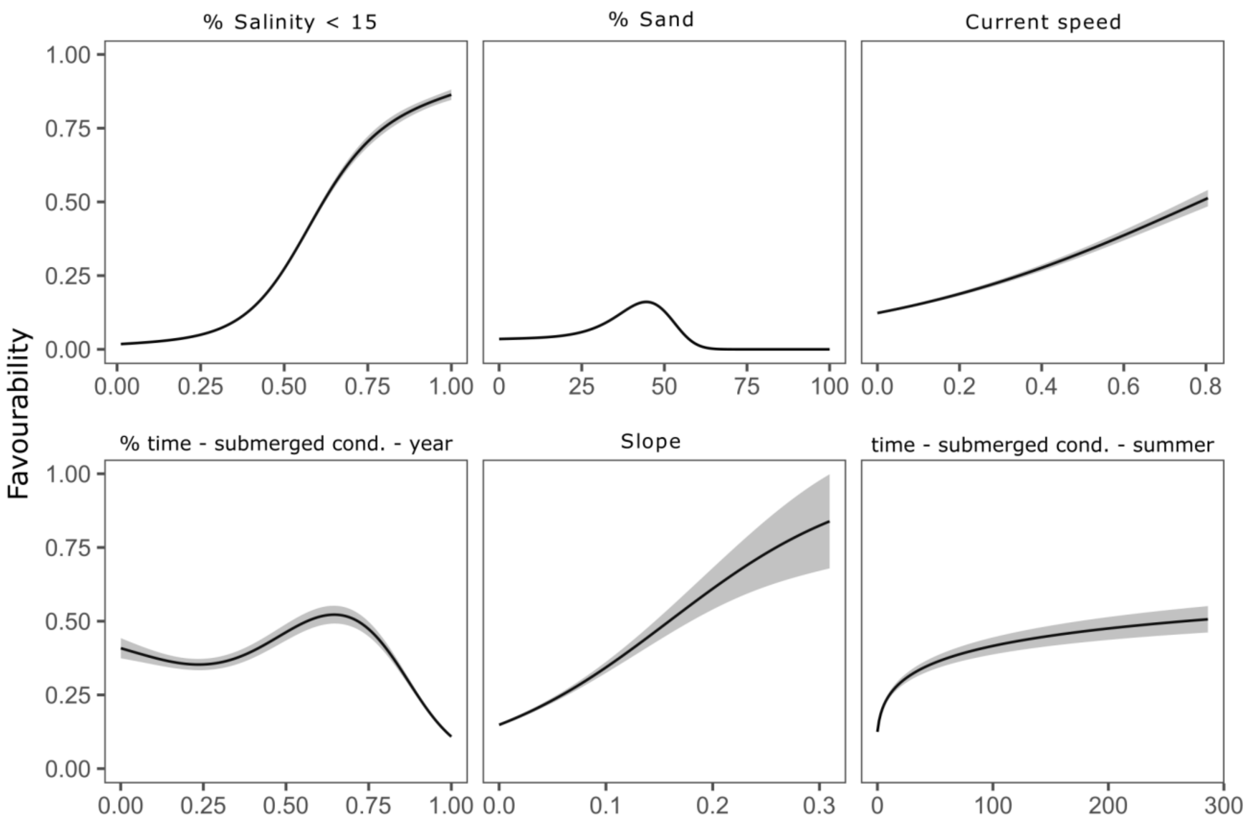



*Figure 17. Average response curves fitted in the reedbeds HSM. Suitability is expressed in term of Favourability (F).*

### 3.2.3 Seagrass HSM

*Zostera noltei* was considered as an indicator species for representing the seagrass meadows habitat suitability in the Delta Po area, being one of the most typical species colonising transitional waters in the northern Adriatic. As the presence of seagrass is marginal in the study area (e.g., few occupied sites; small patches and discontinuous meadows) and distribution data are not available it was not possible to fit a model on the Po River Delta, hence a HSM developed for the Venice lagoon was transferred to the Delta Po.

The model was developed in a similar way to the one described for reedbeds, with the main differences being: the statistical model used for fitting the HSM and the set of environmental variables. Indeed, a binomial Generalised Linear Model was fitted, considering several alternative model formulations evaluating alternative variables combinations and the inclusion of selected second order polynomial terms. The selected model included:

- 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)

Average response curves are reported in Figure 18.

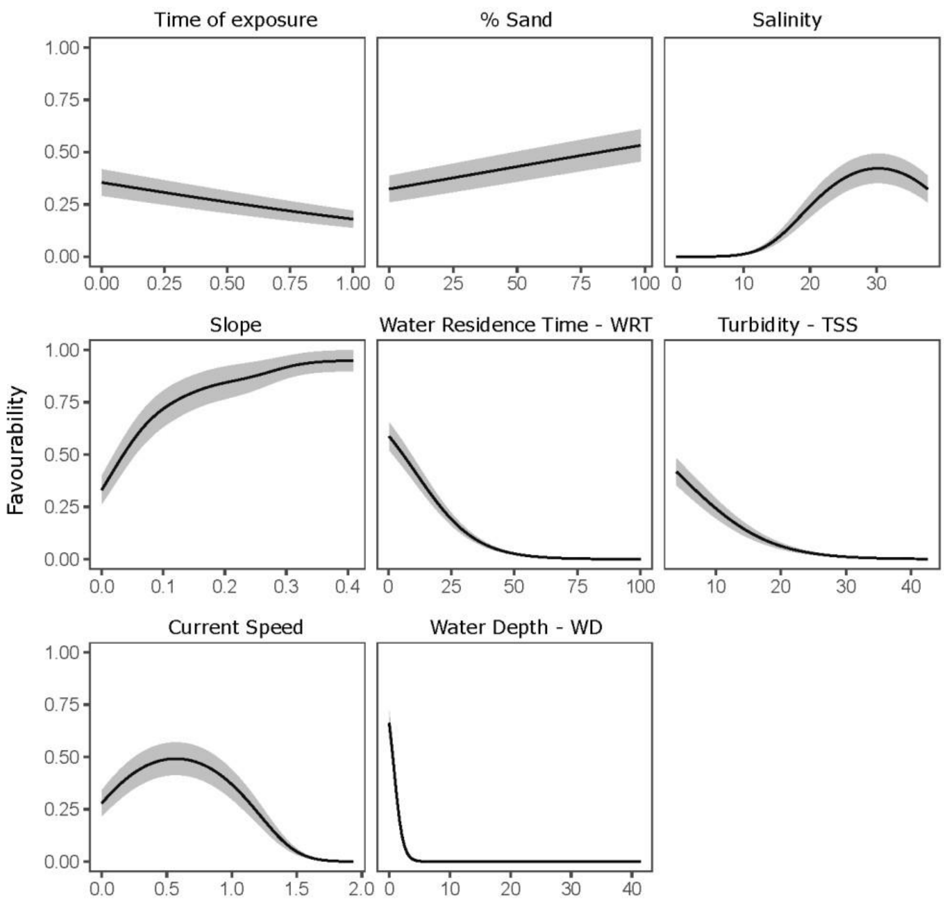



*Figure 18. Average response curves fitted in the seagrass HSM for* Z. noltei. *Suitability is expressed in term of Favourability (F).*

The accuracy of the predictions was characterised by AUC: 0.833; PCC: 0.769; sensitivity: 0.704; specificity: 0.773.

## 3.3 Considered Climate scenarios

The environmental variables (biotic or chemical-physical indicator) that are related to the climate change issues tackled in the Delta Po Pilot Site were collected in Deliverable 3.4.1 while in the Deliverable 3.5 was anticipated how they would be used to project the evolution of the ecosystem within CC scenarios.

In Table 4 a summary of environmental variables, available for the present state and the CC scenario, is reported in relation to the different targets.

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, implemented for the Po River Delta and the shelf in front of it. 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).

Some variables (*e.g.*: slope of the bottom, sand in sediment, chlorophyll-a, dissolved-oxygen) were not considered in the future scenarios (*i.e.* considered fixed in time) as the projection was not available. For seagrass, qualitative "*what-if*" scenarios were built to investigate the possible effect of turbidity on projection of suitability related to this specific parameter.

*Table 4: Environmental variables (biotic or chemical-physical indicator) that are related to the climate change issues tackled in the Po Delta pilot site in relation to different targets*

| Variables | Type of available measures | What is available as CC scenario? | Manila clams | Reedbeds | Aquatic angiosperm |
|---|---|---|---|---|---|
| Salinity (average or evaluation of permanence over specific threshold) | Field data for the period 2008-2018 [D3.4.1, D3.4.2]; simulations from site specific high resolution hydrodynamic modelling [D4.1] | Salinity projections from site specific high resolution hydrodynamic modelling [D4.1] | x | x | x |
| Water temperature | Field data for the period 2008-2018 [D3.4.1, D3.4.2]; simulations from site specific high resolution hydrodynamic modelling [D4.1] | Water temperature projections from site specific high resolution hydrodynamic modelling [D4.1] | x | | |
| Water Residence Time – WRT | Simulations from site specific high resolution hydrodynamic modelling [D4.1] | WRT projections from site specific high resolution hydrodynamic modelling [D4.1] | | | x |

| | | | | | |
|---|---|---|---|---|---|
| Hydrodynamics / current speed | Simulations from site specific high resolution hydrodynamic modelling [D4.1] | Water speed projections from site specific high resolution hydrodynamic modelling [D4.1] | x | x | x |
| Water level / water depth - WD - Bathymetry | Simulations from site specific high resolution hydrodynamic modelling [D4.1] | Water level projections from site specific high resolution hydrodynamic modelling [D4.1] (fixed bathymetry) | x | x | x |
| Submersion/ Exposure to air | Derived from simulated water level and bathymetry | Water level projections from site specific high resolution hydrodynamic modelling [D4.1] (fixed bathymetry) | | x | x |
| Slope of the bottom | Derived from bathymetry | / | | x | x |
| Sand in sediment | Field data for the period 2008-2018 [D3.4.1, D3.4.2]; | / | x | x | x |
| Chlorophyll-*a* | Field data for the period 2008-2018 [D3.4.1, D3.4.2]; | / | x | | |
| Dissolved Oxygen | Field data for the period 2008-2018 [D3.4.1, D3.4.2]; | / | x | | |
| Water transparency / Turbidity (as TSS) | Field data for the period 2008-2018 [D3.4.1, D3.4.2]; | "what-if" scenarios | | | x |

## 3.4 Future evolution of specific species and habitats

The projections of the suitable conditions of the three targets considered in this Pilot Site under future climate scenarios are presented. Differences between suitable conditions under future climate scenarios and present state are discussed.

### *3.4.1 Manila clam HSM – climate scenarios results*

The original HSM formulation to estimate suitable conditions for Manila clam (Vincenzi et al., 2006) and the new proposed formulation including water temperature (see par. 3.2.1) gave a comparable description for the suitability distribution of the present state. Given the focus on the climate evolution of the Delta Po, the projection of suitability under future climate scenarios obtained from the second version of the model is presented in Figure 19. Differences between suitable conditions under future climate scenarios and present state can be appreciated in Figure 20.

Generally, a small reduction (-0.2 - 0) of suitability is reported at Delta large scale, while a slightly increase (0 - +0.2) of suitability is shown in the inner areas of Sacca di Goro, in Scardovari (south-west), at north of Basson, and in the tidal flats close to Caleri inlets.

On Figure 21 the main factors relevant for the differences of Habitat Suitability between CC scenario (2080-2081) and present state (2010-2011) are reported.

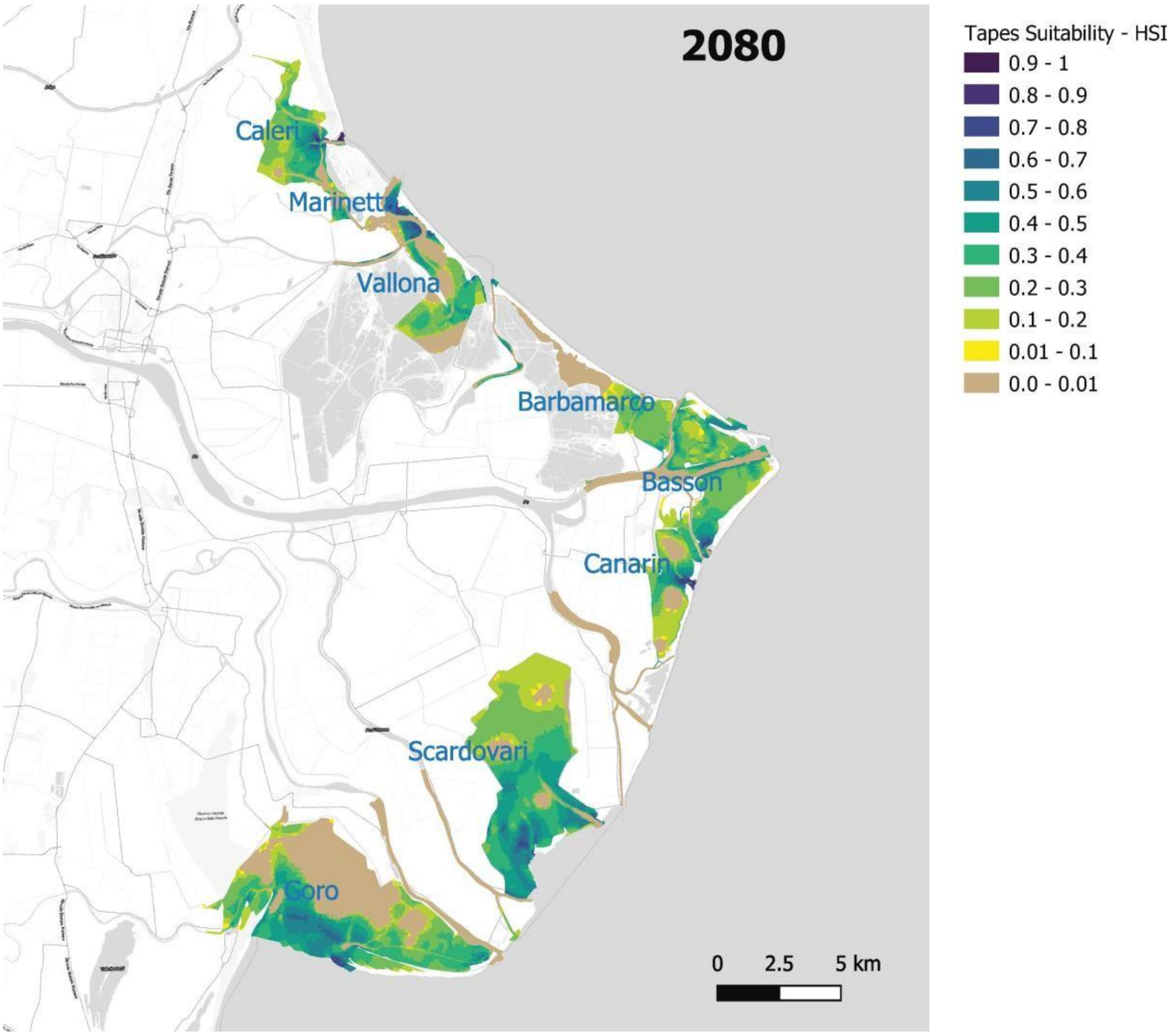



*Figure 19. Habitat Suitability (HSI) for Manila clam in CC scenario (2080-2081)*

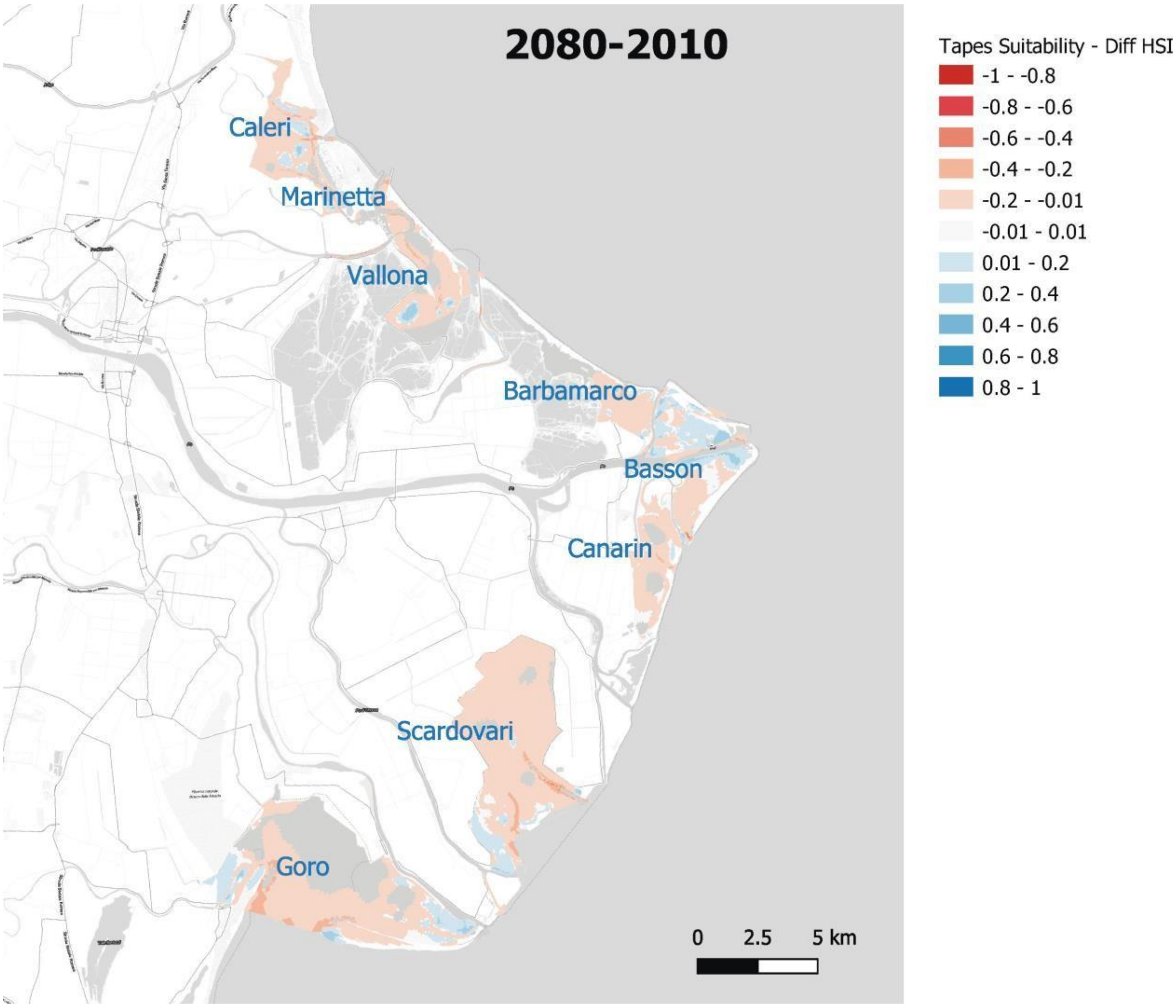



*Figure 20. Differences of Habitat Suitability for Manila clam between CC scenario (2080-2081) and present state (2010-2011)*

Generally, the decrease in suitability is explained by the water depth (bathymetry) parameter (RCP8.5, expected Sea Level Rise-SLR of 0.63 m) while locally for the South Basson area by a variation in salinity (sal, as reported by the results of the hydrodynamic model, see Deliverable 4.1). The slight increase in suitability is related: in Goro/Canarin/Barbamarco to salinity (expected average annual increase of less than 2%); in Goro/Scardovari/ Basson/Po di Maistra-Pila/Caleri to water depth (bathymetry).

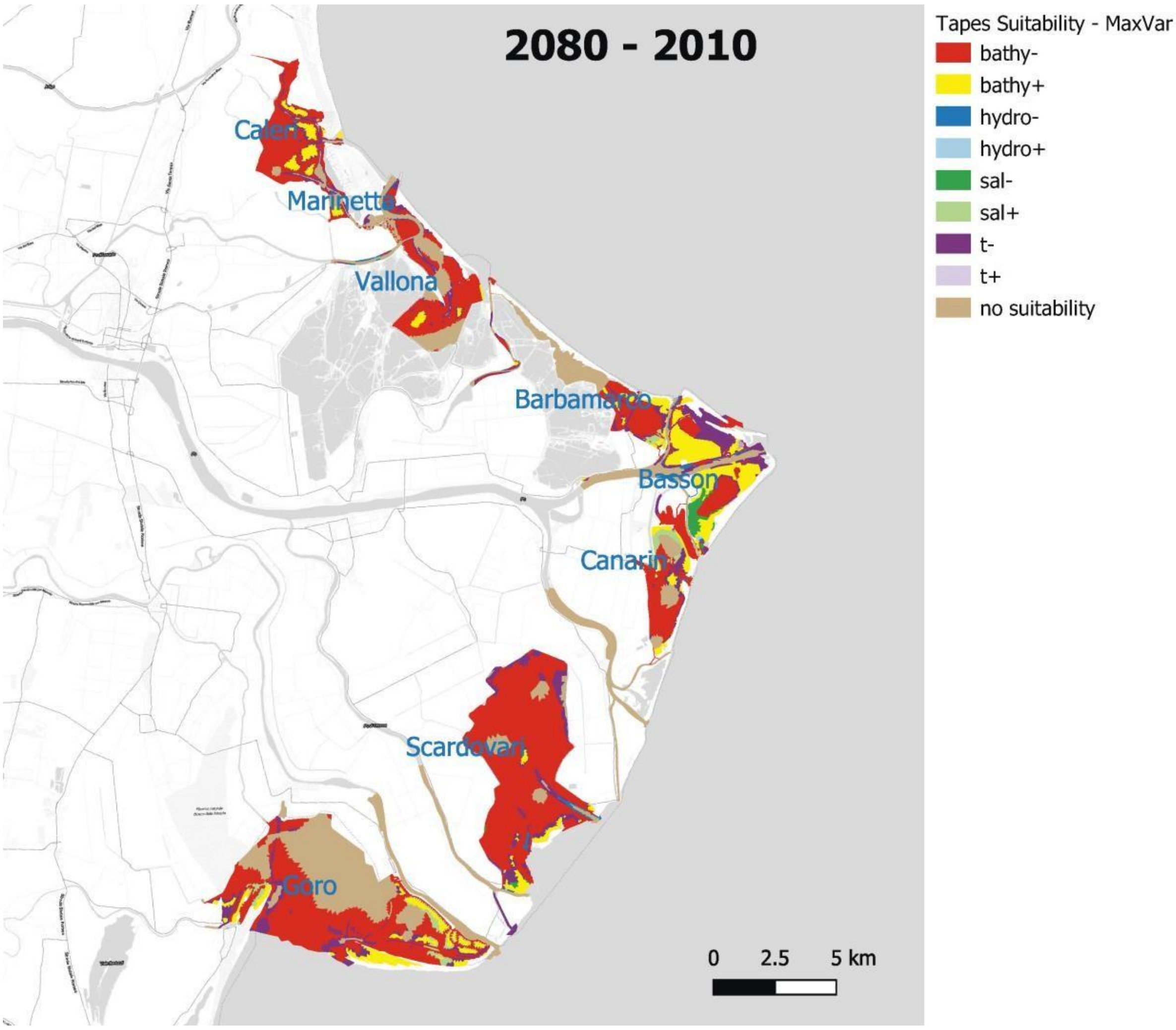



*Figure 21. Factors relevant for differences of Habitat Suitability for Manila clam between CC scenario (2080-2081) and present state (2010-2011)*

Excluding water depth (bathymetry), temperature (t) can be considered to be the second parameter in term of influence on the major suitability variation (Figure 22). In particular, a reduction of suitability is expecting related to RCP8.5 scenario with increase of temperature of 30 - 40% during winter and 20% during summer (see Deliverable 4.1).

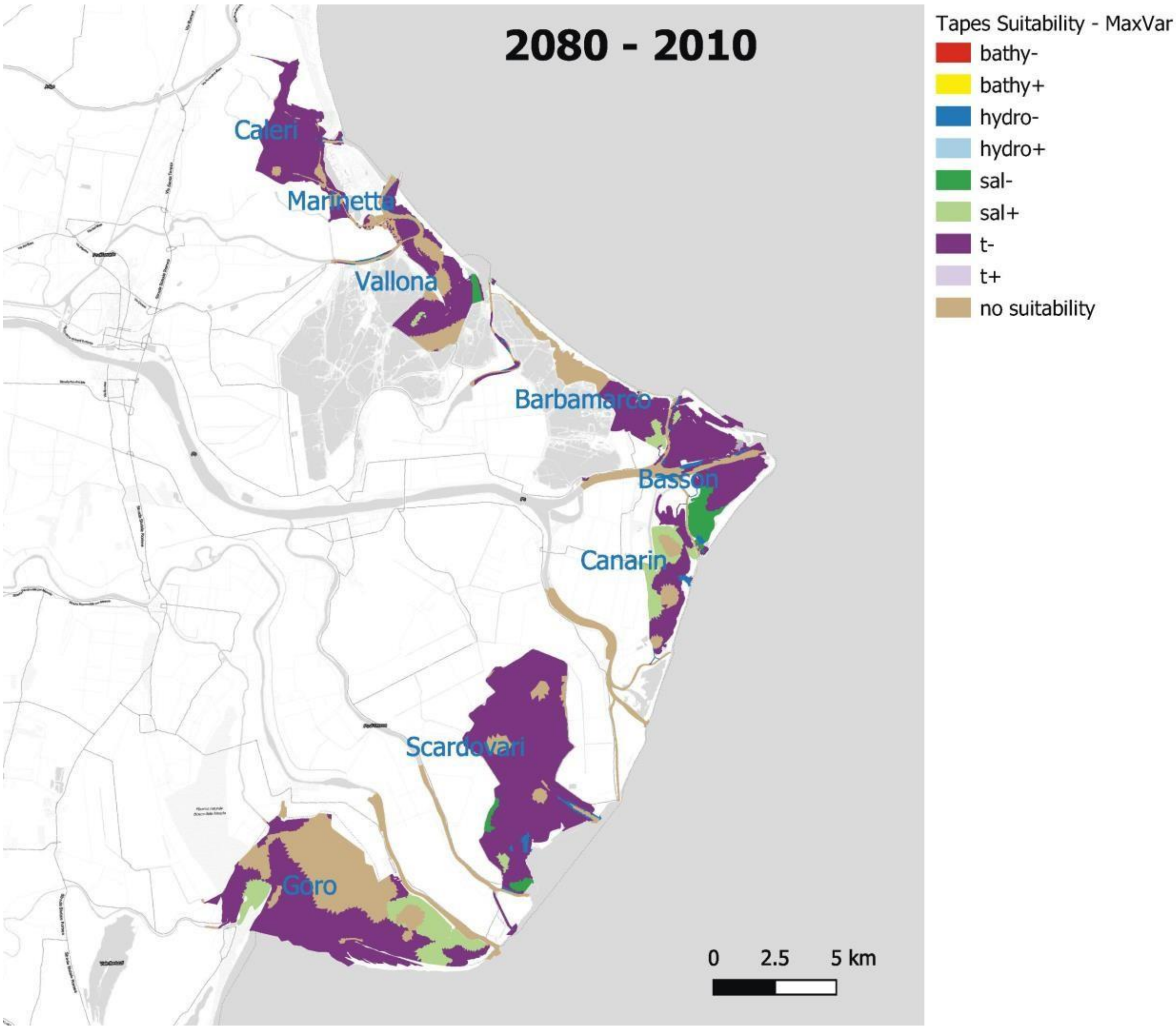



*Figure 22. Factors, excluding bathymetry, relevant for differences of Habitat Suitability for Manila clam between CC scenario (2080-2081) and present state (2010-2011). Temperature (t) is the second parameter in term of influence.*

### 3.4.2 Reedbeds HSM – climate scenario results

The projection of the suitable conditions for Reedbeds under future climate scenarios is presented in Figure 23. Differences between suitable conditions under future climate scenarios and present state can be appreciated in Figure 24.

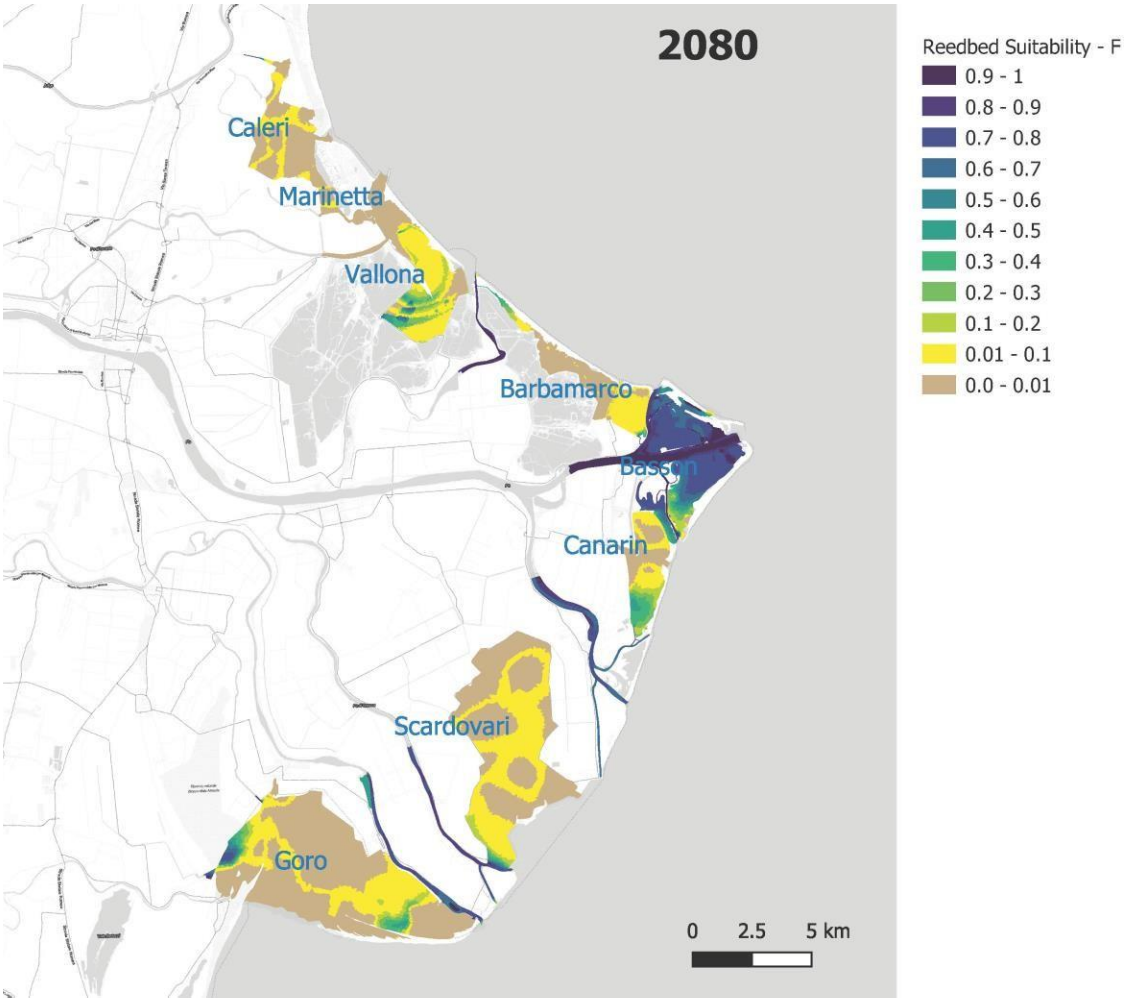



*Figure 23. Habitat Suitability (HSI) for Reedbeds in CC scenario (2080-2081). Suitability is expressed in term of Favourability (F).*

Generally, a reduction (-0.2 - 0) of suitability is reported at delta large scale, with stronger reduction at local scale, while a slightly increase (0 - +0.2) of suitability is shown in Scardovari (south-west) and in the south part of Basson (0 - +0.6).

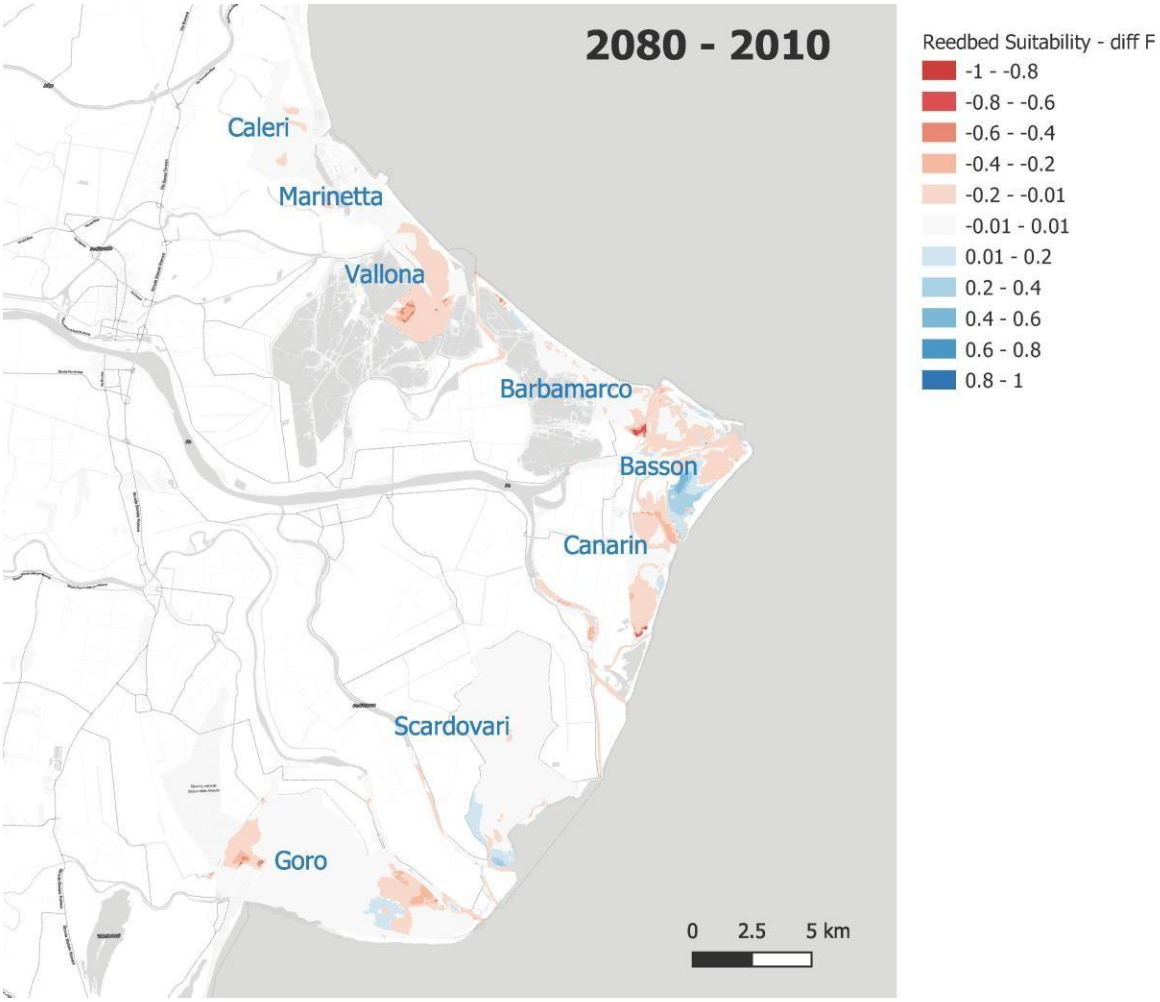



*Figure 24. Differences of Habitat Suitability (expressed in term of Favourability- F) for Reedbeds between CC scenario (2080-2081) and present state (2010-2011)*

On Figure 25 the main factors better explaining the differences of Habitat Suitability between CC scenario (2080-2081) and present state (2010-2011) are reported.

At Delta large scale, the most influential parameters for expected suitability changes are:

- decrease of suitability linked to the percentage of time with salinity lower than 15 PSU, linked to the increase in salinity (RCP8.5 average annual increase of less than 2%), and the percentage of time in submerged condition (annual average), possibly linked to the expected increase of water level (RCP8.5 Sea level rise - SLR of 0.63 m);

- increase in suitability located in the southern area of Basson and in the south-eastern area of Scardovari, influenced by the permanence at salinity below 15 PSU (as shown by the Hydrodynamic model, see Deliverable 4.1).

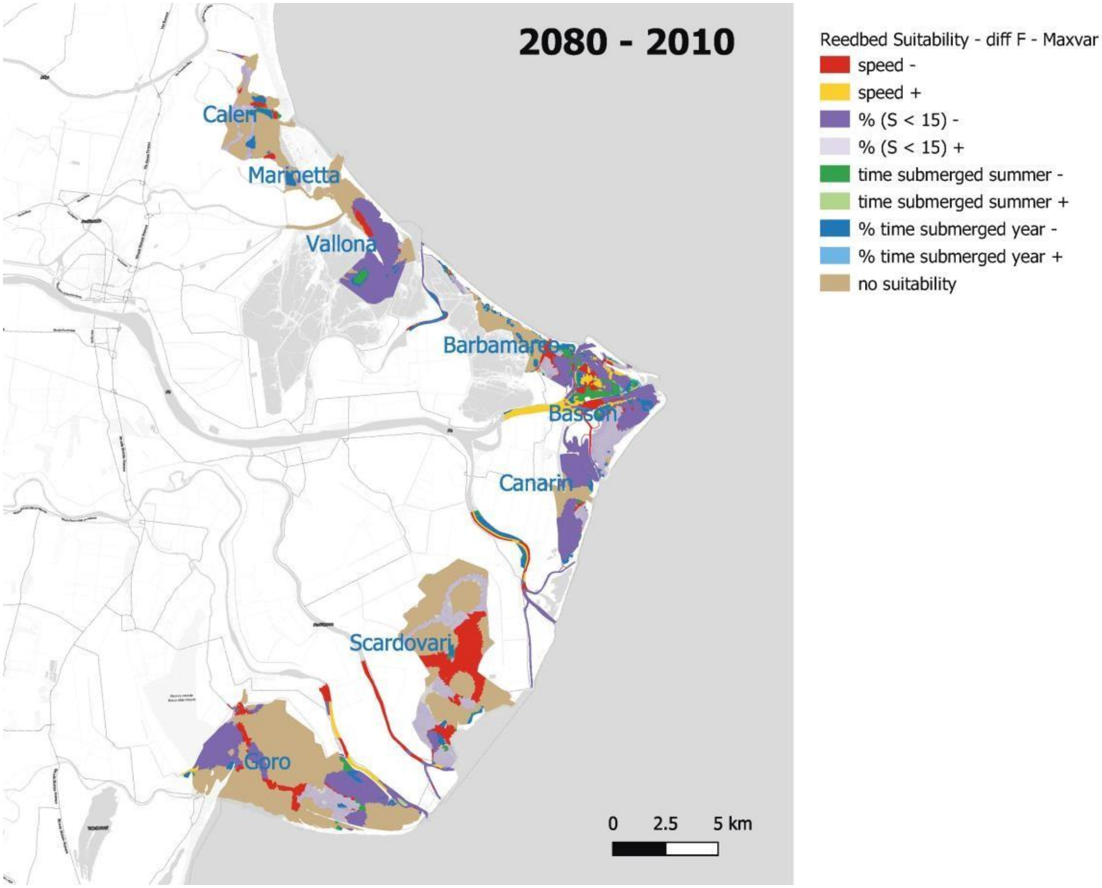



*Figure 25. Factors relevant for differences of Habitat Suitability (expressed in term of Favourability- F) for Reedbeds between CC scenario (2080-2081) and present state (2010-2011)*

### 3.4.3 Seagrass HSM – climate scenario results

The projection of the suitable conditions for seagrass (*Z. noltei*) under future climate scenarios is presented in Figure 26. Differences between suitable conditions under future climate scenarios and present state can be appreciated in Figure 27.

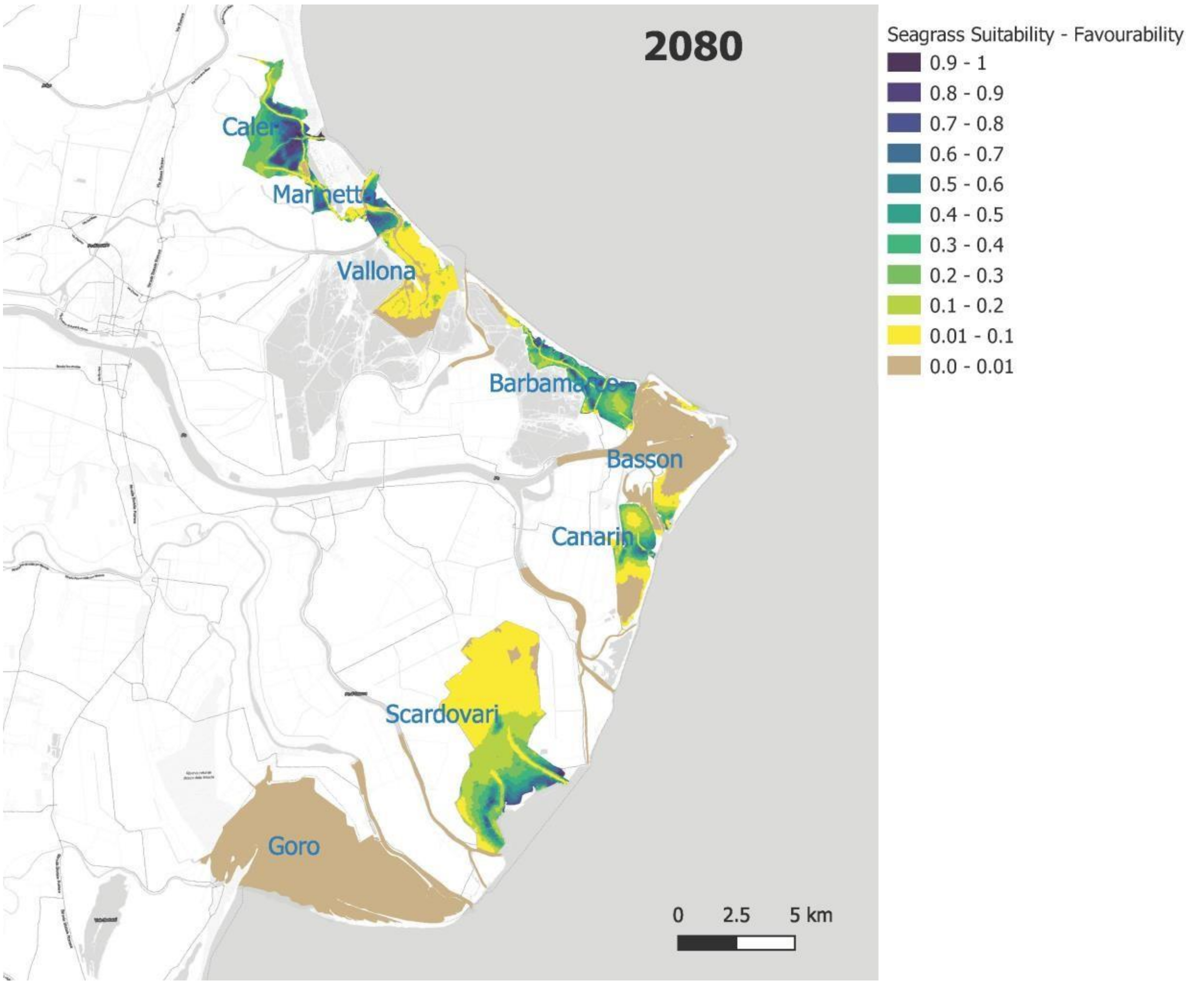



*Figure 26. Habitat Suitability (HSI) for seagrass in CC scenario (2080-2081). Suitability is expressed in term of Favourability (F).*

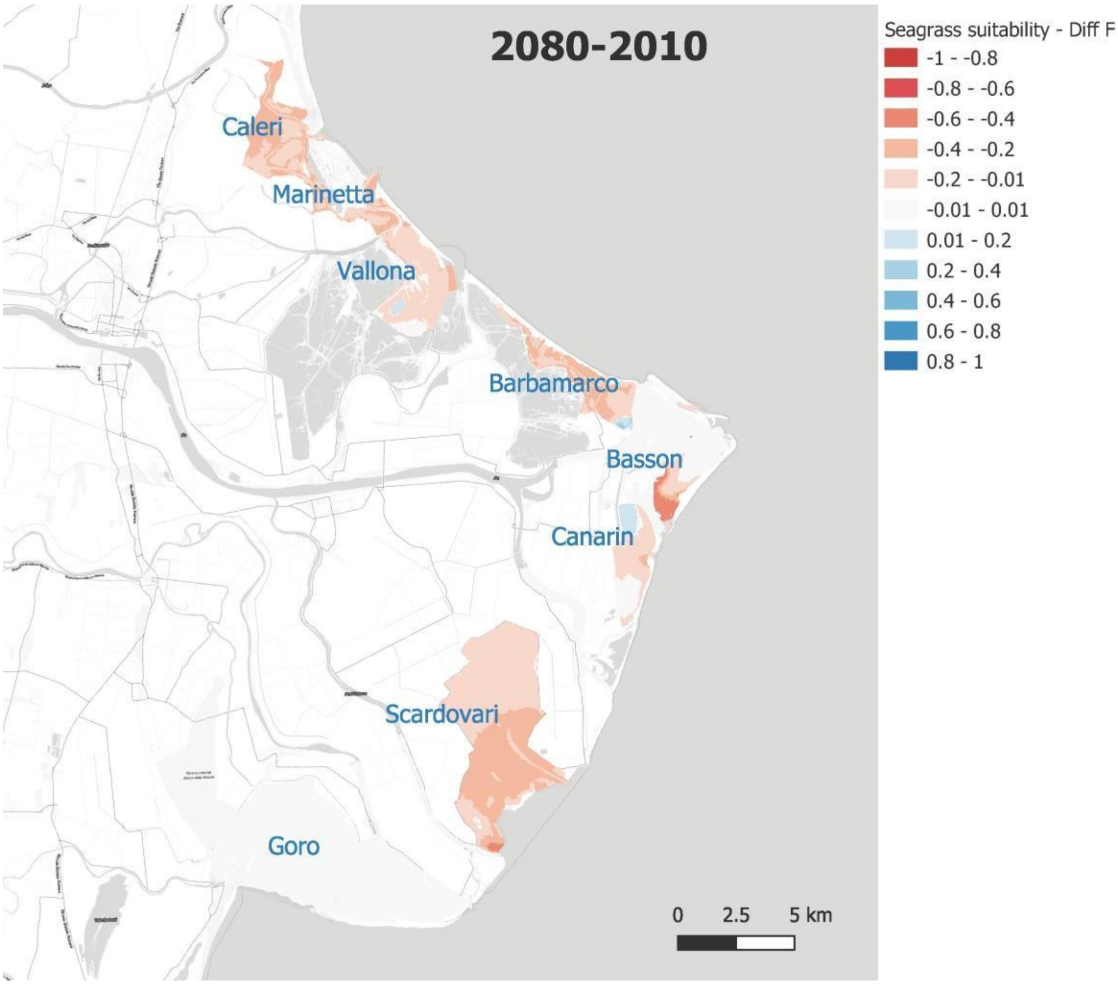



*Figure 272. Differences of Habitat Suitability (expressed in term of Favourability- F) between CC scenario (2080-2081) and present state (2010-2011) for seagrass*

A widespread decrease in suitability for seagrass (-0.4 / -0.2) is expected, more marked (-0.6 - 0.4) in the areas southwest of both Basson and Scardovari. A slight increase in suitability (0 - 0.2/0.4) is reported for localized areas in the southern part of Barbamarco and in the northern part of Canarin.

On Figure 28 the main factors relevant for the differences of Habitat Suitability for seagrass between CC scenario (2080-2081) and present state (2010-2011) are reported.

At delta large scale, considerations for the most relevant parameters for expected suitability changes are:

- widespread decreases in suitability related to the increase in water level (RCP8.5, SLR +0.63 m) and decrease in suitability located in the south-west areas of Basson and Scardovari related to the variation (decrease) of salinity (sal-, coherently with the results of the hydrodynamic model, see Deliverable 4.1);

- increase in suitability located in the southern part of Barbamarco and in the northern area of Canarin linked to the increase in salinity (sal+, coherently with the results of the hydrodynamic model, see Deliverable 4.1).

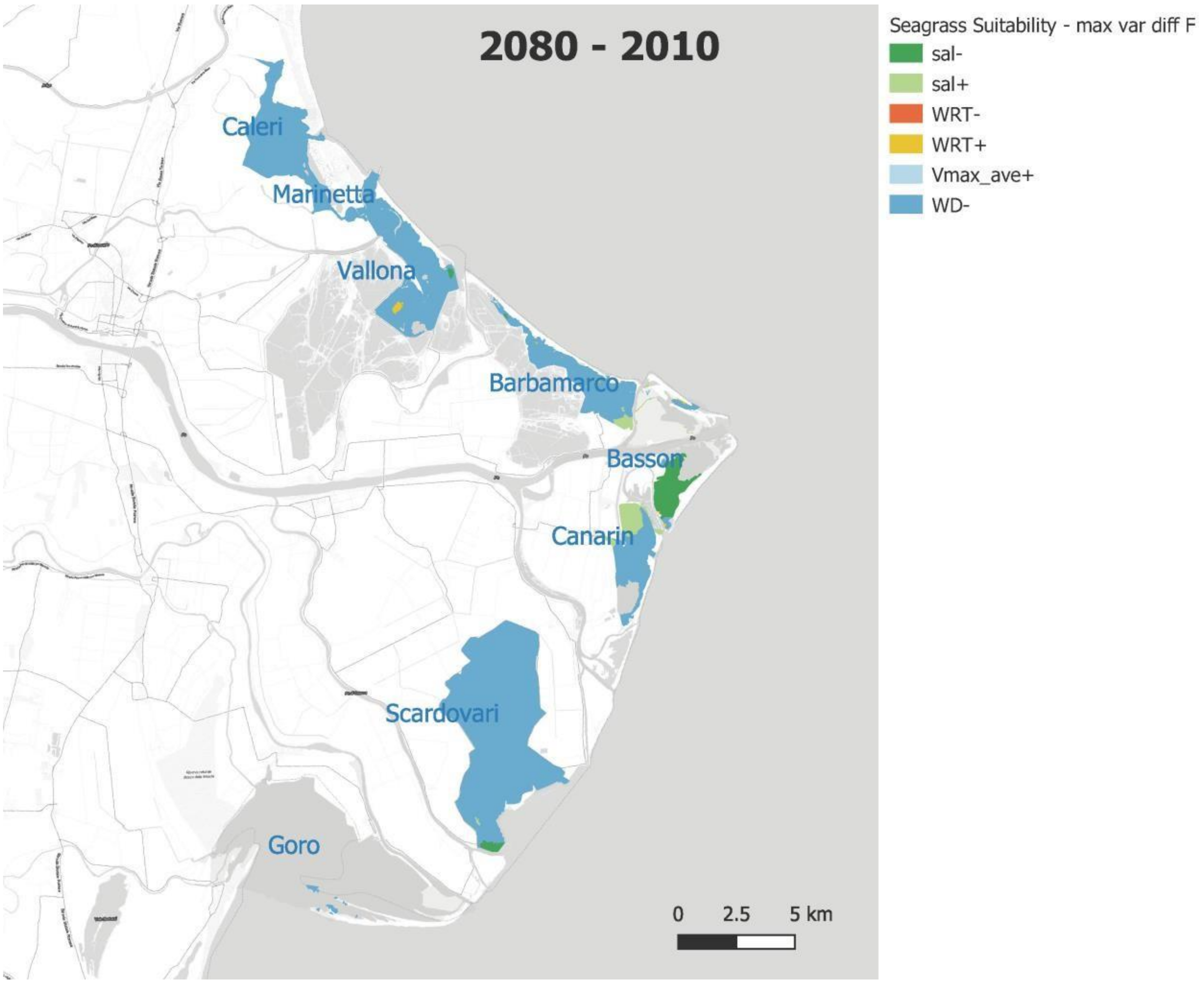



*Figure 28. Factors relevant for differences of Habitat Suitability (expressed in term of Favourability- F) between CC scenario (2080-2081) and present state (2010-2011) for seagrass. Salinity (sal), Water Residence Time (WRT), Current (Vmax_ave) and Water Depth (WD) give relevant positive/negative contributes to Suitability for seagrass.*

On Figure 29 is reported a representation of the most limiting factors among the ones considered for the Habitat Suitability of seagrass in CC scenario (2080). It can be seen that, a part form salinity, TSS (a proxy for turbidity) and current speed may be relevant limiting factors under future conditions.

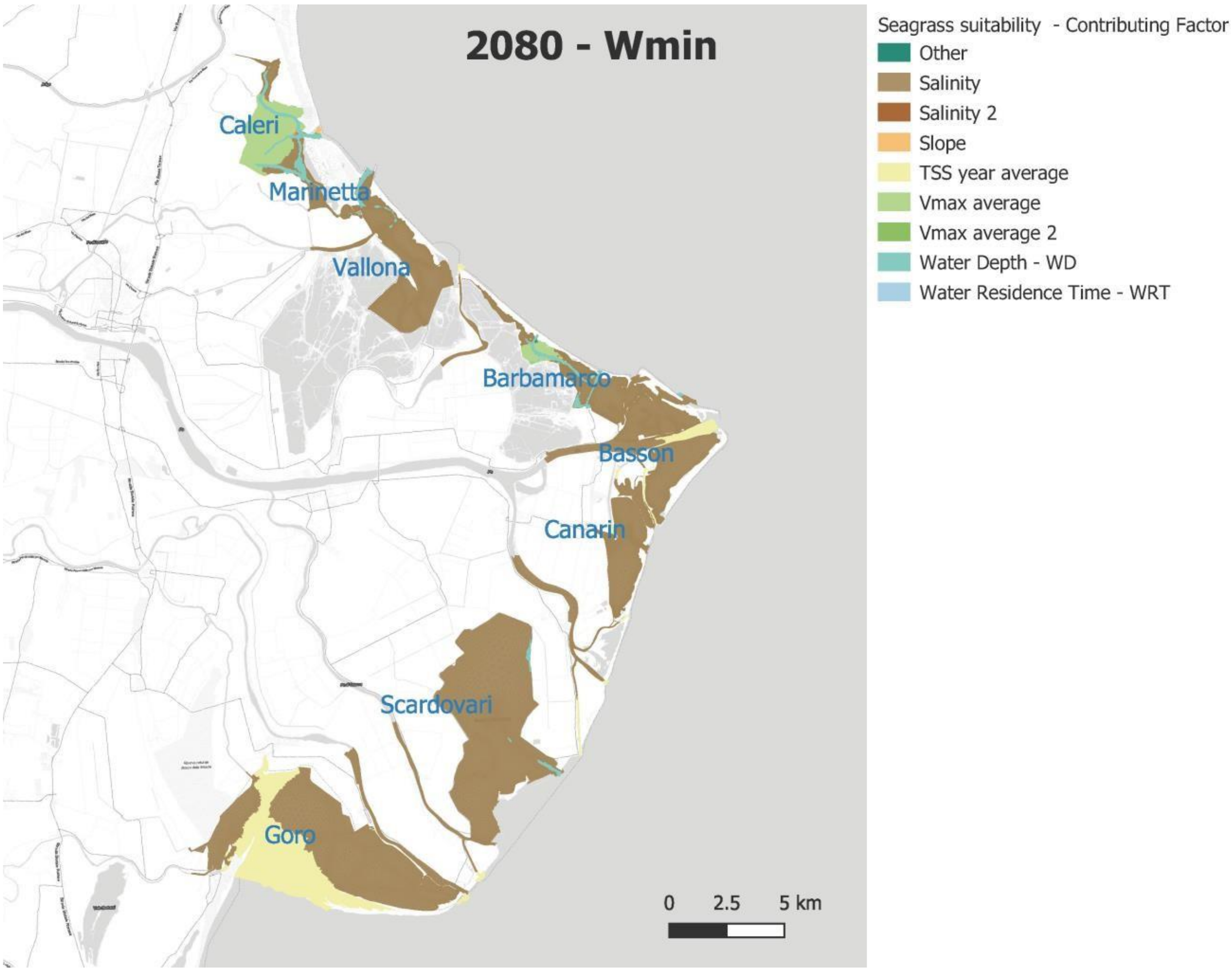



*Figure 29. Contributing factors relevant for the Habitat Suitability for seagrass in CC scenario (2080). The most limiting factors (Wmin) are reported.*

Qualitative "*what-if*" scenarios were built to investigate the possible effect of turbidity variations (± 40 % of TSS) on projection of suitability.

In Figure 30, the projection of the suitable conditions for Seagrass under future climate scenarios with a reduction of 40% of TSS is reported. Differences between suitable conditions under future climate scenarios with reduction of turbidity conditions (-40% TSS) and present state can be appreciated in *Figure 313*.

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Similarly, in Figure 32 is reported the projection of the suitable conditions for Seagrass under future climate scenarios with an increase of 40% of TSS. Differences between suitable conditions under future climate scenarios with increase of turbidity conditions (+40%TSS) and present state can be appreciated in Figure 33.

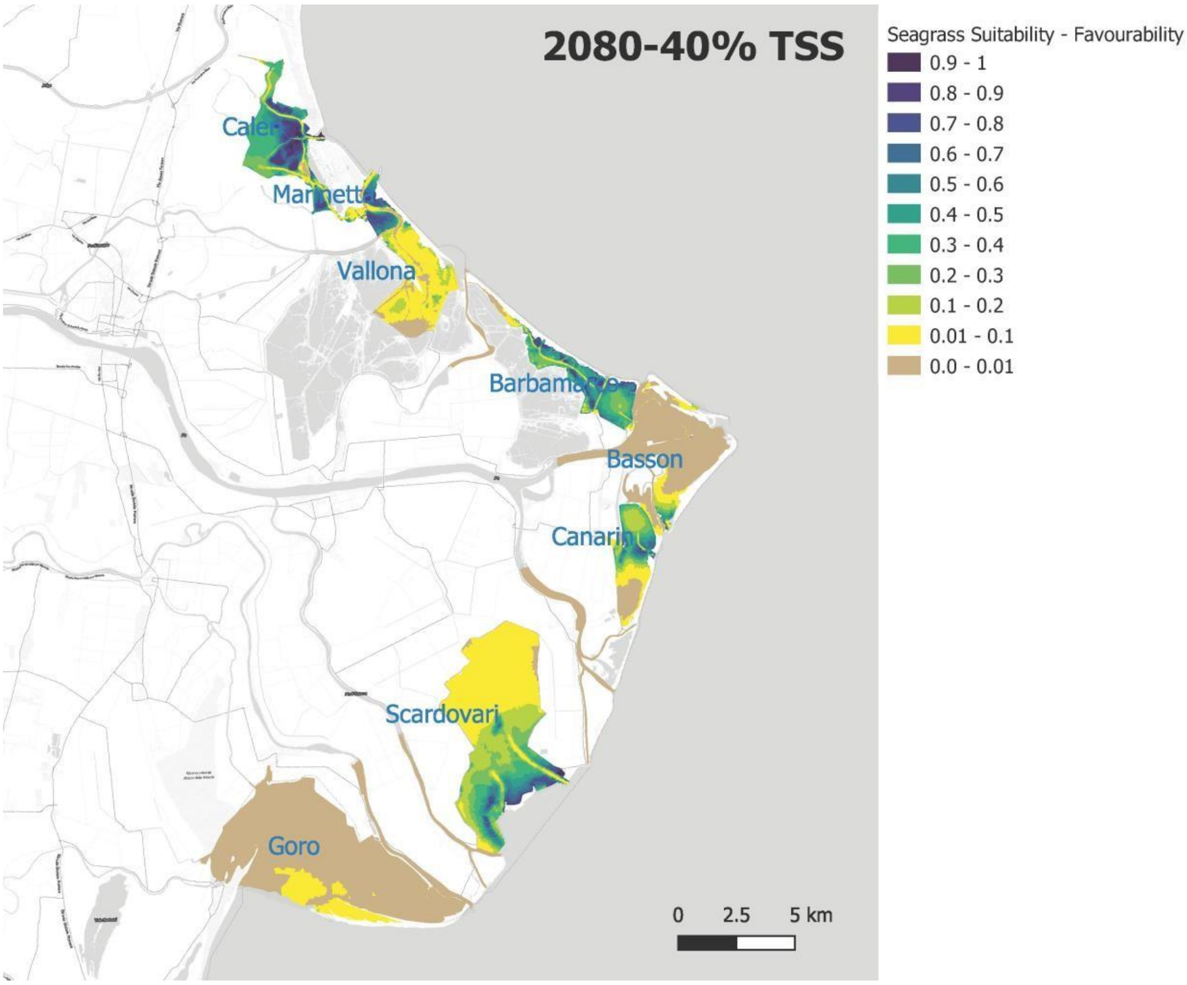


*Figure 30. Habitat Suitability (HSI) for seagrass on "what-if" scenario with variation of turbidity condition (TSS - 40%) on CC scenario (2080-2081) Suitability is expressed in term of Favourability (F).*

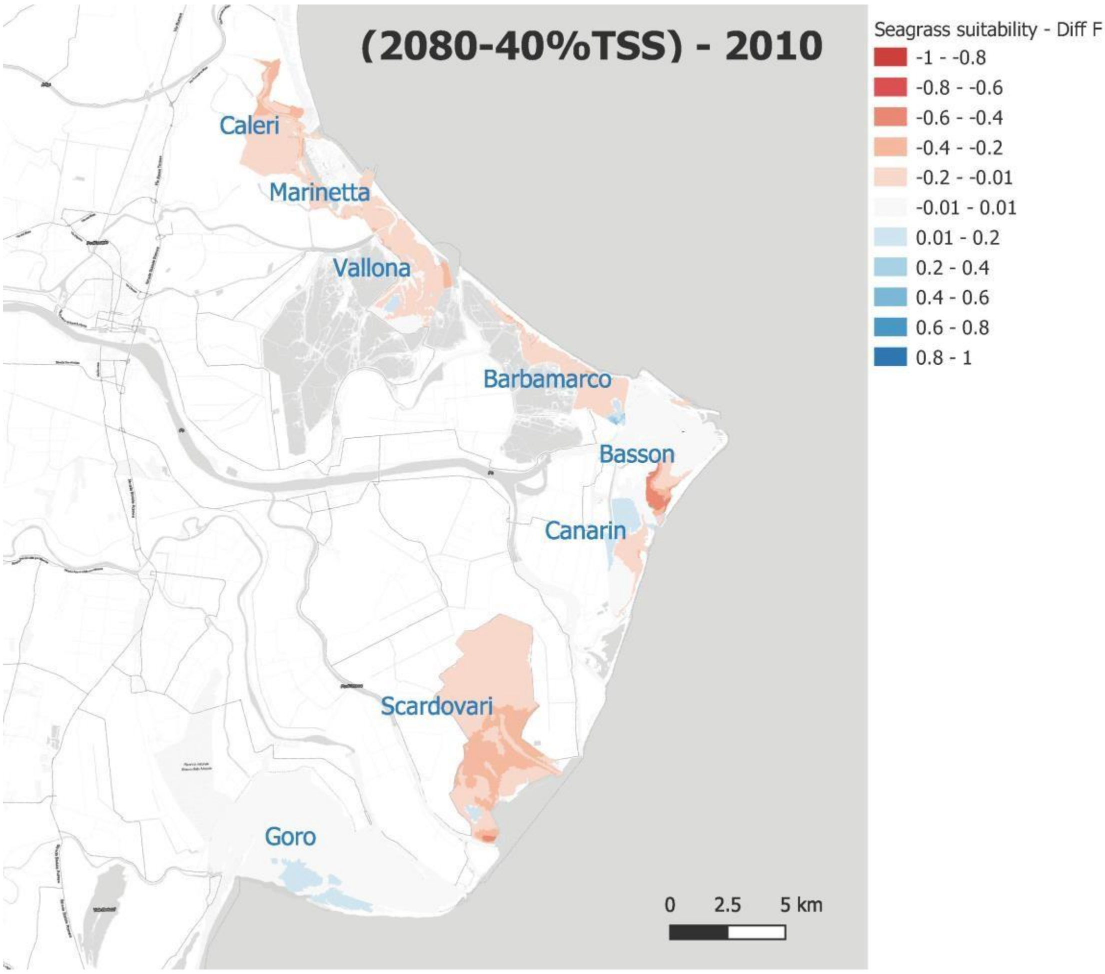


*Figure 313. Differences of Habitat Suitability (expressed in term of Favourability- F) for seagrass between CC scenario (2080-2081) - 40% TSS and present state (2010-2011)*

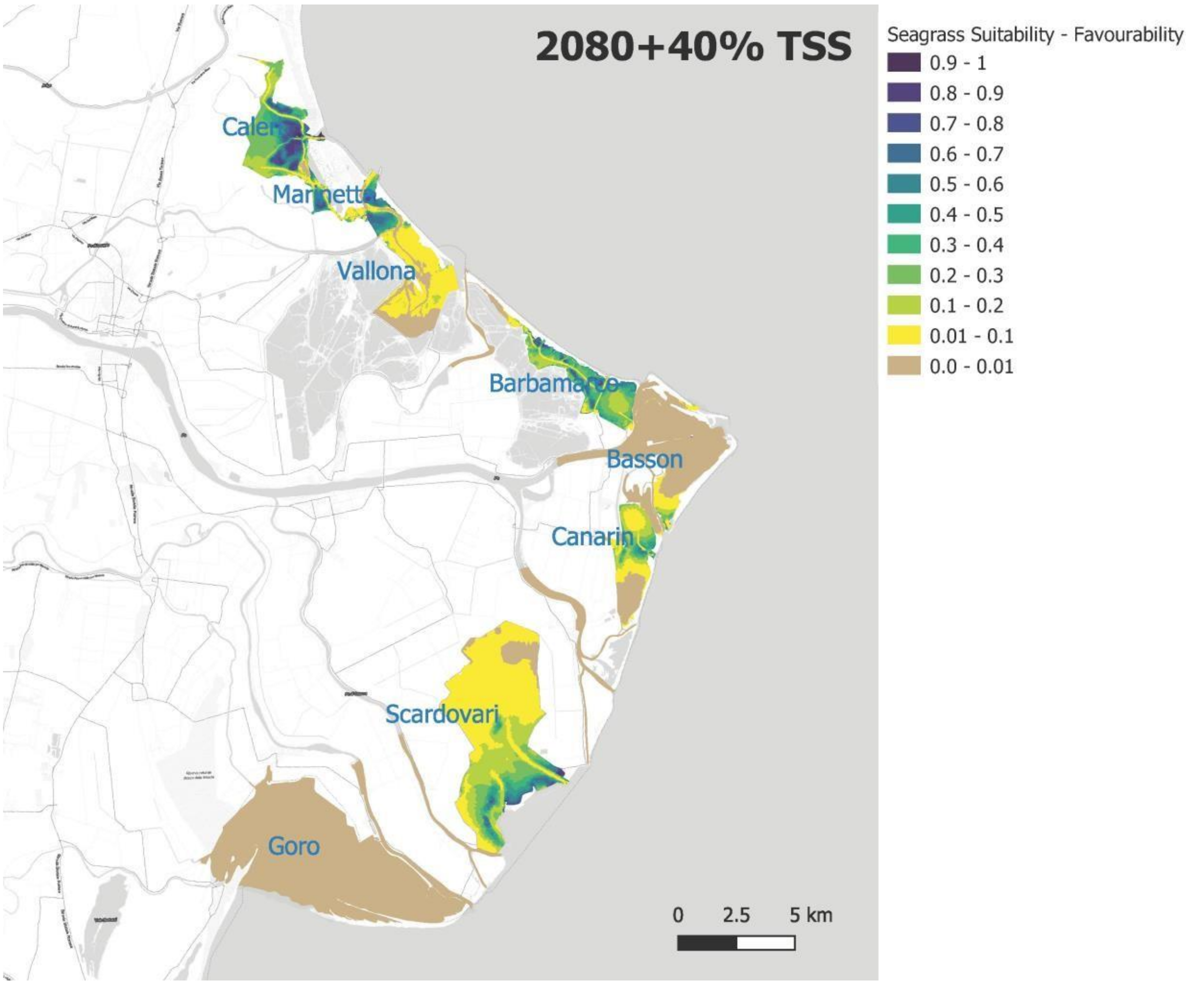


*Figure 32. Habitat Suitability (HSI) for seagrass on "what-if" scenario with variation of turbidity condition (TSS + 40%) on CC scenario (2080-2081)*

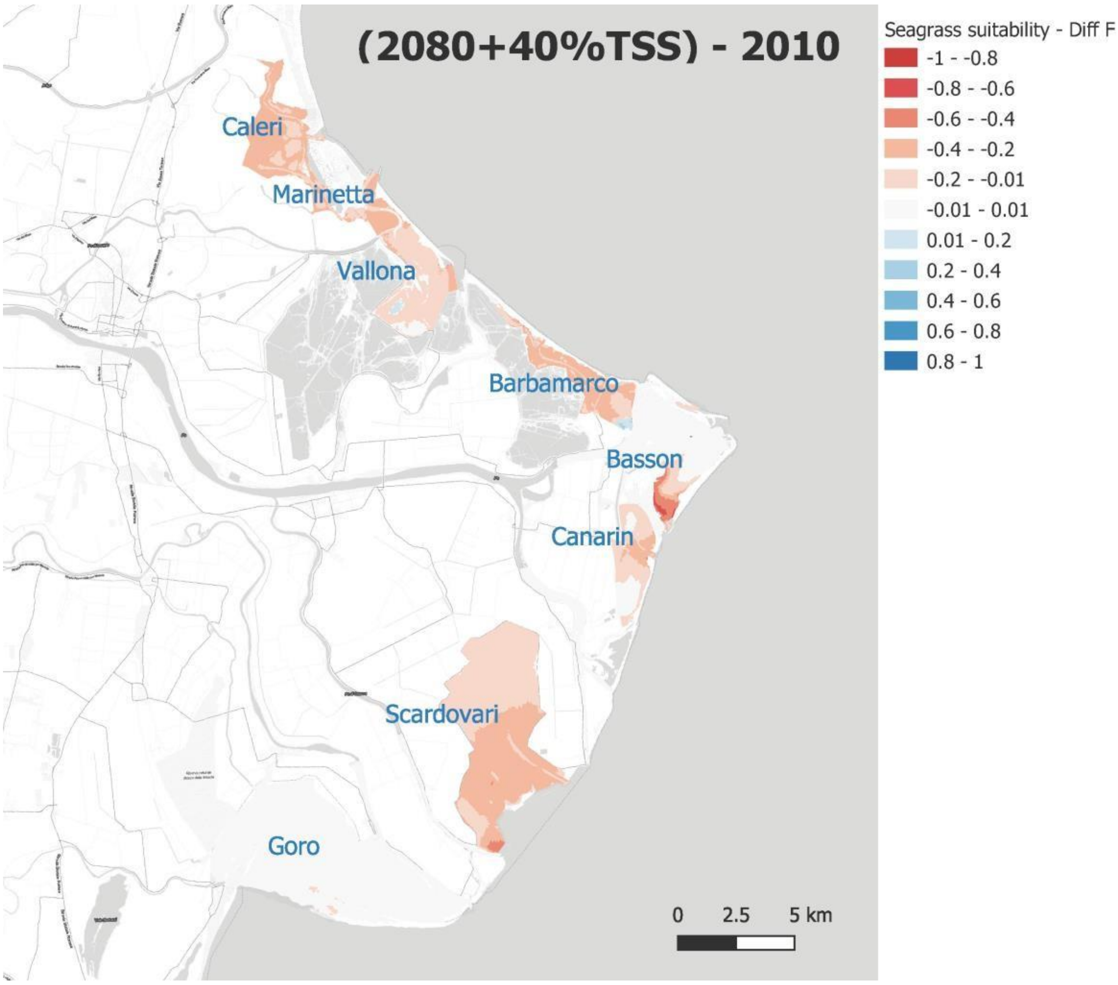


*Figure 33. Differences of Habitat Suitability (expressed in term of Favourability- F) for seagrass between CC scenario (2080-2081) + 40% TSS and present state (2010-2011)*

## 3.5 Conclusions about HSM application

In order to implement the application of Habitat Suitability Models, an homogeneous assessment was conducted at Delta-scale through an integrated analysis of available data.

The implementation of suitability models, specific to the study area, made it possible to evaluate the influence of the different environmental variables on the distribution of the target resource/species/habitat.

The presented models made it possible to assess the expected differences between the present scenario (2010-2011) with the climate scenario (2080-2100) in terms of habitat suitability.

The coupling with hydrodynamic models allowed a detailed description at the scale of the entire pilot site. The expected variability in space and time (e.g. seasons) of suitability for the presence of selected targets, related to different variables, was investigate through the presented methodology.

Once the target-specific model has been prepared and validated, it can be reapplied with new available data and used as a tool to support management decisions.

# 4. Conclusions

The use of models for projecting trends in mean annual temperatures and annual precipitation has proved useful for a more specific discussion of the future evolution of specific species and habitats (phytoplankton, zooplankton, macrophytes and fish) in relation to the salinity and turbidity of the water body.

In general, the application of the HSMs suggests that the environmental conditions expected in the 2080-2100 under the IPCC RCP 8.5 -described in D4.1- are going to negatively affect the three target species/habitat chosen as indicators for this Pilot site. It is interesting to note that 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 spatial patterns are not the same for the three targets and are characterised by local (lagoon basin- or sub lagoon- scale), where also substantial increase in environmental favourability can be observed. The water level rise within the Delta is – in general- the most detrimental variable, even if with a different role for the three targets.

From the work carried out it is clear that it is difficult to hypothesise scenarios on an Adriatic scale because at present the level of knowledge of the various pilot sites is very heterogeneous: in some cases it has been possible to develop evolutionary-conceptual scenarios (e.g. Vransko lake) and in others it has been possible to develop quantitative scenarios (Po delta). However, despite the heterogeneity of the data, some commonalities can be identified, for example with regard to recurring indicator species (seagrasses, reeds, birdlife, etc.) or the recurrence of important physical-chemical parameters (level, salinity, transparency). These commonalities could help to identify monitoring priorities for tracking CC impacts. Data from the present study are available at
https://owncloud.ve.ismar.cnr.it/owncloud/index.php/s/gEYW5U5z3cq1eip

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