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CHANGE WE CARE

EUROPEAN UNION

Report on present state and recent trends of coastal and transitional environments in the Adriatic Sea

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Summary

FOREWORD

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

1 INTRODUCTION: VULNERABILITY OF COASTAL ZONES TO CLIMATE CHANGE. IMPLICATIONS AND NEEDS FOR MANAGEMENT

Climate change is a global phenomenon affecting the whole Earth System and accelerating during the last decades, impacting different assets of human well-being (see for instance Bello et al., 2004; EEA Technical report N° 7/2005; Halpern et al., 2008; EEA, 2010d; Doney et al., 2011; Castellari and Kurnik, 2017). In Europe, likewise in other parts of the world, this brings consequences for human health, biodiversity, ecosystem services, and for social and economic sectors including agriculture, tourism, and energy production. Several climatic variables have reached new records in the last decades, and this trend will continue (possibly intensifying) if no countermeasure is implemented. European regions are experiencing different kinds of impacts (see Table 1, adapted from Castellari and Kurnik, 2017), coming along with a rise in maintenance and recovering costs of societal, natural, and economic networks (Nicholls and Hoozemans, 1996). Worth noting, not all the processes have the same implications in all regions, and the extent of their impacts depends on the interactions with the local characteristics of the territory.

European region	Impacts
Arctic region	Rise of air and sea temperatures Loss of habitats, flora, and fauna Marine ecosystem acidification Loss of traditional livelihoods from indigenous people Sea level rise
Boreal region	Increase of temperature (especially in winter) Increase of precipitation pattern Melt of snow Increase of winter storms Urban flooding
Atlantic region	Coastal and urban flooding Sea level rise Stronger storm surges Extreme precipitation events
Continental region	Increase of heat events Decrease of precipitation event (especially in summer)

	• Drought and forest fires events • River floods in winter and spring
Mediterranean region	• Decrease of precipitation • Increasing temperatures • Less water and crop yields availability • Loss of biodiversity • Changes in human health and well-being • Invasion of alien species • Increasing demands of energy • Relative sea level rise • Coastal erosion

Table 1: Climate change impacts in European regions adapted from Castellari and Kurnik, 2017

Coastal zones in particular are affected by a number of direct and indirect climate change impacts, mostly associated with sea level rise, modification of the precipitation regime, and changes in the meteo-marine regime. These induce increased flooding of urban areas, infrastructures and alluvial plains, increasing of salinity in estuaries and coastal aquifers, rising coastal water tables, and impeded drainage. Changes in sediment dynamics also can represent a major threat, with modification of the coastal landscape and possible coastal erosion. Considering that approximately one-third of the population lives within 50 km of the coast (EEA Technical report N° 7/2005), it is clear that such a heavy rearrangement of environmental processes is tightly intertwined with a modification of ecosystem functions and human activities, and ongoing changes claim for structured management strategies at different levels. Response to climate change is particularly urgent and challenging in the Mediterranean Sea, where a high environmental diversity and unique biotic and abiotic characteristics coexist, not seldom conflicting, with intensive anthropic pressure, evolving and conflicting socio-economical instances and political fragmentation in a framework of sharp ongoing changes. Long-lasting urbanization and intensive agricultural exploitation of naturally dynamic systems such as river deltas, lagoons and open coasts, though sustained by powerful economic drivers, is intrinsically bound to expose human assets to erosion, flooding and salt intrusion hazards, and potentially puts forward severe water management and pollution issues. Tourism sector, increasingly important throughout the northern Mediterranean coast, can exacerbate some of these threats if not addressed by dedicated management practices.

Due to its importance from the environmental, economical, cultural and societal points of view, the assessment and management of risk associated with climate change and the development of specific responses have become in recent decades a hot topic in the regional agenda. In this, general principles such as the importance of a solid support from scientific evidences and monitoring strategies, financial sustainability of the policies, and the active involvement of local stakeholders have been the common ground for a number of trans-boundary policy frameworks fostering the development of responses to climate change, as summarized in Table 2.

Policy framework	Brief description
INTERREG V B MED PROGRAMME 2014-2020	It aims to promote sustainable growth in the Mediterranean area by fostering innovative concepts and practices. It encourages also the sustainable use of natural and cultural resources and supports social integration. It explicitly refers to climate change adaptation in Priority n° 2.
EUSAIR	Beyond the others, one challenge refers to develop cooperation for joint management of common environmental resources as well as climate change and disaster risk management issues, for sustainable development of the Adriatic-Ionian Region. Climate change mitigation and adaptation, as well as disaster risk management, figure as a horizontal topic relevant for all 4 pillars of the strategy.
UNEP Mediterranean Action Plan (UNEP-MAP)	The contracting parties to the Barcelona Convention aim to meet the challenges of protecting the marine and coastal environment while boosting regional and national plans to achieve sustainable development.
UNEP-MAP Mediterranean Strategy for Sustainable Development (MSSD)	Among its objective, for the 2016-2025 period, there is “Addressing climate change as a priority issue for the Mediterranean” and include a wide number of actions.
Protocol on Integrated Coastal Zone Management (ICZM Protocol)	Promoted and implemented by the Barcelona Convention, it includes actions for climate change adaptation along with the coastal system.
Union for the Mediterranean (UfM)	A multilateral partnership established in 2014 a Climate Change Expert Group to foster the exchange of information and best practices across the Mediterranean region.

Regional Climate Change Adaptation Framework for the Mediterranean Marine and Coastal Areas	This document aims to build a common regional strategic approach to increase climate resilience and adaptation capacity.

Table 2: Policy frameworks in the Mediterranean area, information collected from https://climate-adapt.eea.europa.eu/countries-regions/transnational-regions/mediterranean, last visited: 28/08/2020

As shown in Table 2, during recent years there was an increase in national and local adaptation strategies in Europe for further research, awareness-raising, and/or coordination and communication for implementation of measures against climate change and its effects. The implementation phases focused on disaster risk reduction, environmental protection, spatial planning and coastal zone and water resources management. A key requirement for any approach undertaken for the development of integrated measures of mitigation and adaptation of climate change is that effectiveness, efficiency, and coherence are considered into the various levels of governance. Every measure and policy must envisage national, regional, and local strategies and plans to be tailor-made on the territorial needs. Thus there is no universal planning recipe, and not every plan can be implemented in any coastal area, as climate change and relative risks are strongly related to geographical characteristics. For this reason, it is more efficient to carry out all the climate and socio-economical analysis at local or regional level (Torresan et al., 2012).

The Adriatic Sea, with its composite geographical, ecological, socio-economical and political setting is a suitable workbench for framing a planning paradigm allowing to adapt general policy-making principles to site-specific needs and constraints. Overcoming boundary limitations in the creation of easily exportable planning strategies up to the Mediterranean scale is the main goal of CHANGE WE CARE. In this perspective, the present deliverable aims at providing an overview of the main achievements of the multidisciplinary activities carried out within the Project, with particular reference to Work Package 3. The idea is to introduce the non-expert readers to the main features of present state and recent trends of environmental dynamics in the Adriatic Sea and its paradigmatic pilot sites, as well as to provide some guidance for those subjects who need to actively elaborate the knowledge base made available within the Project.

After a brief review of the main evidences emerging from the previous activities, we will provide some deeper insight on the most critical processes associated with the impacts of climate change on the Pilot Sites and their mutual interactions. On this base, we will present an interdisciplinary assessment of ongoing environmental processes focusing on some reference habitats of particular interest, analysing the relations between studied species and environmental conditions, identifying the relevant variables, the possible knowledge gaps and the priorities for further data collection and monitoring. This will pave the way to upcoming formulations of habitat dynamics in climate change scenarios, to be delivered by CHANGE WE CARE as an outcome of Activity 4.3.

In order to foster the creation of a shared knowledge base and the use of common information, the final section of this document will be dedicated to the introduction of the data set made available by CHANGE WE CARE and of some tools for their analysis.

2 STATUS AND RECENT TRENDS IN COASTAL AND TRANSITIONAL ENVIRONMENTS IN THE ADRIATIC SEA

In the present Section we summarize the main processes taking place in the Adriatic Sea and how they affect the current status and recent trends in the coastal environment dynamics, with a focus on the Italian and Croatian coasts.

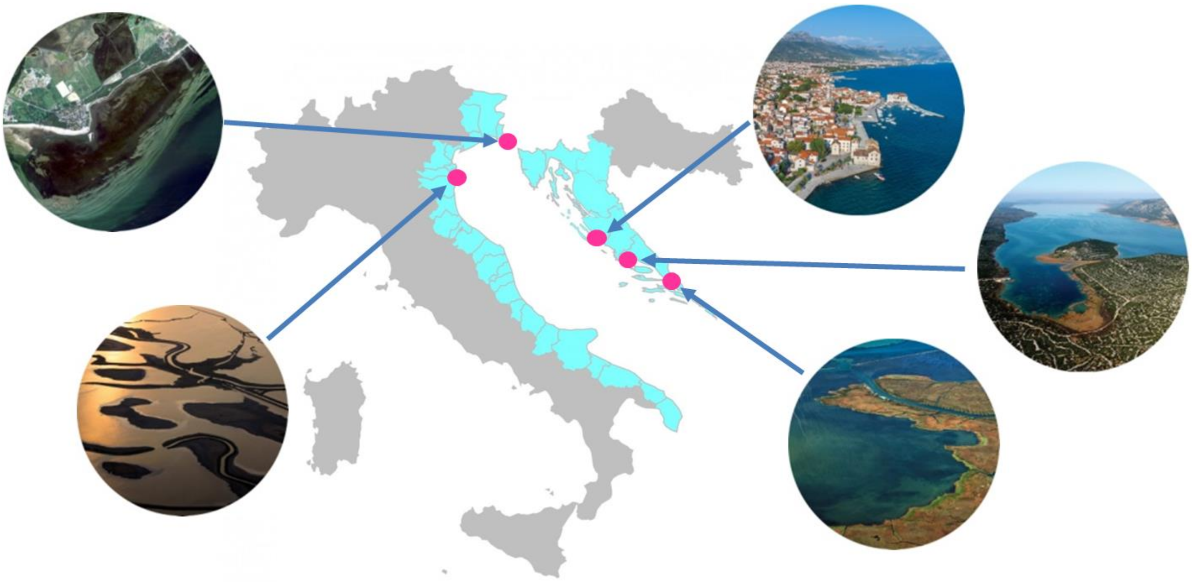

Figure 1: Map showing the Adriatic Sea, the position of the Pilot Sites, and for each pilot site one image representative of the local environment

Different aspects of this topic have been addressed in detail by Activities 3.1 to 3.4 of CHANGE WE CARE (Table 3), where available data from observations and numerical models have been collected and analyzed (or specifically produced, when this was relevant and feasible). The studies undertaken in the framework of these activities address both basin-scale processes and assessments at the scale of the Pilot Sites. Not unexpectedly, this endeavor highlighted a significant heterogeneity in the presence, coverage and availability of the data: a reorganization of the knowledge base and the identification of priorities for further investigations are indeed among the main scopes of CHANGE WE CARE. Climate change is leading to important effects on the Adriatic region, including impacts in terms of sea-level rise, alteration of the meteo-marine climate, and saltwater intrusion. Direct and indirect implications on the environmental dynamics include the modification of habitats such as deltas, low-lying islands, wetlands, and species distribution. The strong anthropic pressure along the Adriatic coasts tends to intensify the pressure on these environments, directly adding stress factors or indirectly limiting the possibility of the system to naturally adapt to the ongoing changes.

Prior to framing an interdisciplinary view of the interactions and feedbacks governing coastal and transitional zones in the Adriatic Sea, this Section aims at providing a synthetic outline of the main evidences emerging from the specialized studies, with a focus on climate-driven changes. For further details, the reader is referred to the specific Deliverables listed in Table 3: specialized CHANGE WE CARE activities and deliverables on status and recent trends of Adriatic coastal processes.Table 3. An overview of the data used and made available within the Project is accessible at the CHANGE WE CARE webGIS (https://gis.changewecare.geof.hr/).

Activity Number/Title	Deliverable Number/Title	Available at
3.1 Hydrological, thermohaline physical and meteo-marine climate setting	3.1.1: Report on present state and ongoing climate changes at Adriatic and local scale.	https://www.italy-croatia.eu/documents/279156/0/3.1_IOF_Present_state_and_changes_at_Adriatic_and_local_scale_v1+%281%29.pdf/cb2364ff-d985-f24a-eabb-594c381e0591?t=1582647755085
3.2 Geological and geomorphological setting and recent history	3.2.1: Pilot areas geomorphological maps	https://www.italy-croatia.eu/documents/279156/0/3.2_RDV_D3.2.1__Pilot+areas+geomorphological+map_rev.pdf/02261cd1-a210-280e-bba4-6a6aebec7f97?t=1614604207922
	3.2.2: Technical report on sediment stocks in the alluvial coastal systems	https://www.italy-croatia.eu/documents/279156/0/3.2_RDV_D3.2.2_Technical+report+on+sediment+stocks_rev.pdf/98102814-dff9-

		b56b-dfdc-e640089958df?t=1614604528566
3.3 Characterization of water and sediment fluxes from the mainland	3.3.1: Report on water and sediment fluxes in the Pilot Sites.	https://www.italy-croatia.eu/documents/279156/0/3.3_PP10_VRANPARK_D3.3.1_Water_and_Sediment_Fluxes_final.pdf/9d07bf18-117e-e011-fa01-52553ab5204e?t=1606148191754
3.4 Habitats and biodiversity mapping and aquatic ecological quality elements: status and trend	3.4.1: Report on existing data and relative gaps	https://www.italy-croatia.eu/documents/279156/0/3.4_PP3_ISPRA_D3.4.1_Report_on_existing_data_and_relative_gaps_final.pdf/1cb4c716-8cb5-4064-e769-b45971e4baca?t=1606150485734
3.5 Relationship between hydro-morphological factors and intertidal and transitional habitats	3.5.1: CHANGE WE CARE WebGIS	https://gis.changewecare.geof.hr/

Table 3: specialized CHANGE WE CARE activities and deliverables on status and recent trends of Adriatic coastal processes.

The Adriatic Sea is a semi-enclosed basin located in the northeastern part of the Mediterranean and elongates from North-West and South-East encompassed by the Apennines to the West, by the Alps to the North and by the Dinarides to the East, and connected to the Mediterranean Sea in the South by the Otranto Strait. The basin is characterized by a broad continental shelf, with a mean depth of 35 m in the north mildly sloping to around 200 m in the central sector, edging the abyssal zones of the Southern Adriatic Pit with a depth exceeding 1200 m. A general assessment of the state-of-the-art of geological and geomorphological aspects and recent evolution of the Adriatic coastal areas was carried out in the framework of Activity 3.2. The resulting picture has been achieved by collecting the available information and elaborating historical maps, aerial photos, satellite images, and topographic surveys.

The Adriatic region appears as an independent microplate within Africa – Eurasia collision zone, which broke away from the African plate and was deformed during the Alpine orogeny when colliding with the Eurasian plate. From the geological point of view, the Adriatic basin is a foreland of the Apennines and the Dinaric chains, characterized by a continental crust with 30-32 km thickness reducing to 24 km towards the South. This configuration results mainly from depositional processes and thanks to glacio-eustatic oscillations occurred during the Quaternary period. The succession of glacial and temperate phases have caused strong fluctuations of the sea level, inducing sequences of deposition and erosion. During the last interval between glacial eras, the sea level low stand permitted a significant and generalized change in the structure and the continental margins. After the Last Glacial Maximum (LGM

.ca 25.000-18.000 years Before Present), another phase of sea-level rise took place bringing to a marine transgression, extending the surface of the basin, and ultimately establishing high-stand conditions in which new depositional processes took place. In this relatively recent period, the western and eastern sides of the Adriatic basin followed parallel evolution pathways. While fluvial sediment accumulated into a thick and relatively continuous mud prism along the western coast, marine transgression drowned the karst reliefs bordering the eastern coast, forming a complex pattern of islands, islets and indented coast. This different geological background led to a likewise variable coastal morphology throughout the basin. The western coast is almost completely alluvial or terraced, dominated by riverine clastic sediments, intermingled with deltas, lagoons, and low-energy tidal environments, and backed by low-lying alluvial plans. The eastern coast is mostly characterized by rocky coasts and cliffs, mainly composed of sedimentary rocks (limestone, dolomite, and carbonate breccias, bauxite, marl, siltstone, sandstone) and in some cases also by Quaternary sediments, characterized by low sedimentation rates, due to karstic hinterland and small sediment supply from the rivers.

One of the most relevant processes controlling the decadal- to centennial-scale geomorphological evolution the Adriatic coast is given by vertical land movements, which is the result of the combination of tectonic processes, isostatic adjustments, and soil compaction. The latter plays a major role in particular in alluvial sedimentary systems morphodynamics, being subsidence one of the main ingredients of the coastal landscape formation. The Lagoon of Venice and the Po Delta are strongly affected by this process, in both cases undergoing the effects of natural as well as anthropogenic dynamics. In these sites, the subsidence rates prior to the industrial development were estimated respectively as 1.2 mm per year and 2.5 mm per year. After the industrial period, due to the intensive exploitation of aquifers and the extraction of gas, these values increased up to 30 cm/y in the inner part of the Po delta, and 1 cm/y and 1.5 cm/y respectively in Venice and its industrial area. After some restrictions, the rates have been brought back to 5 mm per year (Teatini et al., 2011; Interreg IIIB CADSES - Project Monitor). This phenomenon is not limited to the Italian coast only: the Neretva river delta also suffers from soil loss due as a cause of land subsidence in the presence of sediment shortage conditions.

The current state and recent trends of meteo-oceanographic dynamics have been explored in the analysis carried out in Activity 3.1, leading to the production of a report and a thematic dataset.The existing knowledge has been assessed based on available literature and data from long-term records of atmosphere, hydrosphere, and ocean in-situ measurements, as well as on multi-decadal, high-resolution, atmosphere-ocean climate model runs. For the latter, information has been processed at the basin-scale and extracted in the proximity of the pilot sites, also including dedicated downscaling applications, where possible, in order to obtain a more detailed picture of the ongoing processes. The characterization of sediment and water fluxes, crucial for understanding hydrological, geomorphological and ecological dynamics in the study area, has in turn been the focus of Activity 3.3, which put together evidences from the available data from the whole basin and in particular from the pilot sites.

Due to its geographical setting, the classification of the Adriatic Sea includes different zones, from a humid subtropical climate in the northern half to a hot-summer Mediterranean climate in the southern one, the latter strongly influenced by European mainland processes. This basin receives the freshwater discharge from rainy hydrographical catchments, thus collecting approximately 1/3 of the overall load of the Mediterranean. Depending on the latitude and the season, precipitation regimes vary, following a pattern of increase during autumn and winter and at higher latitude, and decreasing gradually during summer and while moving to the South. Precipitation rates also vary longitude-wise, with higher values along the western coast due to local cyclogenesis in the presence of coast-parallel mountain ridges (Poulain and Raicich, 2001). This pattern, combined with the different geological setting, results in a strong difference in freshwater inputs between the western and the eastern coast of the Adriatic sea. Italian catchments provide more than 50% of the overall Adriatic freshwater supply, mostly delivered by Po and other rivers, whereas the input from the Croatian coast is estimated between 15 and 19%, with a significant fraction provided by groundwater fluxes (Sekulić and Vertačnik, 1996; Gačić et al., 2001a; Orlić, 2001), and only a small amount inflowing from the Croatian river, with the exception of Neretva (among the main contributors in the Mediterranean, see Ludwig et al., 2009). A precise assessment and monitoring of the hydrological regimes of the karstic river studding the Croatian coast is technically difficult, and only partial information is available. Nonetheless, groundwater discharges play a fundamental role in the maintenance of coastal brackish and wetland habitats and in contrasting salt intrusion in coastal aquifers.

Sediment supply only partially reflects the distribution of freshwater inflow in the Adriatic basin. Due to the differences in catchment geometry, topography, and lithology, most of the sediment input is concentrated along the north-western (draining the alpine catchment and the Apennine tributaries of the Po river) and the south-eastern (draining the small and steep Balkan basins of Albania) coasts. The importance of small Balkan rivers in the sediment budget of the Adriatic Sea has been increasingly acknowledged in recent years (see Milliman et al., 2016), but the actual extent of their contribution is still poorly known. In fact, steep basin topography, erodible soils, and short hydraulic response time of the Albanian basins lead to a sediment transport regime characterized by impulsive and extremely intense floods, but a sound description of this kind of episodes requires a continuous high-frequency monitoring, which only very recently has been pursued.

Sediments from these different "supply hot-spots" are also subject to different destinies. Sediment coming from the north-western basins reach a broad and shallow epicontinental basin, where they can be easily redistributed by the basin-scale coastal circulation. In turn, floods from Albanian rivers deliver high concentrations of sediment on a very narrow continental shelf, easily triggering turbidity currents that convey through the continental slope a significant amount of the incoming material.

Metocean processes in the Adriatic basin are controlled by Sirocco, a southeastern wind blowing along the main axis of the Adriatic, and Bora, a cold and dry northeastern wind blowing from the orographic gaps in the Karst and the Dinarides. Due to its orientation, Sirocco is the main responsible for severe storms hitting the north and eastern coasts of the Adriatic Sea, giving place to high waves and piling up water masses along the northernmost regions of the basin. This mechanism, combined with the suction enacted by atmospheric lows (so-called “reverse barometer”), the resonant oscillations of the water level (seiches) and the effect of tides, is typically the responsible for intense storm surges impacting the coastal defences and exposing urban systems and infrastructures to extensive flooding. While Sirocco storms are strongly related with cyclogenesis at the Mediterranean scale, Bora is the result of different processes and blows along jets across the basin, leading to sea states characterized by relatively short and less organized waves (known as “wind seas”) impacting the Italian coast. Bora is also the trigger for “dense water formation”, namely the densification of water masses in the northern Adriatic Sea by cooling and evaporation (and subsequent salinization). These water masses, set into motion by wind and by their dynamic imbalance with the surrounding water, move close to the sea bottom along the Italian coast, crossing the continental shelf and ultimately descending into the Southern Adriatic Pit, thus bringing oxygen and nutrient in the deepest regions of the basin and contributing to the Mediterranean thermohaline circulation (Benetazzo et al., 2014). The Adriatic Sea is the major source of dense water in the eastern Mediterranean (Danovaro and Boero, 2019), and is traditionally known as a “cold engine” for Mediterranean circulation. Mean circulation in the Adriatic Sea follows a cyclonic (in this hemisphere, counter-clockwise) pattern, with Bora giving rise to an additional cyclonic gyre in the northern Adriatic and a smaller, anticyclonic one close to the Istrian coast (Carniel et al., 2016). Surface circulation along the Italian coast is strongly influenced by the coastal plume originated from the riverine freshwater and sediment input, and resulting in a relatively low-salinity, high-turbidity, and nutrient-rich buffer bordering the whole western Adriatic coast. Whilst the salinity gradient shows a cross-axis orientation, temperature shows an along-axis northward decrease, with gradient values more marked in winter (sea surface temperature close to 10 °C in the north and to 14°C in the south) and milder throughout the rest of the year.

Within this picture, multi-decadal analyses on the recent trends of the main hydrological and meteo-oceanographic quantities show multiple evidences of ongoing changes. A negative trend in precipitation has been documented throughout the basin, with a consequent decrease in the freshwater load from the mainland. In addition, during the 20th Century, extensive interventions on the basins aiming at hydropower harvesting and, to some extent, to soil protection, strongly impacted the hydraulic regimes of most of the rivers flowing into the Adriatic sea. This resulted in a different modulation of freshwater and sediment discharge, with impacts also for river morphology and even for coastal morphodynamics, with large sectors of the Adriatic coasts brought to a condition of sediment starvation. The dryer precipitation regime emerging in the recent trends (stronger along the northern Italian coast, see Philandras et al., 2011), together with the water management policies undertaken throughout the decades, resulted in a drop in riverine freshwater load in the order of 30%, compared with the mid-twentieth century statistics (Syvitsky and Kettner, 2007; Cozzi and Giani, 2011). Besides resulting in a reduction of the sediment supply, the extension of the flushing time associated with smaller precipitation rates can enhance the accumulation of nutrients and contaminants in the mainland and increased concentration in coastal water bodies. Based on these evidences, the outcomes of Activity 3.3 allowed to identify the priorities for future management assessment and in water resources and sediment management in the pilot sites, as well as tackle the main management issue. The suggested paradigms refers to the approach proposed by Hashimoto (1982), based on the analysis of the system performance considering reliability, resilience and vulnerability (RRV analysis). Meteo-marine climate seems oriented toward a reduction of the wave activity in the Northern Adriatic sea, with a relevant mildening of the Bora storminess only partially balanced by a slight increase in Sirocco storminess statistics (Pomaro et al., 2017). The tendency toward an overall calmer condition in climate change scenario, although with local exceptions, is generally well acknowledged at the Mediterranean scale (see Bonaldo et al., 2020, and references therein). On the other hand, multi-decadal sea level observations show that rise rates are accelerating throughout all the Adriatic coasts, with increasingly frequent floods affecting low-lying coastal plains and cities, including World Heritage sites (Antonioli et al., 2020). It is worth pointing out that ongoing and projected decrease in the storm intensity does not compensate the increase in mean sea level rise: in other words, if the current trends are not reversed, any slightly “less intense” storms will hit the Adriatic from a significantly higher mean sea level, thus resulting potentially more harmful than in present conditions.

Temperature, salinity and dissolved oxygen data show a tendency to increase in stratification with a significant warming of the surface layers, an increase in salinity associated with the decrease of freshwater supply, and a decrease in dissolved oxygen, especially in the deep Adriatic layers. This is related with a weakening in the Adriatic thermohaline circulation and can lead to severe consequences for the Adriatic biogeochemistry.

Information on representative ecological dynamics for the Adriatic Sea has been collected in the framework of Activity 3.4, with particular focus on protected habitats and species as well as on their physical and chemical drivers in the pilot sites. Besides providing a snapshot of the present state and recent trends, this allowed to identify the main uncertainties and knowledge gaps and define a strategy for future data acquisition and frame a sound monitoring program. Extensive details from this analysis can be found in Deliverable 3.4.1, and from the extensive data set made available in the Project webGIS. Here we will summarize the main evidences from the different pilot sites. The overarching feature is a widespread presence of direct and indirect connections and feedbacks between environmental aspects and human activities.

Croatia and its coasts are very important environmental areas in terms of ornithological, ichthyologic and landscape assets, and wetlands in particular are one of the most important biodiversity hotspots. From this point of view, the Neretva river delta is highly threatened by changes in land use (mostly land reclamation and conversion of wetlands into agricultural lands), the progressing salt water intrusion, and the aforementioned morphological changes resulting from relative sea level rise and sediment supply reduction. Besides these alterations in soil characteristics, freshwater regimes and delta morphology, the intensification of human activities throughout the river basin and in its coastal areas led to an increase in contaminant load in water and soil. Under the effect of these factors, a degradation of the environmental quality and a considerable loss of biodiversity has been reported alongside with a decline in life quality for the local communities. Jadro river is another important ichthyologic reserve (established in 1984) and is characterized by not being connected with any other freshwater bodies, becoming the home for many endemic species and subspecies (e.g. *Salmothymus obtusirostris salonitana*). Furthermore, this river is particularly important for its role of providing drinkable water for the neighbouring towns. The environmental quality of this short river (its length is approximately 4 km) is threatened by several anthropogenic factors, such as diversions, increasing of urbanization, overfishing and the increasing presence of alien species like the rainbow trout *(Oncorhynchus mykiss).* While a system of dams and weirs makes the higher course of the river hydraulically independent from the lowermost part, the latter is the most exposed to sea-level rise: combined with the ongoing alteration of the rainfall regime, this increases the flooding hazard in Kastela Bay and the Jadro river mouth. Climate change is also leading to visible effects in the shallow lake located in the Vransko Jezero Nature Park. During the last two decades the effect of sea level rise, rainfall rate decrease, and increase of water usage, favoured the intrusion of salt water from the sea. These factors, combined with the persistence of illegal human activities, result in a modification of environmental and habitat conditions.

Habitat dynamics, land use and management issues, and climate change impacts along the Italian coast reflect the different geological setting of the western side of the Adriatic basin. Banco della Mula di Muggia is an environment dominated by a succession of sandy bars and encompassed by a muddy sand barrier covered by seagrass meadows. This area is particularly important for the presence of birds and seagrass vegetation hosting a population of *Pinna nobilis*, and offshore this sector of the coast sightings of cetaceans have been recorded. Another important wetland reserve, indeed one of the most important in the Adriatic basin, is located in the Po Delta area and characterized by a barrier island system backed by lagoons, fishing ponds, marshes, fossil dunes, canals, coastal pine forests, vast brackish wetlands, and cultivated lands. Such a landscape diversity reflects in a multiplicity of habitats and species normally subject to salinity oscillations but nowadays challenged by the ongoing environmental modifications associated with climate change. Due to the paramount role of Po river in controlling freshwater, sediment and nutrients supply in this region, any changes in its regimes bring along different modifications in terms of habitat and species distribution and composition. Habitat dynamics also undergo the effects relative sea level rise, enhanced by high subsidence rates, and riverine sediment shortage, which are leading to locally significant changes in landscape morphology.

The outcomes of CHANGE WE CARE activities provide a composite picture of processes and interactions throughout the Adriatic coasts. These give rise to a variety of potential threats for the natural and built environment, with common traits and site-specific criticalities summarized in Table 4. Thus, before undertaking an in-depth analysis of the processes affecting some paradigmatic habitats of the Adriatic region, it is worth providing a brief outline of the main physical drivers of coastal dynamics in this area. This is the aim of the next chapter.

Pilot site	Site-specific issues	Common traits
Neretva Delta	Reduced freshwater flow Agricultural land loss Trans-boundary conflicts for water and sediment management	Relative sea level rise Salt intrusion Modification of erosion/deposition patterns Habitat and biodiversity loss
Vran Lake	Illegal landfills in agricultural terrains Draught periods with low water levels	
Jadro River and Kastela Bay	Flood risk for Jadro River Drink water shortage in Split	
Po Delta	Effects of salt gradient on habitat and species (e.g. reedbed and seagrasses) Conflicts between relative sea level rise and aquaculture maintenance	
Banco della Mula di Muggia	Competition between tourism development and natural areas protection Loss of landscape usability	

Table 4: Site-specific issues and common traits in the Pilot Sites

3 CONTROLS ON CLIMATE CHANGE-DRIVEN COASTAL DYNAMICS IN THE ADRIATIC SEA

Coastal and transitional landscape shaping is the result of a number of interacting abiotic and biotic processes. In this chapter we consider the main physical drivers controlling the evolution of coastal landscape and the main implications of their intertwining with habitat dynamics, with a focus on how they are affected by climate change in the Adriatic Sea.

3.1 Sea level rise

Absolute sea level rise is the result of global processes such as thermostatic expansion and ice melting, as a consequence of global warming, combined with oceanographical features that may locally enhance or counteract this tendency. Also the Mediterranean basin exhibits a peculiar behaviour due to its hydrological budget and to the hydrodynamic characteristics of its exchanges with other water bodies, mainly the Atlantic ocean. Only recently the frontiers of ocean modelling have been pushed to a sufficient degree of insight in the physics description (and of spatial resolution) to allow a proper reproduction of these processes and the comprehension of their implications in terms of climate change effects.

When dealing with coastal systems, it is also necessary to consider the relative displacement of the sea surface with respect to the land. This can be subject to vertical movements in either direction under the effect of geological processes such as isostasy (that is, the “buoyancy” of the lithosphere on the asthenosphere), plate tectonics (the movement of the plates on the Earth lithosphere) and soil compaction (namely, the reduction of volume in porous media typically associated with fluid expulsion). Therefore, relative sea level rise depends on the water partitioning in the hydrosphere and cryosphere (mass contributions) and on the spatial behaviour of the water masses as a result of dynamical and thermal forcings (steric contributions), as well as on geophysical and geological contributions acting at different scales (Table 5).

	Local	**Global**
Steric Contributions	• Inverse Barometer • Ocean Circulation	• Thermal expansion
Mass Contributions		• Glaciers and Ice Sheets melting • Ground water pumping and reservoir filling
Geological/Geophysical Contributions	• Tectonic movements • Soil compaction	• Isostatic adjustment

Table 5: Local and global contributions to relative sea level rise (adapted from Le Cozannet et al., 2017)

Latest estimates from IPCC (IPCC, 2019) point out that global mean sea level has increased on average by 1.4 mm/y in the period 1901-1990, progressively accelerating up to 3.6 mm/y in 2006-2015. Projections for the end of this century suggest an increase, with respect to the 1986-2005 benchmark, ranging from 0.29-0.59 m (RCP 2.6 scenario, the most optimistic) to 0.61-1.10 m (RCP 8.5 scenario, pessimistic but not quite unrealistic).

The relevance of this process and its implication for coastal systems has been increasingly acknowledged through decades. An order of magnitude of the extent of the phenomenon and its potential impacts at the global scale can be found in a work by Hinkel et al. (2014), foreseeing that in the absence of adaptation, by 2100 up to 4.6% of global population will experience annual flooding, with expected losses up to 9.3% of global gross domestic product. Furthermore, due to the long adaptation time of ocean and ice sheets to global temperature, the effects of climate change mitigation policies will fully express their efficiency only over centennial time scales, with more evident effects after the 21st century (Brown et al., 2018). The hazard associated with sea level rise (or, more precisely, with relative sea level rise), involves anthropogenic assets such as coastal urban structures and infrastructures, agricultural land reclamations, cultural heritage, as well as natural systems. Besides a direct effect on the frequency and extent of inundation of low-lying coastal areas, relative sea level rise also plays a role in controlling saltwater intrusion and morphodynamic processes, with implications for land use and habitat dynamics that will be outlined in the following sections.

As mentioned in the previous Section, the Adriatic coast is a heterogeneous landscape with strongly variable geomorphological and sedimentological characteristics, and therefore a variable exposure to the effects of sea level rise. In fact, beside a well-known mosaic of low-lying sandy beaches and high rocky coasts, several studies (e.g. Baric et al., 2008; Lambeck et al., 2011; Antonioli et al., 2017; Bonaldo et al., 2019) point out the sharp spatial variability of the tectonic and isostatic rates throughout the basin.

Tide gauge station (period)	RLSR observed rates (mm/y)	Relative Sea Level (mm) RCP2.6, 2050 → 2100	Relative Sea Level (mm) RCP8.5, 2050→2100
Trieste (1901-2009)	1.59 ± 0.05	142 ± 82 →336 ± 197	150 ± 86 → 523 ± 237
Venice (1914-1997)	2.78 ± 0.04	283 ± 103 → 603 ± 217	311 ± 114 → 818 ± 258
Bakar (1949-2008)	0.88 ± 0.15	166 ± 69 → 259 ± 165	182 ± 70 → 475 ± 203
Rovinj (1958-2008)	0.97 ± 0.10	149 ± 65 → 295 ± 164	177 ± 80 → 510 ± 216
Split Marjana (1955-2008)	0.17 ± 0.02	191 ± 106 → 322 ± 213	220 ± 112 → 567 ± 249
Split Gradska Luka (1957-2008)	1.87 ± 0.07	174 ± 106 → 376 ± 240	204 ± 112 → 621 ± 273
Dubrovnik (1959-2006)	1.24 ± 0.05	225 ± 91 → 445 ± 200	246 ± 95 → 681 ± 246

Table 6: Observed relative sea level rise trends and projected sea level compared to 2005 (adapted from Vecchio et al., 2019)

Table 6 provides an overview on the order of magnitude and the variability of the process throughout the Adriatic coast.

On the Croatian side, direct effects of relative sea level rise on coastal erosion are mostly negligible, due to the prevailingly steep and coarse-grained character of the coasts, with two noticeable exceptions in Susak island (northern Adriatic Sea) and the town of Nin (Baric et al., 2008). Nonetheless, extensive portions of urban systems and infrastructures along the Croatian coast can be exposed to increasing flooding hazard, with potentially severe implications for management and planning.

3.2 Meteo-marine climate, circulation, and sediment transport

Landscape evolution in coastal and transitional environments is controlled by the relative weight of sea level variations and factors mobilizing and redistributing sediment throughout the system. The analysis of the morphological evolution of a coastal tract or of a landscape feature is generally described as a set of differential equations expressing a budget among sediment fluxes to and from the system (in this representation, relative sea level rise has the form of a sediment "loss"), in which the net result yields the overall accretion or reduction of the sediment form. In turn, sediment transport is the result of different hydrodynamic and aeolian processes, interplaying with local abiotic (sediment grain size, cohesiveness, bottom slope) and biotic (e.g., vegetation encroachment) factors. Alongside the constraints imposed by long-term variations of the sea level, the main hydrodynamic processes distributing mechanical energy and transporting sediments throughout the system are currents and wind waves. So-called "wave-currents interaction" is a complex and deeply studied process and can be very relevant in coastal hydrodynamics (see for instance the keystone work by Soulsby et al., 1995, for a general framework, or the study by Sclavo et al., 2013, for an application to the Adriatic Sea). Nonetheless, the main features of waves and currents can be relatively easily disentangled and analysed separately.

Wind waves are generated as a response of the energy exchange at the air-sea interface, and propagate in principle as envelopes of oscillations of the sea level at different frequencies, each of whom is associated with a certain energy content. When approaching a shallow region and eventually a coastline, wind waves undergo a set of transformations modifying their shape and their direction, as well as modulating the distribution of momentum along the water column and with the seabed. These processes are particularly intense in the surf zone, namely where waves break after having reached their maximum steepness in response to bottom friction, and the "radiation stresses" thus generated trigger water fluxes in both along- and cross-shore directions. Sediments, mobilized as an effect of bottom friction, are entrained in these flows and participate in coastal morphodynamics over different time scales. Cross-shore transport redistributes sediment across the beach profile, with changes taking place at the event- or seasonal scale. In the natural functioning of a sandy beach, aeolian processes complement hydrodynamics in cross-shore processes, moving sediments across the subaerial zones of the beach and contributing in replenishing the dune system, which in turn acts as a sediment storage for compensating the losses occurring during the storms. The key role of coastal dunes in beach maintenance is guaranteed by vegetation, which facilitates sediment trapping and consolidation. Vegetation can also play a significant role in consolidating sediments and reducing the amount of wave energy impacting the coast, and this is also among the reasons why the conservation of seagrass meadows is a global ocean management topic (Cullen-Unsworth, L., and Unsworth, R., 2013).

Long-shore transport conveys material along the coast, and its gradients (again speaking in terms of sediment budget, the local difference between inflow and outflow) control long-term (annual to decadal time scale) movements of the shoreline. In "natural" (that is, where the natural sediment cycle is allowed) open coast environments, a retreat of the shoreline is not associated *per se* with a loss of habitats. In fact, where the long-term movement of the shoreline is flanked by the seasonal action of cross-shore sediment transport, the landward (or seaward) displacements can actually involve the whole beach profile, with all its morphological features. On the contrary, a rigid defense (seawalls are the typical example for this case) can effectively prevent the landward displacement of the shoreline, but the disruption of the cross-shore sediment cycle results in an alteration of the beach profile with potentially significant loss of habitats (the so-called “coastal squeeze” concept, see Pontee, 2013).

Other mesoscale and sub-mesoscale hydrodynamic features, such as river plume dynamics, wind-driven and thermohaline circulation, and low-frequency waves contribute in modulating the large-scale transport patterns and the exchanges between coastal zones and the open sea as well as the availability of sediment throughout a basin.

Moving from open coast systems to transitional environments, waves generation is limited by shorter fetches, propagation from the open sea is hampered by natural obstacles such as littoral spits or shallow shoals, and the relative weight of currents in controlling sediment resuspension and transport increases (Bonaldo and Di Silvio, 2013). In coastal lagoons, tidal currents are the main factor shaping the structure of the system, controlling the exchanges of sediments with the sea and maintaining the channel network (e.g. Di Silvio et al., 2010). In estuaries and deltas, a significant contribution can also be given by riverine flows. In all these systems, a crucial role in controlling long-term evolution is played by the processes occurring in the intertidal zone, namely the region undergoing the wetting and drying cycle associated with tidal oscillations. Here the effect of tidal currents on the bottom interacts with the breaking of small waves that can be formed even in very short-fetched systems, as well as with the halophyte vegetation which, under appropriate conditions, can colonize these zones (see for instance Townend et al., 2010) and actively contribute to shape the environment (Marani et al., 2013). Vegetated salt marshes, resulting from a balance between relative sea level rise and sediment trapping acted by vegetation, are actually a typical example in which biotic and abiotic factors concur in landscape-shaping processes and in the creation of peculiar ecosystems. In transitional environments, circulation pathways are also fundamental in determining the patterns of key environmental variables such as temperature, salinity, dissolved oxygen, and nutrients.

Meteo-oceanographic processes in coastal and transitional environments are generally characterized by relatively sharp morphological and topographic gradients, which lead to small-scale spatial variability and calls for dedicated monitoring strategies and modelling tools. Accelerating progress in this direction is the focus of increasing efforts at International level, and in particular within EU-funded Programmes (see Carniel et al., 2018), aiming at maximizing the opportunities from the growing numerical modelling potential, enhanced remote sensing technologies, and increasing in situ data availability.

3.3 Hydrological regime

Hydrological regime is another major driver for coastal processes, strongly influencing both natural and anthropic dynamics. One of the most important descriptors of the functioning of a water basin is the time variability of the ongoing processes. Ranging from ecological mechanisms to hydraulic engineering and water resource management, fundamental hydrological concepts do not refer only to time-averages, but also to frequency, periodicity, and extremes within given temporal references. This means that, for a given "time-averaged" water availability, the modulation over time of such supply can be crucial in shaping the structure of an ecological system, in defining the design parameters for hydraulic protection of a river, or in constraining the planning of a water distribution system in an urban settlement.

Precipitation rates are controlled by meteorological and climatic processes at different spatial and temporal scales, being the result of the superimposition of long-term climate trends, interannual oscillations (such as the North Atlantic Oscillation – NAO – or the well known El Niño Southern Oscillation – ENSO), regional processes (e.g. Mediterranean Cyclogenesis) and local features such as deep convective processes or lee waves downwind of mountain ridges. Water runoff in rivers or groundwater systems is further modulated by the physical properties of the hydrological catchment where precipitation actually takes place. As a general principle, water flows in surface or sub-surface rivers (flowing in fractured rocky structures such as the karstic formations along the eastern Adriatic coast) are faster than groundwater flows in alluvial systems, and the hydrological response time tends to increase for larger catchment areas. For this reason, floods in small rivers tend to occur suddenly as an impulsive response to locally intense, and possibly short-lasting, rainfalls, whereas floods from larger rivers are the result of a persistent rainfall over a large geographical region.

It is worth recalling that sediment transport associated with fluvial processes is controlled by water discharge by a relation which is generally superlinear: in simple mathematical terms, this means that the solid discharge is proportional to water discharge raised by an exponent greater than one. For this reason, river floods are much more relevant for sediment transport than they are for water supply, leading to two major implications. On the one hand the extensive damming of river catchments has historically reduced solid loads, besides by physically trapping the sediment, also by laminating the flood peaks, thus leading to the acknowledged decrease in sediment supply to coastal systems. On the other hand, a regime shift toward more intense rainfall events, such as can be the result of climate change, can lead to an increase in the hydrogeological risk (as a consequence of river bed and banks instability), particularly in relatively small and poorly maintained basins.

In hydraulically subcritical conditions (which means that potential energy dominates over the kinetic term), which is the typical condition in mild-slope rivers and in filtrating flows, water motion is mostly controlled by static pressure patterns. As a consequence, water level profile along a segment of a plain river depends on the static pressure at its downstream end, and the fluxes between the river and its surroundings are controlled by the gradient between the static pressure in the river an in the neighbouring groundwater. As long as salinity does not come into play, static pressure is directly linked to water depth, and in the previous sentence “static pressure” is interchangeable with “free surface elevation”. In coastal regions, the presence of the sea adds two elements to the picture. First, sea level is dominated by processes that are largely independent on the flows from the mainland, and acts as a prescribed boundary condition for coastal rivers and groundwater tables. The immediate hydraulic consequence is that a higher sea level (be it due to a climate-driven process or to an episodical Sirocco-induced storm surge) hampers the flow from the mainland water bodies, increasing the flooding hazard along the river course and in the neighbouring low-lying zones. Secondly, salinity enhances water density affecting the static pressure distribution along the water column, shaping the interface between the sea and freshwater bodies into a wedge (“salt wedge”) intruding into the freshwater body. The landward penetration of the salt wedge is the longest close to the lower boundary of the freshwater body (as the static pressure gradient between salt- and freshwater increases with depth), and its elongation is counteracted by the free surface elevation gradient between water bodies. As a result, relative sea level rise and increasing drought events, emerging as widespread issues along the Adriatic coast, concur in reducing the free surface gradient between coastal freshwater bodies (be them rivers, phreatic aquifers in alluvial systems, or karstic groundwater systems) and the sea, fostering landward saltwater intrusion and threatening the quality of agricultural lands and the equilibrium of valuable habitats.

The response to the implications of changes in the hydrological regime in coastal regions calls into play a thorough assessment of the status of coastal environments, river and groundwater engineering options, water resource management strategies at the catchment scale (possibly, such as in the case of the Neretva river, up to a cross-boundary level), and decision making in the presence of land use conflicts.

4 ASSESSING AND PROJECTING ENVIRONMENTAL PROCESSES IN TRANSITIONAL AREAS

In this chapter we aim at taking stock of the evidences emerged in the assessment phase of CHANGE WE CARE in order to identify the environmental processes associated with climate-induced changes on coastal ecosystems. Based on the outcomes of the previous activities, we will first discuss the potential, the limitations, the bottlenecks and the strategies for projecting the evolution of the environmental status in the pilot sites. Then, for each pilot site, for each target considered to describe the evolution of the ecosystem, the associated environmental variables (biotic or chemical-physical indicator, Deliverable 3.4.1) will be listed, specifying how they will be used to project the evolution of the ecosystem within CC scenarios.

4.1 Strategies for the projection of environmental status in the pilot sites

4.1.1 Neretva River Delta

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

- 5 ornithological special reserves: *Prud, Pod Gredom, Orepak, Modro oko and jezero Desne, Kuti;*
- 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 the 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 included in the Natura 2000 networks with the HR1000031 (SPA) and HR5000031 (SCI) sites.

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.

Salt water intrusion in Neretva River Delta, reduced inflow of fresh water and reduced sediment deposit represent great threat for delta. Due to this there is a change in the environment conditions in the coastal sea, and the fresh water ecosystems which results in reduction of wetlands. All of this directly affects the biodiversity of the area, target species and the habitat Natura 2000.

Furthermore, as a consequence of human activity in the area, there is the distribution of contaminants in water and soil. All previously listed has a direct impact on reducing the quality of life of local communities, and loss of extremely valuable areas of biodiversity.

Neretva River Delta is an area with a lot of different influences, so there are numerous activities that have or could have negative impact on the natural values site Delta Neretve, such as: planned tourist zone in Natura 2000, kite surfing activities close to Ichthyological - ornithological special reserve *Ušće Neretve,* illegal land reclamation, illegal hunting etc.

The future of this area should be based on balancing the need for further development and the need to protect natural resources. Within the Project it’s important to define guidelines to effectively oppose salt water intrusion without obstructing fish migration, as well as guidelines for preservation of wetland area in Neretva River Delta, all respecting the needs of the development of the local communities.

4.1.2 Jadro River – Kastela Bay

Assessment of hydrological and physical quantities of the river Jadro under climate change scenarios is a complex and difficult task. There are several reasons for this, the most important of which are following. Hydrological system of the river Jadro is complex and still insufficiently defined due to the complex configuration and hierarchy of hydrological elements which gradually change under the influence of man. Most of the hydrological quantities and fluxes are generated by the ground water basin of the spring Jadro and only a smaller topographic catchment area of the river Jadro. However, ground water basin divides are not firmly fixed since surface water divides are fixed by topographic highs and due to the construction of hydroelectric power plants and reservoirs on the river Cetina, there was a limited surface water inflow in karstic aquifers. In this way the watershed of the spring Jadro was indirectly extended to the river Cetina. That why the components karst surface water/ground water system are in region of fluviokarst and doline karst. The association of these basins in the wet and dry period of the year is not fully known so it is very difficult to study the influence of climate on hydrological quantities and fluxes.

Climate of river Cetina, groundwater basin of spring Jadro and topographic basin of river Jadro are very different so it is difficult to define input into the system (precipitation (P)– evapotranspiration (ET)). For now, climate change forecasts are still general and difficult to apply locally to determine / predict interseasonal and interdecade hydrological magnitudes and fluxes of groundwater (Gw) and surface water (R).

The formed Jadro watercourse flows to a lesser extent through the natural catchment of the basin and to a greater extent through the urbanized catchment basin, which is constantly being urbanized. Topographic catchment area and river basin gradually becomes urban basin. Changes in the basin are constant and thus changes in climate and hydrological quantities and fluxes.

The relationship between the trend of changes in the groundwater basin and the topographic basin of the river Jadro has not been studied and is relatively unknown. The topographic basin is small and its area is within the scope of regional climate forecasts and sizes. However, due to the impact of urbanism / city on the local climate, regional climate change needs to be adapted to local characteristics in order to be used for calculations of future hydrological quantities and fluxes. This is especially true for the dry period of the year in which the local ratio (P-ET) changes significantly relative to regional forecasts. For the time being, there are no such modified local climate variables for the area of the topographic river basin Jadro (town of Solin). Therefore, the quantities (Gw) and (R) cannot be calculated / predicted.

In conclusion, there are currently no inputs that could seriously analyse future changes in hydrological quantities and fluxes. Only general guidelines in principle as given in this document can be provided. When analysing the quantities and fluxes of sediment and water quality parameters (substances), the situation with the necessary data for analysis is even more unfavorable. Therefore, the quantities and the impact of climate change on them, as well as the relevant quantities and fluxes, cannot be more reliably determined. Only a general overview of the possible state and trend of changes can be made in this document.

Overland, interflow and ground water flow rapidly transferred water and water constituents to river Jadro. Once in river stream, constituents are transported in solution, in suspension, or attached to particles in the sea. The fastest and the most transfer occurred in the wet period of the year. Water in river is short-lived (several hours) and no significant metabolic activity takes place that changes the characteristics of water quality parameters (water chemistry). All substances, as well as sediment, quickly end up in the sea where they are integrated into coastal water metabolic activities. This means that climate change will not have a significant impact on the state of the water in the river itself (fresh water resources). However, the concentrations of sediment and particulate matter derived from physical detachment and chemicals derived from the flushing of the land surface or shallow subsurface tend to increase with stream discharge and the proportion of surface or storm runoff in the stream. This means that any future changes and increases in precipitation will result in a greater impact on the sea. The greatest loads of substances and sediment will occur during the winter period in days with heavy rains, as much as today.

4.1.3 Vransko Lake nature park

For Vransko lake Nature Park the good environmental status can be defined as a state of balance between the trophic categories of phytoplankton, zooplankton and macrophytic algae.

Changes in the composition and abundance of above mentioned groups affect the composition of food sources (phytocomponents) and suspended organic matter, as well as predators, which can potentially shift the current state of water from relative transparency to a turbid lake state of increased eutrophication. These conditions potentially lead to a decrease in macrophytic constituents, an increase in sediment resuspension, and in the extreme situations to the occurrence of hypoxic conditions.

The best data collection strategy has to be developed to achieve a good modelling design. Main modelling parameters would be salinity and water level, that are directly correlated with the percipitation rates in the catchment area, is allready used in Vransko lake area to model climate change impacts. The salinity and water level together with the nutrient concentration are the main initiators of changes in the composition and abundance of above mentioned groups.

4.1.4 Banco della Mula di Muggia

For the Banco della Mula di Muggia pilot site, the evolution of seagrass meadows will be studied by means of the application of Habitat Suitability Models (HSMs). In particular, this approach will be followed by implemented *as hoc* HSM for the species present in the study area (*Zostera noltei* and *Cymodocea nodosa*) focusing on the role of geomorphology of the shore, whose dynamic represents the main focus of this pilot site. The development of the HSMs will be possible after a field activity aimed at a fine scale characterization of the vegetation distribution, originally scheduled for spring 2020, and delayed due to the COVID-19 emergency. The projection of the habitat suitability will be carried out relying on the outcome of the Activity 4.2, that will provide the expected geomorphological evolution under the hydrological and meteo-climatic conditions predicted for the Northern Adriatic (D4.1.1).

4.1.5 Po Delta

For the Po Delta pilot site, the evolution of some characteristics of the ecosystem will be studied by means of the application of Habitat Suitability Models (HSMs). In particular, this approach will be implemented for three habitats/species: a) manila clam, *Venerupis philippinarum*, a species particularly relevant for the farming activities in several lagoons of the Delta; b) reed beds, an 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; c) seagrass species, protected species, scarcely present in the Delta but showing positive trends in other Northern Adriatic transitional areas.

For Manila clam, the suitability of the different lagoons will be assessed using existing models (Vincenzi et al., 2006a; 2006b; 2007; 2011; 2014; Zucchetta, 2010). As regarding Reed beds, the suitability of the different lagoons will be assessed using HSM developed within the project (A4.3). Concerning Seagrass distribution, the suitability of the different lagoons will be assessed using Species specific HSM adapted within the project (A4.3; originally developed for the Venice lagoon).

With respect to all the three habitats/species, some of the variables needed for the application of the HSM are already available for the study area, as they are simulated by means of the high resolution hydrodynamic model used for this pilot site (Deliverable 4.1). This means that for these variables also the projection to 2080 under CC are directly available. Other variables will not be considered in the future scenarios (i.e. considered fixed in time), because the projection is not available, the link with CC is not clear, or because these variables are not the main focus of the issues tackled in the pilot site. For other variables, qualitative "*what-if*" scenarios will be built for the projection of the suitability of the farming areas. When possible, the scenarios will be set up by leveraging the empirical relationships existing between available data (Deliverable 3.4.1 - 3.4.2) and the variables modelled and projected with hydrodynamic model.

4.2 Environmental variables and targets in the pilot sites

Pilot site	Delta Neretva					
Specific target	**Water quality**					
CC issue addressed	**Negative impact of intensive agriculture to the water of Neretva River Delta**					
Relation between the studied species and environmental conditions	**Variables (relevant variables for the species)**	**Type of available measures**	**What will be available as CC scenario?**	**Gap for realising the habitat/species projection**	**Strategy for filling the gap?**	**Tools for the projection (To be presented within A4.3)**
	Salinity	/	Salinity projections in the scope of Investigation of physical-chemical factors of climate change in Neretva River Delta [D5.2.3]	/	/	Comparison of historical and recent levels of physical-chemical factors in the Neretva delta with emphasis on the impact of climate change and other causes of change in investigated ecosystems [D5.2.3]
	Dissolved Oxygen	/	Dissolved Oxygen projections in the scope of Investigation of physical-chemical factors of climate change in Neretva River Delta [D5.2.3]	/	/	Comparison of historical and recent levels of physical-chemical factors in the Neretva delta with emphasis on the impact of climate change and other causes of change in investigated ecosystems [D5.2.3]
	pH value	Field data for the period 2015-2017 [D3.4.1]	pH value projections in the scope of Investigation of physical-chemical factors of climate change in Neretva River Delta [D5.2.3]	/	/	Comparison of historical and recent levels of physical-chemical factors in the Neretva delta with emphasis on the impact of climate change and other causes of change in investigated ecosystems [D5.2.3]
	Water temperature	Field data for the period 2015-2017 [D3.4.1]	Water temperature in the scope of Investigation of physical-chemical factors of climate change in Neretva River Delta [D5.2.3]	/	/	Comparison of historical and recent levels of physical-chemical factors in the Neretva delta with emphasis on the impact of climate change and other causes of change in investigated ecosystems [D5.2.3]
	Physical-chemical parameter of water	Field data for the period 2011-2017 [D3.4.1]	/	No projection for the future	Developing simple qualitative scenarios of physical-chemical parameters of water	Comparison of historical and recent levels of physical-chemical factors in the Neretva delta with emphasis on the impact of climate change and other causes of change in investigated ecosystems [D5.2.3]

Table 7: variables, strategies and tools for addressing CC impacts on water quality in the Neretva Delta

Pilot site	**Nature park Vransko lake**					
Specific target	**Natura 2000 habitat: Hard oligo-mesotrophic waters with benthic vegetation of *Chara ssp***					
CC issue addressed	**Water use conflicts in Vransko lake catchment area, maintaining the ecological flow**					
Relation between the studied species and environmental conditions	**Variables (relevant variables for the species)**	**Type of available measures**	**What will be available as CC scenario?**	**Gap for realising the habitat/species projection**	**Strategy for filling the gap?**	**Tools for the projection**
Characea are Natura 2000 Habitat indicating oligothrophic/mesotrophic conditions which are a desired ecological state supporting the highest biological diversity	Nitrogen compounds, pH, Chlorophyll a, transparency	more than 50% of the lake is covered with submerged macrophytes, out of which Chara ssp are dominating (species P. pectinatus less than 50%, more than 5 different Chare species present) - according to dataset 2010 - 2019	salinity projections, precipitation projections, water level projection	missing model, unconsistent data collection for the period of collection	model design and data collection for achieving good modeling	To be defined within A4.3
	salinity, water level	data set 2010-2019,	salinity projections, precipitation projections, water level projection	irregularity in data aquisition and measuring points depending on the year	model design and data collection for achieving good modeling	To be defined within A4.3

Table 8: variables, strategies and tools for addressing CC impacts on Hard oligo-mesotrophic waters with benthic vegetation of Chara ssp in the Vransko Lake Nature park

Pilot site	**Banco della Mula di Muggia**					
Specific target	**Seagrasses**					
CC issue addressed	**Sea level rise; Meteo-marine climate, circulation, and sediment transport; Loss of landscape usability**					
Relation between the studied species and environmental conditions	Variables (relevant variables for the species)	Type of available measures	What will be available as CC scenario?	Gap for realising the habitat/species projection	Strategy for filling the gap?	Tools for the projection
	Water level And water depth	Historical and recent data on bathymetry, morphology and hydrodynamic conditions (D3.1.2, D3.2.3)	Morphology projection (Activity 4.2) Water level scenarios used for the Northern Adriatic basin [D4.1.1]	/	/	Species specific (*Zostera noltei, Cymodocea nodosa*) Habitat Suitability Model developed within Change We Care (A4.3). The feasibility of building a morphologic-oriented Habitat suitability models will be evaluated in relation to the realisation of the field campaign originally planned for 2020 and delayed for the COVID-19 emergency.
	Sediment characteristics	Recent data will be integrated with field observations collected during the campaign originally planned for 2020 and delayed for the COVID-19 emergency.	/		Business as usual	
	Salinity; Nutrient in the sediment; Water transparency	Not considered (the HSM will focus on geomorphology)			Not considered	

Table 9: variables, strategies and tools for addressing CC impacts on seagrasses in the Banco della Mula di Muggia

Pilot site	**Po Delta**					
Specific target	**Manila clam**					
CC issue addressed	**Conflicts between relative sea level rise and aquaculture maintenance**					
Relation between the studied species and environmental conditions	**Variables (relevant variables for the species)**	**Type of available measures**	**What will be available as CC scenario?**	**Gap for realising the habitat/species projection**	**Strategy for filling the gap?**	**Tools for the projection (To be presented within A4.3)**
	Salinity	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]	/	/	Habitat Suitability Model (from literature: Vincenzi et al., 2006a; 2006b; 2007; 2011; 2014; Zucchetta, 2010)
	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]	/	/	Habitat Suitability Model (from literature: Vincenzi et al., 2006a; 2006b; 2007; 2011; 2014; Zucchetta, 2010)
	Water Residence Time	Simulations from site specific high resolution hydrodynamic modelling [D4.1]	WRT projections from site specific high resolution hydrodynamic modelling [D4.1]	/	/	Habitat Suitability Model (from literature: Vincenzi et al., 2006a; 2006b; 2007; 2011; 2014; Zucchetta, 2010)
	Trophic state (i.e. nutrient concentration)	Field data for the period 2008-2018 [D3.4.1, D3.4.2];	/	No projection for the future	What-if scenarios (i.e. qualitative changes explored)	Habitat Suitability Model (from literature: Paesanti & Pellizzato, 2000)
	Sand in sediment	Field data for the period 2008-2018 [D3.4.1, D3.4.2];	/	No projection for the future	Business as usual (i.e. changes not considered)	Habitat Suitability Model (from literature: Vincenzi et al., 2006a; 2006b; 2007; 2011; 2014; Zucchetta, 2010)
	Water level / water depth	Simulations from site specific high resolution hydrodynamic modelling [D4.1]	Water level projections from site specific high resolution hydrodynamic modelling [D4.1] (fixed bathymetry)	/	/	Habitat Suitability Model (from literature: Vincenzi et al., 2006a; 2006b; 2007; 2011; 2014; Zucchetta, 2010)
	Water speed	Simulations from site specific high resolution hydrodynamic modelling [D4.1]	Water speed projections from site specific high resolution hydrodynamic modelling [D4.1]	/	/	Habitat Suitability Model (from literature: Vincenzi et al., 2006a; 2006b; 2007; 2011; 2014; Zucchetta, 2010)
	Chlorophyll-*a*	Field data for the period 2008-2018 [D3.4.1, D3.4.2];		No projection for the future	What-if scenarios (coherent with other variables; e.g. Trophic state)	Habitat Suitability Model (from literature: Vincenzi et al., 2006a; 2006b; 2007; 2011; 2014; Zucchetta, 2010)
	Dissolved Oxygen	Field data for the period 2008-2018 [D3.4.1, D3.4.2];		No projection for the future	What if scenarios based on empirical relationships between available observations and modelled data (D3.4.1. - D3.4.2). High frequency dynamics will be considered, in order to explore changes in likelihood of hypoxia/anoxia events	Habitat Suitability Model (from literature: Vincenzi et al., 2006a; 2006b; 2007; 2011; 2014; Zucchetta, 2010)

Table 10: variables, strategies and tools for addressing CC impacts on Manila Clam in the Po Delta

Pilot site	Po Delta					
Specific target	**Reed beds**					
CC issue	**Effects of salt gradient on habitat and species (e.g. reedbed and seagrasses); relative sea level**					
Relation between the studied species and environmental conditions	Variables (relevant variables for the species)	Type of available measures	What will be available as CC scenario?	Gap for realising the habitat/species projection	Strategy for filling the gap?	Tools for the projection [To be defined within A4.3]
	Salinity	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]	/	/	Habitat Suitability Model developed within Change We Care (A4.3)
	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]	/	/	Habitat Suitability Model developed within Change We Care (A4.3)
	Water Residence Time	Simulations from site specific high resolution hydrodynamic modelling [D4.1]	WRT projections from site specific high resolution hydrodynamic modelling [D4.1]	/	/	Habitat Suitability Model developed within Change We Care (A4.3)
	Trophic state (i.e. nutrient concentration)	Field data for the period 2008-2018 [D3.4.1, D3.4.2];	/	No projection for the future	What-if scenarios (i.e. qualitative changes explored)	Habitat Suitability Model developed within Change We Care (A4.3)
	Sand in sediment	Field data for the period 2008-2018 [D3.4.1, D3.4.2];	/	No projection for the future	Business as usual	Habitat Suitability Model developed within Change We Care (A4.3)
	Water level / water depth	Simulations from site specific high resolution hydrodynamic modelling [D4.1]	Water level projections from site specific high resolution hydrodynamic modelling [D4.1] (fixed bathymetry)	/	/	Habitat Suitability Model developed within Change We Care (A4.3)
	Water speed	Simulations from site specific high resolution hydrodynamic modelling [D4.1]	Water speed projections from site specific high resolution hydrodynamic modelling [D4.1]	/	/	Habitat Suitability Model developed within Change We Care (A4.3)
	Water transparency (as TSS)	Field data for the period 2008-2018 [D3.4.1, D3.4.2];		No projection for the future	What if scenarios, taking into account empirical relationships between available data (D3.4.1. - D3.4.2) and variables modelled and projected with hydrodynamic model.	Habitat Suitability Model developed within Change We Care (A4.3)

Table 11: variables, strategies and tools for addressing CC impacts on reed beds in the Po Delta

Pilot site	**Delta Po**					
Specific target	**Seagrasses**					
CC issue addressed	**Effects of salt gradient on habitat and species (e.g. reedbed and seagrasses); Sea level rise**					
Relation between the studied species and environmental conditions	**Variables (relevant variables for the species)**	**Type of available measures**	**What will be available as CC scenario?**	**Gap for realising the habitat/species projection**	**Strategy for filling the gap?**	**Tools for the projection [To be defined within A4.3]**
	Salinity	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]	/	/	Species specific - Habitat Suitability Model adapted within Change We Care (A4.3; originally developed for the Venice lagoon)
	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]	/	/	Species specific - Habitat Suitability Model adapted within Change We Care (A4.3; originally developed for the Venice lagoon; Zucchetta, 2010; Corila 2014; 2015; 2016)
	Water Residence Time	Simulations from site specific high resolution hydrodynamic modelling [D4.1]	WRT projections from site specific high resolution hydrodynamic modelling [D4.1]	/	/	Species specific - Habitat Suitability Model adapted within Change We Care (A4.3; originally developed for the Venice lagoon; Zucchetta, 2010; DAIS-CORILA, 2015; 2016; 2017)
	Trophic state (i.e. nutrient concentration)	Field data for the period 2008-2018 [D3.4.1, D3.4.2];	/	No projection for the future	What-if scenarios (i.e. qualitative changes explored)	Species specific - Habitat Suitability Model adapted within Change We Care (A4.3; originally developed for the Venice lagoon; Zucchetta, 2010; DAIS-CORILA, 2015; 2016; 2017)
	Sand in sediment	Field data for the period 2008-2018 [D3.4.1, D3.4.2];	/	No projection for the future	Business as usual	Species specific - Habitat Suitability Model adapted within Change We Care (A4.3; originally developed for the Venice lagoon; Zucchetta, 2010; DAIS-CORILA, 2015; 2016; 2017)
	Water level / water depth	Simulations from site specific high resolution hydrodynamic modelling [D4.1]	Water level projections from site specific high resolution hydrodynamic modelling [D4.1] (fixed bathymetry)	/	/	Species specific - Habitat Suitability Model adapted within Change We Care (A4.3; originally developed for the Venice lagoon; Zucchetta, 2010; DAIS-CORILA, 2015; 2016; 2017)
	Water speed	Simulations from site specific high resolution hydrodynamic modelling [D4.1]	Water speed projections from site specific high resolution hydrodynamic modelling [D4.1]	/	/	Species specific - Habitat Suitability Model adapted within Change We Care (A4.3; originally developed for the Venice lagoon; Zucchetta, 2010; DAIS-CORILA, 2015; 2016; 2017)
	Water transparency (as TSS)	Field data for the period 2008-2018 [D3.4.1, D3.4.2];		No projection for the future	What if scenarios, taking into account empirical relationships between available data (D3.4.1. - D3.4.2) and variables modelled and projected with hydrodynamic model.	Species specific - Habitat Suitability Model adapted within Change We Care (A4.3; originally developed for the Venice lagoon; Zucchetta, 2010; DAIS-CORILA, 2015; 2016; 2017)

Table 12: variables, strategies and tools for addressing CC impacts on sea grasses in the Po Delta

5 DATA SETS FOR CLIMATE ANALYSIS AND TOOLS FOR THEIR USE

5.1 CHANGE WE CARE dataset and webGIS: main features and user guide

CHANGE WE CARE Web GIS was created within the activity 3.5.1. for easy and fast dissemination, sharing and displaying of spatial information collected during the different WP3 activities on the pilot sites Neretva River, Jadro River, Nature Park Vransko Lake, Banco di Mula di Muggia and Po River Delta.

High level architecture, based on Geoserver as a web GIS server and PostgreSQL/PostGIS as an object oriented relational database management system (ORDBMS) was implemented for effective dissemination, sharing and management of CHANGE WE CARE datasets over the internet. Basemap selection for depiction and overlay of the thematic CHANGE WE CARE data includes a variety of choices, including topography (Google Terrain), imagery (Google Satellite), and streets (Google Maps or OpenStreetMap). Other implemented functionalities include: basic measurement tools (length, area, radius, location coordinate), data search/filter by coverage and by attribute (search + zoom, search + show results on map) and print to pdf option (paper format and orientation, print scale, legend).

The Web GIS application can be accessed through a generic internet browser with the address https://gis.changewecare.geof.hr. Easy-to-use nature of Web GIS allows public users (who have no GIS background) to examine and interact with data. For selected group of users i.e. project partners, user authentication to confirm a user's identity is required before granting access to data editing options.

CHANGE WE CARE Web GIS will be updated according to project needs along the project implementation and evolution, including data from the upcoming activities as soon as they become available.

5.2 Other public data repositories for climate analysis

Although the data collection provided by CHANGE WE CARE has been purportedly assembled in the perspective of fulfilling the Project scopes, a broad set of sources allows free (although generally under some conditions) access to a large wealth of high-quality data usable for climate analysis, encoded in standard formats, and encompassing a regional to global geographic horizon. The purpose of the brief outline given in this paragraph is not to provide a comprehensive list of such sources, nor to describe each of them in detail, but rather to increase the awareness of their existence within a broad audience of possible users, with special focus to local operators and public bodies who could greatly benefit from a direct access to this information.

The **Copernicus Climate Change Service** (C3S, https://climate.copernicus.eu/) is a service provided by the EU Copernicus Earth Observation Programme, implemented in synergy with the member states and several European Institutions such as the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium-Range Weather Forecasts (ECMWF), and Mercator Océan. In the framework of the Copernicus Programme, C3S focuses on the delivery of data and services supporting the assessment of climate trends, projection of future scenarios, and the design of adaptation and mitigation policies. The data provided include observations and model reanalyses, seasonal forecasts, and climate projections, related to ocean, atmosphere, land and cryosphere. C3S data are available on the Climate Data store (https://cds.climate.copernicus.eu/#!/home), and tools are embedded in the web portal for their browsing, subsetting, visualizing, and processing. Training events are periodically organized, also in remote form, for maximizing the accessibility and encouraging the use of the data and tools, and advertised at the page https://climate.copernicus.eu/events.

Another valuable data source within the Copernicus Programme, not specifically devoted to climate analysis but focused on marine data over different time scales and therefore most useful for coastal planning application, is given by the **Copernicus Marine Environment Monitoring Service** (CMEMS, https://marine.copernicus.eu/). Besides a number of services and activities such as monitoring and reporting on the state of the marine systems, CMEMS provides global and regional observational and numerical modelling data about physical and biogeochemistry in the ocean. Likewise in C3S, CMEMS has a specific line dedicated to training and education, with periodic training events and workshops addressed to different kinds of users.

An important repository for marine data is also provided, again at the European level but collecting data from all over the world, by the **European Marine Observation and Data Network** (EMODnet, https://emodnet.eu/en). With the scope of increasing the accessibility and the quality of marine data in a “blue growth” perspective, EMODnet gathers the efforts of a network of organisations supported by the EU integrated marine policy into the observation of the sea and the delivery of data processed and formatted following international standards. Data are collected in seven thematic domains (Bathymetry, Geology, Seabed Habitats, Chemistry, Biology, Physics, Human Activities) and, although long time series for climate assessment purposes are not always available, are framed in a long-term initiative addressing “marine industries, decision-making bodies and scientific research”.

Beyond the European Union framework, modelling projections from climate models over different regions worldwide can be obtained from the **Coordinated Regional Climate Downscaling Experiment** (CORDEX, https://cordex.org). Based on regional climate downscaling techniques, CORDEX experiments provide relatively high-resolution projections for a broad set of physical quantities under different model settings and climate change scenario. The uses for this kind of data range from the estimate of hydrological budget at the regional scale, to the forcing of high-resolution numerical models (as in the case of the multi-decadal ROMS simulation over the Adriatic Sea discussed in Deliverable 4.1.1.

5.3 Software and tools for data analysis

Following an established standard, data from the sources listed in the previous Section are provided (also) in NetCDF (Network Common Data Form) format. NetCDF is an open standard tailored for the creation, access and sharing of self-describing and machine-independent data, especially for scientific purposes. Thus, a file encoded in the NetCDF format contains a set of metadata which, besides facilitating the user in the analysis and interpretation of the data (e.g. space and time references and conventions, units of measurement, origin and quality of the data), allows the specific access to subsets of the data without need for opening (and storing, although temporarily, in the memory) the whole file. This proves particularly efficient from the computational point of view in the case of geophysical data (oceanography, meteorology and climate science are among the main domain of use for this standard). In such applications, a number of multi-dimensional variables (typically 3D in space + time) associated with several processes over a given geographical area and through a given time window can typically be stored in large files on the order of Gbs or tens of Gbs, of which the user may need, for instance one single variable in a very narrow time frame and/or geographical domain. Thanks to the structure of NetCDF files, this kind of operations is made quick and efficient reducing the memory requirements and the computing time.

NetCDF files (which come with extension ".nc") are accessible via a number of tools and libraries, allowing different degrees of insight and processing and with different degrees of complexity for the user. While a number of commercial suites (e.g. Matlab) embed specific libraries for NetCDF handling, in this brief outline we will dedicate some attention to a far-from-complete set of freely available tools for visualizing and analyzing data in this format. **Panoply** (https://www.giss.nasa.gov/tools/panoply/) is an application released by NASA and supported by the main operating systems (among which Windows, Linux and Macintosh) for viewing and performing basic operations (summing, differencing, averaging, creating and exporting plots and animations) on data in different formats, including NetCDF. Focusing on NetCDF browsing alone, **Ncview** (http://meteora.ucsd.edu/~pierce/ncview_home_page.html) is another simple tool for UNIX platforms, allowing a quick view on the data and metadata contained in a file. For somewhat more in-depth analysis and with a focus on climate applications, it is worth mentioning out the **Climate Data Operators** (CDO, https://code.mpimet.mpg.de/projects/cdo), a set of command-line instructions for computing climate analysis and statistics on several data formats, among which netCDF. Another suite of tools for handling and analyzing netCDF data is provided by the **netCDF Operators** (NCO, http://nco.sourceforge.net/), whose use is quite widespread in the scientific community. NetCDF data can also be manipulated within GIS platforms such as QGIS and ArcGIS, that process those files as raster layers. The actions that can be undertaken include browsing the NetCDF metadata, classifying the NetCDF layer with a specific colour map, displaying and exporting (as GeoTiff files) specific time steps, thus allowing to perform additional operation with other software. Furthermore, traditional native operation of GIS software, e.g. "Raster calculator" and "Graphical modeller", are available. The QGIS software allows also to install plugins (e.g. Crayfish and GIS4WRF) from repository permitting to conduct additional analysis.

Even more powerful options for data access, handling and analysis is given by dedicated modules and libraries for programming languages. This field offers extremely open possibilities at the cost of some background expertise in programming, and specific toolkits have been created throughout the decades for a number of compiled and interpreted, freely available and commercial languages, characterized by different degrees of complexity, community support and development. Within this multitude, a versatile option is given by **Python** (https://www.python.org/) and its modules, providing tools allowing to handle the whole pipeline from data collection from repositories, to the extraction of data from the collected files, their analysis, the visualization of the results and their export in different formats. Python runs on the most common operating systems, is open-source and broadly established in the scientific, data-analysis and programming communities, which led to the availability of a broad wealth of resources, scripts, and community-supported solutions for multiple purposes. Among the many modules that can be embedded to the python core within a programming script, for the applications discussed in this paragraph it is worth mentioning **numpy** (https://numpy.org/) for functions and scientific computing tools, **netCDF4** (https://unidata.github.io/netcdf4-python/netCDF4/index.html) for the use of netCDF files, **pandas** (https://pandas.pydata.org/) for data analysis and in particular for structured dataframes, **shapely** (https://shapely.readthedocs.io/en/stable/manual.html) for spatial analysis, and **matplotlib** (https://matplotlib.org/) for visualizing data and results in python.

6 CONCLUSIONS

The present document aims at providing a brief overview of the outcomes of the thematic studies on status and recent trends in Adriatic coastal areas, carried out in the third Work Package of CHANGE WE CARE, in the framework of an interdisciplinary view aimed at developing a set of planning responses to climate change in coastal and transitional systems. Besides summarizing the information collected, facilitating its access for further insight, and emphasizing the connections between the different processes involved and with the broader picture of adaptation policies, the goal was to create a logical bridge between assessment of the present and projection of future scenarios for an aware decision making. This operation requires to narrow down the field of analysis to a selected subset of variables or systems to be identified based on their representativeness of the relevant processes, on the availability of data, and on a realistic estimate of what can reasonably be achieved in the future. The analysis presented in Chapter 4 and referred to the Project pilot sites was undertaken as a step in this direction, in the perspective of the projection and planning activities envisaged for the next phases of CHANGE WE CARE. The results highlight a significant diversification in the data availability, in the assessment and management priorities, and in the potential for deeper investigations in the selected fields. This information will be capitalized in a thorough reflection on data and knowledge needs that will constitute the very conclusive activity of WP3. Feedbacks and strategies emerging from such reflection will be crucial in fine-tuning the workplan for the next steps of the Project, and will pave the way towards the definition of a planning paradigm flexible enough to fit within this broad variability.

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