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WP3- Evaluation of the Small-Scale Fishery sector

D3.3.1. REPORT ON SSF VULNERABILITY TO CLIMATE CHANGE IN GSA17

WP3

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INTRODUCTION

Adriatic Sea is considered as a hydrologicaly distinct Mediterranean sub-system. It is the northernmost area of the Mediterranean (excluding the Black Sea) and this fact influences some of its physical properties even in its southernmost areas. It is generally divided into three subdivisions, North, Middle and South Adriatic. Also, the eastern and western coasts are different; the former is high, rocky and articulated with many islands while the western coast is flat and alluvial with raised terraces in certain areas (UNEP, 2014). Due to presence of numerous islands, eastern coast is characterized by abundance of coastal habitats. The depth gradually decreases from south to north and depths in the North Adriatic never exceed 100 meters. Greatest depth in the area of Middle Adriatic is 273 m in the Jabuka/Pomo Pit while the South Adriatic is characterized by the presence of the South Adriatic Pit, deepest point in the Adriatic Sea with depth of 1233 m. Mean depth of the Adriatic is around 252 m (Jardas et al., 2008). The thermohaline properties of the Adriatic Sea are determined mainly by the air-sea interaction, water exchange through the Otranto Strait, river discharge, mixing, currents, and topography of the basin. The annual temperature range at the surface is 18 0C in the South and 25 0C in the North Adriatic. As a whole, the Adriatic is a temperate warm sea. The extremes of surface temperature have a large range, from 6 0C to 29 0C. Temperatures of even the deepest layers are for the most part above 10 0C. The South Adriatic is 8-10 0C warmer than its central and northern parts during winter. In other seasons the horizontal temperature distribution is more uniform. Generally, the open sea is warmer than the coastal waters (Zore-Armanda, 1999). Salinity is relatively high with significant ranges and highest salinity occurs in the area of South Adriatic (38,4-38,9) especially in the intermediate layer. Generally, salinity decreases from south to north and from open sea to the coast. The North and western Adriatic are more influenced by river floods (mainly Po river) which affect circulation through buoyancy input and the ecosystem by large nutrient influx (Marini et al., 2015).

The present-day flora and fauna of the Adriatic Sea is a result of the numerous geological, geographical, climatic and biological processes occurring during its formation. Those processes are crucial even today and Adriatic ecosystem actually depend on these factors. Although the Adriatic Sea is a part of the Mediterranean, it is also an independent biogeographical and ecological subunit, which is manifested in the composition and properties of its life communities (biocoenosis). The marine biodiversity of the Mediterranean Sea is nowadays facing substantial structural changes in flora and fauna (Coll et al., 2010). It is rapidly changing due to the increasing arrival of non-indigenous species (Zenetos et al., 2010). Such changes were recorded in the Adriatic Sea, as well. During the last few decades, various factors including climate change, anthropogenic activity and “lessepsian migration” have altered the composition of Adriatic ecosystem, ichthyofauna in particular (Dulčić and Grbec, 2000; Lipej and Dulčić, 2004; Lipej et al., 2012; Pećarević et al., 2013).

1. Climate drivers and pressures in the Adriatic Sea

The Mediterranean Sea is a temperate sea characterized by high salinities and oligotrophic conditions, surronded substantially by land, which in turn significantly defines its atmosphere and ocean climate. Its northermost part, the Adriatic Sea, is exhibiting a substantial influence of the European land processes, for which freshwater load is substantial to the sea, about 1/3 of all Mediterranean load. Therefore, the Adriatic's salinity is lower than the Mediterranean salinity. The prevailing currents flow counterclockwise from the Strait of Otranto, along the eastern coast and back to the strait along the western (Italian) coast. The Adriatic Sea is a microtidal basin, with tides rangint from 20 cm in southern to a metre in the northern Adriatic. According to the Köppen climate classification, the upper half of the Adriatic is classified as humid subtropical climate (Cfa), with wetter summers and colder and drier winters, and the southern Adriatic is classified as hot-summer Mediterranean climate (Csa).

Characteristics of basic atmosphere and ocean climate parameters, their trends in present and future climates, will be presented in this chapter, which are found important for marine life and fisheries in the coastal Adriatic. That includes (1) air temperature, which reflect energy budget at the sea surface, (2) precipitation, dry and wet days, river discharges, which are being reflected dominantly in salinity and nutrient concentrations in coastal areas, (3) ocean temperature and salinity, which is found important for defining habitat of fish species in coastal regions, (4) ocean chemistry, which reflects the trophic status of the area, and (5) sea level rise, which is a general parameter threatening coastal regions.

1.1. <u>Air temperature</u>

By analysing long-term meteorological stations in the coastal Adriatic and inland (Branković et al., 2010) (Fig. 1), one can detect several characteristics: (i) there is a strong interannual and decadal variability in air temperature, and (ii) the trends in air temperature are becoming larger when being computed over a recent period. Increase of mean annual air temperature continued and is amplified by the beginning of the 21st century, when 5 and 6 warmest years during the whole measuring period were recorded in stations Crikvenica and Hvar. The annual temperature trend was as high as +0.35 ^{o}C over decade at Hvar to 0.75 ^{o}C over decade at Crikvenica, being the largest during summer and autumn.

The same rate of air temperature increase will propagate to the future climate (Branković et al., 2012), at least as projected by climate simulation (Fig. 2). The largest increase in the coastal Adriatic will be in summer, above 2.5 ^{o}C in summer (JJA) between 2041 and 2070, while the increase is projected to be lower during winter (DJF) and spring (MAM), to about 1.5 ^{o}C in the period 2041-2070. This will reflect to the increase in hot days, whose number will substantially increase in the future climate (Fig. 3).

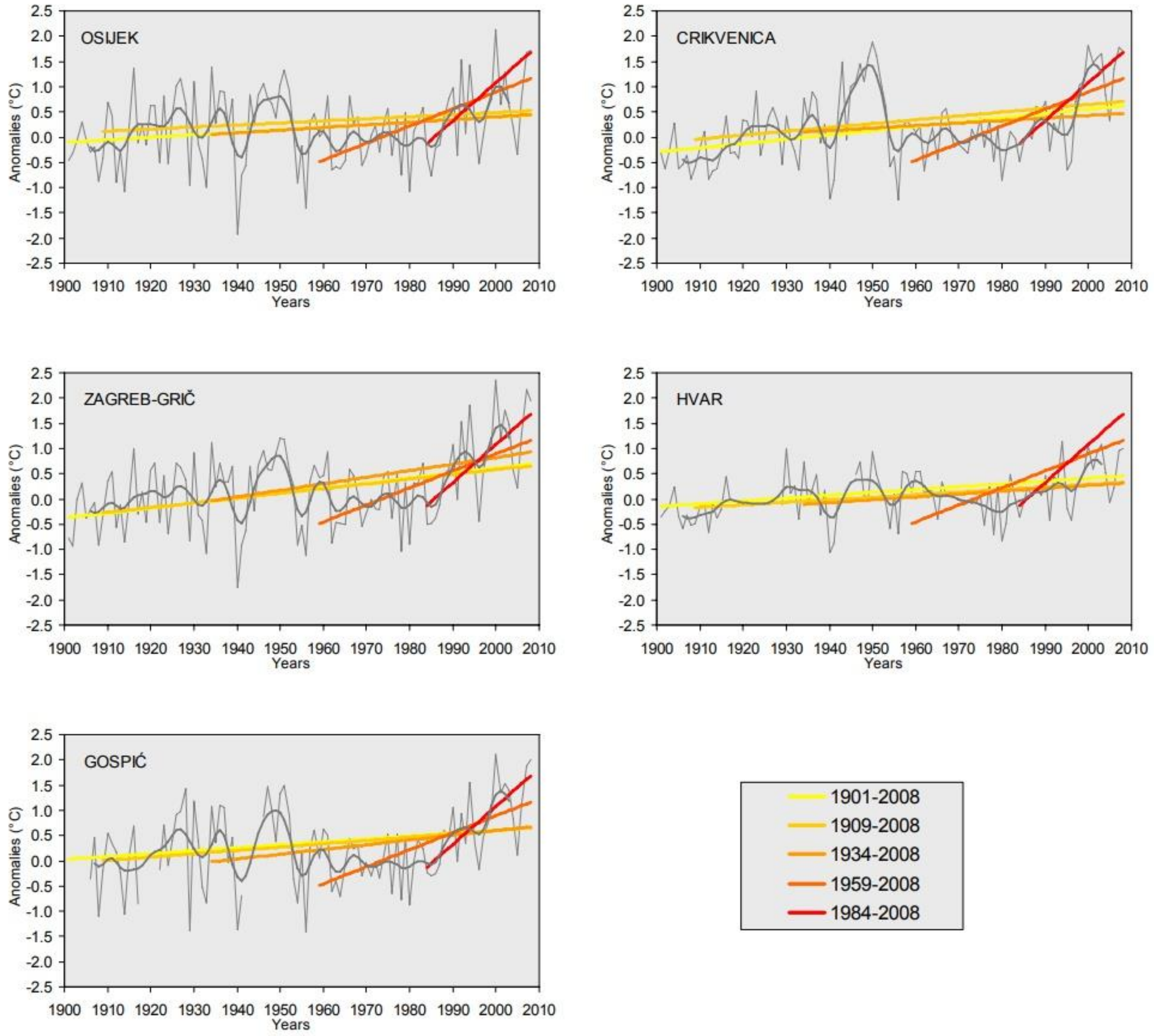

Figure 1. Time series for the mean annual air temperature related 11-year binomial moving averages, and trends for 108-, 100-, 75-, 50- and 25-year period for long-term stations in Croatia. Unit is anomalies (°C) with respect to 1961-1990 average. Source: Branković et al. (2010).

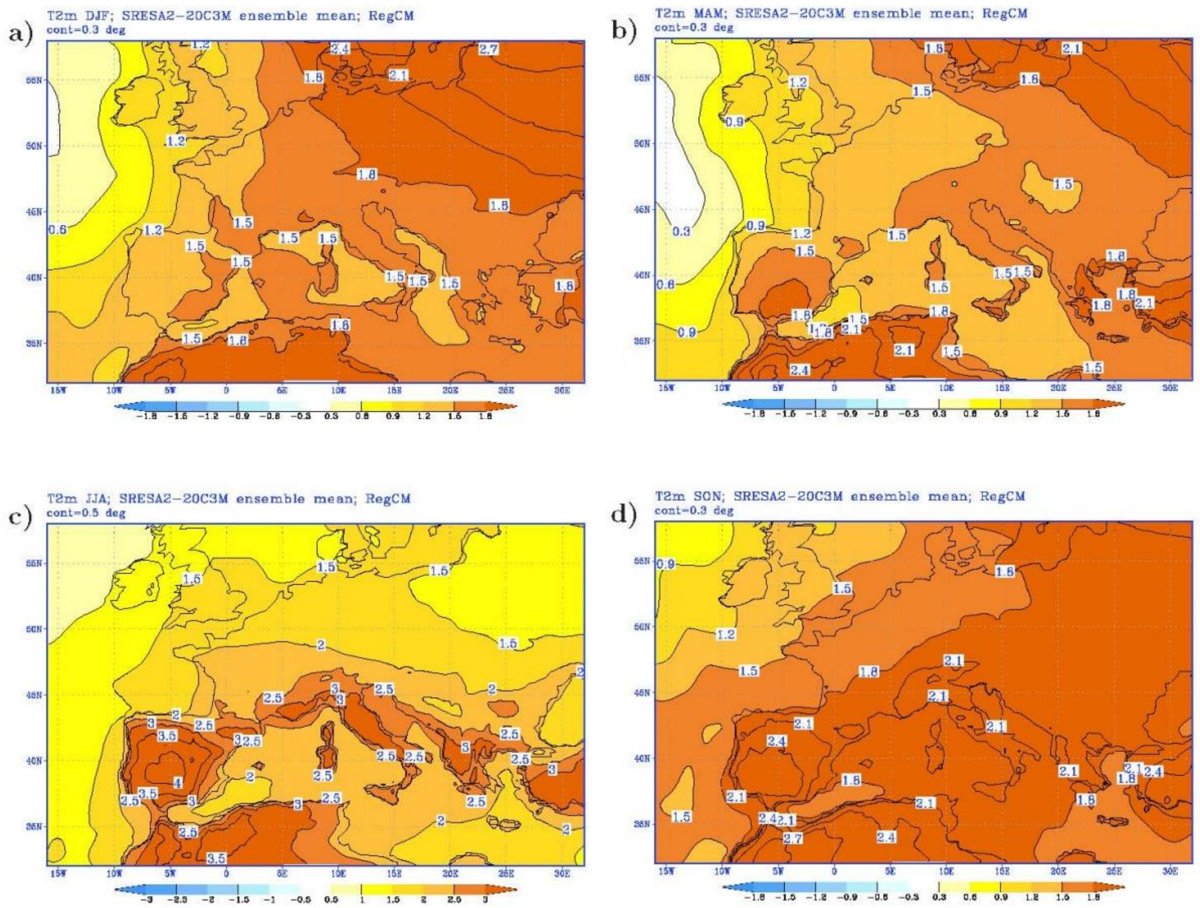

Figure 2. Temperature at 2 m, future climate minus the climate of the 20th century: a) winter, b) spring, c) summer, d) autumn. Isolines every 0.3 degrees in a), b) and d), and every 0.5 degrees in c). Source: Branković et al. (2012).

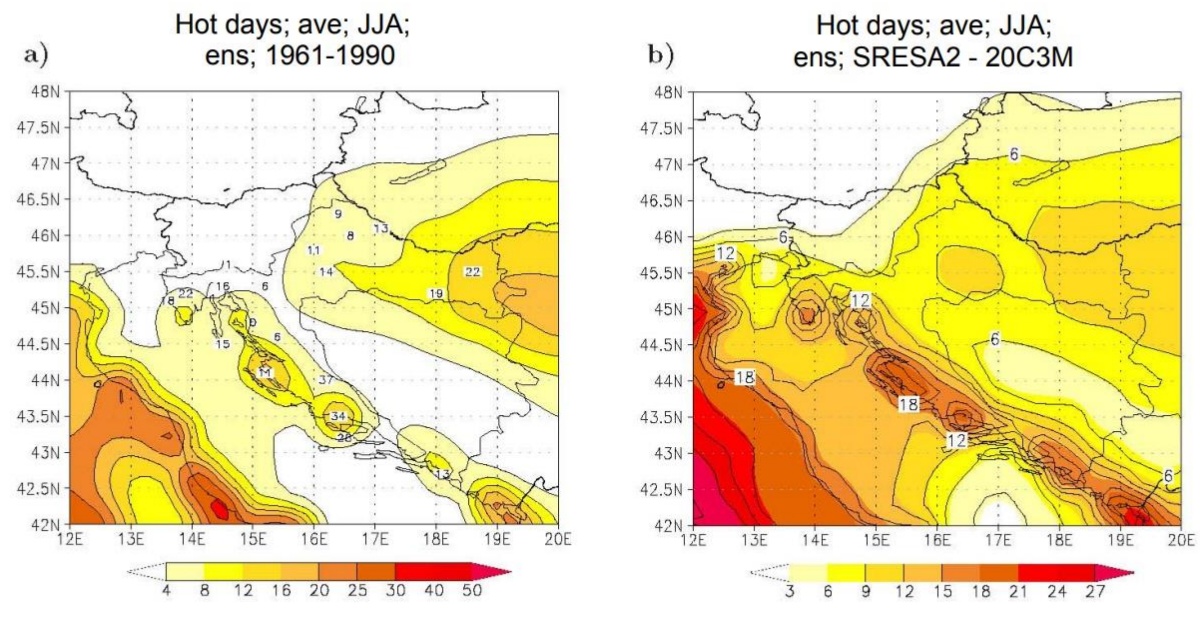

Figure 3. Median number of hot days (T>30 °C) a) for the period 1961-1990, b) change of the number of days minus the climate of the 20th century (1961-1990). Source: Branković et al. (2012).

1.2. Precipitation, dry and wet days, river discharges

Precipitation in the coastal Adriatic area has been recorded with a negative trend (Fig. 4), from -1.8% over 10 years in Crikvenica to -1.2 years over 10 years in Hvar. The trend is largely defined by a climate shift observed in 1940s, when several periods with less precipitation occurred. In the area of northern Adriatic (Crikvenica) decrease in all seasonal precipitation amounts has been observed, mostly expressed during summer (-2.7% in 10 years), then in spring (-2.2% in 10 years) and winter (-1.8% in 10 years). On Dalmatian islands (Hvar) decrease in annual precipitation amounts is a result of decline in winter (-2.9% in 10 years) and spring (-2.0% in 10 years) precipitation amounts.

Change in precipitation regime patterns can be also indicated by tendency in frequency and intensity of precipitation extremes defined by number of days in which the precipitation amount Rd exceeds defined thresholds (dry days, wet days and very wet days). Dry days are defined as days in which Rd<1.0 mm, wet days have Rd ≥ 75th percentile and very wet days Rd ≥ 95th percentile of daily amounts, determined by the sample of all precipitation days (Rd≥1.0 mm) within standard reference period 1961-1990. In the period 1901-2008 there was statistically significant increase of annual number of dry days in the coastal Adriatic (Fig. 5), while mostly negative trend of wet days significant in the northern Adriatic (Crikvenica).

The precipitation decrease is reflected in a decrease of the freshwater load to the Adriatic Sea (Fig. 6), which is also important as bringing nutrients to the coastal regions. The decrease is particularly relevant after 1970s. The decrease is projected also for the future climate, as being driven by the precipitation decrease over the catchment area of the Adriatic rivers (Fig. 7). The decrease in precipitation will be particularly strong in summer (JJA) and autumn (SON), while the precipitation during winter (DJF) will slightly increase at the most of the Adriatic coastlines.

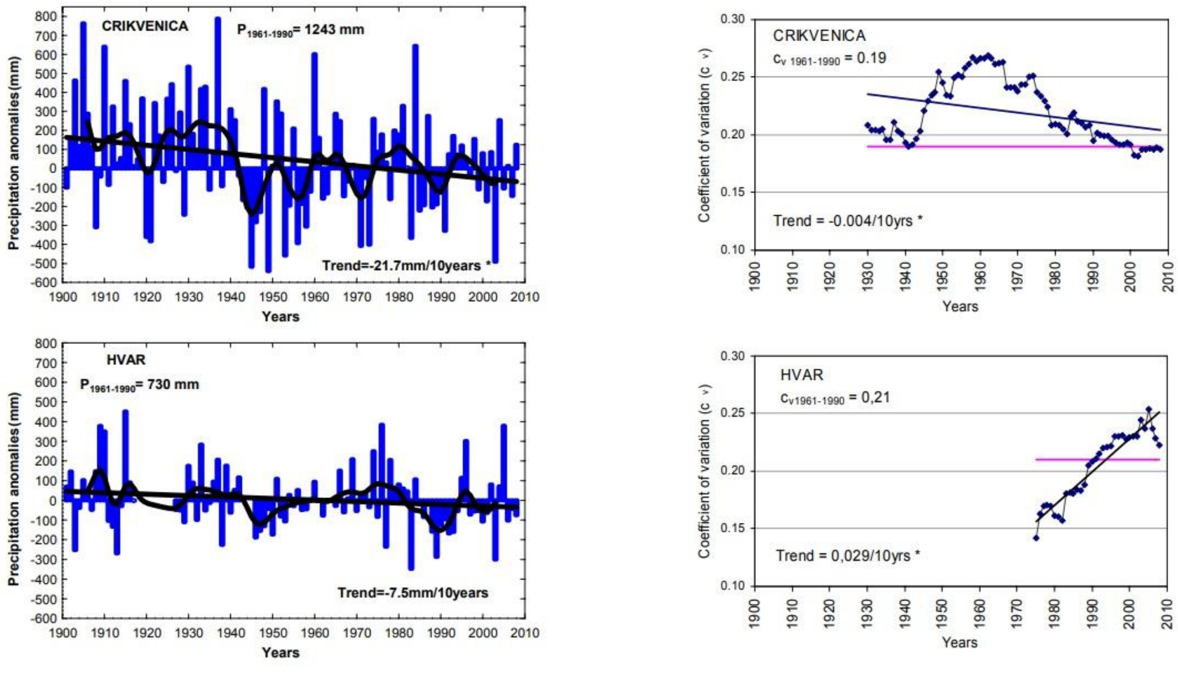

Figure 4. Time series for the annual precipitation amounts, related 11-year binomial moving averages and trends (left, unit is anomalies (mm) with respect to 1961-1990 average). Time series for the coefficients of variation for 30-year periods with one year shift and trends (right). (*

- trends significant at the 5% level). Period: 1901-2008. Source: Branković et al. (2010).

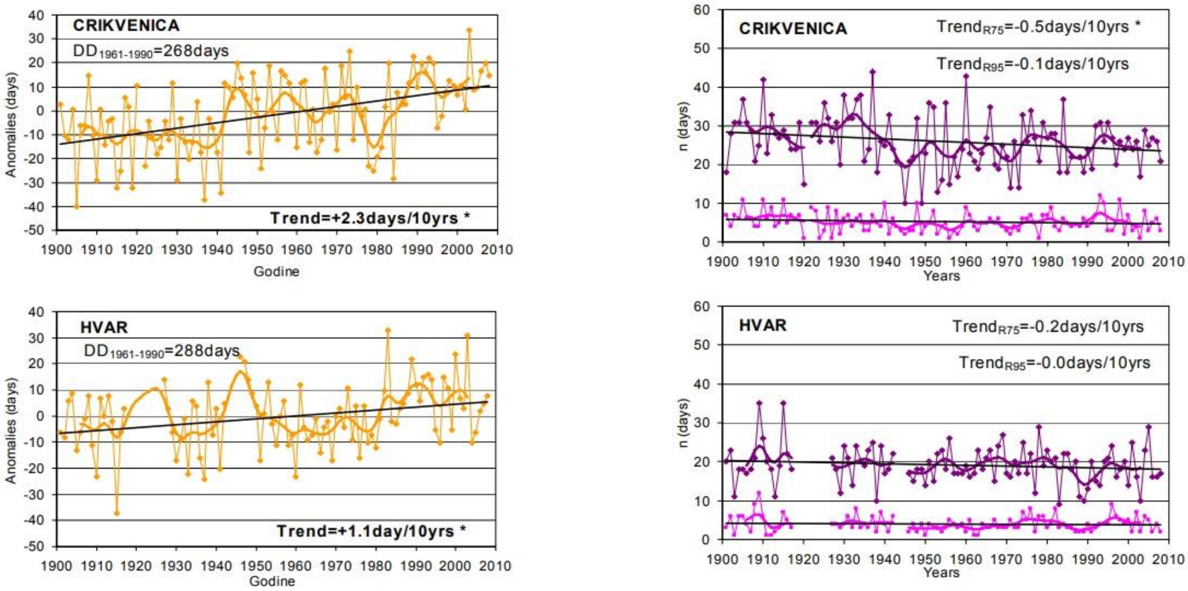

Figure 5. Time series for the number of dry days (left), unit is anomalies (days) with respect to 1961-1990 average. On the right time series for the number of moderate wet days (Rd>R75% - above) and very wet days (Rd>R95% - below), related 11-year binomial moving averages and trends (* - trends significant at the 5% level). Period: 1901-2008. Source: Branković et al. (2010).

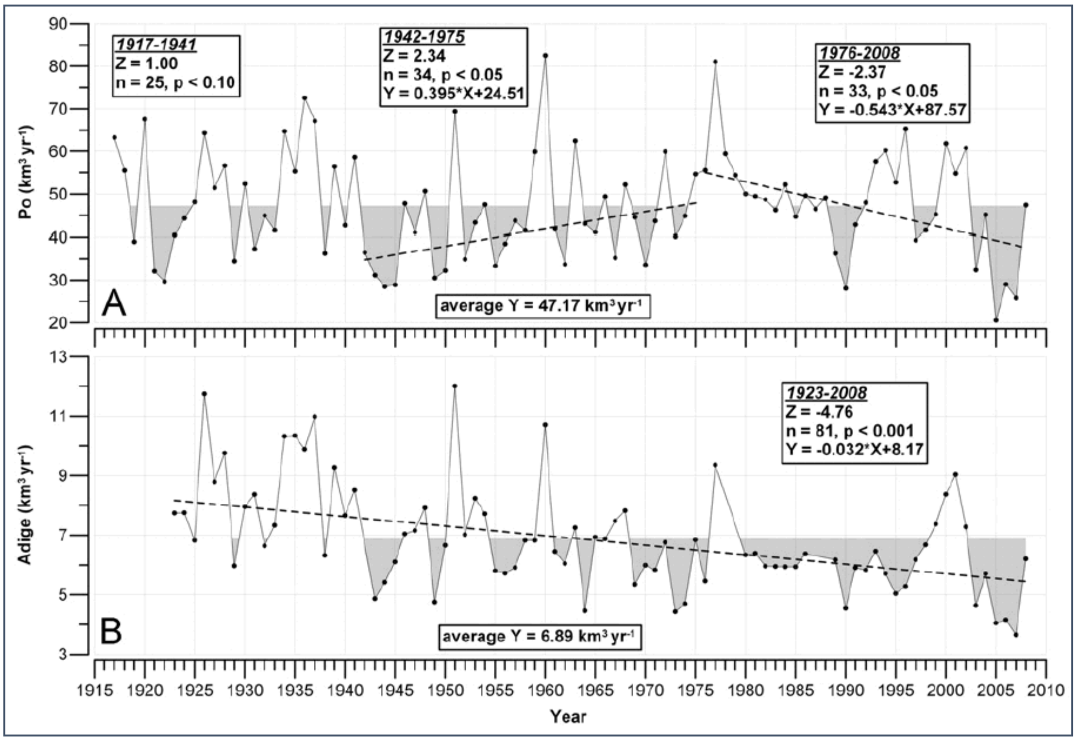

Figure 6. Annual average discharges of two largest northern Adriatic rivers, Po and Adige. Source: Cozzi and Giani (2011).

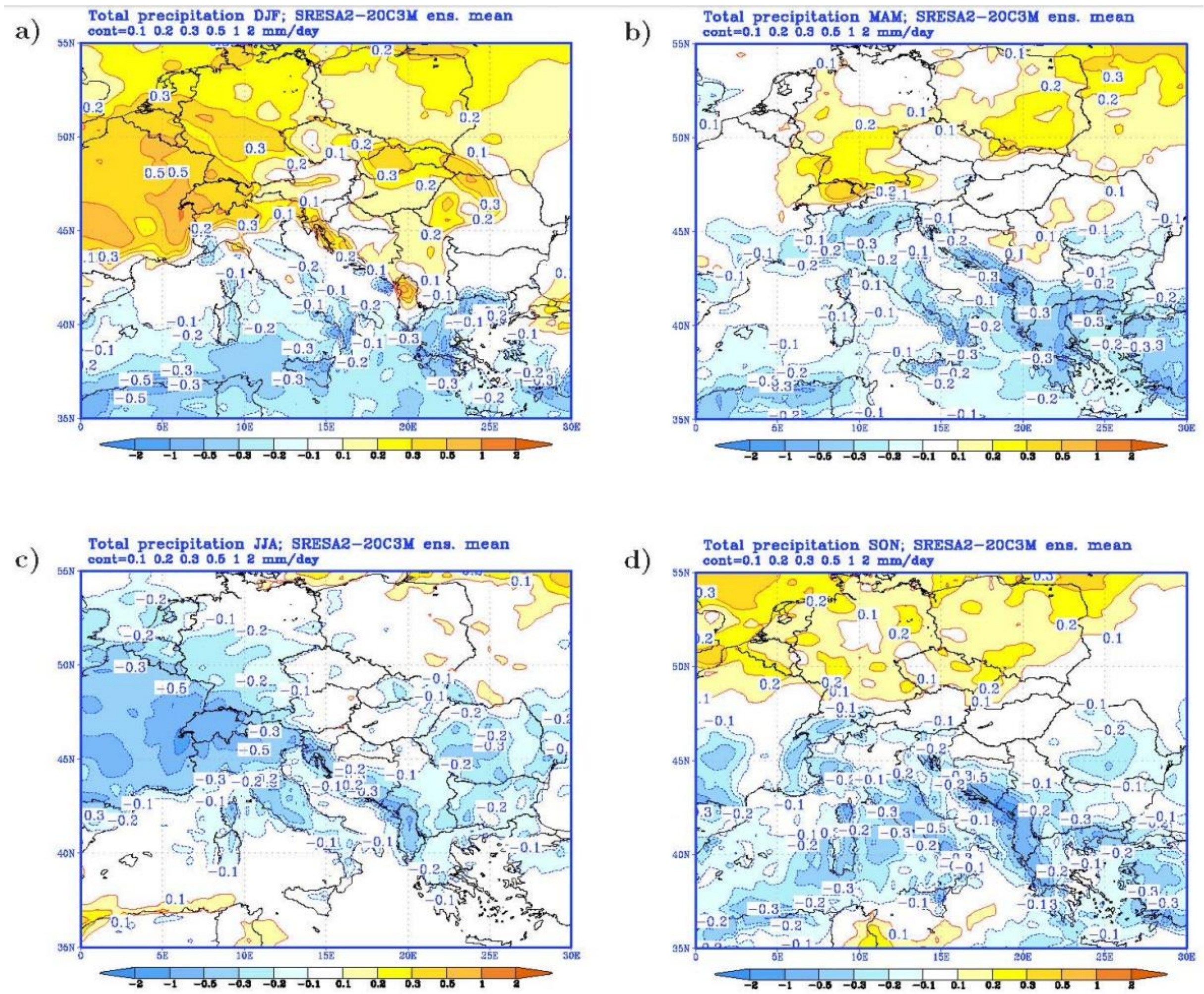

Figure 7. Total precipitation, future climate minus climate of the 20th century: a) winter, b) spring, c) summer, d) autumn. Isolines 0.1, 0.2, 0.3, 0.5, 1, 2 mm/day; bold lines positive values, dashed lines negative values. Source: Branković et al. (2012).

1.3. <u>Ocean temperature and salinity</u>

Ocean temperature in the Adriatic Sea is decreasing from the entrance, where defined by an inflow of warmer Eastern Mediterranean waters, to the northern Adriatic influenced by severe winter outbreaks and generally loosing more energy than in the southern Adriatic. The along-Adriatic surface temperature (Fig. 8) is reflecting during winter (JFM) lowest temperatures (>10 ^{o}C) in the northern Adriatic, while being higher in the southern Adriatic (close to 14 ^{o}C). The temperatures in the rest of a year doesn't reflect such a strong gradient, yet being lower in the coastal eastern Adriatic, where lot of freshwater load is coming through submarine springs and lower rate of energy gain is occurring.

Surface salinity in the Adriatic Sea (Fig. 9) is mainly driven by large freshwater load in the northern Adriatic, ranging from 38.5 in the southern Adriatic to less than 36.0 off the Po River delta.

Long-term trends of temperature, salinity and dissolved oxygen (Fig. 10) are indicating a weakening of the Adriatic thermohaline circulation, i.e. lower water mass exchange between the Adriatic and the Ionian Seas. For that reason the temperature trends are negative in intermediate layer, while salinity has the largest trends in coastal regions due to decreasing of freshwater load in time. Further, dissolved oxygen trend is indicating less ventilation of deep Adriatic waters, i.e. lower rates of dense water generation during wintertime in the northern Adriatic. As a consequence, deep pelagic and benthic organisms can be affected by these changes, especially in the biodiversity of niches such as found in the nearby Jabuka Pit, which serves as a collector for dense water from the northern Adriatic Sea.

Warming and saltening of the Adriatic waters will continue in the future climate (Figs. 11 and 12). The largest rise in temperature is foreseen in the RCP8.5 climate scenario, which is reflecting business-as-usual socio-economic development of the world economy. In this scenario, ocean surface temperature will rise for about 3 ^{o}C till the end of the 21th century. Salinity is also projected to rise throughout the 21st century, although the low (RCP2.6) and the mid (RCP6.0) scenarios are projecting a decrease in salinity in far future (2071-2100) compared to the middle future (2041-2070). This would happen as more waters will be advected to the Adriatic from the Western Mediterranean, reflecting in strengthening of the Adriatic-Ionian Bimodal Oscillating System (BiOS) anticyclonic phase in the future climate.

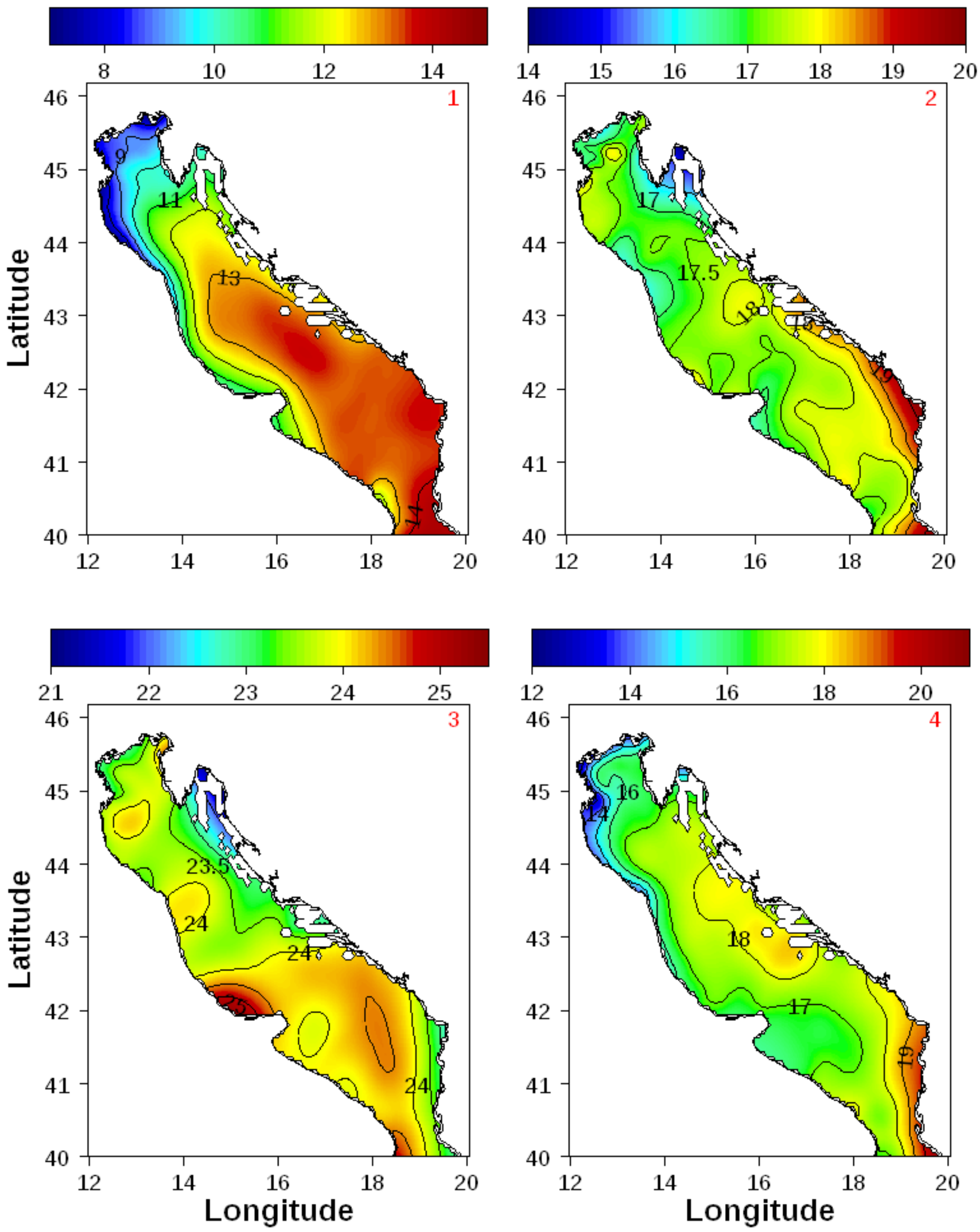

Figure 8. Surface ocean temperature in the Adriatic Sea during winter (JFM, top left), spring (top, right), summer (bottom, left) and autumn (bottom, right) as computed from centennial Adriatic in situ measurements. Source: Lipizer et al. (2014).

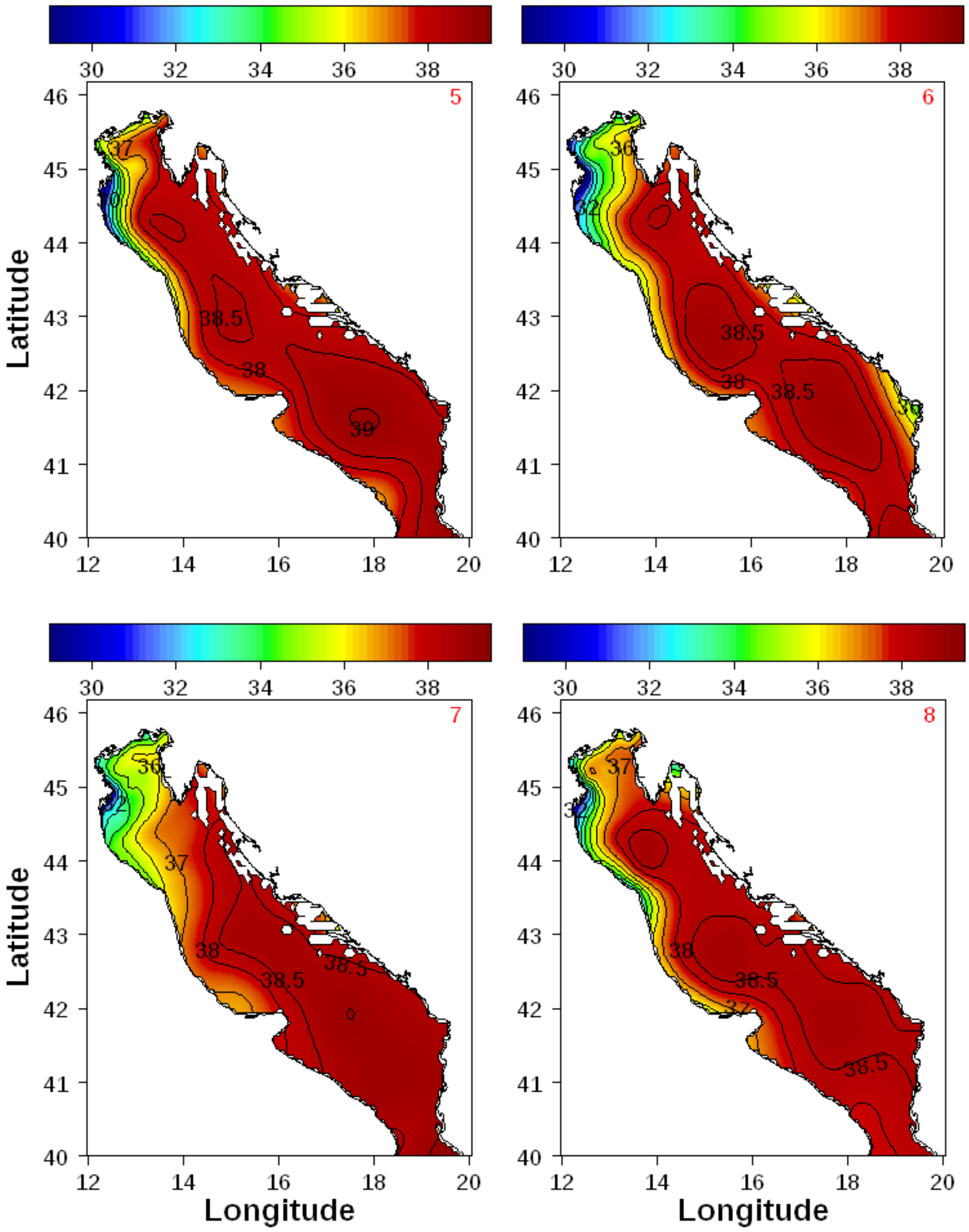

Figure 9. Surface salinity in the Adriatic Sea during winter (JFM, top left), spring (top, right), summer (bottom, left) and autumn (bottom, right) as computed from centennial Adriatic in situ measurements. Source: Lipizer et al. (2014).

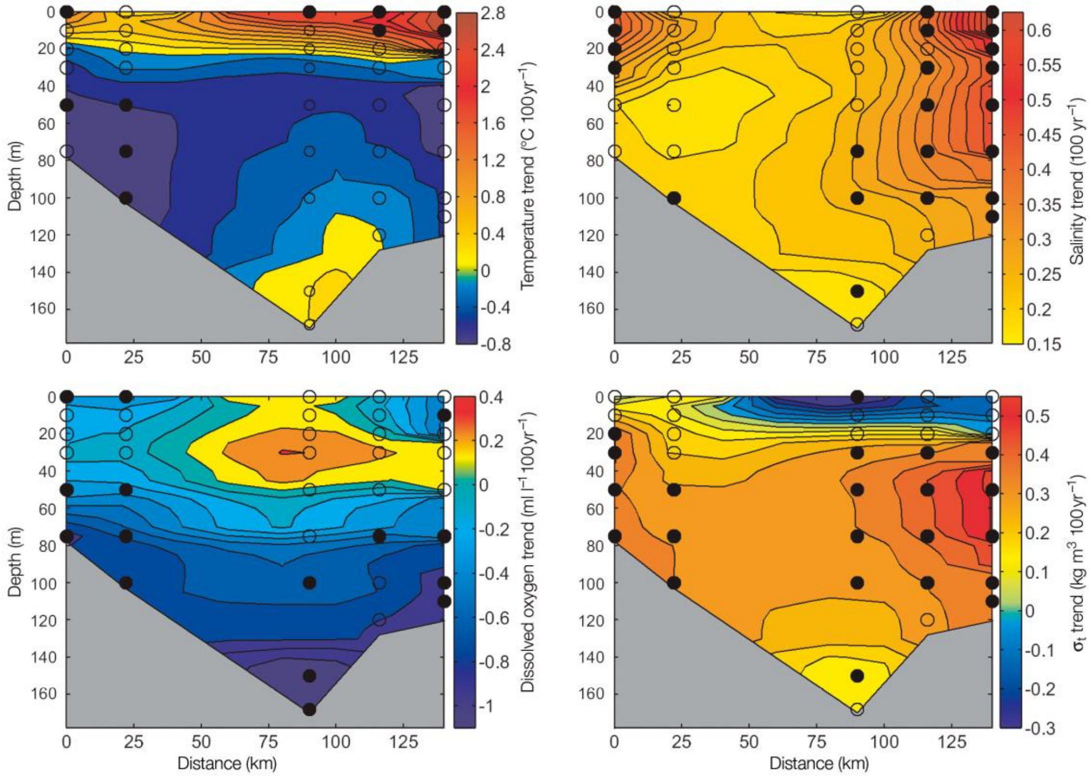

Figure 10. Trends in ocean temperature, salinity dissolved oxygen and density as computed from the Palagruža Sill data (1952-2010). Source: Vilibić et al. (2013).

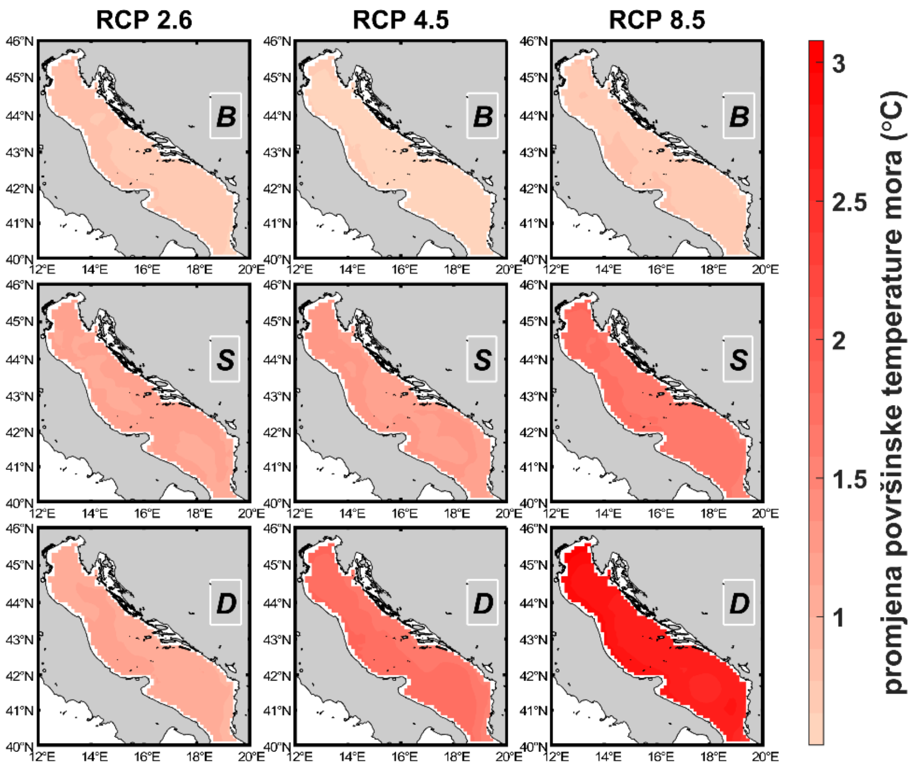

Figure 11. Surface ocean temperature projected for the near (B, 2011-2040), middle (S, 2041-2070) and far (D, 2017-2100) future by CNRM-RSM4 climate model. Source: Dunić (2019).

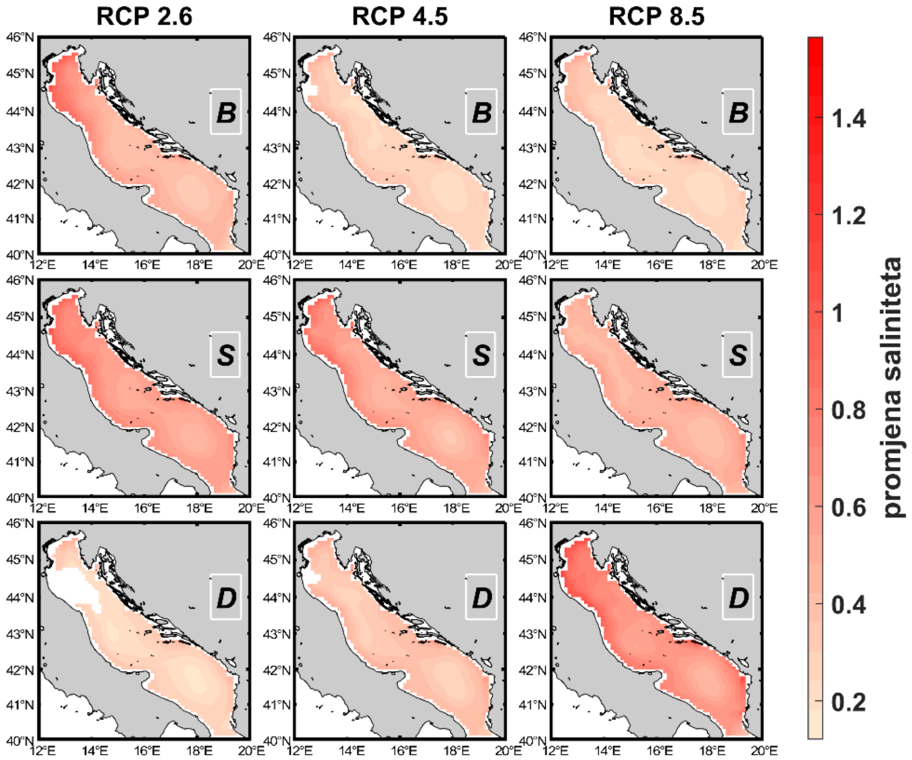

Figure 12. Surface salinity projected for the near (B, 2011-2040), middle (S, 2041-2070) and far (D, 2017-2100) future by CNRM-RSM4 climate model. Source: Dunić (2019).

1.4. Ocean chemistry

Concerning the ocean chemistry of the Adriatic Sea, the most relevant issue is a decrease in dissolved oxygen content in deep Adriatic layers due to weakening of the Adriatic thermohalice circulation (Fig. 13). Such a decrease migh have a substantial influence to the bethic organisms, including also in coastal regions. On top of that, large interannual and decadal variability may be noticed, peaking in the 1990s during the Eastern Mediterranean transient (Klein et al., 1999). Nutrients were much higher during that period, as waters mainly come to the Adriatic from the Western Mediterranean which have higher nutrient content. Such a change also reflected in N:P ratio, reducing limitation in phosphorus known to dominate in the Eastern Mediterranean (Krom et al., 1991). According to climate projections, such events will become more frequently in the future climate.

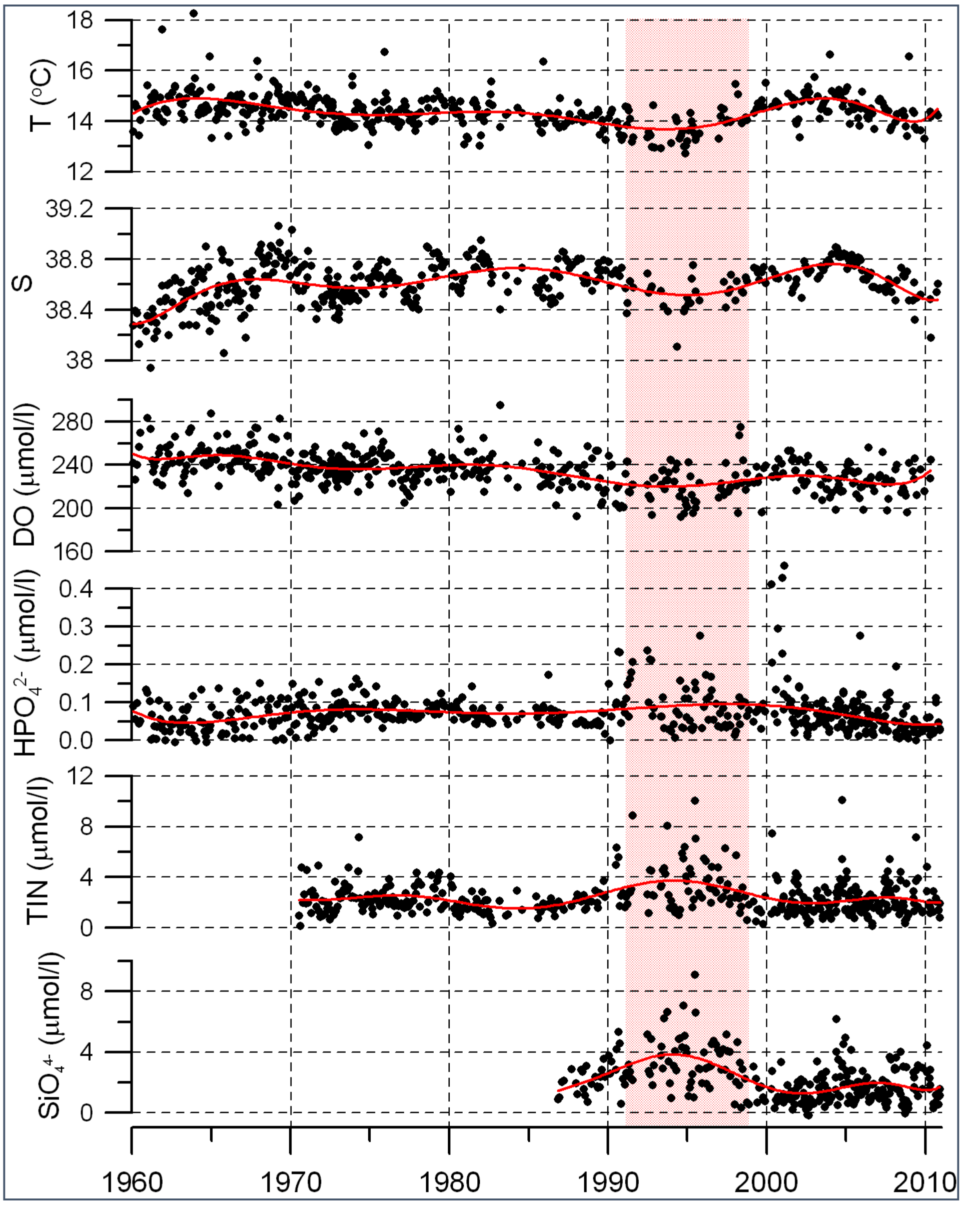

Figure 13. Temperature, salinity, dissolved oxygen and nutrient concentrations measured at the bottom of the Stončica station. Source: Vilibić et al. (2012).

1.5. Sea level rise

Sea level rise in the Adriatic sea is reflecting the overall changes in the Adriatic current and thermohaline regimes. The rise is found to accelerate (Figs. 14 and 15) in all coasts of the Adriatic, what is also projected in the future. Currently, sea level trends are at rates of approximatelly 45-55 cm per century, what are several times higher than these accounting the last 100 years.

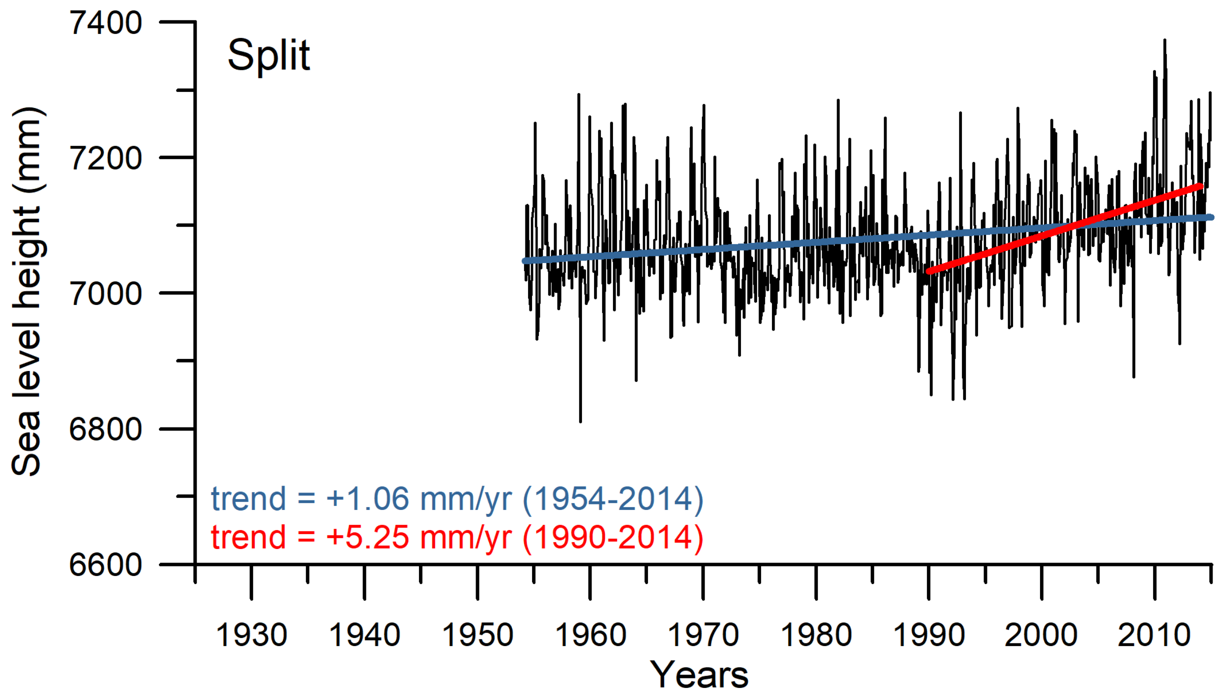

Figure 14. Monthly sea level data and sea level trends at tide gauge Split.

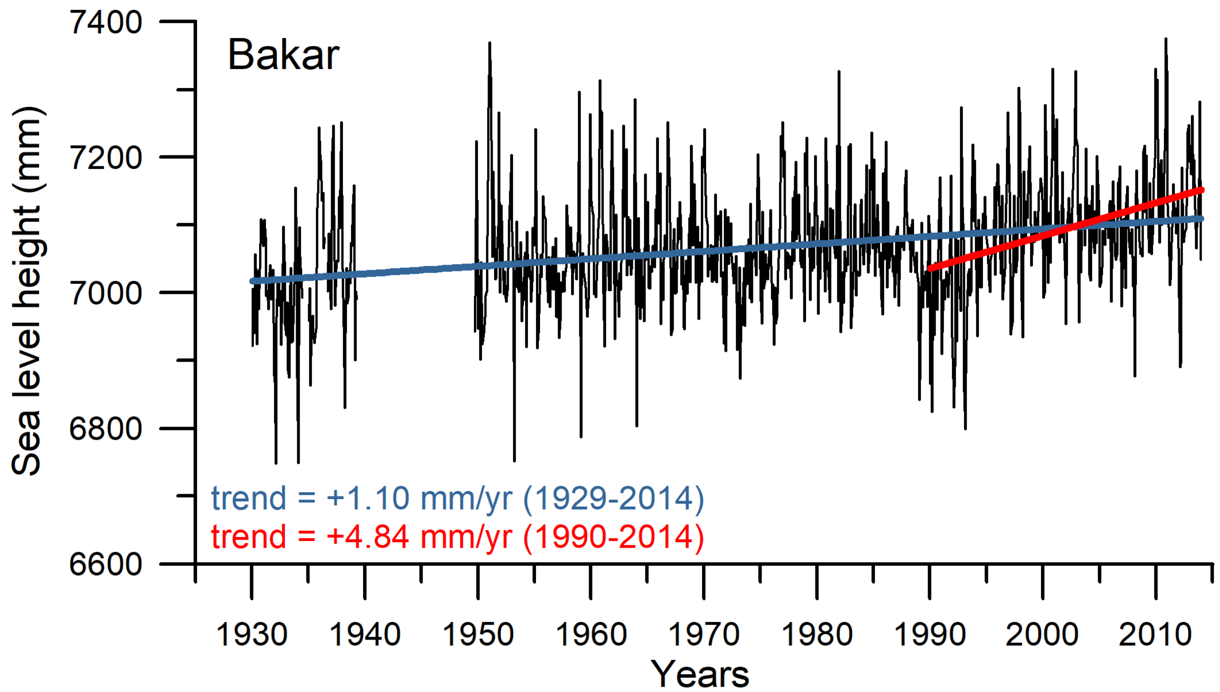

Figure 15. Monthly sea level data and sea level trends at tide gauge Bakar.

INFLUENCE OF CLIMATE CHANGE

Although discussion on the origin and mechanism of climate change can be lead from different angles and is a source of controversy (scientific evidence, however, leave little maneuvering space for climate change denialists), the fact that climate change is actually happening stands stronger than ever before. It is usually perceived through a rise in mean atmospheric temperature, but several features of the earth's climate such as atmospheric circulation, ocean patterns and mixing, stratification, hydrological and seasonal patterns are influenced by the build-up of carbon dioxide and other greenhouse gases in the atmosphere (Monteiro, 2016).

Climate is one of the most important determinants for living organisms, shaping the distribution of plants and animals all over the planet through the combination of direct and indirect effects. In poikilothermic organisms such as fishes, the temperature may shape population and community structures, through its direct influence on the survival, reproduction and patterns of resource use of single individuals (Azzuro, 2008). Effects of temperature on marine organisms can be also mediated by indirect effects such as by the modification in water circulation, with clear consequences on larval dispersal and recruitment [13]. Fishes have long been used as indicators of environmental changes (Stephens et al., 1988; Bettoso and Dulčić, 1999). Their high dispersal potential, ecological differentiation, general non-resilience, sensitivity to temperature, large size and ease of identification, make them excellent candidates for the study of the effects of climate variability. Beside this, climatic changes have been known for their deleterious impact on the biology, fecundity, growth and biodiversity of aquatic, terrestrial and aerial animals (Eissa and Zaki, 2011). It is predicted that climate change has an effect on individual organisms during all life stages hence affecting populations of a species, communities and the functioning of the ecosystem (Pörtner and Peck, 2010).

It seems that detection of influence of climate change on the Mediterranean hydrology and hydrobiology is rather difficult due to significant variability in local climate which masks trends in the „noise" of natural fluctuations (Karas, 2000). However, in the recent decade, significant progress has been made to tackle this issue. This is especially relevant for the Adriatic basin where local athmospherical conditions significantly influence hydrological properties. Ferrarese et al. (2009) pointed out that the Adriatic Sea circulation and temperature patterns change abruptly at onset and growth of strong winds (i.e. Bora and Scirocco). Indeed, highest seasonal variability of sea surface temperature (SST) in the Mediterranean has been documented for the area of North Adriatic (Shaltout and Omstedt, 2014). Vilibić et al. (2013) pointed out that weakening of thermohaline circulation in the Adriatic Sea due to climate change can potentially affect deep pelagic and benthic organisms especially biodiversity in niches such as found in the nearby Jabuka Pit. In the last decade a significant amount of papers acknowledged influence of climate change on hydrological and biological processes in the Mediterranean and Adriatic Sea, as well.

Potential responses to climate warming include a wide array of taxa seeking cooler enviroments by shifting toward poles and higher latitudes, higher global extinction rates and reorganization of local communities resulting from local extinctions and expansion of thermophilic species (Ben Rais Lasram et al., 2010). In case of fishes, climate change can influence their distribution and abundance through changes in growth, reproduction, survival or response to changes at other trophic levels (Perry and all., 2005). Other authors predict the species niche reductions by the middle and the end of the 21st century that might result from sea temperature increase (Ben Rais Lasram et al., 2010).

There are few theoretical conseqences that can be experienced by the mobile fauna (especially fishes) of the Adriatic Sea which can be perceived as an increase of abundance of certain species but due to different mechanism. One is the extension of the northern limit of species distributions which usually affects thermophillic species (northward expansion), and the other is the reduction of

distribution of species of cold water affinity with subsequent northward shift of center of population distribution (seeking refuge in northern areas). Thermophilic fishes have evolved in tropical or subtropical marine environments and hence are adapted to warm waters. In the Mediterranean (including Adriatic sea), these species can be broadly categorized into two major groups, which are distinguished by different histories: a) native species (with tropical or subtropical affinity and origin), and b) exotic species recently entered in (Azzuro, 2008). Beside phenomenon of shift in population distribution (usually northward) by native Mediterranean species which is usually termed „meridionalization", a process of „tropicalization" (arrival of alien species) also plays an important role in carving of the faunal assemblages of the Mediterranean and Adriatic Sea.
It is presumed that coldest parts of the Mediterranean Sea (Gulf of Lyon and North Adriatic) could initially serve as a sanctuary for cold-temperate species, but with the continuation of warming those areas could become „cul-de-sac" for those species. This is especially important for endemic species which could go extinct due to the trapping effect (Ben Rais Lasram et al., 2010).

RECENTLY REPORTED ICHTHYOFAUNAL CHANGES

As previously mentioned, one of the main consequences of the climate change on the biodiversity, or at least easily observable, is the shift in species geographical distribution. There are numerous examples of such shifts in the world oceans including the Mediterranean and Adriatic Sea. In the last two decades, the advance of thermophilic species has represented most cited evidence of the linkage between climate change and distribution patterns of Mediterranean Sea biodiversity. When consequences of climate warming still had a hypothetical character, these 'unusual occurrences' provided the first indication of changes that were still not clearly evident in the temperature records (Riera et al., 1995; Francour et al., 1994). Great number of 'northward shift records' came from the Adriatic Sea (Dulčić and Grbec, 2000; Dulčić et al., 2004 and references therein included), where even juveniles of various thermophilic fishes (e.g. *Trachinotus ovatus*, *Sparisoma cretense*, *Pomatomus saltator*, *Stromateus fiatola* and *Campogramma glaycos*) have been recently registered.

Presence or increase in abundance of certain thermophilic species in the Adriatic Sea is usually attributed to the water warming, but it is a very complex task to distinguish it from other potential drivers. However, it is most likely that majority of possible drivers are essentially related to the increased average sea temperature. In the last 20 years numerous thermophilous fish species have been recorded for the first time in the Adriatic Sea and their presence might be related to climate change. There is also an interesting issue of the presence of lessepsian fish species whose presence can not easily be attributed to climate change but is certainly facilitated by it.
It is a gradual change and its effects are observable at least on a decadal scale, however, certain phenomenons are represeted by rapid changes, i.e. population explosions. On the eastern coast of the southern Adriatic Sea, it is easily to notice a triggerfish (*Balistes carolinensis*) eating hard shelled animals of the bridge pier, beautifully colored ornate wrasse (*Thalassoma pavo*) graciously moving among the weedy rocks and, if you are lucky enough, you might witness an elaborate mating of parrotfish (*Sparisoma cretense*) somewhere in the waters off Korcula island (Figure 16). These fishes were a rare sight even in the Southern Adriatic, but they are now becoming increasingly abundant and slowly progressing toward northern areas. Any regular visitor of the fishmarket in Split (for example) can witness increasing occurence of previously unknown fish species in the last decade.

Figure 16. A) triggerfish (*Balistes carolinensis*); B) ornate wrasse (*Thalassoma pavo*); C) parrotfish (*Sparisoma cretense*): Source: https://sealifecollection.org/p/2310

Bluefish (*Pomatomus saltator*), dolphinfish (*Coryphaena hippurus*), atlantic lizardfish (*Synodus saurus*), yellowmouth barracuda (*Sphyraena viridensis*) are now frequent fishmarket items, although only ten years ago they were either ultra rare or totally absent from fishmarkets. Even native sea bream (*Sparus aurata*) has become exceptionally abundant in the last few years. Are effects of climate change the only factor that influences these changes? Probably not. But in any event, climate change might still be a significant if not major culprit for these changes. The reason for uncertainity is quite a large number of variables involved in the Adriatic ecosystem equation, or any for that matter. Brander (2010) stated that an important issue in assessing the influence of climate change on fish populations is the disentanglement of its effects from those of other drivers (i.e. fishing). First of all, overfishing of commercial fish stocks can be considered as the primary source of fluctuations in this complex web of ecological interactions. Heavy fishing can influence success of non-commercial species by reducing competition by the commercial species for the same resources hence allowing previously rare species to establish more numerous and resilient populations. Secondly, since Adriatic Sea is not isolated from the rest of the Mediterranean, changes occurring in other areas have consequences for the Adriatic ecosystem. This is especially important for the presence of lessepsian fish species whose arrival in the Adriatic is not only facilitated by climate change but also by the presence of already established populations in the southern regions which probably act as recruitment areas for subsequent northward spreading (Mavruk and Avsar, 2008).

There has been numerous studies connecting spreading and arrival of species of tropical affinity into new areas as a consequence of water warming. Beside arrival and spreading of non-native species there are also certain changes affecting populations of native fishes. This is evidented through either increased abundances, northward extension or decline in occurence of some species. If latter case is concerned, it is very difficult to resolve whether decline of particular fish species is due to unsuitable hydrological conditions or is overfishing, food chain instability, disease or some other factor affecting its population. However, it is very likely that some cold water species will be negatively affected by the water warming while thermophilious species will benefit from it. This issue is of particular importance for the Adriatic Sea since the impacts of the global warming are particulary critical in semi-enclosed seas (Pozdnyakov et al., 2007). There are already indications that some coldwater fish species, particullary Sprattus sprattus, are in decline in the last few decades (Grbec et al., 2002).

Effects of water warming probably influenced shifts in distributions of some native species which is usually being perceived as an increase in abundance (or vice versa) of such species. Scarcity of historical data usually don't allow for more elaborate investigation of some of such cases, but there is a growing number of reports on the unusual occurences of certain species. It is much easier to track changes in the distribution and dynamics of colonization of the species whose presence is recently reported for the first time as such records usually provide a baseline for the tracking based on subsequent occurrences. Due to increased research interest, advance of social media and awareness raising campaigns, a possibility of drawing biased conclusions based solely on the occurrence reports is very much possible. In the future collection of data based on local ecological knowledge (LEK) are necessary and such attempts have already been undertaken for the Mediterranean Sea (Azzurro et al., 2011; Boughedir et al., 2015).

Perhaps the most striking change in the fish communities is an increase in abundance of beforementioned bluefish (*Pomatomus saltator*) (Figure 17). For the area of northwestern Mediterranean it is documented that this species reacts to the increased sea surface temperatures (SST) by shifting areas of distribution and reproduction northward in the northwestern Mediterranean (Sabates et al., 2012). An unusually large catch (1.5 tonnes) of this species has been documented for the area of Northern Adriatic in winter of 2003 (Dulčić et al., 2005). Additionally, there is evidence that this species causes significant negative effects on populations of native fishes such as mugils especially in the area of Neretva estuary (Glamuzina et al., 2008). However, preliminary results originating from local ecological knowledge survey (LEK) indicate a rise in abundance of this species in the last decade (unpublished data).

Figure 17. Bluefish (*Pomatomus saltator*).
Source: https://www.pecesdelmarmediterraneo.com

Presence of thermophillic dolphinfish *Coryphaena hippurus* is not new for the Adriatic Sea. This species regularly enters Adriatic waters in the warmer period of the year but was considered rare in the older literature (Jardas, 1996.). However, results of the LEK survey among sports fishermen in Croatia indicated that abundance of this species is on the increase in the recent years (unpublished data). This is in agreement with results of the LEK study performed by Azzurro et al., (2011). It is also suggested that this species reproduces in the Adriatic waters which is indicated by the presence of larvae and early juveniles (Dulčić, 1999; Dragičević et al., 2010). Unfortunatelly, lack of detailed landing data on this species for the Adriatic Sea, as is the case with Pomatomus saltator, makes it particulary hard to establish a scientifically based connection between perceived changes in population abundance and water warming.

Figure 18. Dolphinfish, *Coryphaena hippurus*. Source: https://pelagicgear.com/blogs/news/new-pending-california-state-record-yellowfin-tuna-caught

There are interesting cases which consider thermophillic species of Carangidae family, namely *Caranx crysos* and *Caranx rhonchus*. Adriatic Sea experienced very rapid, but somewhat overlooked colonization by these two species. Both appeared recently for the first time in the Adriatic waters, in 2009 and 2011, respectively (Dulčić et al., 2009; Kožul and Antolović, 2013). According to Psomadakis et al. (2011), recent increase in the occurence of *C. crysos* in the Tyrrhenian Sea is probably indication of displacement of the northern limit in the Mediterranean and is attributable to the „tropicalization" phenomenon currently occuring in the Mediterranean. This is even more indicative for the Adriatic scenario since northernmost occurence of this species in the Mediterranean was recorded in the area of North Adriatic. Similar is the case of *C. rhonchus* for which, after its first occurence, few catches of significant quantities from the area of Southern Adriatic (Montenegrin coast) were reported.

Indications on the distributional shifts among some thermophillic native fishes are based mostly on increased number of reports in the recent decade. Among the most interesting examples of increases in abundances in the Mediterranean area, probably due to distributional shift, are those of *Sphyraena viridensis*, *Synodus saurus*, *Dactylopterus volitans*, *Thallasoma pavo*, *Balistes carolinensis*, *Pseudocaranx dentex*, *Sparisoma cretense* and *Enchelycore anatina* (Dragičević et al., 2016). Previously predominant in the southern Adriatic, species of Serranidae family also experienced northwrd shift. This is especially indicative in the cases of *Epinephelus aeneus* and *Mycteroperca rubra*, which, after their first records from Southern Adriatic in 1999 and 2000, respectively, experienced an northward expansion and are now occasionally reported from the areas of southern and middle Adriatic Sea (Glamuzina et al., 2002; Dulčić et al., 2006).

SSF VULNERABILITY TO CLIMATE CHANGE

Any changes in marine ecosystems have a definite impact on the users of marine bio-resources, primarily on fisheries. As previously stated, the effect of sea warming on marine populations may be direct, through individual physiological adaptations, and indirect, through alterations in the abiotic environment and prey availability (Tzanatos et al., 2014). Projections of the impacts of climate change on marine ecosystems are a key prerequisite for the planning of adaptation strategies, yet they are inevitably associated with uncertainty.

Climate induced changes are expected to affect ecosystem services (e.g. fisheries and aquaculture) all around the world (Gamito et al. 2015). Particulary, the impact of climate change on the marine fisheries sector is complex, due to the fact that the effects can be both positive and negative in economic terms. The consequences of climate change on fishing communities will depend on their exposure to this factor, the sensitivity of target species and ecosystems to climate change and fishermen's ability to adapt to climate change (Gamito et al., 2015). Fisheries should be affected by both ''meridionalization'' and ''tropicalization'' of catch, i.e. an increase of warmer-water species in relation to colder-water ones, since shifts in distribution are expected to affect their availability to fisheries (Rijnsdorp et al., 2009; Cheung et al., 2013). This scenario is already taking place in the Adriatic waters where a significant number of thermophilic species occur in the catches more often, especially in the coastal areas (*Sphyraena viridensis, Synodus saurus, Balistes carolinensis, Pseudocaranx dentex* etc.). Landings may change in relation to global warming (Teixeira et al., 2014), and this may induce changes in the intensity and spatial distribution of fishing effort (Haynie and Pfeiffer, 2012). In particular, the vulnerability of a fishery to climate depends on previously induced changes in fish stocks that affect species composition and thus abundance in commercial catches (Fortibuoni et al., 2015). As an example, the change in the mean temperature of the catch (MTC) of official and survey catches, parameter proposed as one method which can light up changes in catch composition, in the Ionian and Aegean Seas indicated that the relative catch proportions of species preferring warmer waters and those preferring colder waters have changed in favor of the former and that this change is linked to sea surface temperature increase (Tsikliras et al., 2015). Generally, mean catches of polar and temperate species were higher in years of warm winters in the large marine ecosystems located in the northern part of the species range and in years of cold winters in large marine ecosystems of the southern regions of their ranges. Mean catches of subtropical species were higher in cold years in LMEs of lower latitudes and in warm years in large marine ecosystems of higher latitude regions. The results obtained for fish catches agree with a poleward shift of fish species as a response to ocean warming, posing challenges for future fisheries management (Gamito et al., 2015). These effects occur with certain shift in phase and we need reliable and long series of oceanographic data for correlation.

For sure, climate change will provoke changes that will be reflected in all fishery sectors, professional and recreational. Both artisanal and industrial sectors may adapt to these changes mainly through expansion of fishing grounds that will consequently increase operation costs. Trawlers may be more adaptable and less vulnerable to climate change, given the high mobility of their fleet. For example, the poleward movements of northeast Atlantic (NEA) mackerel (*Scomber scombrus*) catches, possibly linked to climate change, are causing a major international disagreement over quotas. A practical implication of the reported changes in catch since 1977 is that vessels are now reportedly fishing further offshore, which has implications for fuel consumption and profitability of the fishery (Hughes et al., 2015). However, Belhabib et al. (2016) highlighted that historical changes in target species are more common in industrial than artisanal fisheries. This result challenges the prevailing assumption that artisanal fisheries, given their limited movement capacity, would adapt to climate change by shifting target species and/or gear type, pointing that will make them potentially less vulnerable to climate change.

The exposure of a fishing community will be greatest where other pressures, such as overfishing, are already stressing the socioecological system (Miller et al. 2010). Also, fish stocks, if already overexploited, are more strongly affected by climate change. This is due to reduced age structure, restriction of geographic distribution, loss of diversity etc. (Rijnsdorp et al. 2009; Perry et al. 2010; Planque et al. 2010). Unfortunately, most of the Mediterranean fish stocks are currently overexploited (Colloca et al. 2011), making them particularly vulnerable to climate change, as observed, for instance, for the Northern Adriatic Sea (Pranovi et al. 2013). In that fishery, commercial catch is entirely composed of species from cold and temperate latitudes that have decreased during the past decade as a consequence of global warming. As previously mentioned, northern Adriatic can be considered as particularly vulnerable area that hosts several species that are adapted to boreal climatic conditions and it is configured as a cul-de-sac that prevents the northward migration of species (Ben Rais Lasram et al., 2010; Pranovi et al, 2016). However, it is shown that the relatively healthy condition of fisheries is likely to assist successful adaptation on climate changes (Johnson and Welch, 2016).

Hare et at. (2016) suggested that the overall climate vulnerability is high to very high for diadromous and benthic invertebrate species. In addition, the majority of assessed species have a high potential for a change in distribution in response to projected changes in climate. Negative effects of climate change are expected for approximately half of the species assessed, but some species are expected to be positively affected (e.g., increase in productivity or move into the new region).

Due to their sensitivity to climate forcing that may alter their abundance and distribution, small pelagic fish are important ecological indicators of the state of the current systems. They are schooling, planktivorous fish that provide forage for higher trophic levels. The links between the physical and biological forcing and the structure and condition of their habitats, their patterns of movement, productivity, and stock structure (where information is available) can be described in relation to the fisheries. It appears that the combined effects of fishing and climate change may sufficiently alter habitat characteristics so that both the distribution and productivity of a population are shifted (Valencia-Gasti et al., 2015). Thus, the high sensitivity of small pelagic fishes to the effects of climate change makes the purse-seine fisheries particularly vulnerable to climate change.

The effect of sea warming on the marine faunal composition is particularly evident in the eastern Mediterranean Sea because of the invasion of alien species of indo-pacific origin through the Suez Canal (Lessepsian immigrants), which is facilitated by temperature increase (Golani et al., 2002). Over 435 species have invaded the Mediterranean Sea through the Suez Canal, and about 20% are fishes (Nunes et al., 2014). These invaders, some of which have established viable populations, certainly change the faunal composition but may also cause severe alterations to ecosystem structure and function (Sala et al., 2011; Bianchi et al., 2014). In certain areas of the eastern Mediterranean some alien fishes are commercially exploited (Kallianiotis and Lekkas, 2005; Giakoumi, 2014) but their catches are not yet officially recorded (Tsikliras and Stergiou, 2014), at least not as separate records. Similar scenarios are expected for the Adriatic also given the fact that the presenc of Lessepsian species is on the increase. Some of them are top predators like the bluespotted cornetfish, *Fistularia commersonii* which can potentially affect populations of native fish species like sardine, anchovy, boque and picarel. Possible impacts don't have to necessarily be of ecological or economical nature. Health problems due to consumption of certain toxic species, like *Lagocephalus sceleratus* or other members of tetraodontidae family, should also be considered.

The most comprehensive catch records of alien species have been made for the Israel fishery. The catch of the lessepsian species has been estimated at approximately a third of the total landing since 1954 (Galil, 1993). Nearly half of the trawl catches along the Israeli coast consists of lessepsian fish (Golani and Ben Tuvia, 1995). Similar scenario is practically following the path of succession of these species as new areas are being conquest, i.e. Aegean Sea (Lefkaditou et al., 2010). This species is not targeted but if caught they are offered for sale by individual fishers directly on the market.

A potential replacement in the catches of autochthone species by alien species is expectable due to the fact that alien species are usually more successful in competition for space, shelter and food. Replacement of native mullets (Mullus sp.) with the goatfishes (Upeneus spp.) (e.g., Bianchi et al., 2014), of salema, *Sarpa salpa* with spinefoot species (Siganus spp.) (e.g., Giakoumi, 2014; Dulčić et al., 2012) and/or anchovy, *Engraulis encrasicolus* with round-eye herring *E. golanii* (e.g., Kallianiotis and Lekkas, 2005) is on the way in certain areas and there is a growing evidence for increasing contribution of alien species of Indo-pacific origin in the Aegean Sea catches (Zenetos et al., 2011). The alien fish *Upeneus moluccensis* and *U. pori*, formed 87 % of the mullid catch off the coast of Israel at depth of 20 m, and 50 % at 55 m, whereas the native mullids are more abundant in deeper waters (Golani and Ben Tuvia, 1995). Ismen (2002) stated that in the eastern Mediterranean 98 % of the total biomass of *U. pori* was trawled in less than 50 m deep water and its market increased in the recent years. The percentage of the Erythrean mullids in the total mullid catch has increased steadily; from 30 % in 1980, 42 % in 1984, to 47 % in 1989 (Golani and Ben Tuvia, 1995).

A replacement in the catches of sardine *Sardina pilchardus* and sprat *Sprattus sprattus* with round sardinella *Sardinella aurita*, which is also distributed in the Greek Seas already occurs (Tsikliras, 2008) because of round sardinella's expansion (Sabates et al., 2006).

Numerous findings of some new species which are economically important in the area of their former distribution could have a positive echo in recreational fishing and aquaculture. As an example, in the last decade, a 3 new species of groupers were recorded in Adriatic Sea: the orange-spotted grouper *Epinephelus coioides,* the white grouper, *E. aeneus*, and the mottled grouper, *Mycteroperca rubra*. These two latter species already show signs of established populations (especially *E. aeneus*) in the eastern Adriatic coast. This is not surprising since the native groupers also show positive response to sea warming. Namely, successful spawning of groupers in the Southern Adriatic resulted in better recruitment and new colonization of groupers in middle and northern Adriatic, particularly of adult dusky grouper, *E. marginatus* with still unconfirmed spawning in spreading areas. Those facts suggest a significant expansion of groupers in the last 10 years. In shallow waters, juvenile groupers represent the strongest carnivores and possible strong ecological impact through prey-predator relationship is expected (Dulčić et al., 2012).

Among economically important species that have potential to establish or have already established population in the Adriatic Sea are tripletail, *Lobotes surinamensis* and beforementioned spinefoots, *Siganus luridus* and *S. rivulatus*. The tripletail is a tasty fish and have economic importance along the western Atlantic coast. It is also becoming increasingly abundant in the area of Maltese islands and its presence in the Adriatic waters is showing similar trend but with lack of juvenile records (Deidun et al., 2010; Dulčić et al., 2014). There were unsuccessful attempts of introducing *S. luridus* in the Mediterranean aquaculture but this species asks for special attention due to competitive behavior toward *S. salpa*. Moreover, the landings of S. *rivulatus* in the eastern Mediterranean are significant and point out the economic potential of this species as fishery resource in the spreading areas of its distribution. Nowdays, *Siganus* spp. represents dominant fish family in the Israel inshore fisheries (trammel-netting and hook-and-lining).

Representatives of *Sphyraena* family are very interesting in socio-economic sense for purse- and beach-seine fisheries in the Adriatic Sea. Beside native European barracuda, *Sphyraena sphyraena*, two new species have been recorded in the recent decades: yellowstripe barracuda, *S. chrysotaenia* and yellowmouth barracuda, *S. viridensis*. The latter became quite abundant in the recent years but due to similarity of both species to native *S. sphyraena*, fishermen have difficulty in distinguishng those species which makes it difficult to track their spreading. The catch statistics of sphyraenids landings in Israel do not separate the Red Sea blunt barracuda from native Mediterranean species *S. sphyraena* and *S viridensis*. However, the examination of the landed catch showed that the lessepsian barracuda had outnumbered the native sphyraenids in inshore trawl and purse-seine catches. Similar scenario can be expected along the Mediterranean coast, although *S. chrysotaenia* is still very rare in the Adriatic Sea.

The brushtooth lizardfish, *Saurida undosquamis* also have certain fisheries potential since it has significant share in demersal catches along the Turkish coast where it is numerous and abundant. It was caught in Israel for the first time in 1952; only three years later 266 tonnes were landed by local trawlers, constituting almost 20 % of the total trawler catch (Ben-Yami and Glaser, 1974). On the other side, this species is also in prey-predator relationships with native sardine and anchovy and thus can have possible negative influence on local communities and biomass of those pelagic species (Dulčić et al., 2012). Due to great similarity to native lizardfish *Synodus saurus*, it's status in the Adriatic is still unclear.

For alien species that are frequently being caught in commercial fisheries in the Mediterranean Sea, it is necessary to boost their value through public awareness-raising campaigns. These could be aimed at educating about their nutritional value, creating new processed products and promoting fresh and processed products in the market. The best way to reduce the pressure of the populations of alien species like *S. luridus*, *S. rivulatus* and *F. commersonii* on native species is to stimulate the commercial fishery to target these species. This shouldn't include only alien species but also other (thermophilic) species whose populations are experiencing significant increase like *Pomatomus saltator*, *Sphyraena viridensis* or *Balistes carolinensis*. The aim of such process should not only be a reduction of pressure induced by alien and other climate-driven species, but also reduction of fishing pressure on native, overexploited stocks. This would also contribute to the maintenance of the good environmental status (GES) of coastal marine ecosystems and the sustainable exploitation of species of fisheries concern. Eventually, this will lead to the improvement of the knowledge on alien species life history and their role in the marine ecosystem, as well as on the spatio-temporal variation of their landings.

Although the influence of climate change is easily seen through the emergence of new species in the areas where they were previously absent, it is necessary to simultaneously monitor populations of native species and track their adaptation to changing ecosystem. Groupers and bluefish are real examples of how changes in distribution of fish species may lead to changes in income of fisheries sector with both positive and negative consequences. Specifically, local fishermen still don't have effective fishing gears for catching bluefish (great damages on gillnets) and *P. saltatrix* is a predator of the flathead grey mullet, *Mugil cephalus* and it almost completely wiped out mullets from native habitats in Neretva Estuary. On the other side, groupers occupied ecological niches of overfished sparids, particularly of the white seabream, *Diplodus sargus* which is ecologically unacceptable but their catches might compensate for economic loss of decreasing abundance and biomass of sparids. Besides that, positive effects of sea warming on some physiological processes which influence spawning and reproductive succes, namely better survivorship and recruitment, are observed. Such effects are later reflected in greater landings and were confirmed for several species, particularly for *Mullus* spp. and *Sparus aurata*. A particular problem related to aquaculture and sea warming is the case of *S. aurata* since higher abundance and biomass recorded in last years along the Mediterranean coast are probably result of multiple sources, but escape from aquaculture as a result of poor husbandry measures on fish farms or incidents caused by bad weather conditions (unexpected severe storms) are undoubtly contributing to this phenomenon.

Previous studies highlight the winners and losers in fisheries under climate change based on shifts in biomass, species composition and potential catches. Identifying changes in population processes of target species due to environmental influences is important in order to enable climateenhanced management strategy evaluations to elucidate the potential benefits and costs of changing management targets. Understanding how climate change is likely to alter the fisheries revenues of maritime countries is a crucial next step towards the development of effective socio-economic policy and food sustainability strategies to mitigate and adapt to climate change (Lam et al. 2016). Particularly, fish prices and cross-oceans connections through distant water fishing operations may largely modify the projected climate change impacts on fisheries revenues. Global fisheries stand to lose approximately $10 billion of their annual revenue by 2050 if climate change continues unchecked, and countries that are most dependent on fisheries for food will be the hardest hit (Lam et al. 2016). Regionally, the projected increases in fish catch in high latitudes may not translate into increases in revenues because of the increasing dominance of low value fish, and the decrease in catches by these countries' vessels operating in more severely impacted distant waters. Therefore, Lam et al. (2016) suggest the need to conduct full-fledged economic analyses of the potential economic effects of climate change on global marine fisheries.

While many communities are considering aquaculture, also known as fish farming, as a solution to ease the financial burden of fishing losses and improve food security under climate change, Lam et al. (2016) suggest that aquaculture may drive down the price of seafood, leading to further decreases in fisheries revenues. For sure, aspects identified as critical to the ultimate success of future aquaculture along the Mediterranean coast in the framework of overfishing and climate change are: open and transparent lines of communication with stakeholders; building of trust and confidence with key stakeholders over sustained periods; use of strategic and business planning documents to guide activities; commissioning of high quality technical information to support and justify activities in aquaculture; representative leadership structures, and effective use of 'two-way learning' across scientific and expert knowledge systems.

As conclusion, many coastal communities rely on living marine resources for livelihoods and food security. These resources are commonly under stress from overfishing, pollution, coastal development and habitat degradation. Climate change is an additional stressor beginning to impact coastal systems and communities, but may also lead to opportunities for some species and the people they sustain (Hobday et al., 2016). We need future work designed to contribute to improving fishing community adaptation efforts by characterizing, assessing and predicting the future of coastal-marine food resources, and co-developing adaptation options through the provision and sharing of knowledge across fast-warming marine regions, like Mediterranean Sea. They represent natural laboratories for observing change and concomitant human adaptive responses, and for developing adaptation options and management strategies for enhancing coastal resilience, capacity building and local empowerment in order to minimize negative outcomes and take advantage of opportunities arising from climate change. However, developing comparative approaches across countries that differ in political institutions, socio-economic community demographics, resource dependency and research capacity is challenging. Strong partnerships within and between Mediterranean countries are critical to scientific and political support for development of effective approaches to reduce future vulnerability.

VULNERABLE SPECIES

The Adriatic Sea is an area of extremely productive fisheries; this is due to the strong outflow of nutrients from rivers, intense agricultural and industrial activity and the high population density along the coasts, and the periodic mixing of nutrients from the Mediterranean.

Fish production in the Adriatic Sea in the period 2014-2016 was about 190,000 tons on average, representing about 16% of the total landings in the Mediterranean Sea and Black Sea region; most of the catches were carried out by the Italian (54%) and Croatian (41%) fleets. In accordance with data recorded at the Mediterranean level, small pelagic species are the most fished. Among these, sardine is the most fished species in the Adriatic, followed by anchovy. These species spend most of their life cycle in the water column above the continental shelf and make seasonal migrations, approaching the coast typically during the summer season. Large pelagic fish, including tuna, are also relatively frequent in the catches, but they prefer the open sea and are caught in the Adriatic Sea along migratory routes. These species are followed, in terms of catch, by demersal species, which live mainly near the seabed. These species can be found near the coast: typical examples are mullets, mainly caught in coastal lagoons, or flat fish, which can be found more in continental shelf areas. (FAO, 2018; Papaconstatinou et al., 2000).

The fishing fleet operating in the Mediterranean and the Black Sea area has approximately 90,000 ships, 12% of which operate in the Adriatic (FAO, 2018). The fishing fleet in the Adriatic reached its peak between the 1990s and 2000s. The most important categories of fishing vessels operating in the Adriatic are: 1) the so-called multi-purpose, which use different fishing equipment; 2) the vessels equipped with fixed equipment, used for small-scale fishing; 3) those equipped for bottom fishing, such as trawlers (Mannini et al., 2004).

Overfishing, i.e. the depletion of fish stocks due to over-exploitation of fish resources, is a problem recognised in the Adriatic. Most fish stocks in the Mediterranean continue to be fished beyond biologically sustainable limits. Despite this, the percentage of overexploited stocks fell by 10 % between 2014 and 2016, from 88% to 78%.

The fishing effort in the Adriatic follows the general trend found on a Mediterranean scale. As shown in Figure 19., it can be considered constant or in slight decline since the 1990s. The decrease of the effort, quantified in terms of engine power, is counterbalanced by the increase in the efficiency of the fishing tools and in the technological innovations (such as sonar and radar) that have allowed fishermen to become more and more efficient.

In recent decades, the problem of climate change has been added to this picture. Climate change acts on biodiversity in a variety of ways, such as causing changes in the trophic network – favouring the intake of thermophilic alien species, often in competition with local ones – and altering the biological cycles of acclimatised marine species to temperate-cold climates. These problems become critical factors for the survival of species, especially in a semi-closed basin, such as the

Adriatic, where species do not have the ability to move to higher latitudes to avoid warming of the waters, being in a real "cul-de-sac" (Lasram et al., 2010).

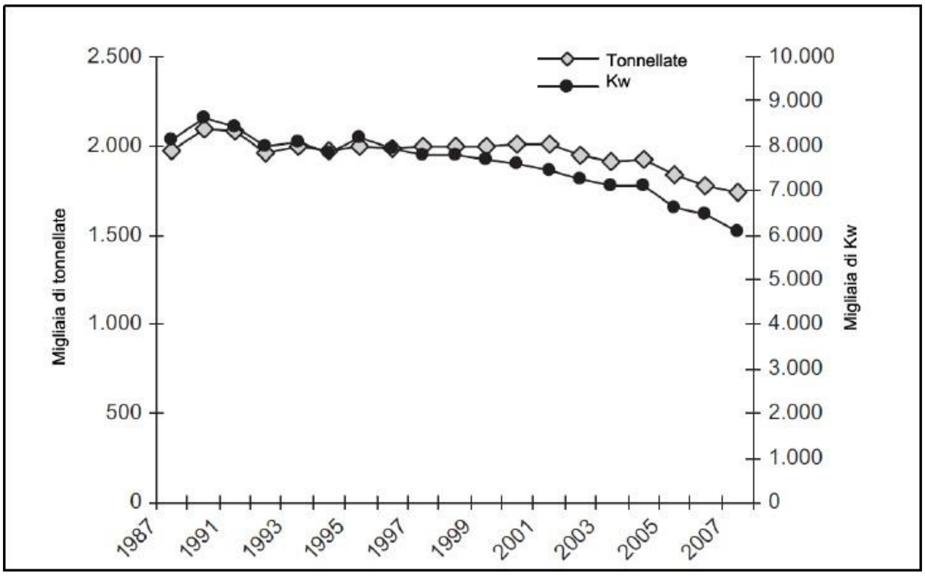

Figure 19. Trends in the fishing effort of European navies in the Mediterranean Sea (Eurostat, 2010).

Here we reconstruct and analyse the temporal performance of catches of some fish species in the Adriatic since 1985, through the consultation of the FAO landing database and the Chioggia Fish Market database. Secondly, using predictive models of spatial distribution, we try to identify the future scenarios of the probability of presence of this group of species in relation to the effects of climate change, in order to assess how climate change can, in the near future, affect part of the fish stocks fished in the Adriatic.

The time-series of the catch in the Adriatic was built using statistics made available by the Food and Agriculture Organisation (FAO), accessible freely thanks to the Fishstat programme, which can be downloaded from the organization's website. For the purposes of the study, the period between 1985 and 2016 was chosen. Previous years have not been considered as the data is often affected by errors and shortcomings and the taxonomic aggregations used are too broad (Pauly, Zeller, 2016). In geographical terms, the analysis focused only on statistics relating to the Adriatic sub-basin (code 37.1.2 or GSA17). Subsequently, the trend of the landing at the Chioggia Fish Market was reconstructed and analysed, using the official statistics reported in the database available on the website of the Department of Biology of the University of Padua. The database was created as part of the project "CLODIA: for the sustainable development of the ambitious coastal institutions", presented by the University of Padua, the Municipality of Chioggia and Legacoop Veneto–Lega Fisheries and funded by the Veneto region as part of the interventions provided for by Regional Law 15/2007. Historically the Fish Market of Chioggia is the major of the Adriatic Sea and one of the most important centres of storage, sale and processing of fish in Italy, therefore the statistics from it are useful to understand the changes of biodiversity and the role that man plays in such changes, mainly due to overfishing. Understanding local-scale time variations of species can help in developing targeted management strategies in a context of fish stocks depletion and climate change.

Based on a set of criteria described below, the species considered in the present report are:

- the tub gurnard, *Chelidonichthys lucerna*;
- the seabass, *Dicentrarchus labrax*;
- the leerfish, *Lichia amia*;
- the smooth-hound, *Mustelus mustelus*;
- the flounder, *Platichthys flesus*;
- the turbot, *Scophthalmus maximus*;
- the brill, *Scophthalmus rhombus*;
- the cuttlefish, *Sepia officinalis*;
- the common sole, *Solea solea*;
- the gilt-headed seabream, *Sparus aurata*;
- the mantis shrimp, *Squilla mantis*.

These species where chosen because they best represent SSF catches in the northern Adriatic. Furthermore, they are the most commercially important species, both for contribution in terms of landing and for their economic value. The choice did not include pelagic species, such as sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*). Indeed, it has been observed how pelagic species are less affected by climate change respect to demersal and bentonic species (Pecl et al., 2017; Rutterford et al., 2015; Perry et al., 2005). In addition, species selection was also made on the basis of climate/zonal criteria. All species, except for leccia fish, are considered temperate/cold affine species (Pranovi et al., 2016; Rings Monti et al., 2014). These categories are the most vulnerable to an increase in average sea temperature. In fact, one of the main consequences of climate change in the marine environment and the possible decrease in the survival capacities of species most sensitive to temperature rise. Such changes may generally result in lower fishing yields. Specifically, in the Adriatic, a semi-closed basin with peculiar climatic characteristics that make it similar to semi-boreal seas, a negative relationship between temperature and biomass of "cold" species has been demonstrated, and a negative relationship between temperature and biomass of "cold" species has been demonstrated. In contrast, hot affixed species have exhibited a marked positive relationship (Pranovi et al., 2014).

While the study of historical series provides us with a "photograph" of the state of fish resources in an area, through a modelling analysis it is possible to predict future conditions of species as environmental (or forcing) conditions change. Therefore, the next step is the realization, for each of the species in question, of maps of probability of presence in the Adriatic Sea, in relation to a plausible future scenario.

MaxEnt (Maximum Entropy Species Distribution Modelling) program was used to calculate the probability of a species to be present in a given geographical area conditioned to a set of environmental predicotors. The first step of the analysis associates the environmental variables of the present distribution of a species with each known geographical point (where the presence of the species under consideration is certain). Secondly, the algorithm looks for points in the globe with similar environmental parameters and associates a probability of adequacy for the species (i.e. a probability of presence). In this way, areas where the species studied is not present but can survive on the basis of the environmental predictors considered can be observed.

Also, through this program, for each species analysed, it was possible to build two probability maps, using two sets of environmental variables, referring respectively to the present environmental conditions and a future scenario, subject to climate change (see below for details). The resulting maps can be viewed and activated with a Geographic Information Siystem (GIS) software, such as QGIS.

An example of the probability maps processed for a species and visible in Figure 20.

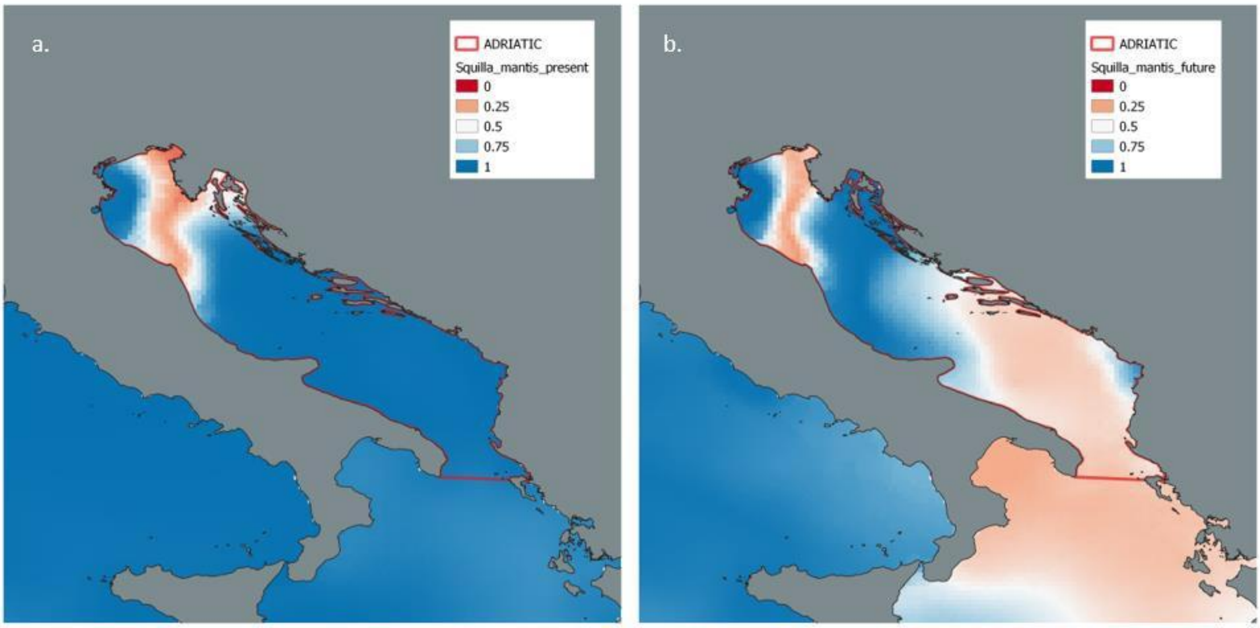

Figure 20. Example of probability maps for the mantis shrimp *Squilla mantis*: present (a) and future (b)

Since it is not always possible to intuitively capture the differences between the two probability maps generated by MaxEnt, a third map, called 'comparison map', has been made for each species., showing the R-index, which has been calculated from the probability of the species' current and future presence. The formula used for theR-index is: $R = P_f / (P_f + P_p)$, where P_f indicates the probability of the species' presence in the future and P_p the present probability of presence. The R index is always comprised between 0 and 1. If $R < 0.5$, the probability of presence is greater in the present, while in the future the probability of presence will be lower. For $R = 0.5$, the present probability of presence is equal to the future probability. If $R > 0.5$, the species will be more likely to be present in the future (Figure 21).

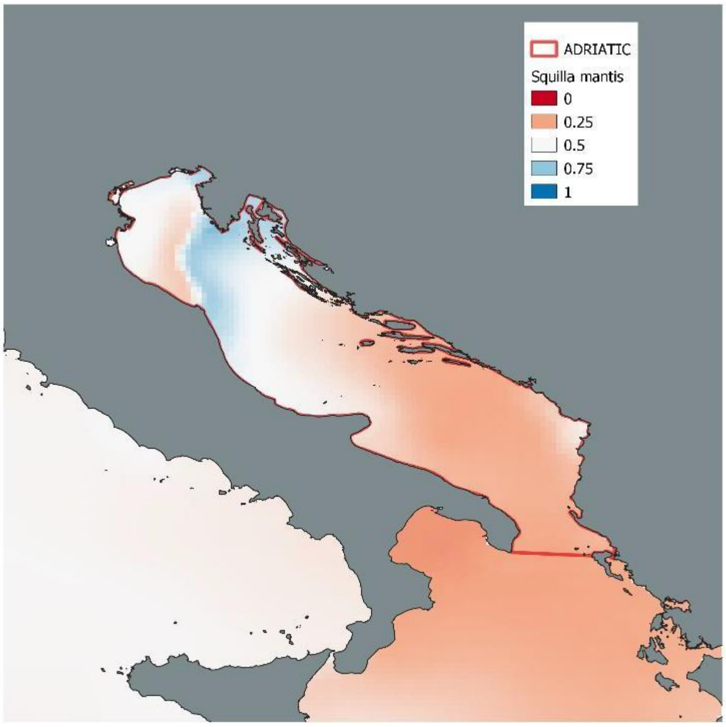

Figure 21. Example of a comparison map between future probability and present probability for the mantis shrimp *Squilla mantis*

The set of geospatial reporting data of the different species was then obtained from the Ocean Biogeographic Information System (OBIS) platform (Figure 22), accessible on the www.obis.org website. Developed in 1997 and constantly updated, it provides free information on the distribution and abundance of some 120,000 species that inhabit the seas and oceans.

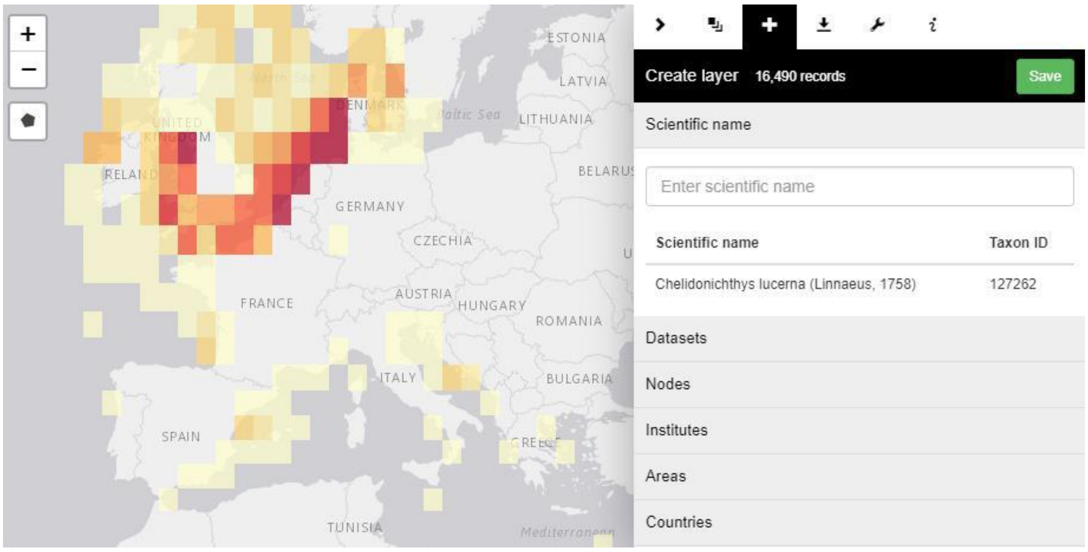

Figure 22. Example of a map with positional data, as available on the OBIS database

The environmental forces that were considered in the construction of the present and future probability maps were the average temperature and the average surface salinity, referring to the present state and future scenario in relation to the effects of climate change from the so-called Concentration Representative Pathway 8.5 (CPR).

The variable sets were downloaded from the database available on www.bio-oracle.org. For the present scenario, the average values of the available variables in the database are calculated from the monthly recorded data for the period 2000-2014. It was chosen to use the variables referring to a short-term future, i.e. between 2040 and 2050, according to the scenario CPR 8.5, which foresees a steady increase in greenhouse gas levels in the next century. It was chosen to consider this scenario because of the current lack of attention of international governments to environmental issues and because climate change mitigation measures, mainly related to emission reductions, are still unreliable, inefficient and insufficient. Figures 23. and 24. show the graphic representation of the environmental forces used in the realization of probability maps. The current average temperature in the Adriatic (Figure 2.8) is between 17 and 19 degrees Celsius, with the lowest values recorded in the northwest. It could increase by at least 2 degrees Celsius throughout the basin, reaching 21 degrees Celsius in the southern Adriatic. With regard to salinity (Figure 24), however, there is no great difference between the future and the present situation, other than a slight increase in the central and southern Adriatic. The lowest salinity values - about 30 psu – characterize the area in front of the Venice Lagoon and the Po river delta, while moving southwards salinity increases gradually to 37-38 psu.

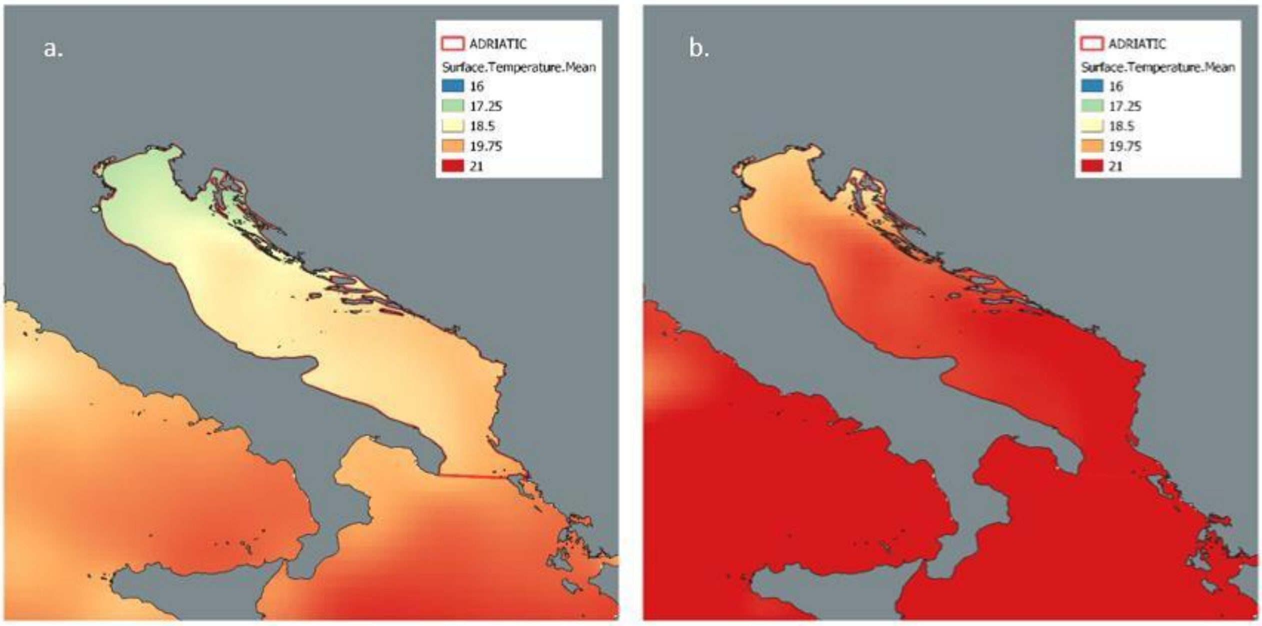

Figure 23. Maps of the average surface temperature of the Adriatic, present (a) and future (b)

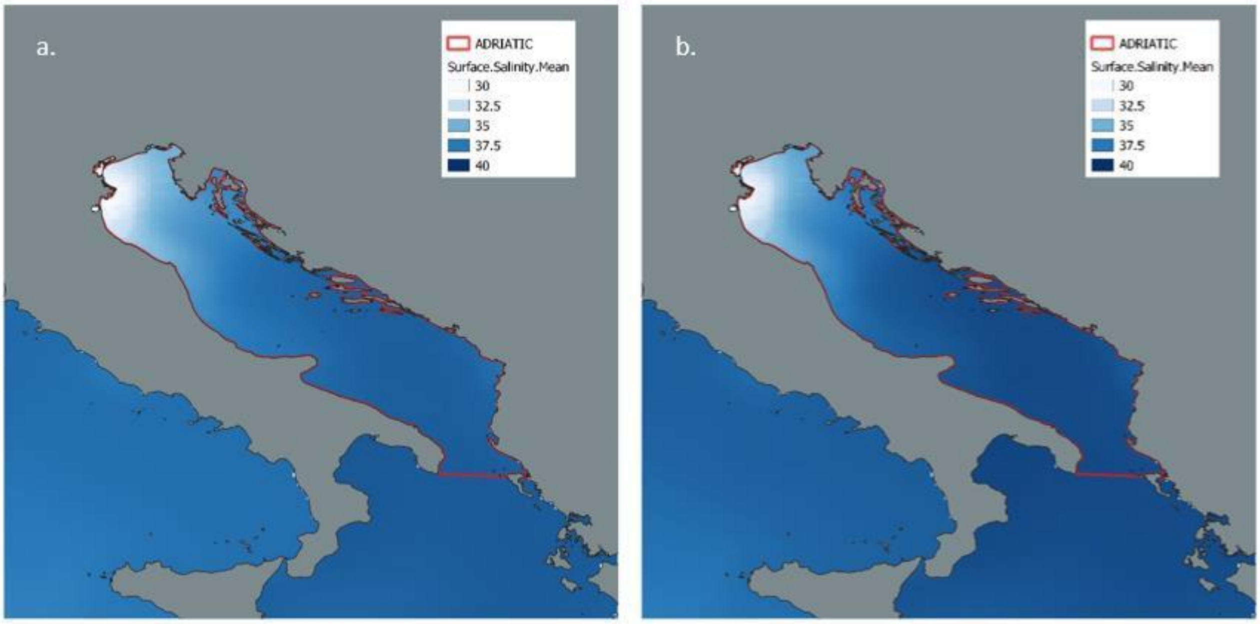

Figure 24. Maps of the average surface salinity of the Adriatic, present (a) and future (b)

Future distribution of species in the Adriatic

This section shows comparison maps for each considered species, created from current and future presence probability maps (2040-50) in the Adriatic, generated by MaxEnt. The red-pink coloration of the following maps indicates that in the future the probability of presence for these species will be reduced, the blue-blue colouring that the probability will be greater and the white one that it will remain unchanged.

Figure 25 show the comparison maps for the flounder (Platichthys flesus), the two species of turbot (Scophthalmus maximus and S. rhombus) and the common sole (Solea solea). For these species, production is expected to decline overall in the near future, which is very evident in the north-western Adriatic, especially for the flounder and the two species of turbot. However, for the species S. rhombus and the soil, there is a slight increase in probability in the area across the Adriatic Sea comprised between Istria and Marche.

The maps generated for the tub gurnard (Chelidonichthys lucerna) and the seabass (Dicentrarchus labrax), illustrated in Figures 26 and 27 are similar to the previous three, although in the southern Adriatic the decrease is less noticeable and in the central Adriatic the probability of presence will not change. The situation to the northwest of the sea bass looks very similar to the flounder (Figure 27), with a marked decrease in the probability of presence.

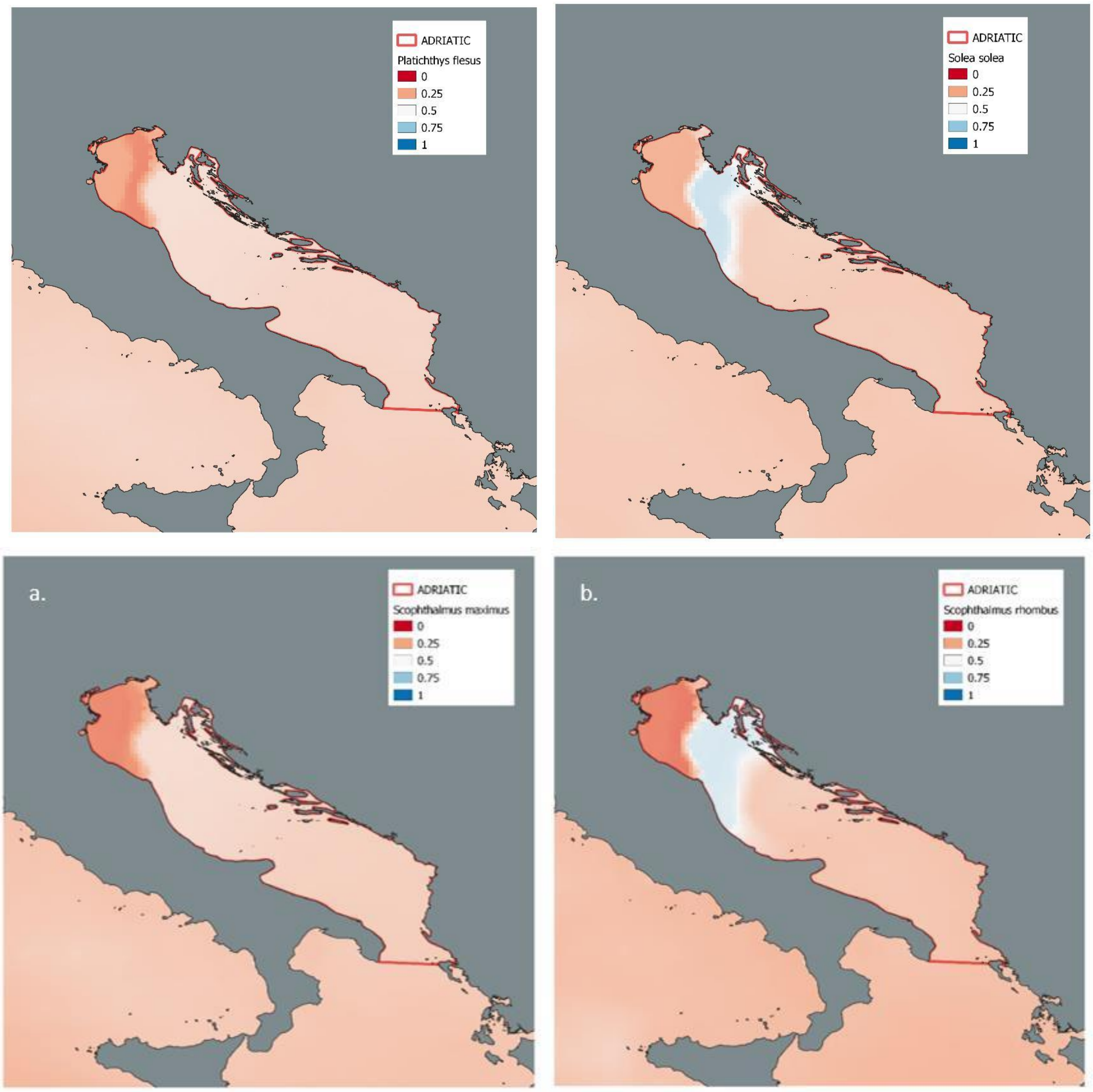

Figure 25. Predicting the future distribution of the flounder (*Platichthys flesus*), the common sole (*Solea solea*) and the two species of turbot (*Scophthalmus maximus*, a; *S. rhombus* in the Adriatic

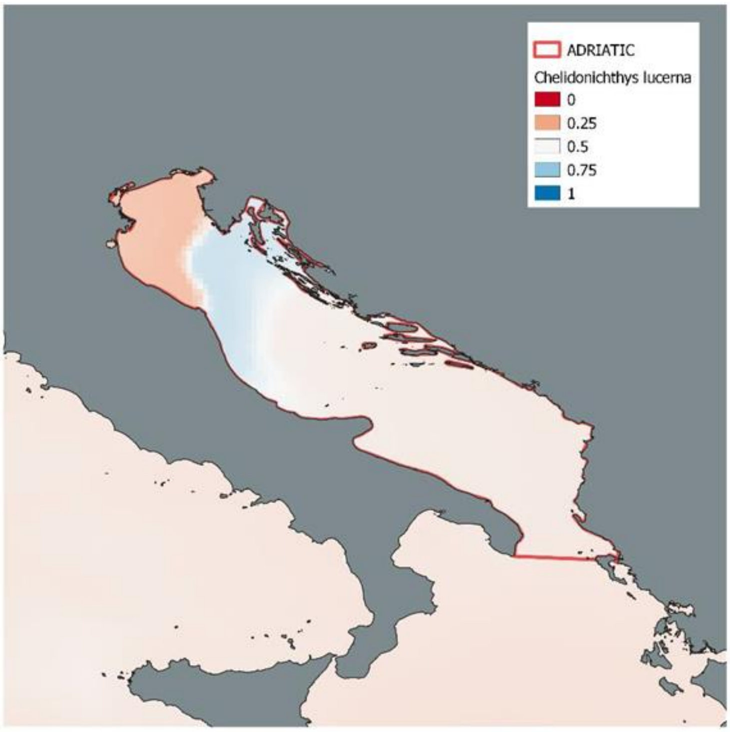

Figure 26. Prediction of the future distribution of the hen (*Chelidonichthys skylight*) in the Adriatic

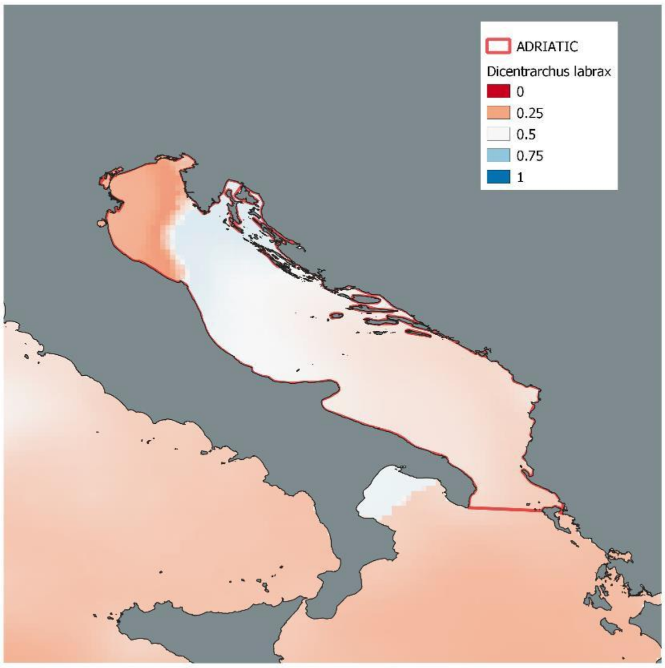

Figure 27. Predicting the future distribution of sea bass (*Dicentrarchus labrax*) in the Adriatic

Figures 28, 29, 30 and 31 represent the probability maps created, respectively, for the smooth-hound (*Mustelus mustelus*), the cuttlefish (*Sepia officinalis*), the leerfish (*Lichia amia*) and the mantis shrimp (*Squilla mantis*). They have in common a marked decrease in the probability of presence in the southern region of the Adriatic basin, which is very evident for the smooth-hound. In addition, for all these species the situation of the area in front of the Veneto and Emilia-Romagna coast would remain unchanged. In the remaining areas, the maps have many differences and trend reversals, which are encountered by moving from north to south. Of particular importance is the overall increase for the cuttlefish, in the area between the northern coast of Croatia and the Marche coast, together with the evident decrease of leerfish in the thin range that joins Istria to Ancona.

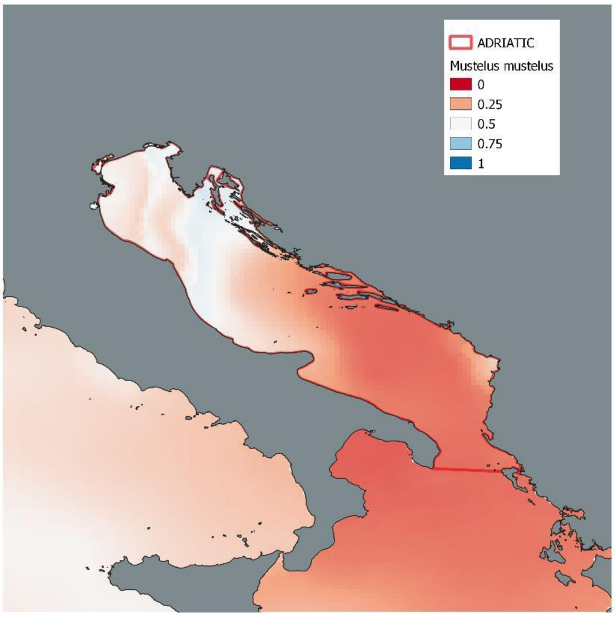

Figure 28. Forecasting the future distribution of palombo (*Mustelus mustelus*) in the Adriatic

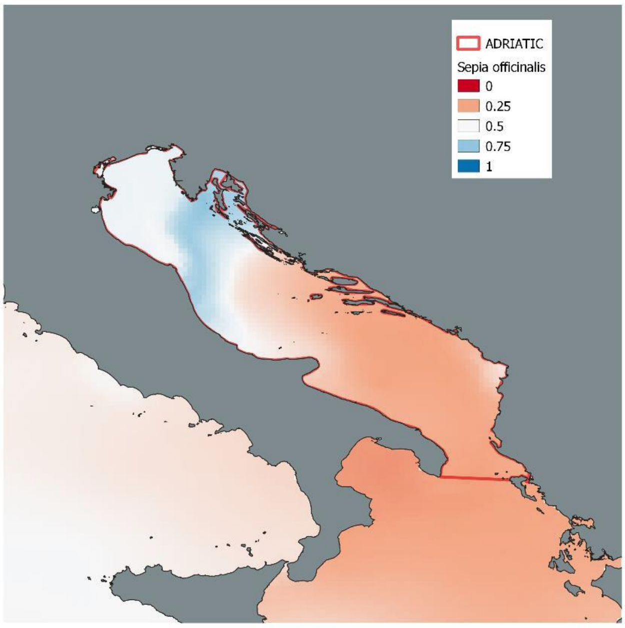

Figure 29. Prediction of the future distribution of cuttlefish (*Sepia officinalis*) in the Adriatic

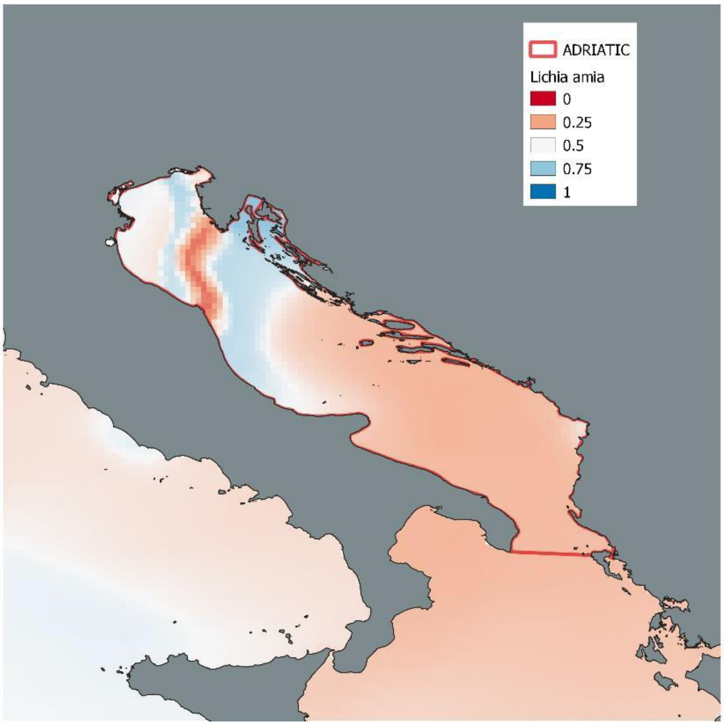

Figure 30. Prediction of future distribution of the leccia (*Lichia amia*) in the Adriatic

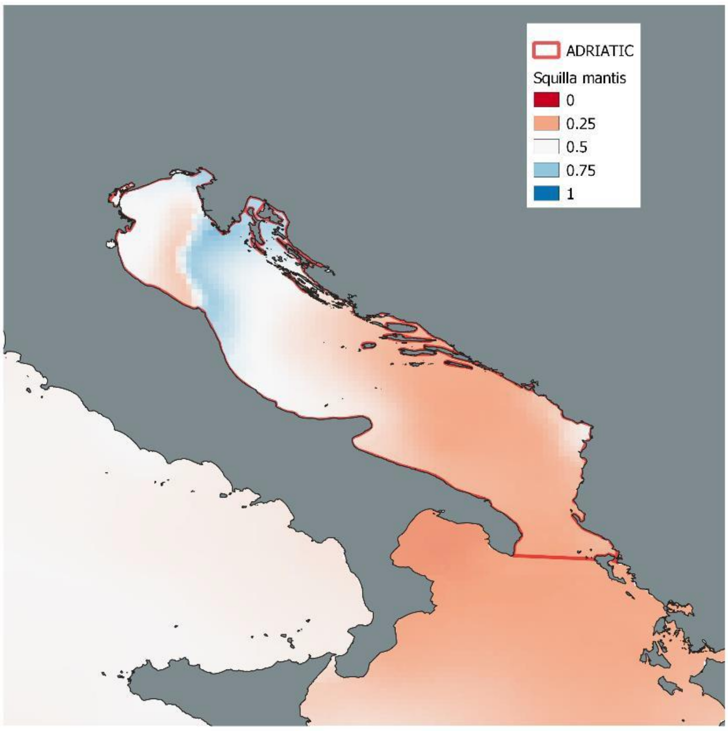

Figure 31. Prediction of the future distribution of the canoe (*Squilla mantis*) in the Adriatic

The last comparison map analysed and that of the gilt-headed seabream (*Sparus aurata*) in Figure 32. The distribution of the species in the Adriatic is expected to remain relatively similar to the current one, with the exception of the Gulf of Trieste and the band between Istria and the Marche region, where an increase may occur.

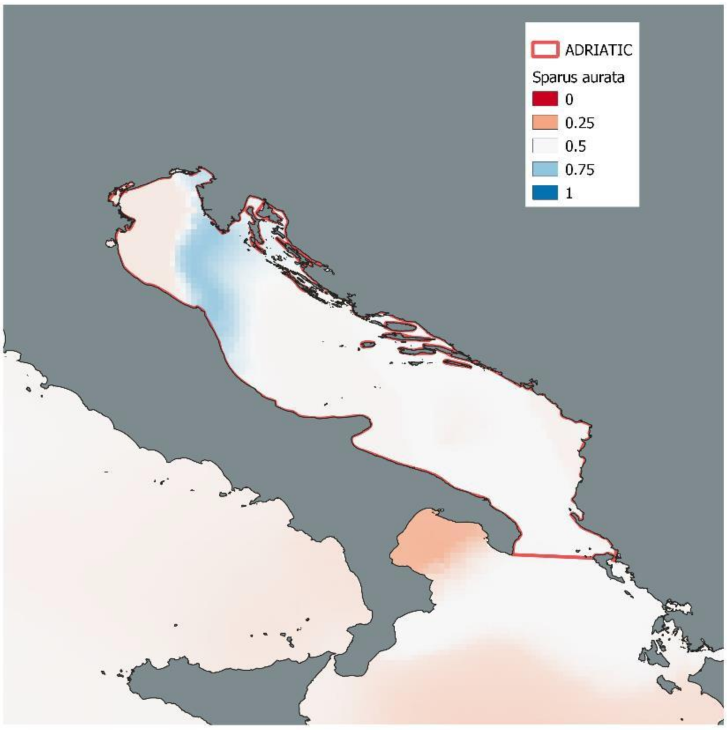

Figure 32. Prediction of future sea rose distribution (*Sparus aurata*) in the Adriatic

Overall results

The information on the species covered by this study, derived from the analysis of historical series and comparison maps between the current presence and the probable future presence, was finally included in a summary table (Table 1). It contains, for each species, information on trends relating to the last period, taken from the graphs of the catch in the Adriatic and the Fish Market of Chioggia, together with the average of the values of the R index that characterize the different pixels that make up the comparison maps, with the relative standard deviation.

The table shows that for all species, with the exception of sea rose, the total reduction in the catch (average R < 0.5) is expected by 2050. You may have the worst situation, represented by the dark red cells, for the palombo, the flounder, and the two species of turbot, which have an average R < 0.4. The current trend of landing in the Adriatic, declining for all these species, and in accordance with this vision.

Table 1. Final table with mean R values

Species	R Medio	SD
Chelidonichthys skylight	0.48	0,08
Dicentrarchus labrax	0.45	0,10
Lychee amia	0.46	0,13
Mustelus mustelus	0.39	0,12
Platichthys flesus	0.38	0,07
Scophthalmus maximus	0.37	0,07
Scophthalmus rhombus	0.39	0,12
Sepia officinalis	0,48	0,14
Solea solea	0,40	0,09
Sparus aurata	0,52	0,07
Ringman	0,47	0,11

Most of the Mediterranean's fish resources are still over-exploited (FAO, 2018), despite a growing environmental concern. Several studies have also shown a critical state, in the near future, for different fish species due to climate change (Lasram et al., 2010). In this context, it is assumed that in the future the demersal and benthic species with a temperate-cold thermal affinity may be more affected, as they cannot move as easily as pelagic organisms (Pecl et al., 2017; Pranovi et al., 2016; Rutterford et al., 2015; Rings Monti et al., 2014; Perry et al., 2005). The key species considered in this study have these characteristics and, in the in most cases, the recent and steady decline in their landing throughout the Adriatic basin confirms what is found today and what is expected for the future.

Considering the entire Adriatic basin, for most of the species analysed, an overall reduction in distribution is expected by the years 2040-50. The maps show that the species most susceptible to the effects of climate change are the brill, the turbot, the flounder, the smooth-hound and the common sole, for which a more noticeable decline is expected. For other species it may be milder, with the exception of the gilt-headed seabream, which is thought to have a similar distribution to the current one. However, these maps also allow for considerations on a regional scale. One of the most vulnerable areas is the north-western Adriatic, facing the Venetian and Emilian coast. In this region, the model foresees a marked decrease in the case of the two species of turbot, the sparrow and the sea bass. The same fate, although with a lower incidence, could happen for the tub gurnard and the common sole. Another critical area is the south-central Adriatic, where almost the totality of species –

as many as 8 out of 11 – could suffer in the near future a decline in distribution. Here, the most dangerous situation will be faced by the smooth-hound. This could be evidence in favour of the hypothesis that species with temperate-cold thermal affinity, as the average sea temperature rises will tend to move northward, in order to seek cooler waters (Lasram et al., 2010). In the case of the Adriatic, as well as for the whole Mediterranean, the consequences of this could be more serious. Indeed, it is a closed basin that would not allow organisms to find suitable habitats for their survival and could expose them to a greater risk of disappearance.

One the other side, the Adriatic is a sea with a north-south development. As a result, it has a temperature gradient, due to latitude, and a saline gradient, due to the flow of fresh water from the large rivers that cross the Po Plain (Po, Adige, Brenta, Piave, Tagliamento, etc...). This is evident by looking at the generated maps, which in most cases have "sanctuary" areas, where species could in the future maintain the same current distribution, or even be more present. They are given by a combination of salinity and temperature values that are found in a range about 200 km long in a north-south direction, with a width of 80 km, which ideally connects Istria to the coasts of Marche. This area is superimposed, for example, on an area used by the common sole for reproductive purposes (Bastardie et al., 2017).

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