D3.3.1

Report on SSF vulnerability to Climate Change in GSA17

The Adriatic Sea is a extremely productive area for 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 and are the most important category in SSF landings: typical examples are mullets, mainly caught in coastal lagoons, or flat fish, which can be found more in continental shelf areas (FAO, 2018).

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. To cope with this situation, according to the EU fishery policy, also in the Adriatic Sea several initiatives were put in place in order to reduce the fishing capacity. As shown in Figure 1, the Italian SSF fleet of GSA17 lose nearly 25% of vessels, from 2005 to 2018.

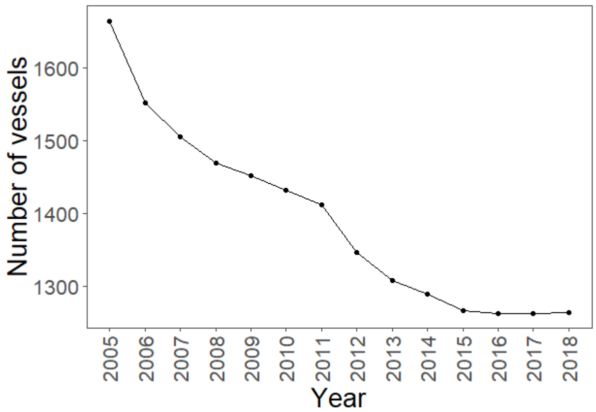

Figure 1. Temporal trend in the fishing vessels number for the GSA17, Italian side.

The decrease of the capacity, quantified in terms of number of vessels, however, was 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, while vessels characteristics (in terms of size, tonnage, engine power and age) do not show significant variations (Figure 2).

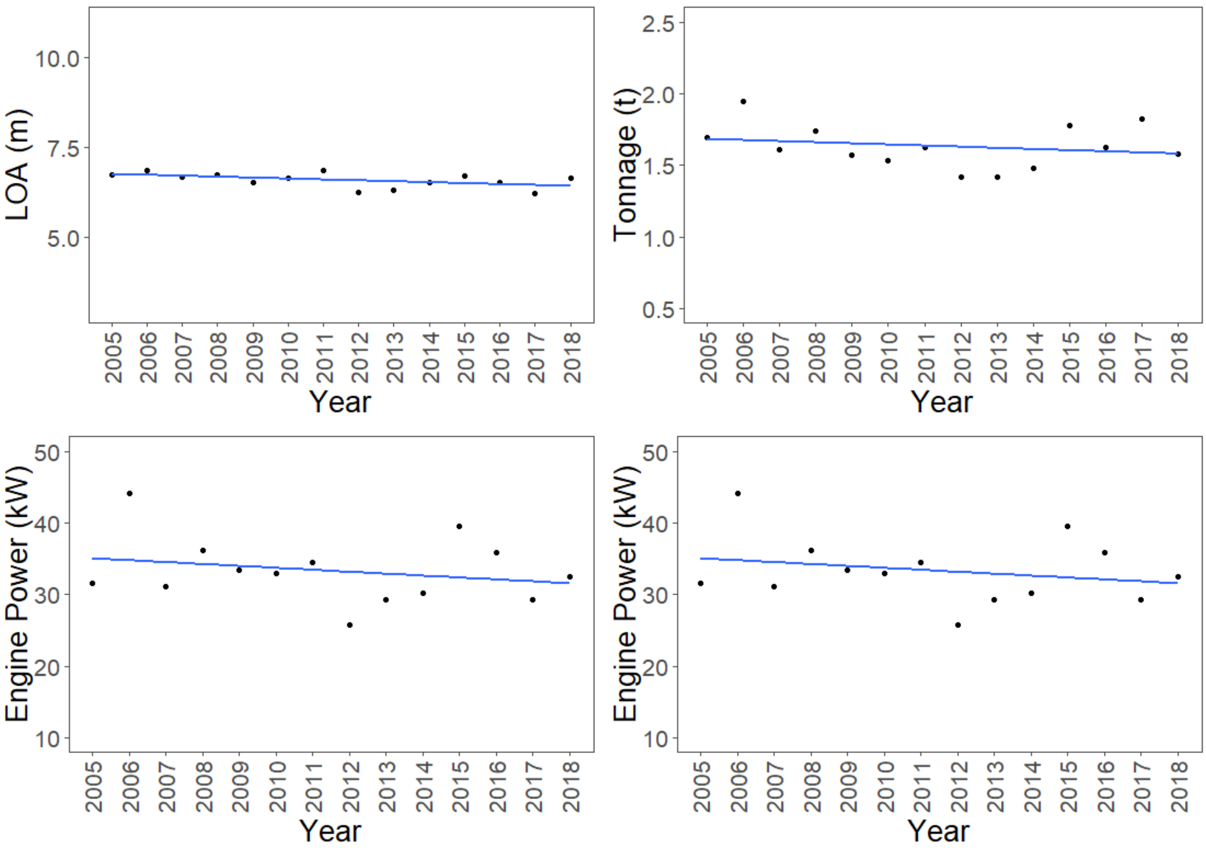

Figure 2. Figure 1. Trends in some SSF fleet characteristics in the Italian part of GSA17: LOA (vessel lenght), Tonnage, Engine Power and Age.

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).

Indeed, chemical-physical and oceanographic features of the North Adriatic have been modified by the combined effects of the anthropogenic impact and regional climate changes, thus leading to changes in its biological communities. Analyses of temperature data at the sea surface temperature in the North Adriatic have evidenced markedly higher temperatures (up to 5° C) in all seasons of the period 1988-1999 with respect to the period 1911-1987 (Russo et al., 2002). Comparison between these two periods indicated also a significant increase of surface salinity, mainly due to a reduction of freshwater discharge occurred after 1988 (Giani et al., 2012). Historical ecological studies suggest that the North Adriatic fish community structure has been changing for centuries (Fortibuoni et al., 2010; Lotze et al., 2011): a decline of elasmobranches, tuna, swordfish, marine mammals and large demersal/large-sized/late maturing species proportion in fish composition as well as diadromous fish (eels, sturgeons) and small pelagic has been observed by many authors (Grbec et al., 2002; Santojanni et al., 2006; Ferretti et al., 2008; Coll et al., 2010; Fortibuoni et al., 2010; Lotze et al., 2011). At our days, some descriptors such as the total biomass, the average trophic level of fish community or the demersal/pelagic ratio for many species still show a decreasing trend. The observed changes could be the result of the combined effects of fishing effects, driven by technological evolution and market dynamic, coupled with environmental effects, influenced by anthropogenic and natural stressors (Giani et al., 2012). Pressures can induce indirect effects, such as the modification of nursery areas changes in juvenile's survival potentially induced by changes in phenology and consequent lack of synchronisation between predator requirements and presence of prey, successful invasion of alien species, evolutionary changes. In particular, in the last decades an increasing number of thermophilic taxa have been reported to be expanding northward in the North Adriatic Sea (Dulčić et al., 2004; Azzurro et al., 2011).

Here, using predictive models of spatial distribution, we try to depict future scenarios of the presence probability of a set of species in relation to the effects of climate change, in order to assess how climate change could, in the next future, affect part of the Adriatic fish stocks.

The selected species represent the main SSF targets (frequency > 5% in the catches; as reported in the D3.1.3) in the Northern Adriatic Sea (Table 1). Some exceptions were added, such as *Scophthalmus maximus*, since the analysis would have included anyway the congeneric *S. rhombus*. 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). That is why also *Chelidonichthys lucerna* was included in the analysis. Also, *Mustelus asterias* and the five species of mullets were considered in the analysis, given the local importance in some areas of the basin. In addition, species selection was also made on the basis of climate/zonal criteria. Except for *Lichia amia* which was included since its frequency is increasing in SSF catches due to northward expansion in the Adriatic, most of the species are considered temperate/cold affine species (Pranovi et al., 2016; Anelli 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. For this reason, also *Platichtus flesus* was also included, since it is considered a glacial relict.

For each one of these species, climatic affinity (Table 1) has been assessed according to the latitude-based method proposed by Pranovi et al. (2013). In order to assess the thermal affinity of each species, distributional data for the Northern hemisphere were obtained from the online database of the Ocean Biogeographic Information System (OBIS; www.iobis.org) within the Global Biodiversity Information Facility (GBIF; http://data.gbif.org/). Arbitrary latitudinal thresholds were set at 30° N (southern limit of the Mediterranean Sea basin) and 45°N (northern limit of the basin, excluding the northernmost parts of the Adriatic and Black Seas), defining a northern cold zone (> 45°N), a central temperate zone (between 45° and 30°N; typical of the Mediterranean Sea) and a southern warm zone (< 30°N). The main latitudinal ranges for the species were estimated by means of the median and interquartile range of the latitudinal component of the distributional data. Finally, the restricted climatic affinity for each taxon was attributed based on whether its median fell in the cold, temperate or warm zone. In cases where the interquartile range was not fully included in the same zone as the median, an intermediate thermal affinity was attributed, leading to six groups of climatic affinity: cold, cold-temperate, temperate, temperate-warm, warm and ubiquitous species.

Table 1. Climatic affinity of the SSF target species considered in the present report.

Latin name	Common name	Climatic affinity	Restricted climatic affinity
Atherina boyeri	sand smelt	temperate	temperate
Chelidonichthys lucerna	tub gurnard	ubiquitous	ubiquitous
Chelon auratus	golden grey mullet	cold	cold
Chelon labrosus	ticklip grey mullet	cold	cold
Chelon ramada	thinlip grey mullet	temperate/cold	cold
Chelon saliens	leaping mullet	temperate	temperate
Dicentrarchus labrax	seabass	cold	cold
Lichia amia	leerfish	temperate/warm	warm
Lithognathus mormyrus	sand steenbras	temperate	temperate
Mugil cephalus	flathead grey mullet	warm	warm
Mustelus asterias	starry smooth-hound	cold	cold
Mustelus mustelus	smooth-hound	ubiquitous	temperate
Platichthys flesus	flounder	cold	cold
Scophthalmus maximus	turbot	cold	cold
Scophthalmus rhombus	brill	cold	cold
Sepia officinalis	cuttlefish	temperate/cold	temperate
Solea solea	common sole	cold	cold
Sparus aurata	gilt-headed seabream	temperate	temperate
Squilla mantis	mantis shrimp	Temperate]	temperate

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 of maps of probability of presence in the Adriatic Sea, in relation to a plausible future scenario, for a subset of the most commercially important species, both for contribution in terms of landing and for their economic value.

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 predictors. 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 Syistem (GIS) software, such as QGIS.

An example of the probability maps processed for a species is reported in figure 2, with a clear reduction of presence probability under the future scenarios.

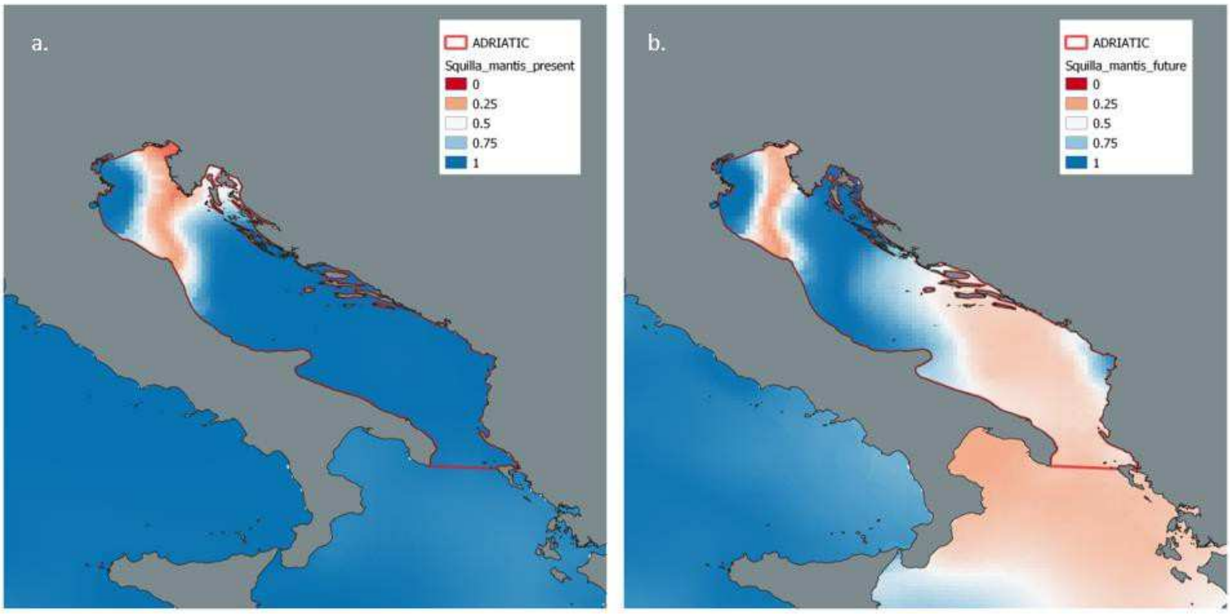

Figure 2. Example of probability maps for the mantis shrimp *Squilla mantis*: present (a) and future (b)

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' (Figure 3), has been made for each species and presented here, showing the R-index, which has been calculated from the probability of the species' current and future presence. The formula used for the R-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.

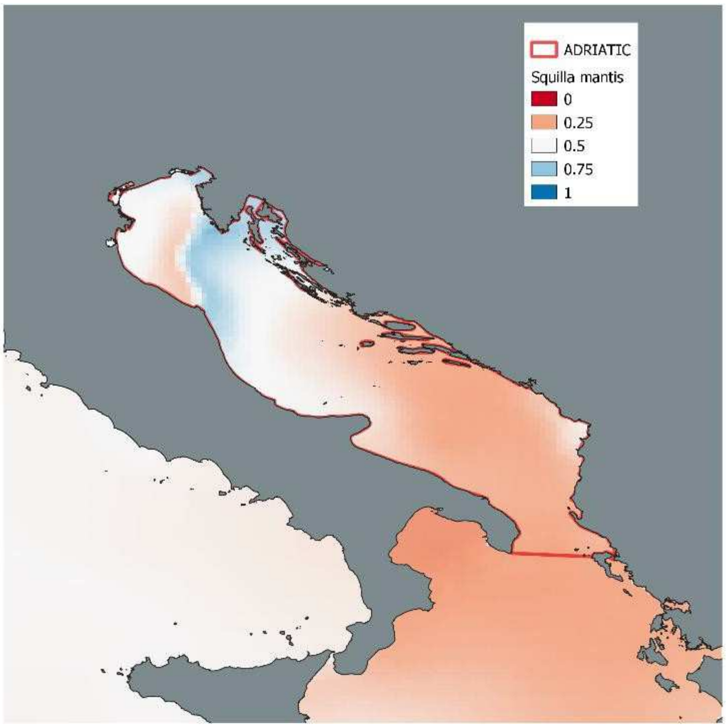

Figure 3. Example of a comparison map between future probability and present probability for the mantis shrimp *Squilla mantis*

The set of geospatial reporting data of the different species was then obtained from the Ocean Biogeographic Information System (OBIS) platform, accessible on the www.obis.org website (Figure 4). 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.

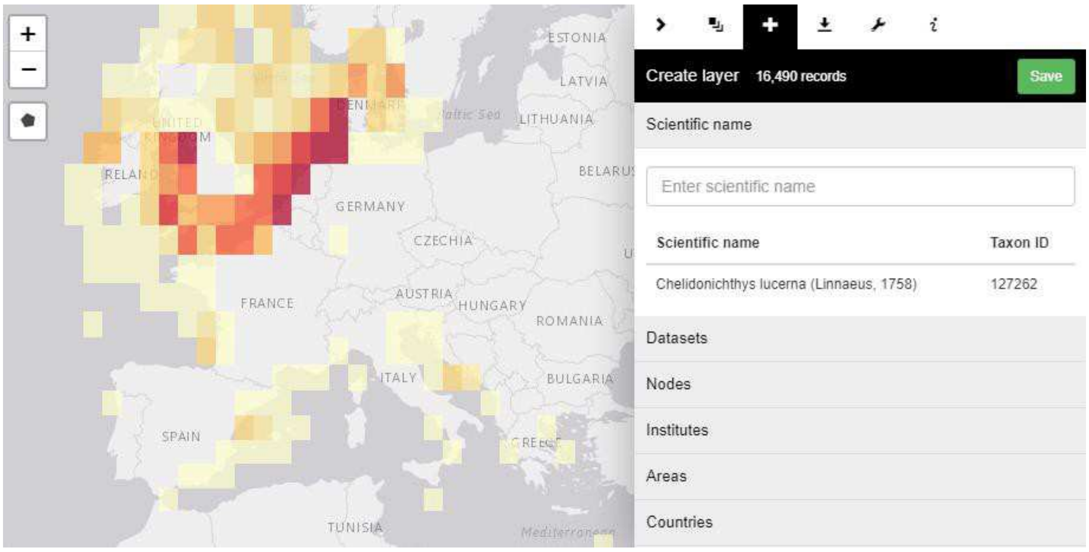

Figure 4. Example of a map with positional data, as available on the OBIS database

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. The current average temperature in the Adriatic (Figure 5) 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 6), 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.

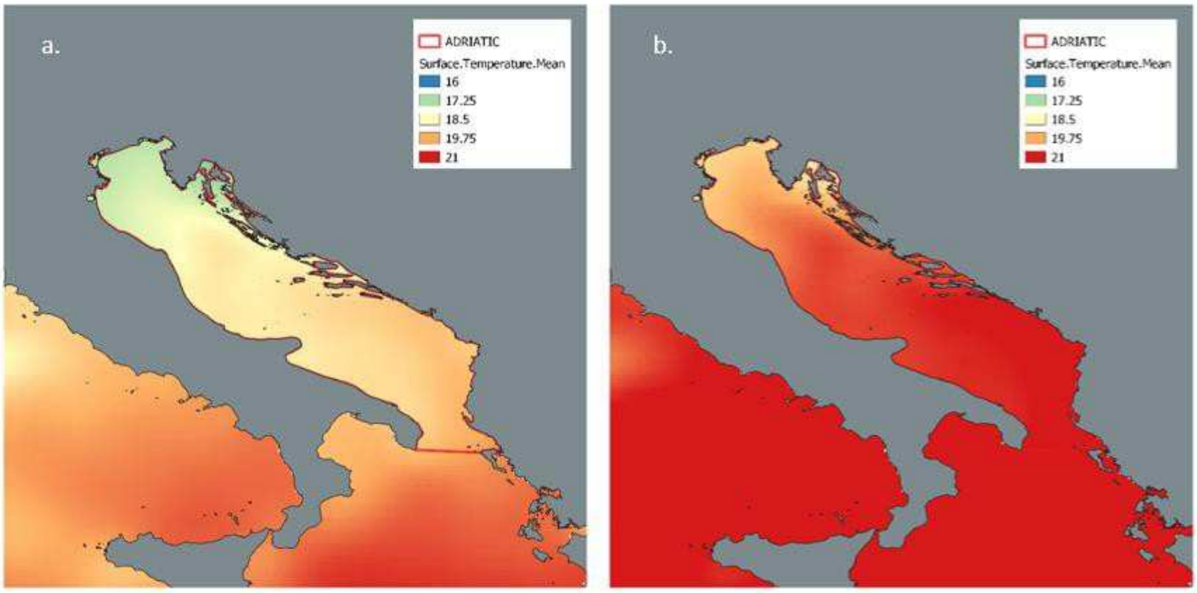

Figure 5. Maps of the average surface temperature of the Adriatic, present (a) and future (b)

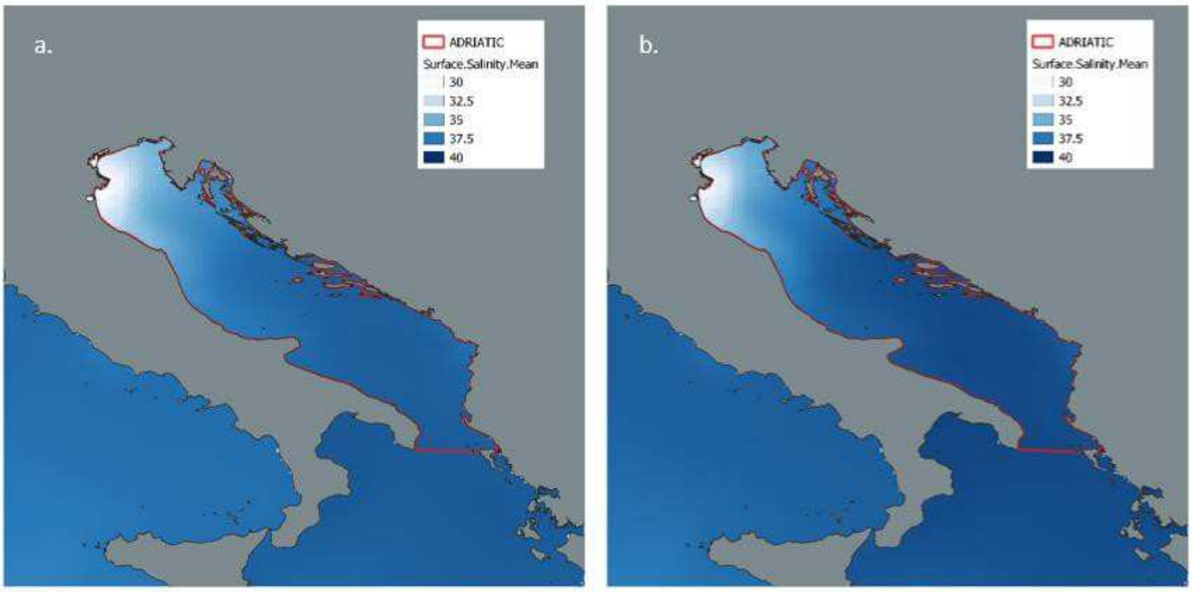

Figure 6. Maps of the average surface salinity of the Adriatic, present (a) and future (b)

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 7 shows 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.

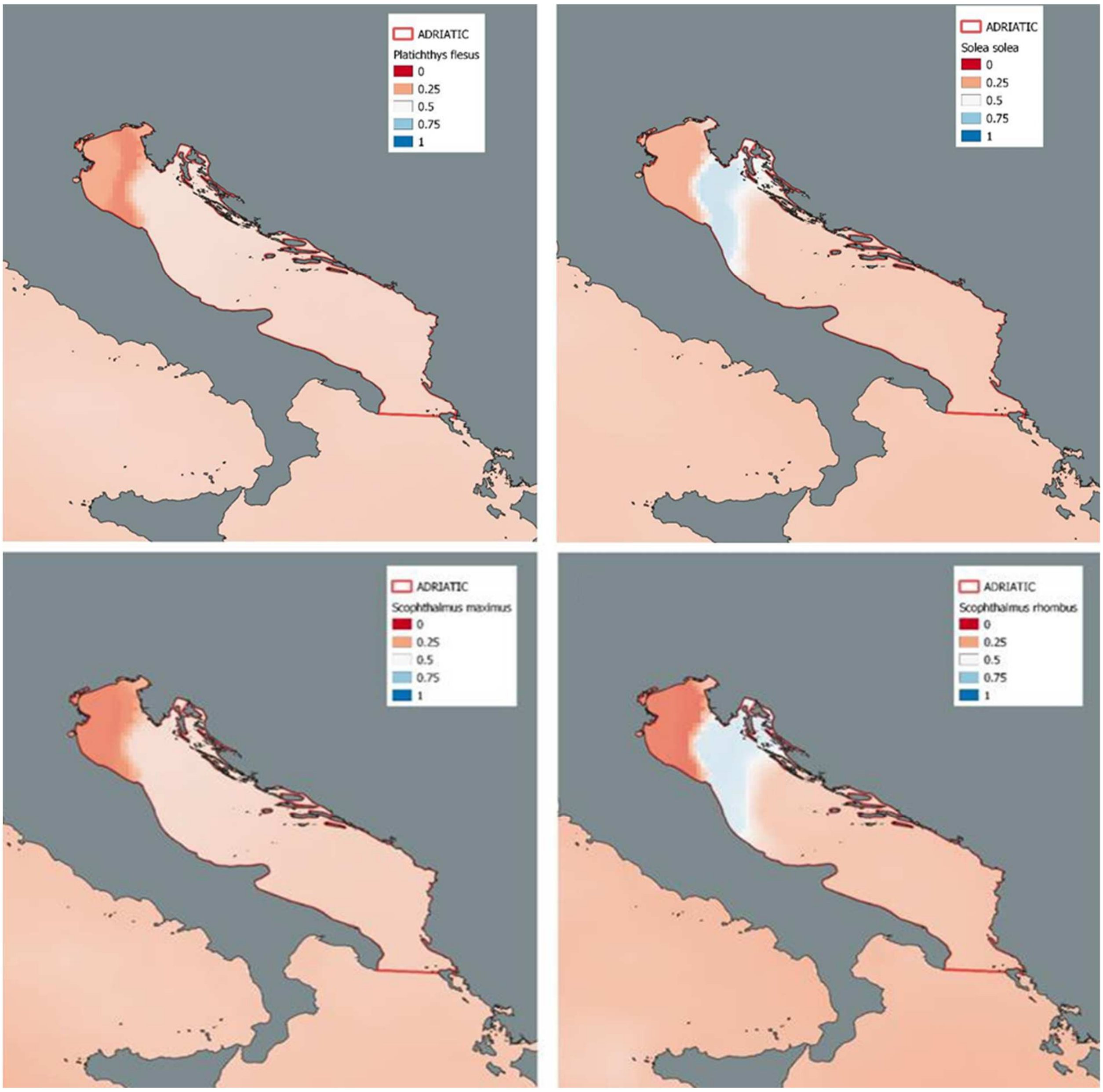

Figure 7. Predicting the future distribution of the flounder (*Platichthys flesus*) and the common sole (*Solea solea*) and the two species of turbot (*Scophthalmus maximus* and *S. rhombus*) in the Adriatic

The maps generated for the tub gurnard (*Chelidonichthys lucerna*) and the seabass (*Dicentrarchus labrax*), illustrated in Figures 8 and 9, 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 7), with a marked decrease in the probability of presence.

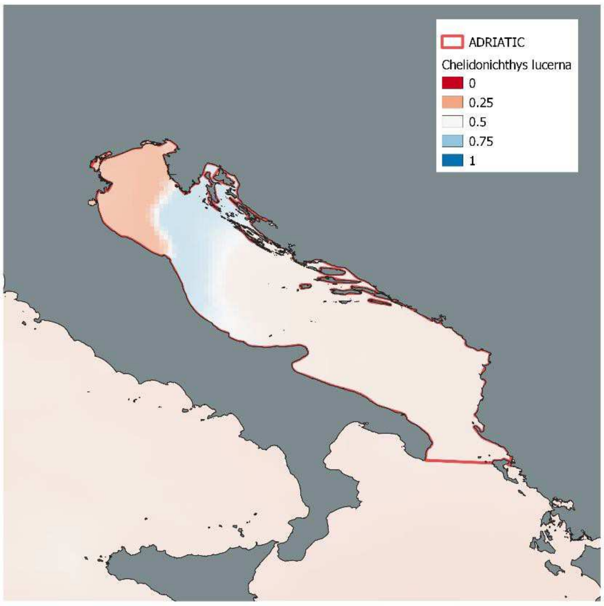

Figure 8. Prediction of the future distribution of the tub gurnard (*Chelidonichthys lucerna*) in the Adriatic

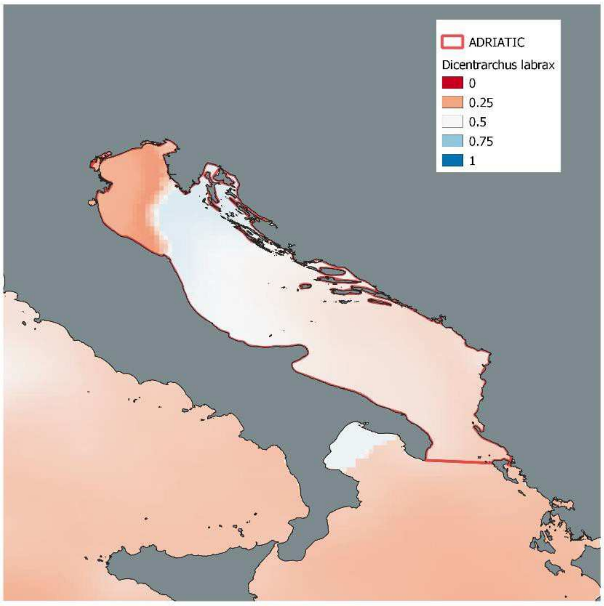

Figure 9. Predicting the future distribution of sea bass (*Dicentrarchus labrax*) in the Adriatic.

Figures 10 represents 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.

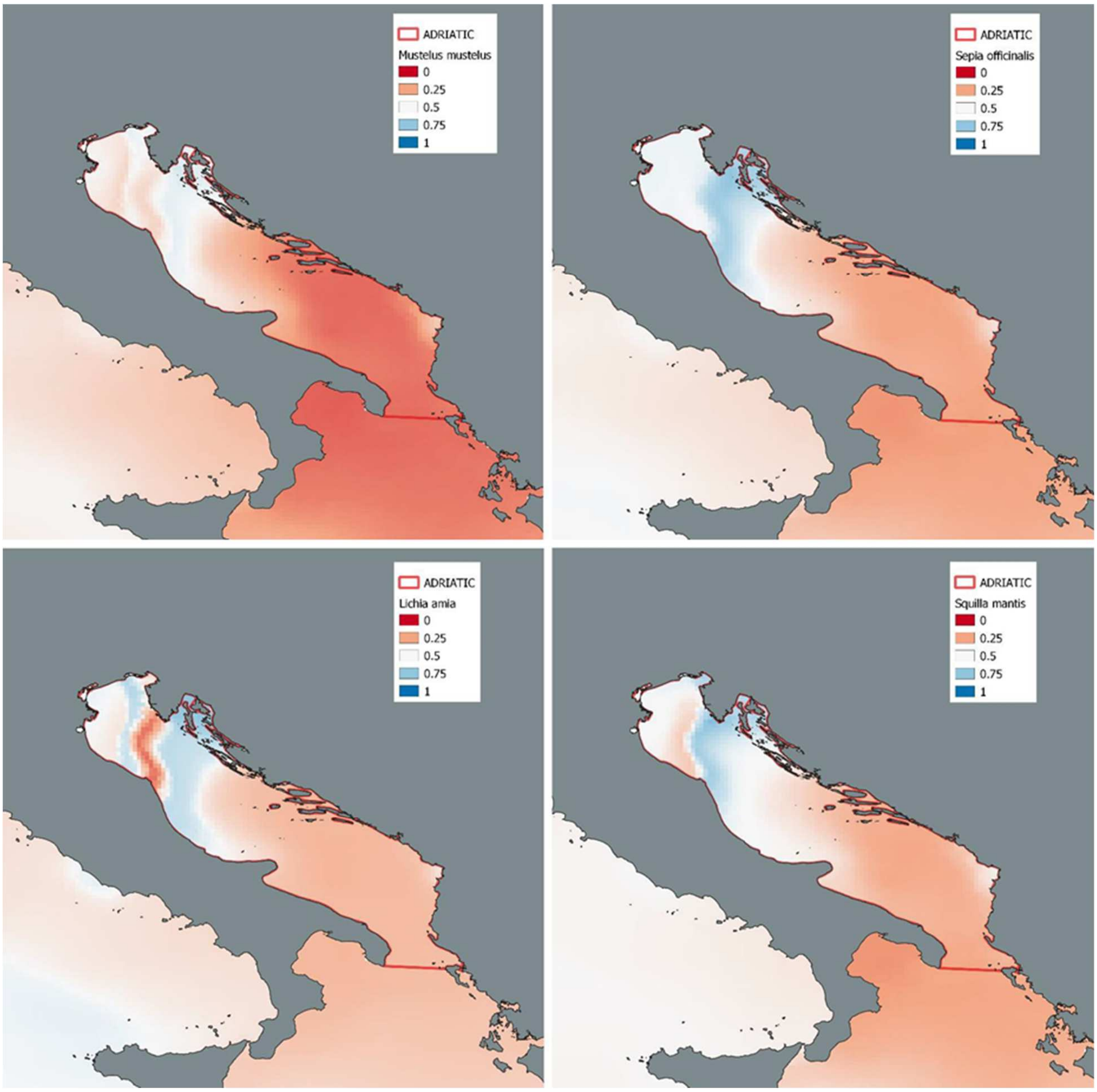

Figure 10. Forecasting the future distribution of smooth-hound (*Mustelus mustelus*), cuttlefish (*Sepia officinalis*), leerfish (*Lichia amia*) and mantis shrimp (*Squilla mantis*) in the Adriatic.

The last comparison map analysed and that of the gilt-headed seabream (*Sparus aurata*) in Figure 11. 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.

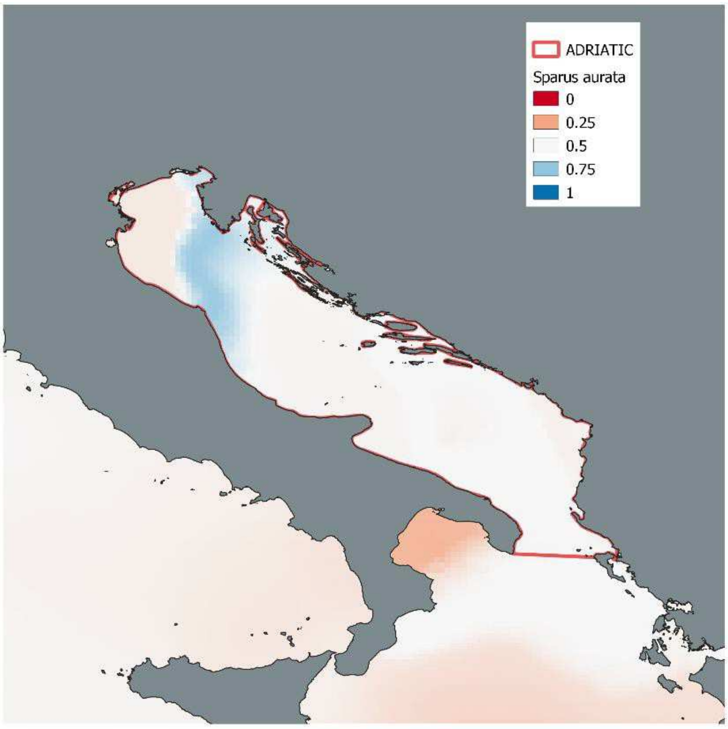

Figure 11. Prediction of future distribution of the gilt-head seabream (*Sparus aurata*) in the Adriatic

Also for *A. boyeri* and *L. mormyrus* the distribution in the Adriatic is expected to remain relatively similar to the current one, with the exception of the band between Istria and the Marche region, where an increase may occur. Northward, in the Gulf of Trieste, the two species show a different distribution: *A. boyeri* seems to slightly decrease, while *L. mormyrus* seems to slightly increase.

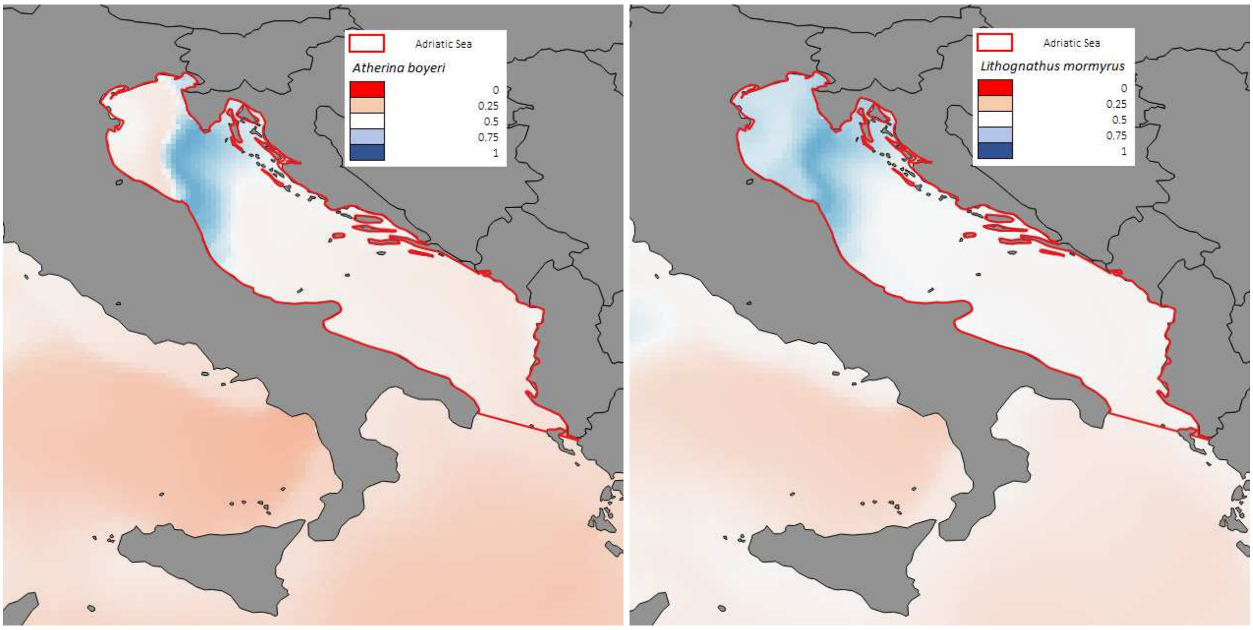

Figure 12. Prediction of future distribution for the sand smelt (*Atherina boyeri*) on the left and the sand steenbras (*Lithognathus mormyrus*) on the right.

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 2). It shows, for each species, the average values of the R index that characterize the different pixels that make up the comparison maps, with the relative standard deviation.

Table 2 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. The worst situation, represented by the dark red cells, occurs for *Mustelus mustelus*, *Platichthys flesus* and the two species of turbot, which have an average $R < 0.4$. The current trends of landing in the Adriatic, declining for all these species, are in accordance with this vision.

Table 2. Final table with mean R values

Species	R	S.D.
Atherina boyeri	0.51	0.09
Chelidonichthys lucerna	0.48	0.08
Dicentrarchus labrax	0.45	0.1
Lichia amia	0.46	0.13
Lithognathus mormyrus	0.54	0,.08
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	0.4	0.09
Sparus aurata	0.52	0.07
Squilla mantis	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 etal., 2016; Rutterford et al., 2015; Anelli 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 northwestern 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.

On 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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