DORY - Capitalization actions for aDriatic marine envirOnment pRotection and ecosYstem

PA 3 – Environment and cultural heritage
Specific Objective 3.2 - Contribute to protect and restore biodiversity
Application ID – 10041641

Title of the deliverable	**D3.3.2-CB Report on spatial management scenarios for fisheries** **D3.4.1- Report on feasibility of setting-up a CB protected areas**
Work Package:	WP3 - Implementation of sustainable fisheries management model
Activity	3.3 Testing bio-economic model "DISPLACE" for the spatial management of shared stock in Adriatic Sea 3.4 Testing the bioeconomic model "DISPLACE" for CB fishery protected area setting-up("sole sanctuary")
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Status	Final
Distribution	Public
Date	31/06/2019

1. Introduction

This report includes D3.3.2 Cross-Border Report on spatial management scenarios for fisheries and D3.4.1 Report on feasibility of setting-up a CB protected areas, and is drafted by CNR-IRBIM and IZOR, with PPs contribution. It describes the results of the bio-economic model DISPLACE simulations with the current (baseline) and alternative spatial management measures for fisheries. The results will improve Maritime Spatial Planning process and allow to evaluate effects of smaller and larger marine area restrictions on stocks and fisheries. It also includes the economic assessment of spatial restrictions for fishery and the bio-economic consequences of fishing effort re-allocation.

2. Description of the bio-economic model: DISPLACE

2.1 Model approach

The DISPLACE model project (Bastardie et al. 2014) is developing a research and advisory platform to transform fishermen's detailed knowledge and micro-decision-making into simulation and management evaluation tools. This involves advanced methods to assess and provide advice on the bio-economic consequences for the fisheries and fish stocks of different fishermen decisions and management options. DISPLACE is an agent-based simulation model developed to fisheries, habitat conservation, maritime spatial planning and management issues, especially from the perspective of the fisheries. A particular feature of the approach is to model processes at the spatial (2 × 2 km) and the time scale (hourly time steps) closer to the spatial and time dynamics occurring in human decision-making and fish populations dynamics. It is also closer to the appropriate scale for dealing with spatial management issues. The model integrates process-based mechanistic relationships that should give the advantage of being able to better predict in novel conditions and incorporate the spatial and temporal details. DISPLACE models fleet/skipper decision facing changing catch rates and limited by fisheries management including quotas or effort harvest control rule (overall capacity reduction, limits in days at sea, temporal spatial closure to fisheries) embedded in multi-annual management plans in a CFP context (i.e. FMSY). The overall spatio-temporal pattern of effort allocation between fisheries, and eventually the differential catchabilities and partial fishing mortalities, emerge from all of the individual fisher's decisions and the displacement of fishing vessels with varying catching powers.

So far, important progress has been made in a row of applications including the Adriatic Sea, the Ionian Sea, the Black Sea, the Baltic Sea and the Irish Celtic Sea. Regional scale applications are currently being developed for the North Sea and the Baltic Sea fisheries. On the Mediterranean side, DISPLACE is applied to the north Adriatic (GSA 17) to the Italian demersal fisheries (Bastardie et al. 2017). We applied the fish and fisheries model to assess the impact of a suite of spatial plans suggested by practitioners that could reduce the pressure on the six demersal stocks of high commercial interest in the GSA 17, and that could promote space sharing between mutually exclusive activities. The 2017 Adriatic Sea application has been recently updated with most recent fish stock assessment data, extended to include the Croatian fisheries. One major shortcoming in the current Adriatic application (resulting from the nature of the scientific survey data used to parameterize the current application) is the assumption of stationary in the spatial distribution of the harvest stocks over the projected years. The model, however, accounts for different distributions along the growth of a stock.

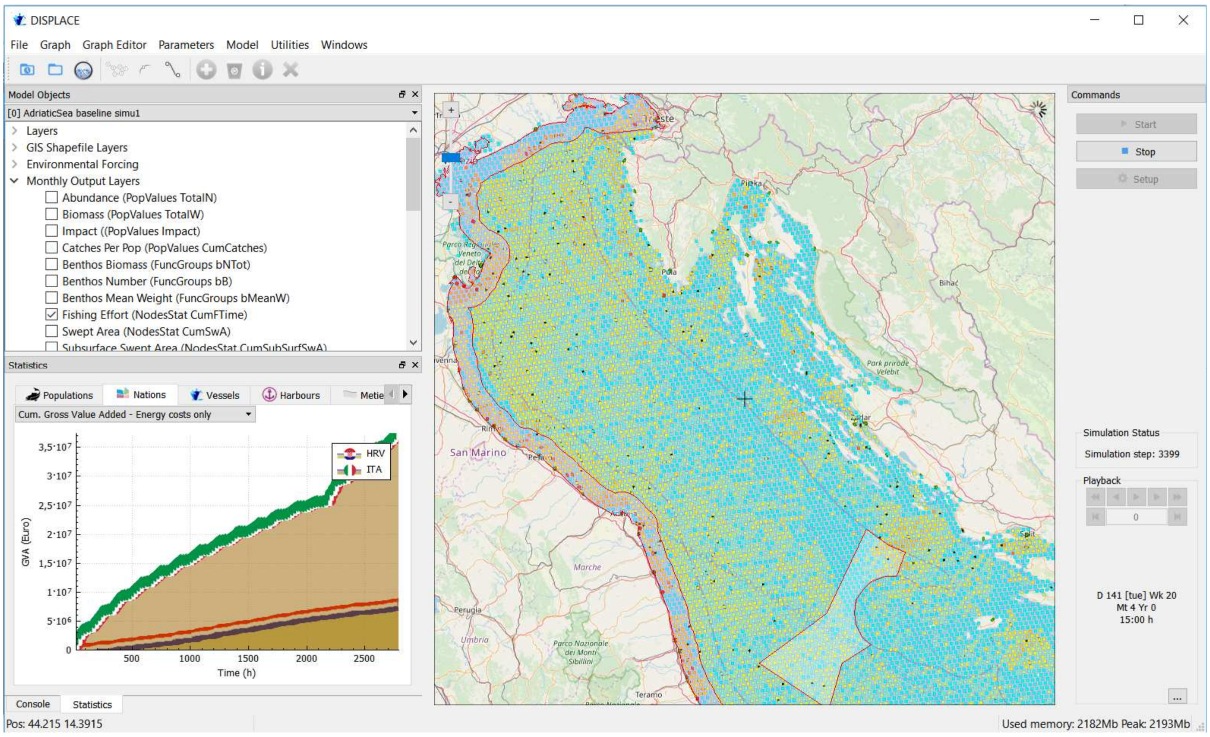


Fig. 1 - Random snapshot of the DISPLACE User Interface for the Demersal Italian & Croatian demersal fisheries in the northern Adriatic (GSA17). Movement and catches of individual fishing vessels are simulated at hourly time steps on a 6-years time horizon. DISPLACE projects EU MSFD and AER bio-economic indicators which can then be aggregated at various levels (Vessels, to Metiers, to Harbours, to Nations) and simultaneously mapped in a unified framework.

2.2 Fleet dynamics

We obtained average values for Italian and Croatian fishing vessels using trawl or set nets in the GSA 17 and targeting demersal fish. For larger vessels, the relative spatial fishing effort distributions per activity were obtained from the Automatic Identification System (AIS), which is a an automatic tracking system that uses transponders on ships and is used by vessel traffic services (VTS), in use in all the fishing vessels with a length over all ≥15 m LOA (EC No. 2009/17/CE; EC No. 1224/2009; EC No. 2011/15/UE).

Information on the fishing grounds of the small-scale gillnet fishery, for which AIS data are not available, was obtained from index suitability maps; these maps were defined by the relative likelihood of the fleet to visit the potential fishing grounds based on the suitability of these areas (according to bathymetry, distance to coast, etc.; Kavadas et al. 2015). The simulation assuming that fishing vessels land only in their home harbor. A geographical range was assumed around each home harbor (80 km for trawlers and 15 km for set netters), and each vessel distributed its effort within this range and per zone relative to the frequencies given by the relative effort data layer that was given as input at the initial stage.

Fishing gear-specific selectivity ogives and fixed, stock-specific, spatial catch rates were applied per type of activity and vessels. Considering the differences among the body shape of the target species, selectivity was assumed to be species-specific (Fabi et al., 2002). The mesh sizes considered to define selectivity curves were 68 mm stretched for Italian gillneters, 80 mm inner mesh for Croatian trammel netters (300 mm outer meshes), 50 mm diamonds for Italian otter and rapido trawlers, and 80 mm for Croatian rampon trawlers, with these mesh dimensions being the most used in the GSA 17. The Italian vessels considered in this simulation usually do not change gear during the year, while Croatian trawlers use also rampon in different part of the year. . However, exceptions were made by some gillnetters, who in some rare cases switched to bottom trawling or rapido; this modification never occurred during a trip. For the Italian fleets, each trawler vessel was assumed to work from Monday to Thursday, leaving the harbor each day at 4 a.m. and returning at 10 p.m., in agreement with the regulation that allows a vessel to spend a maximum of 72 h at sea per week (Regulation 03/07/2015). Catch rate of each vessels were assumed to increase by 3% a year to account for a so-called “technological creeping” effect. In total, 797 “agent” vessels were simulated, comprising 351 set netters, 432 otter trawlers, and 19 rapido trawlers.

2.3 Stock dynamics

Species

The model was designed to handle the spatial population dynamics of six important commercial species in the area: hake (*Merluccius merluccius*), common sole (*Solea solea*), red mullet (*Mullus barbatus*), Norway lobster (*Nephrops norvegicus*), spottail mantis shrimp (*Squilla mantis*) and cuttlefish (*Sepia officinalis*). These species have been assessed by the FAO-GFCM management and STECF for estimating the stock levels.

Parameters

The fish body size-population structure (using total length for fish) was discretized into 3-cm bins classes for all species (3 mm carapace length for Norway lobster and spottail mantis shrimp, 3 cm mantle length for cuttlefish); growth parameters were the same used in the last stock assessments developed for these species, from which population estimates are derived.

Scientific survey

The population spatial distributions were obtained from data collected during scientific surveys. In particular, the SoleMon survey is being conducted by the National Research Council (CNR-IRBIM, Italy) in cooperation with the National Institute for Environmental Protection and Research (ISPRA, Italy), the Institute of Oceanography and Fisheries of Split IOF (Croatia), and the Fisheries Research Institute of Slovenia FRIS (Slovenia) using rapido trawls (width = 3.69 m, weight = 200 kg, and codend stretched mesh size = 40 mm; Grati et al. 2013).

Abundance and spatial distribution

By applying geostatistics to the survey data, interpolated levels of stock abundance can be obtained by the categories of fish sizes. For each species, the spatial distribution was described according to three size groups on the basis of commercial categories (small, medium, and large individuals) to accommodate the variation along the growth of the individuals relative to where they locate themselves in the marine environment during the life cycle. The spatial distribution of the species (variable: kg/km2) was estimated by means of Ordinary Kriging, a geostatistical method of interpolation, which is the procedure for predicting the value of attributes at unsampled sites from measurements made at point locations within the same area or region.

2.4 Intertwined stock and fleet dynamics

The harvest (in kilos) from each active vessel at sea in DISPLACE depletes the underlying stocks, as the individual catch rates are specific to the species and affect the size structures of the population according to the varying selectivity for body size of the fishing vessel gear. This size-structured depletion dynamically links back to the underlying population models as detailed in Bastardie et al. (2016). Contrary to that, the catch rates were not assumed to depend on the available biomass by locality (unless the catch is greater than the total available biomass). Therefore, the difference in the amount and price of the catch from a vessel or from one trip to the next mainly arises from the varying duration of the fishing event, the specific selectivity of the various gears being used, and the variation in the mixture of species and abundance per size on the localities where the vessel is fishing. Hence, an assumption is made of hyperstability in catch rates (e.g., Harley et al. 2001) that are in agreement with the best data because we do not have data on spatial catch rates that will allow us to index catch rates according to the various levels of stock abun- dance. Rapido and otter trawlers are assumed to target the five species, whereas the set netters are assumed to target common sole and spottail mantis shrimp, as the hake is very rare in the set netters' fishing grounds and the red mullet is not retained by the mesh sizes used in gillnets. After each trip, simulated fishing vessels return to port and earn money from the landings in harbor where the fish prices were informed per marketable category. These fish prices were assumed not depending on the demand conditions for seafood. In an additional step, the revenue from the landings from the previous trip was determined using the amount of the catch represented by species other than the five studied species in the total revenue (revenue times 2.5, 3.3, and 2 for the otter trawlers, gillnetters, and rapido trawlers, respectively). For each vessel, the probability of visiting a certain fishing ground is updated over time from information obtained at the end of each trip concerning the expected profit the vessel could make on each ground and the expected profit according to the catch rates during this last trip. Finally, estimated depletions in the stock numbers in each of the localities, obtained mainly from other countries active in the Northern Adriatic and other catches from Croatia and Slovenia, were applied evenly over the spatial distribution of the stocks inside their respective exclusive economic zones.

2.5 Benthic habitats

Benthic habitats were described according to the information included in Santelli et al. (2017), who analyzed the megazoobenthic fauna collected during the SoleMon survey and clustered the samples in four different ecological associations. The different stations were then interpolated to obtain a picture of the study area at the scale of the Central and Northern Adriatic. Group A was dominated by *Holothuria* (*Panningothuria*) *forskali*, followed by *Amathia semiconvoluta*, *Parastichopus regalis*, *Phallusia mammillata*, and *Holothuria tubulosa*. Group B included *Ocnus planci*, *Astropecten irregularis*, and *Suberites domuncula*. Group C included three main species: *A. irregularis*, *Anadara kagoshimensis*, and *Anadara transversa*. Group D was dominated by *Liocarcinus depurator*, followed by *A. irregularis*. The presence of the group A (i.e., combinations A000, AB00, ABC0, ABCD, A0C0, A0CD, and A00D) is an object of focus because it includes holothurians, which exhibit evisceration if subjected to physical or chemical stress; this evisceration causes problems to fisheries because this event makes the fish less suitable for market- ing (“yellow fish” problem). This behavior, together with the high presence of the bryozoan *A. semiconvoluta*, which obstructs the nets and compromises their efficiency, discourages fishing in this area, which is actively avoided by trawling activities. Thus, gillnetters represent the only gear fishing in these grounds and catch many sole, skates, and other large fish.

2.6 Fleet economy

Fish prices per marketable category (small, medium and large fish) per harbor from Bastardie et al. (2017). Fish prices evolve from a year to the next according to a price flexibility equation with parameter at 25%. The vessel cost structure additional to the operating costs that are directly simulated were informed from economic Indicators collected in STECF AER 17-12 Table 5.53 for the Italian fleet and Table 5.12 for the Croatian fleet.

2.7 Management and population scenarios

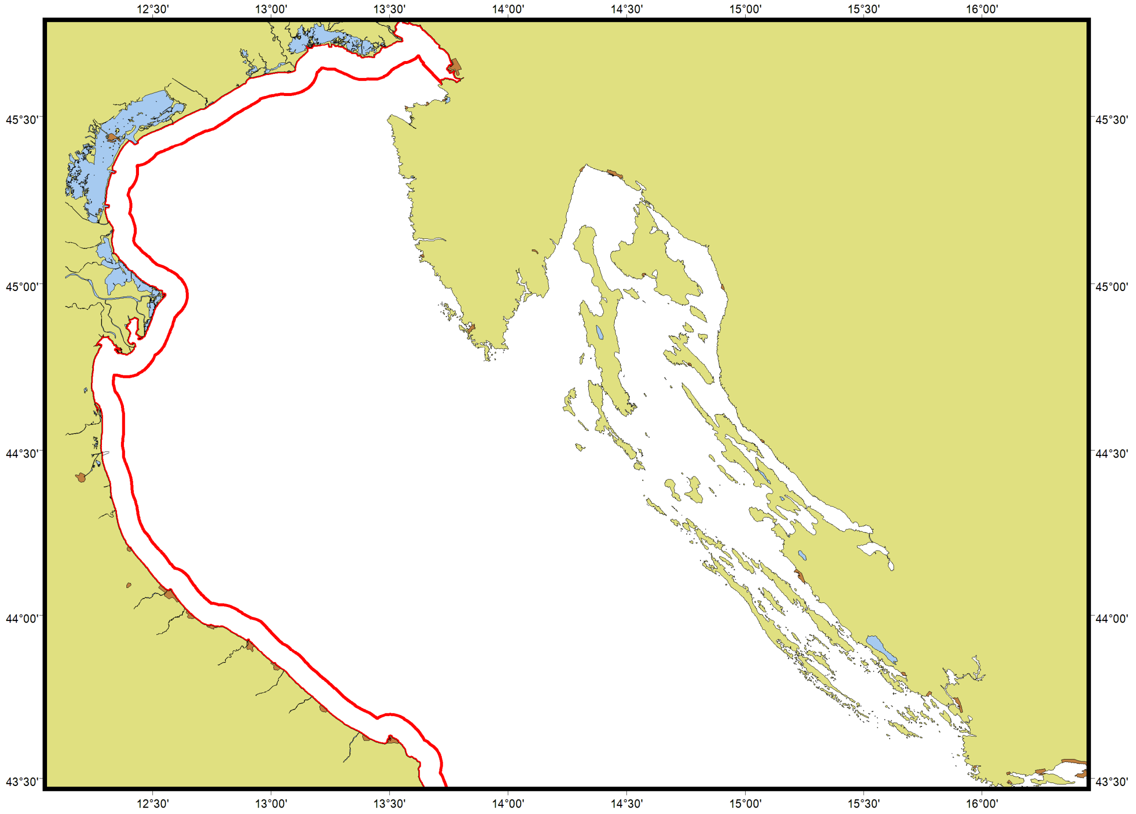
The effects of seven spatial management scenarios on six stocks (hake, common sole, red mullet, Norway lobster, spottail mantis shrimp and cuttlefish) were analyzed. We tested the bio-economic model including data for all the six species in order to have a complete picture of the main target species. In this report a special focus on common sole and cuttlefish will be done.

The scenarios tested referred to:

1. scebaseline – it is the baseline scenario (*status quo*), considering recent fisheries regulation roules in Italy, Croatia and Slovenia.

2. sceallyear4nm - The 4-nm trawling ban along the Italian coasts (GSA17), which is supposed to reduce fishing pressure on this vulnerable area (Figure 2); it represents one of the most relevant nursery area for many species, especially for common sole and cuttlefish;

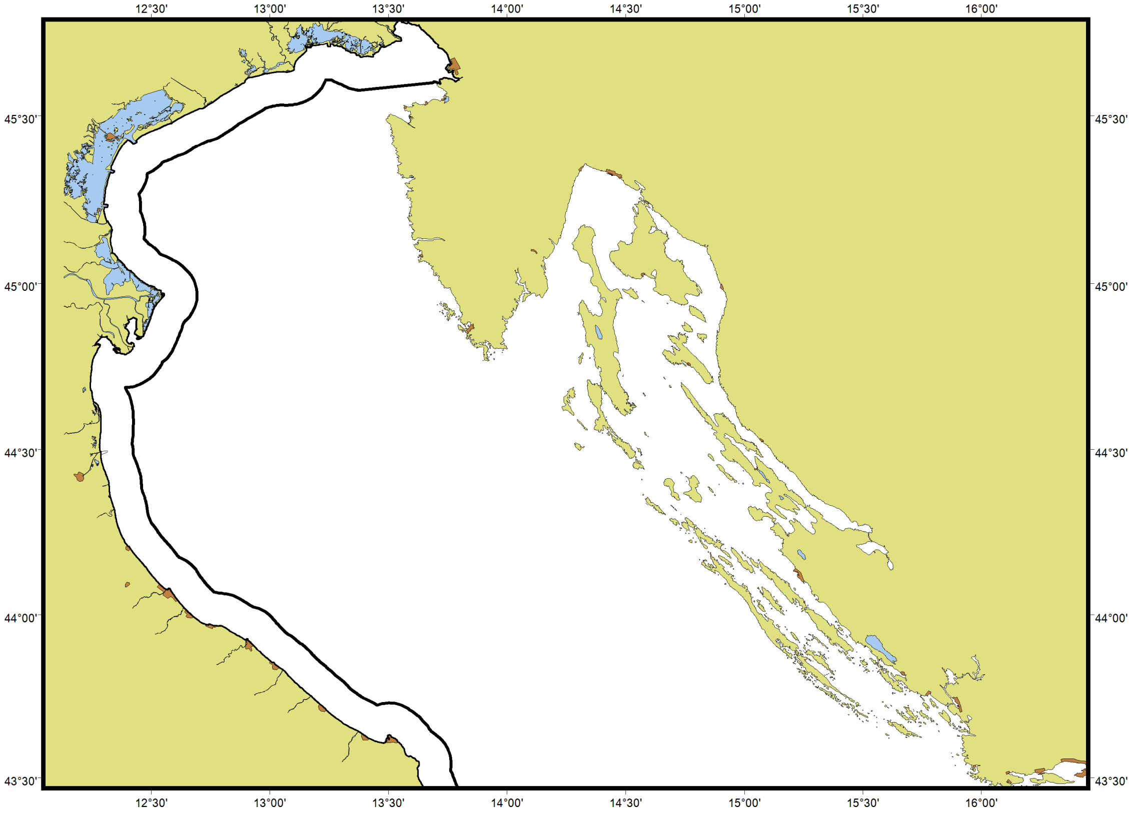
Fig. 2 – Map showing the 4-nm buffer along the Italian coast.



3. sceallyear6nm - The 6-nm trawling ban along the Italian coasts (GSA17), which is supposed to reduce fishing pressure on this vulnerable area (Figure 3); it represents one of the most relevant nursery area for many species, especially for common sole and cuttlefish. This scenario excludes Croatia and Slovenia's waters due to existing strict fisheries regulations and complex geomorphological characteristics of eastern Adriatic coast, as well as the Maritime Departments of Monfalcone and Trieste. Colloca et al. (2015) have demonstrated that the only nurseries consistently protected in European Mediterranean waters are those of coastal species, such as red mullet, common Pandora and common sole with 66.8%, 54.1% and 46.1% respectively of persistent nursery areas under protection. This is mostly due to the trawling ban within 3 nautical miles of the shoreline or 50 m depth, applied through current management measures as defined by Article 13 of EU Council Regulation 1967/2006. This situation is particularly evident for the Northern Adriatic Sea. Based on

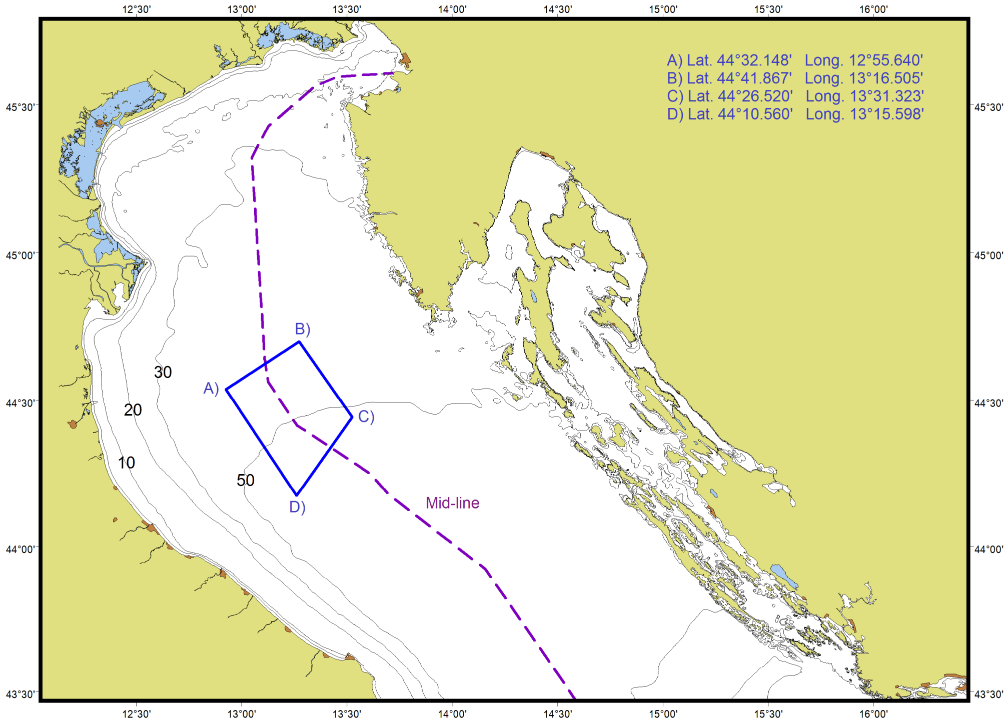
this evidence, the implementation of the spatial management measure currently in force (3 nautical miles) with an extension to the 6 nautical miles would have the potential to substantially improve current fisheries exploitation patterns.

Fig. 3 – Map showing the 6-nm buffer along the Italian coast.



4. scesolesanctuary - a permanent closure of the “sole sanctuary” area (Figure 5) for bottom otter and rapido/rampon trawlers (both Italian and Croatian fleets). Again, the closure of this area highlights the importance of reducing the fishing pressure on vulnerable areas (e.g., spawning areas) that are considered of biological interests for commercial species.

Fig. 5 – Map of the “sole sanctuary”.



5. scesoleselectivity - Increase the selectivity of gillnet through the adoption of a 72mm stretched mesh size and increase of the common sole minimum landing size to 25 cm TL (the current one is 20 cm TL);

We obtained a quantification of the changes provoked by the implementation of alternative plans by running Monte Carlo simulations that projected the scenarios with varying spatial harvest patterns (from the activity of individual vessels), comparing them against the baseline situation where the current management was applied. A total of 20 stochastic runs were conducted per scenario and provide quantified changes to the activity-specific impacts on the economic return, on the sustainability of the harvesting strategies for the species considered in this study, and on the fraction of underlying seafloor habitats enduring the fishing pressure.

3. Results

3.1 Fishing effort redistribution

Figure 6 shows how the fishing effort would redistribution per tested scenario. The baseline scenario highlights that the highest fishing pressure concentrate in the northern and western parts of the GSA17, with peaks of 55 fishing hours/year per km^2 (all gears combined).

The 4-nm ban would mostly increase the fishing effort along the external border of this buffer and, with less extent, also to the fishing grounds located more offshore.

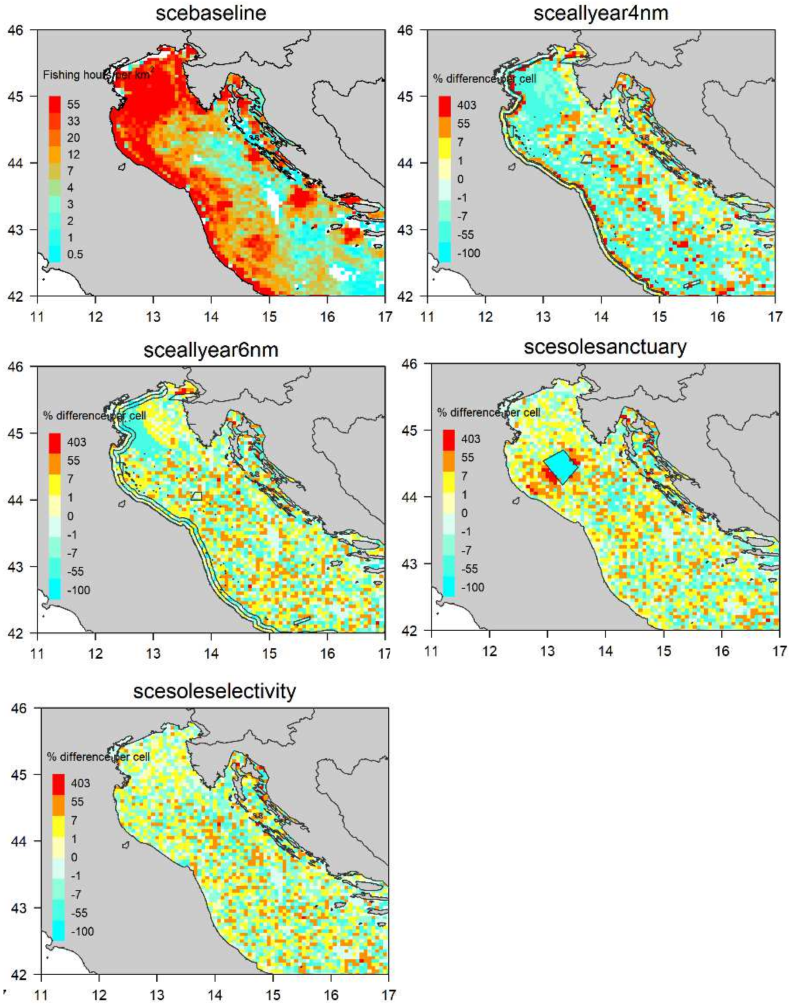


Fig. 6 – Maps reporting the redistribution of the fishing effort as an effect of the different scenarios.

The 6-nm limit for trawlers would have the effect of pushing the vessels more offshore (outside the 12 nm), discouraging the explotation of more coastal fishing areas.

The “sole sanctuary” would concentrate the fishing effort in the proximity of the FRA, but mostly in fishing grounds located close to Italy and Croatia. As a consequence, the highest concentrations of the fishing pressure would be expected in the surroundings of the sanctuary, with two hotspots in correspondance with the Italian and Croatian sides, South-West and North-East, respectively.

The scenario “sole selectivity” would generate a slight increase of the fishing pressure only offshore.

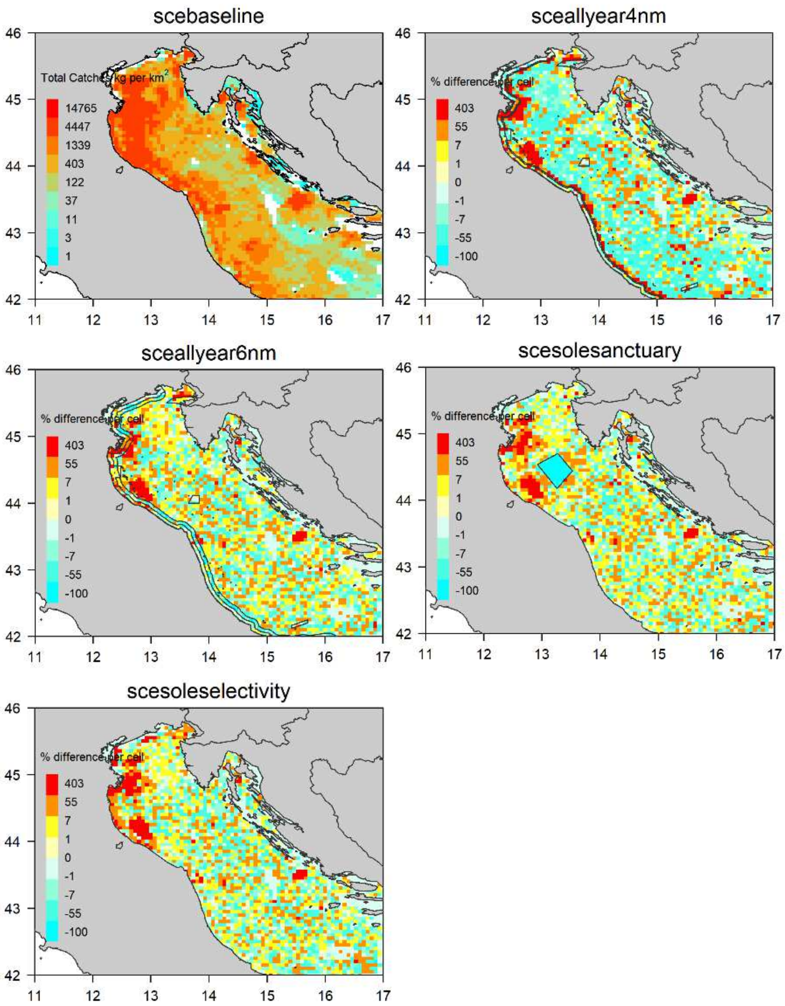
3.2 Catches

Similarly to what already observed for the fishing effort, the baseline scenario shows that most of catches are concentrated in the Northern and Western part of the GSA17 (Figure 7), with peaks of about 15 tons/year per km^2.

All the scenarios tested show two hotspots where catches would be expected to increase: 1) off the Po River mouth; 2) the Southern portion of Emilia Romagna coast.

Common sole - Figure 8 shows the likely distribution of common sole catches as the effect of the four scenarios tested with DISPLACE. The closure of the 4 and 6-nm would slightly increase the sole catches along the buffer zones and more consistently in the central portion of the basin, where larger specimens concentrate. The “sole sanctuary” would slightly increase sole cathes only in the surroundings of the buffer area in the directions North-East, South-East and South-West. The scenario concerning the sole selectivity would produce a general increase of sole catches, which would be more evident along the italian coast, thanks to both the higher selectivity of gillnets used inside the nursery areas of this species, and to the larger MLS.

Fig. 7 – Maps reporting the redistribution of the cumulative catches (all species) as an effect of the different scenarios.



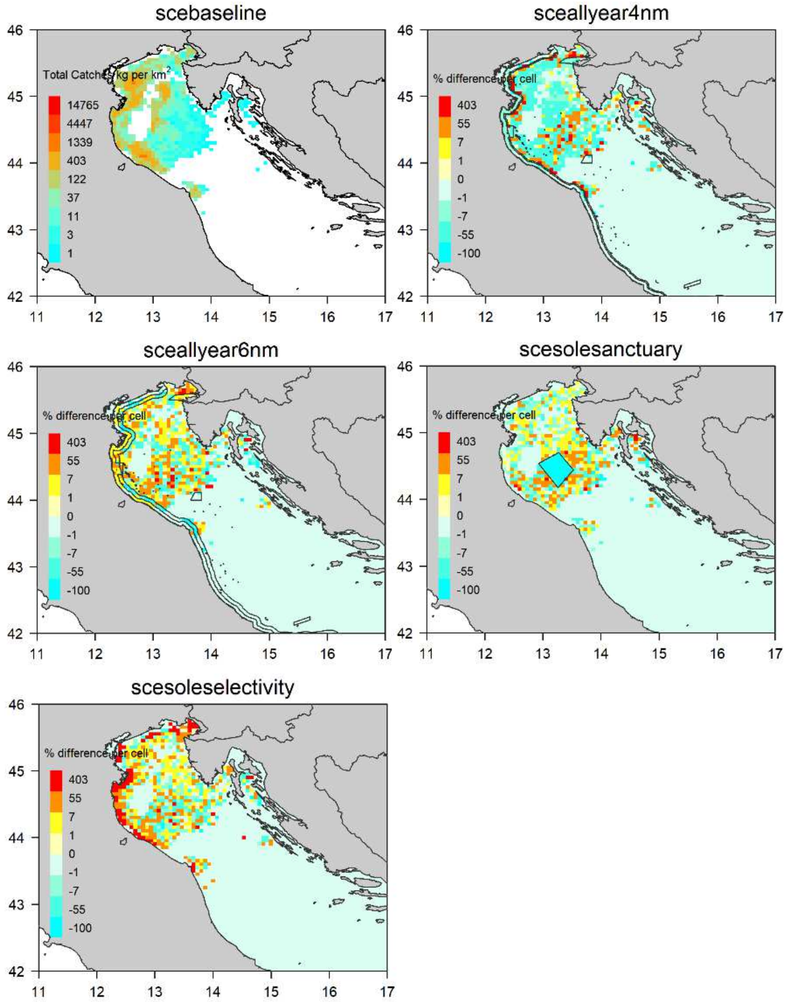


Fig. 8 – Maps reporting the redistribution of the common sole catches as an effect of the different scenarios.

Cuttlefish - Figure 9 shows the cuttlefish catches spatial redistribution on the basis of the effects of the four scenarios tested with DISPLACE. The closure of trawling inside the 4-nm would increase the catches of this cephalopod along the borders of this buffer along the italian coasts. The closure for trawlers inside the 6-nm would cause a general increase of cuttlefish catches in the offshore fishing grounds located in the central and southern portions of the basin.

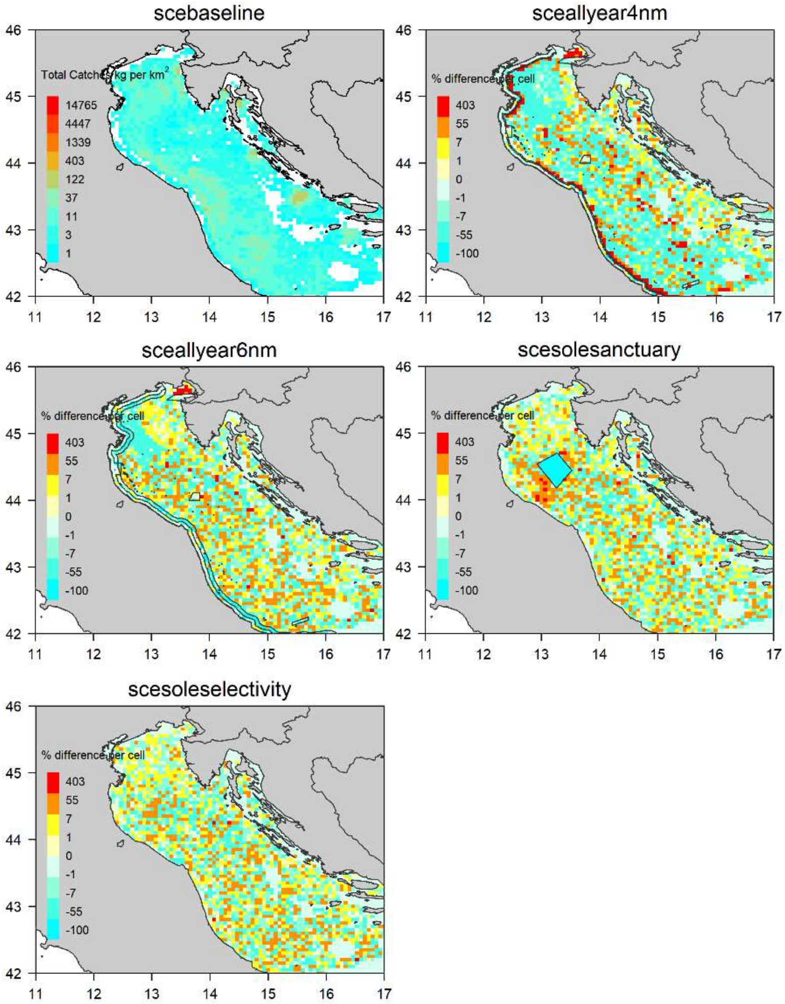


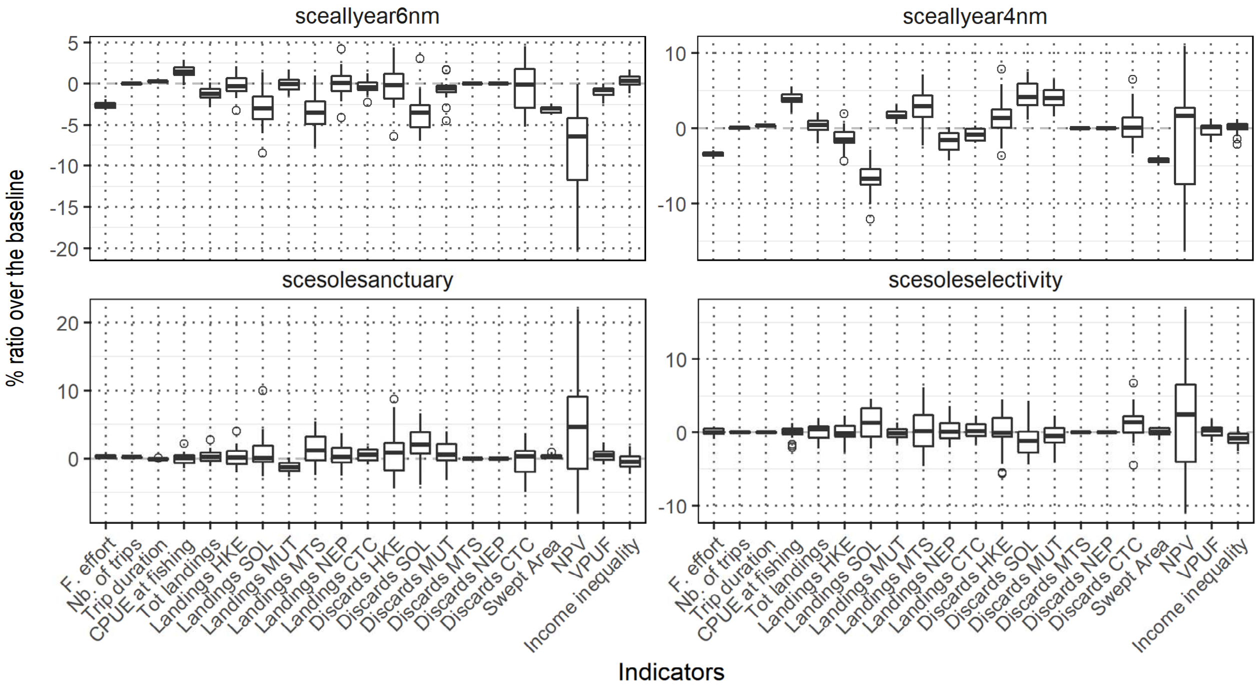
Fig. 9 – Maps reporting the redistribution of the cuttlefish catches as an effect of the different scenarios.

The “sole sanctuary” would mostly increase cuttlefish catches in the proximity of the Italian side, from the South-Western limit of the sanctuary to the coast. As expected, the scenario aimed at increasing sole selectivity has little effect for cuttlefish catches.

3.3 Indicators

The biological and economic indicators for bottom otter trawlers calculated by DISPLACE for the four scenarios are presented in Figure 10. The closure of 4 and 6-nm would produce a decrease of the fishing effort, because the vessels would exploit more offshore fishing grounds, and hence they will need more time for navigating and less time remaining for fishing.

Fig. 10 – Bottom otter trawlers - biological and economic indicators generated by DISPLACE model for each scenario.



Concerning the common sole, even though this species is not targeted by bottom otter trawl representing an occasional catch, the closure of both the 4 and 6-nm would generate a decrease of landings (Figure 10). In terms of discard rates, the 4-nm closure would increase the sole discard because the vessels would probably concentrate their fishing effort between the 4 and 6-nm strip. While, as expected, the closure of the 6-nm would significantly decrease the discard rates of sole. Landings of sole would slightly increase in case of sole selectivity scenario, while the discard rates of this species would decrease.

Landings of cuttlefish seem to remain similar to the ones of the baseline for the 4 and 6-nm scenarios.

The economic indicators show that the Net Present Value (NPV) would significantly decrease in case of a 6-nm ban, while it would increase for the “sole sanctuary” (+5%).

Figure 11 shows the biological and economic indicators for rapido trawlers calculated by DISPLACE for the four scenarios. The closure of the 6-nm would slightly increase common sole landings, as well as Catch Per Unit Effort (CPUE) and total landings. This is an interesting result confirming the importance of preserving nursery areas from impacting fishing gears, as the rapido. The closure of the “sole sanctuary” to rapido trawlers would decrease sole landings and increase sole discards, as the vessels would concentrate more fishing effort on coastal fishing grounds, which are characterised by the presence of smaller specimens. The scenario “sole selectivity” shows worthy results for this species increasing the landings (+5%) and decreasing the discard rates (-2.5%).

Landings of cuttlefish do not seem to be significantly affected by most of tested scenarios, with the exception of the 4-nm closure, that would protect juveniles increasing the subsequent catches of adult specimens. In terms of discard rates, the 4-nm closure would also increase the cuttlefish discard because the vessels would probably concentrate their fishing effort between the 4 and 6-nm strip.

The economic indicators (Figure 11) show that both the Net Present Value (NPV) and the Value Per Unit of Fuel (VPUF) would significantly increase in case of both a 6-nm ban and the “sole selectivity” scenarios, while they would decrease in case of a 4-nm ban and the institution of a “sole sanctuary”.

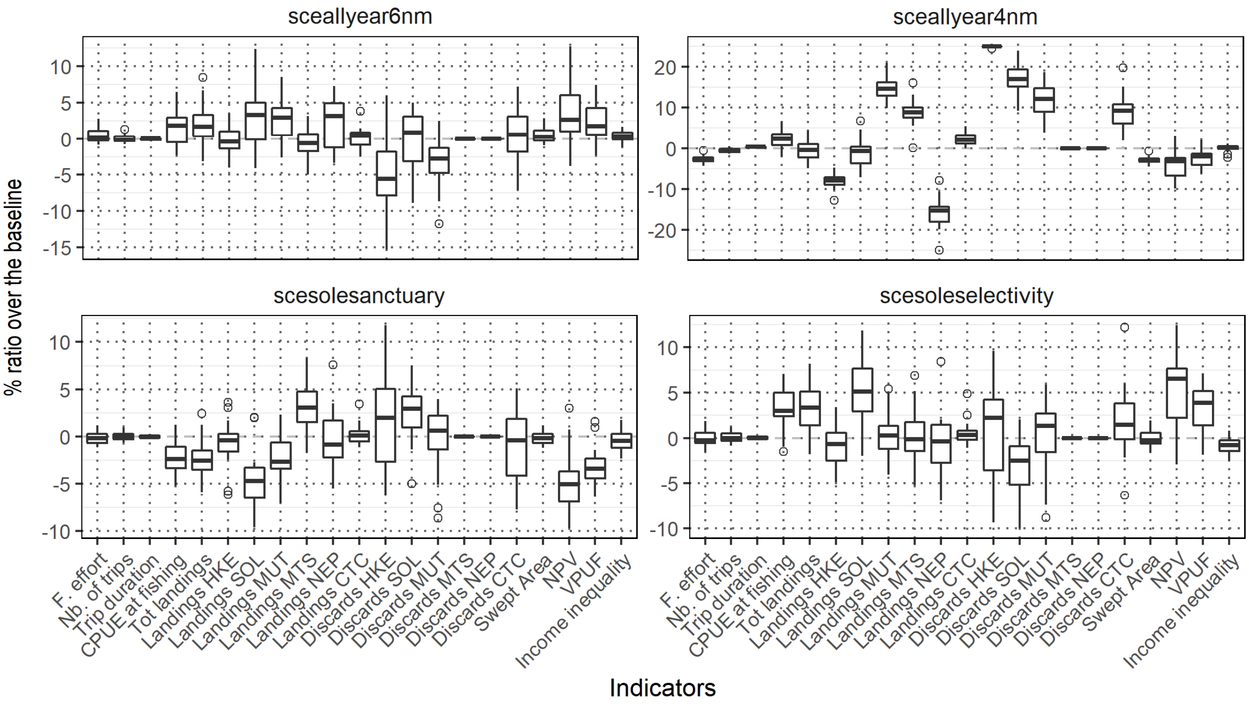


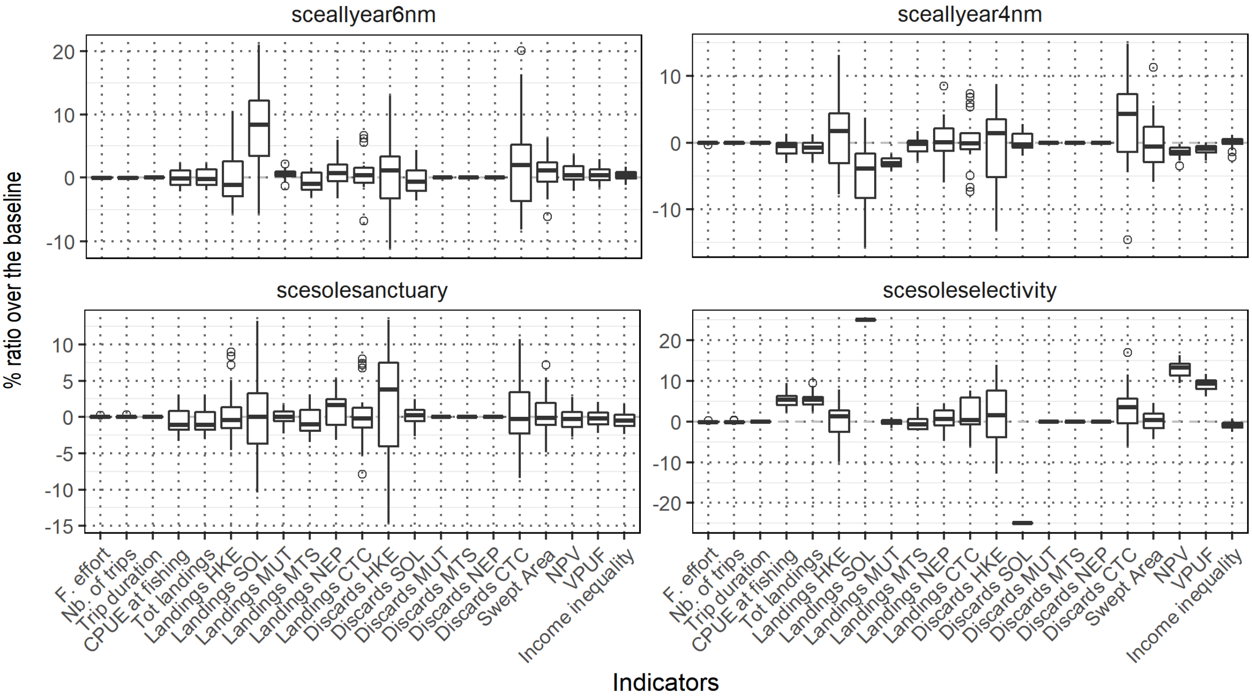
Fig. 11 – Rapido trawlers – biological and economic indicators generated by DISPLACE model for each scenario.

Figure 12 shows the biological and economic indicators for gillnetters calculated by DISPLACE for the four scenarios. The closure of the 6-nm to trawlers would significantly increase common sole landings (+8%) of gillnetters. A greater increase of sole landings (+30%) would be expected in the case of a “sole selectivity” scenario. The cuttlefish landings would not be affected by the tested scenarios, as this species is not a target of gillnets and hence may enter only occasionally in catches.

Concerning sole discard, as expected, the “sole selectivity” measure would significantly decrease sole discard rates by around 30%.

The economic indicators (Figure 12) show that both the Net Present Value (NPV) and the Value Per Unit of Fuel (VPUF) would significantly increase in case of the “sole selectivity” scenario.

Fig. 12 – Gillnetters - biological and economic indicators generated by DISPLACE model for each scenario.



3.4 Income inequality

The income inequality has been calculated based on the Hoover Index, also known as the Robin Hood index or the Schutz index, which is a measure of income metrics. It is equal to the portion of the total community income that would have to be redistributed (taken from the richer half of the population and given to the poorer half) for there to be income uniformity. This index gives an idea of the economic performances of each scenario at port level. The effects of the 4-nm scenario were similar to those of the 6-nm one, and hence only this last one has been reported.

Figure 13 shows the income inequality between Italian and Croatian fishing harbors for the revenues of all the species combined. The 6-nm ban and the "sole sanctuary" will affect in a similar way the fishing harbors of both countries. The "sole selectivity" scenario will favor mostly the fleets operating in the north-western Adriatic Sea, as a result of the nursery grounds protection for many species.

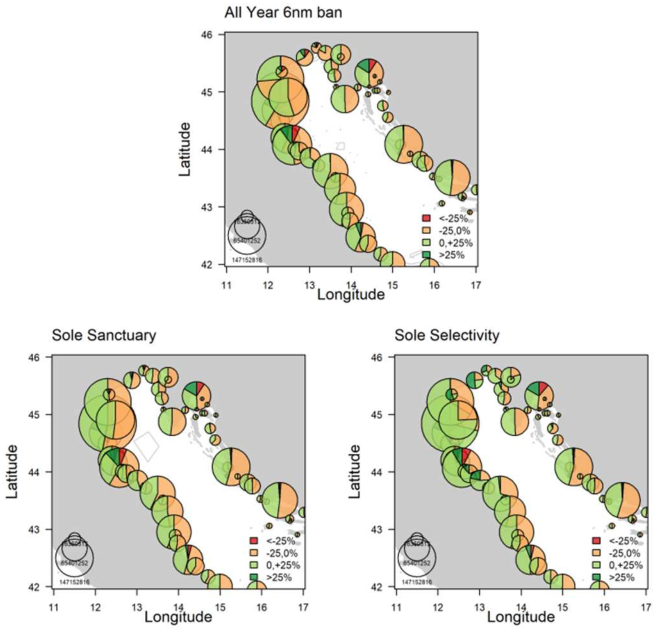


Fig. 13 – Income inequality between Italian and Croatian fishing harbors for the revenues of all the species combined.

Figure 14 shows the income inequality between Italian and Croatian fishing harbors for the revenues associated with the common sole. Due to the relatively limited home range of this species, this analysis involves only the fishing fleets operating in the central and northern GSA17.

The pie charts show that 6-nm ban and the "sole sanctuary" will affect in a similar way the fishing harbors of both countries. The "sole selectivity" scenario will significantly favor mostly all the fleets, as a result of the of the nursery grounds protection for this species.

Fig. 14 – Income inequality between Italian and Croatian fishing harbors for the revenues of the common sole.

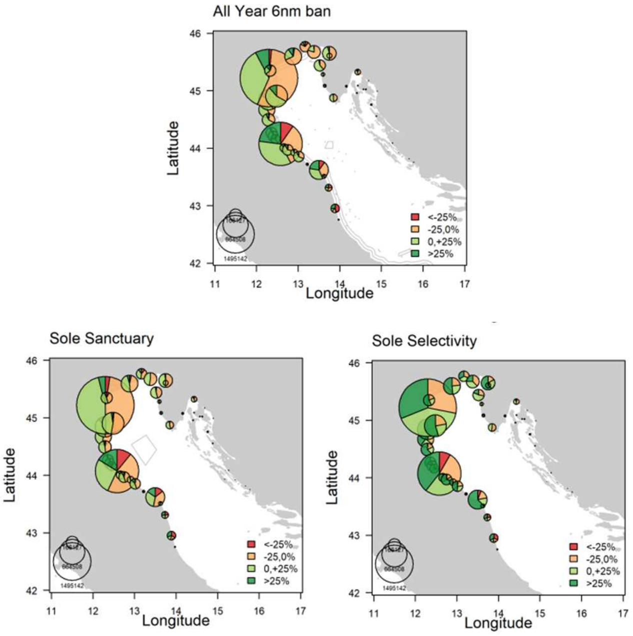


Figure 15 shows the income inequality between Italian and Croatian fishing harbors for the revenues associated with the cuttlefish. The pie charts show that the four scenarios do not affect the income inequality in both the Italian and Croatian side.

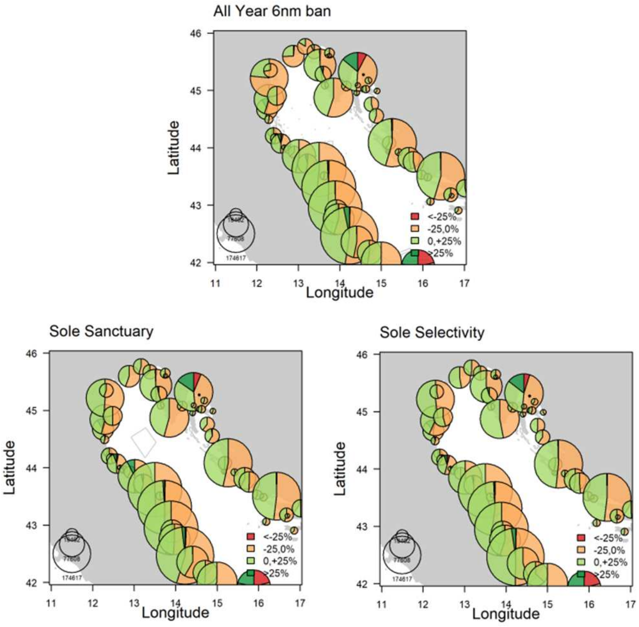


Fig. 15 – Income inequality between Italian and Croatian fishing harbors for the revenues of the cuttlefish.

4. Conclusions

The results obtained in the present study will improve Maritime Spatial Planning process and allow to evaluate effects of alternative spatial management plans on stocks and fisheries. It also includes the economic assessment of spatial restrictions for fishery and the bio-economic consequences of fishing effort re-allocation. The tool used for the data analysis is DISPLACE model project (Bastardie et al. 2014), a research- and advisory platform aimed at transforming fishermen's detailed knowledge and micro-decision-making into simulation and management evaluation tools. The model was designed to handle the spatial population dynamics of six important commercial species in the area, hake (*Merluccius merluccius*), common sole (*Solea solea*), red mullet (*Mullus barbatus*), Norway lobster (*Nephrops norvegicus*), spottail mantis shrimp (*Squilla mantis*) and cuttlefish (*Sepia officinalis*), and to assess the impact of a suite of spatial plans suggested by stakeholders and scientists, that could reduce the pressure on these stocks in the GSA 17, and that could promote space sharing between mutually exclusive activities. We tested the bio-economic effects of four spatial management scenarios including data for all the six species in order to have a complete picture of the main target species, but in this report only the common sole and cuttlefish have be described.

Fishing effort and catches are mostly concentrated in the norther part of the GSA17, confirming this area as one of the most productive of the whole Mediterranean. Fishing effort redistribution shows that, in general, vessels would displace their effort in the surroundings of the closed areas, and in only few cases (e.g., 6-nm ban) they will change target by exploiting fishing grounds with different ecological characteristics.

For the common sole, the trawling ban inside the nursery areas (4 and 6-nm) would increase the catches in the spawning grounds, as a result of the spillover effect between these two priority habitats for this shared stock. The protection of the spawning ground of the sole (e.g. sole sanctuary) would slightly increase catches only in the surroundings of the buffer area, without influencing the nursery areas. This is probably due to the fact that the spawning stock biomass of this species is consistent over time, as currently most of trawlers are not able to exploit this area because of the presence of a peculiar macrozoobenthic community (Santelli et al., 2017).

For the cuttlefish, the closure of trawling inside the 4-nm would increase its catches along the buffer zone along the Italian coasts, while the 6-nm ban would cause a general increase of catches in the offshore fishing grounds. This is a fishing strategy somewhat connected with the fishermen’s choices typical of a multi-species context, where the driver could be not directly correlated with the cuttlefish but with other species.

Bio-economic indicators of bottom otter trawlers show that the tested scenarios might have a minor impact on the sole, as this species is not targeted by this fleet segment representing only a small portion of the total catch. The economic performances on bottom otter trawlers show that NPV would significantly decrease in case of a 6-nm ban, while it would increase for the “sole sanctuary” (+5%).

Differently, for rapido trawlers both the common sole and the cuttlefish are important targets. For this fleet segment the results highlight and confirm the importance of preserving nursery areas from those fishing gears having a high impact on the ecosystem and stocks. The scenario “sole selectivity” might improve the harvest of the sole by increasing the landings (+5%) and decreasing the discard rates (-2.5%). The 4-nm closure would protect juvenile cuttlefish, increasing the subsequent rapido catches of adult specimens. The economic indicators for rapido trawlers show that both the Net Present Value (NPV) and the Value Per Unit of Fuel (VPUF) would significantly increase in case of both a 6-nm ban and the “sole selectivity” scenarios, while they would decrease in case of a 4-nm ban and the institution of a “sole sanctuary”.

The bio-economic indicators obtained for gillnetters confirm that the closure of the 6-nm to trawlers would significantly increase common sole landings (+8%) of this fleet segment. Also, higher sole landings (+30%) and lower discard sole rates (-30%) would be expected in the case of a “sole selectivity” scenario. This last scenario would bring also some economic benefit in terms of NPV and VPUF.

The income inequality, calculated for both the common sole and the cuttlefish with the Hoover Index, shows that the “sole selectivity” scenario might favor all the fleets, as a result of the protection of the nursery grounds of this species.

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