How different fishery methods and linked management measures interfere each other both at biological and socio-economic level

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Executive summary

WP3 has the aim of setting a common governance framework for the Adriatic institutions dealing with fishing and aquaculture and partners of the ARGOS project. The ultimate object of WP3 is to create an organism able to express scientific advice about the protection and management of shared resources. The framework for governance is thus structured by 2 strictly-linked organisms: 1) the AAC (Adriatic Advisory Committee), coordinated by WP responsible and composed of 1 scientific representative delegated by each partner and 4 representatives, 2 from fishery and 2 from aquaculture associations of operators, respectively for Italy and Croatia; 2) the Steering Committee (SC), given its authoritative role and due to the high supervision role taken by the 2 Ministries for fisheries (Associated Partners), approves and puts into effect theproposals/recommendations from the AAC. In a such well-defined and coordinated process for governance, the AAC manages all technical-scientific topics, finally established by the SC. Such harmonized process for governance will in the future promote coordinated interventions and management measures in the Adriatic partnership area, provide addresses for shared schemes for the reduction of human pressures, and the promotion of sustainable management of fisheries, both at environmental and socio-economic levels, in the framework of the Common Fishery Policy(CFP) and Water Framework Directive.

First of all, current compulsory management measures will be described in general (additional details can be found in D3.3.1), then how different fishery methods and linked management measures interfere with each other will be discussed based on the bibliography. After that, DISPLACE model runs will be used to test management scenarios suggested by the AAC through stakeholder consultations. These results will be useful in analyzing in detail the possible consequences and interactions at the fishery level.

List of acronyms

ABFT: Atlantic BlueFin Tuna

ANE: European anchovy

CL: carapax length

CFP: European Common Fisheries Policy

CTC: Common cuttlefish

GFCM: General Fisheries Commission for the Mediterranean

GNS: Set Gillnet

GSA: Geographical Sub Area

HKE: European hake

LOA: Length Overall

MP: Management Plan

MPAs: Marine Protected Areas

MTS: Spot–tail Mantis shrimp

MUT: Red mullet

NEP: Norwegian lobster

OTB: Bottom Otter Trawl

PIL: European sardine

PS: Purse Seine

PTM: Pelagic Midwater Trawl

SOL: Common sole

SSB: Spawning Stock Biomass

SSF: Small Scale Fishery

STECF: Scientific, Technical and Economic Committee for Fisheries

TBB: "Rapido" Trawl

TGS: Caramote prawn/Tiger shrimp

TL: total length

1. MANAGEMENT SCENARIO: *Status quo*

European and national fisheries policies are aimed at restoring sustainable exploitation of fisheries resources, guaranteeing economic and social sustainability in the medium to long term for fishing activities (Article 2 EU Reg. 1380/2013).

Improved management of fisheries requires not only an understanding of the axioms and working assumptions underlying the current approaches and how these evolved in response to regional or local conditions and target species, but should also promote the integration of methodologies that better reflect local situations and can be expressed in the form of one or more working paradigms (Caddy, 1999).

In Italy, the history of the management of fishing activities started at the beginning of the 80s. Law 41/82 laid the foundations for a management system based on fishing effort control; in fact, given the intrinsic characteristics of Italian and, more generally, Mediterranean fisheries, the management system based on the control of fishing effort was considered the most appropriate for many years. However, in light of the current state of demersal resources, the management of effort based on input measures did not give rise to the expected results (Colloca et al., 2017) and it was questioned in favor of the inclusion also in the Mediterranean of output-based management measures, such as catch quotas (Cardinale et al., 2017).

Fishing effort management was implemented through fishing capacity control e of the activity of fishing vessels. The two key tools on which fishing capacity control is based are: (a) fishing licenses, only a regular license issued by the public administration authorize to professionally exploit fish resources (Law 41/1982); (b) Fishing capacity may not exceed the established limits by the Common Fisheries Policy (PCP) (Annex II Reg. EU 1380/2013) which for Italy is 173,506 GT and 1,070,028 kW. The entry and exit of fishing vessels from the fleet must be managed in such a way that the entry of a new capacity into the fleet is offset by the preliminary withdrawal of at least an identical capacity.

The maximum engine power of bottom trawlers in Croatia is limited to 184 kW in major part of inner fishing sea (except in certain parts of the Northern Adriatic channels, where the limit is 110 kW), while in the outer fishing sea it is limited to 662 kW.

In addition to control measures based on restrictions on fishing capacity, they are being implemented various technical measures introduced by Reg. EU 1967/2006 amended by Reg. EU 1241/2019.

Technical measures, in general, aim to control various aspects of fishing operations, ranging from gear restrictions to bycatch limits and closed areas. They represent an important toolbox in the management policy of many fisheries around the world, including Europe. One of the main reasons for imposing technical measures, particularly those related to gear restrictions, has been to create conditions that minimize the capture of juveniles of commercially important species or incidental catches of non-target species (Suuronen & Sardà, 2007).

The Mediterranean Regulation, in addition, providing a series of technical measures, has introduced the Management Plans (Article 19) that the Member States of the Mediterranean are required to adopt for some fishing activities in territorial waters. The goal of the European Commission was to introduce an approach to fisheries management based on a decentralized decision-making process and the creation of multi-annual management plans at the national and community level capable of combining effort management with specific technical measures. Starting from 2011 and until 2019, four separate management plans entered into force in GSA 17 and 18, two for bottom trawling and two for others for fishing systems called "other systems" that exploit demersal species, mainly gillnets. From 2013 GFCM issued yearly recommendations (n. 37-42) specifically directed to small pelagic fisheries to implement a multiannual plan for the management and conservation of these stocks in the whole Adriatic basin.

The most important regulation measures in Croatia are temporal and spatial bottom trawl fishing restrictions (temporary or permanent prohibitions in certain areas). This is a complex system created as a consequence of a long-lasting evolution process in balancing exploitation needs with the necessity for the protection of demersal resources. The basis for the management of bottom trawl fishery in the Republic of Croatia is the national management plan for bottom trawling in territorial waters (hereinafter: MP). MP consists in a comprehensive overview of bottom trawl fishery in Croatia with detailed information on fleet capacity and activity. It also brings an overview of catch dynamics and compositions, complemented with scientific results from monitoring,onboard sampling, and specific surveys. MP also brings economic analysis based on the best available data at that time.

MP foresees the implementation of a complex spatial management framework of bottom trawling, particularly in the channel areas. This framework has been in force for over two decades (with some amendments over time) and proves to be effective in terms of resource management. This can be seen in the quantitative distribution of target species in terms of abundance and biomass, which shows that the status of targeted species is much better in the inner and territorial waters than in the area outside territorial waters. This framework includes spatial and temporal rules for the closure of specific areas but also limitations in terms of fleet capacity where only vessels with certain power are allowed to operate in the inner sea.

MP also foresees several actions to be taken to achieve a sustainable level of exploitation. One of the most important ones introduced by the MP is the authorization process, which implies issuing special permits in addition to the existing licenses. This process limited fleet capacity and thus prevented the increase of both fishing effort and capacity. This process in the end resulted in the reduction of the total number of vessels authorised to use bottom trawl from 599 in 2013 to 351 in 2021.

MP also provided the basis for the temporal and permanent cessation of fishing activities which has been in place in the past period.

All measures arising from the MP have been implemented based on the provision of the Marine Fisheries Act and through the Ordinance on commercial fishing with bottom trawl (OG 102/17, 74/18, and 20/19), Ordinance on temporal and spatial limitations for commercial fishing with bottom trawl (adopted on annual basis) and Ordinance on the issue an authorization for commercial fishing with bottom trawl with a validity period until 30 June 2022 (OG 107/20).

A third set of management measures in the Mediterranean Sea incorporate the establishment of permanent marine protected areas (MPAs). However, the extension of MPAs is still rather limited in the Mediterranean Sea, covering around 9.5% of the EU water within 200 nautical miles (NM) and being mostly located in the Western Mediterranean (European Environment Agency, 2021).

Details regarding the actual management scenario, together with the possible socio-economic effects on the demersal and pelagic fisheries deriving from these, were discussed in D3.3.1.

2. Possible interactions between fishery methods and linked management measures

Achieving fisheries sustainability requires simultaneously embracing multiple objectives, including conservation, food security, and livelihoods. Fisheries scientists attempting to realize these multiple objectives must consider a vast set of complex interactions between humans, institutions, and ecosystems. These methodological and analytical challenges are difficult to be solved using traditional fisheries science approaches. While traditional approaches often focus on policies that prioritize conservation and economic aspects, sustainability science expands the focus to include societal objectives of equity and well-being. Specifically, understanding the complex relationships within and among diverse ecological and social system components, that is socio–ecological interactions is critical to meeting the multiple objectives of sustainability.

In general, analyzings socio–ecological interactions for fisheries sustainability requires approaches that incorporate multiple, complementary methods that are disciplinarily and theoretically rooted across the social and natural sciences.

To focus on the topic of this Deliverable, it can be stated that between the different fishing methods, the interactions resulting from the current management measures in the study area are rather low. Since the fisheries analyzed in this project are categorized as pelagic and demersal, the relationship between these two classes is quite none, since they do not compete for space, resources, and revenues.

On the other hand, some interactions could be identified in the demersal category itself, namely between SSF and bottom otter trawlers in general. Currently, Italian small-scale trawlers (e.g. IV category fishing license "coastal fishery") operate between 3 and 6 nautical miles. OTB generally exploits offshore fishing grounds, except for large-scale TBB, which usually operates in shallow water fishing grounds (depth < 50 m).

2.1 Fishing effort

The main technical management measure identified is the regulation of the fishing effort through a progressive reduction in fleet capacity or fishing days; plus to the period of the fishing ban, additional days of arrest are foreseen, the number of which varies according to the GSA and the LOA.

North-East Atlantic and the Mediterranean Sea fisheries are governed by the European Common Fisheries Policy (CFP). Although both areas are managed under the same broad fishery management system, a large discrepancy in management performance occurs, with the recent considerable improvement of stock status witnessed in the North-East Atlantic and a rapidly deteriorating situation in the Mediterranean Sea (Cardinale et al., 2017). Here, there is no apparent relationship between nominal effort and fishing mortality for all species; fishing mortality (F) has remained stable during the last decade, for most species, even if nominal effort decreased. Also, the current F is larger or much larger than the reference point (FMSY) for all species. According to the recent GFCM stock assessments in the recent years, there is a clear decrease in F for the majority of demersal species, as well as an increase in the SSB. Despite catch advice being produced by STECF each year, the realized catches have usually been much larger than scientific advice.

It could be concluded that, in managing fishing effort, no interaction between fishery methods is identified.

2.1.1 Fishing ban

In Italian waters, temporal closures regarding bottom and midwater trawl fleets are mainly enforced for 30-45 days, mostly during the summer season, when the majority of the stocks recruits in coastal areas where juveniles tend to aggregate (Grati et al., 2018).

During this time frame SSF, which normally compete for space with bottom trawlers (Grati et al., 2022b), have bigger areas in which to safely deploy their gears. In fact, combining the increase in available space and the fact that they are almost the only ones selling fish, the most productive season for this fishery is summer.

In general, a positive effect on the resources deriving for the fishing bas has been recognized across the assessed stocks. When the fishery restarts after the ban, a lot of recruits can be seen in the catches.

2.2 Technical measures

2.2.1 Spatial restrictions

The advantages of the application of spatial restrictions, such as FRAs, have been demonstrated by the closure of the Pomo/Jabula pit. This area represents a successful example of efficient spatial planning and international cooperation, that has involved both the Italian and Croatian administrations, but also the relevant stakeholders, thus ensuring ownership of those involved and proper implementation of the measures.

Moreover, the scientific surveys carried out within the Pomo/Jabuka pits reported higher catches and bigger individuals, this is particularly true for hake and Norway lobster, which are the species for which this is of relevant importance. Also, the hake stock assessment presents a continuously increasing trend in spawning stock biomass (SSB) in the most recent years; this is also shown, together with an increase in recruitment, by the preliminary assessment of Norway lobster presented at the last GFCM (GFCM, 2022).

However, the effect of the Pomo Pit ban in the Italian area resulted in the effort being redirected toward the surrounding areas but also toward some more remote areas when vessels searched for other opportunities far from the closed areas.

Based on the literature, the exclusion of some fishing methods from an area (e.g. FRAs) generates always a redistribution of the fishing effort, and at the same time, based on the function of the banned area on the ecology of a species, it could increase the CPUE and landings of some animals. For example, the exclusion of trawlers from some nautical miles in coastal areas could generate spatial conflicts along with potential socio-economic issues for this fleet segment. Moreover, since the coastal area is the location of aggregation of juveniles of different species, the protection (excluding) fisheries in this area would decrease the discard of small animals under the MCRS.

2.2.2 Gear restrictions and Minimum Conservation Reference Size (MCRS)

In general, any improvement in selectivity will (in the long term) most strongly benefit stocks characterized by greater growth overfishing, which are typically large-bodied and late-maturing (e.g., hake stock), while small-bodied and fast-growing species have less to benefit in terms of yield. In some cases, increased selectivity for these species would lead to decreasing yield, but it would always result in larger SSB. In addition, a selectivity improvement that achieves higher protection of juveniles of any stock often produces a higher increase in long-term yield. However, any long-term increase in yield linked to a change in selectivity will imply, in general, a short-term loss in yield, but this short-term loss is generally similar to the short-term loss that would result from reducing current F to the F levels under the scientific advice under current selectivity. Those short-term losses will be more than compensated by long-term gains (STECF, 2021).

Even in this case, no interaction between fishing methods was identified concerning this management measure.

The minimum landing size for the Common sole is 20 cm, not corresponding with the length at first maturity estimated to be around 25 cm (Vallisneri et al., 2000); and 25.8 cm (Fabi et al., 2009). Based on the Length-at-age relation, exploitation could be predictable almost on all the age classes from 1 to 4+, but concerning the STECF (2017) data, it is dominated by ages 0 and 1-year specimens.

Demographic erosion affects not only the spawning capacity of the stock but also the average market price and revenues from fishing activities. For example, the increase in the MCRS for this species, shifting the target toward the adult portion of the sole population. To avoid the impoverishment of the stock, protecting juveniles that tend to aggregate inshore, it would also be useful to make changes in the mesh size of the SSF. A 72 mm mesh size would help to avoid the common sole target bycatch (under-sized), and then all the juveniles. From the literature, the estimated income at the medium-term should grow, due to the increase in the medium size of landings of common sole specimens.

3. Description of the MSP tool: DISPLACE

3.1 Model approach

The DISPLACE model framework (Bastardie et al. 2014) is developing a research- and advisory-based platform to transform fishermen's detailed knowledge and micro-decision-making behavior 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 fishers' decisions and management options. DISPLACE is an agent-based simulation model developed for fisheries, habitat conservation, maritime spatial planning, and management issues, especially from the perspective of the fisheries. Agent-based models aim to consider the socioeconomic and ecological processes at the individual scale (e.g., the fishing vessels) to capture the effects of human decisions at that level and then go through the individual processes up to the aggregated dynamics (e.g., the fisheries as a whole, or other marine ecosystem components). A particular strength of the agent-based approach is that it is an adequate level to model processes at the spatial (2 × 2 km) and the time scale (hourly time steps) closer to the spatialand time dynamics occurring in human decision-making and fish population dynamics. It is also closer to the appropriate scale for dealing with management issues such as marine spatial planning. The agent-based approach is also keen on integrating process-based mechanistic relationships that should give the advantage of being able to better predict novel conditions. Accordingly, DISPLACE should be able to incorporate the spatial and temporal details to obtain anecessary understanding of the integrated fisheries, behavioral and resource dynamics. DISPLACE can address fleet/skipper behavior facing the experienced catches and the fisheries management in force including Effort Regime (overall capacity reduction, limits in days at sea, temporal & spatial closure to fisheries) together with multi-annual management plans in a CFP context (i.e. FMSY). The aim is to capture individual vessel characteristics that are potentially majordrivers for predicting the effect of fishing on the harvested resources, such as the running costs offishing activities (i.e., the variable fishing cost depending on vessel-specific effort allocation in time and space), as well as important differential aspects among fishers related to their various economic drivers or other individual incentives. The overall pattern of effort allocation between fisheries, space, and time, and eventually the differential catchabilities, emerge from all of the individual fishers' decisions and varying fishing vessel catching power.

DISPLACE model framework in general is structured as resumed in Figure 2. Raw data are used to generate spatial input information on fishing effort displacement and species distribution at sea, as well as to fulfill tables collecting market prices, growth parameters, characteristics of the different vessels, etc.. Those inputs are transformed into structured text files through some parametrization routines developed in the R environment (R Core Team, 2021). The text files generated are so ready to be coupled with spatial information regarding the management scenario to be tested, the so-called simulation phase. As a result of the different simulations new text files will be generated, and they can be analyzed and discussed after another parametrization step in the R environment producing plots and tables.

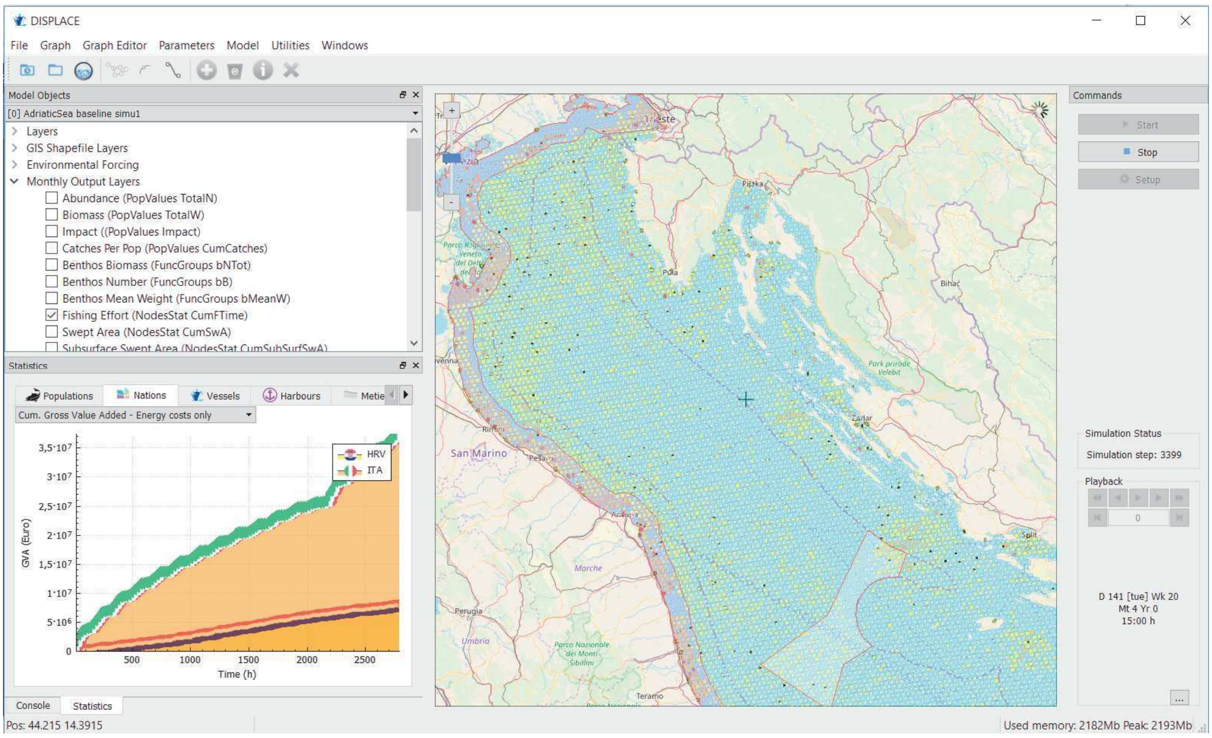

Figure 1 – Random snapshot of the DISPLACE User Interface for the Demersal Italian & Croatian demersal fisheries in the northern Adriatic (GSA17).

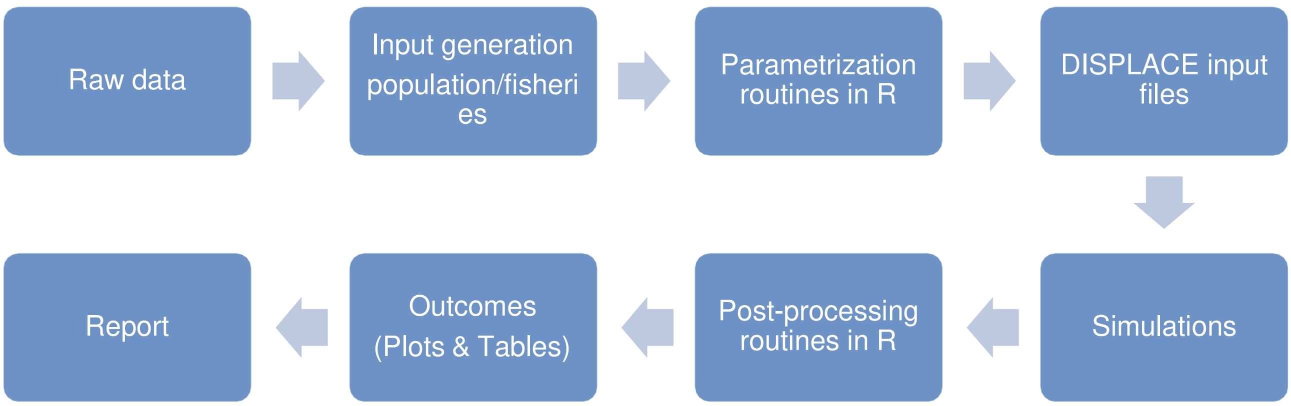

Figure 2 – Schematization of the DISPLACE framework.

3.2 Model configuration

For running those simulations it was used DISPLACE version 1.1.7.

The Case study was structured as follows:

- Area -> GSA17 + GSA18 (Adriatic Sea),
- Nations actively involved and modeled -> Italy and Croatia (other countries included but not modeled as single vessels),
- Fisheries modeled -> OTB (pomo/non-pomo), TBB, PS, PTM, SSF (gillnetters small/big),
- Species included -> HKE, SOL, MUT, TGS, MTS, ANE, PIL.

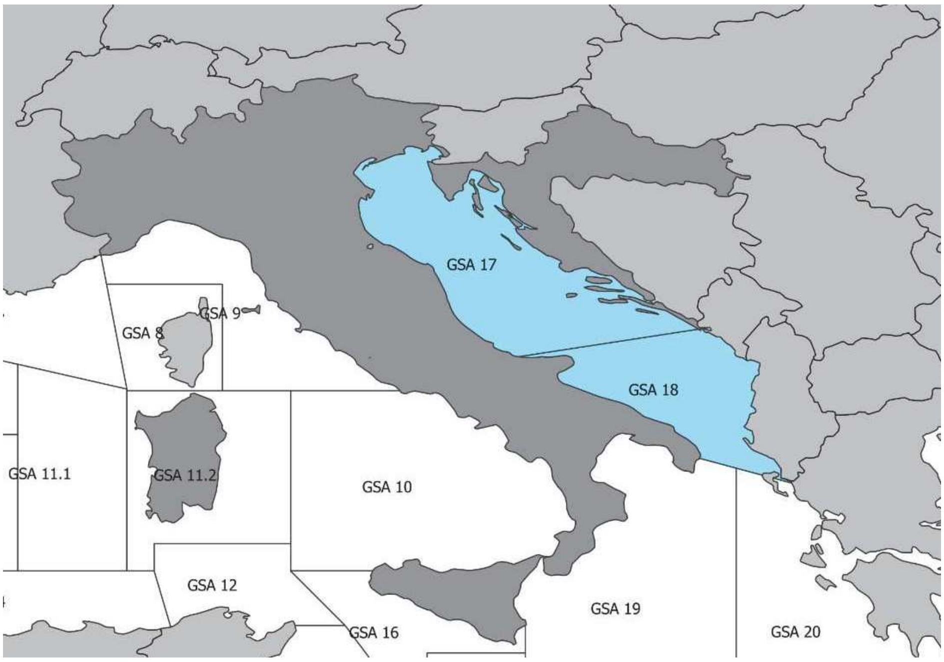

Figure 3 – Case study area, highlighted in blue the GSAs and dark gray the countries taken into account.

3.2.1 Fleet dynamic

The model was configured to capture the individual fishing fleet dynamics of demersal trawlers, set netters, and pelagic trawlers and purse seiners. The number of fishing vessels per harbor was obtained from official statistics for the Italian country, while it was retrieved from the EU fleet register for the Croatian one. In this case, the fishing vessels below 5m LOA were excluded from the list.

The spatial distribution of the fishing effort per activity was obtained through AIS data, apart from small-scale gillnetters for which those data are not available. To cover the information on the fishing grounds of this specific fleet it was directly used the map published by Grati et al., 2022.

Specific selectivity ogives for each fishery-stock combination using a combination of papers and official stock assessment results, while spatial catch rates were applied per type of activity and vessels using case-by-case the best information available (fishery dependent or independent, namely survey, data).

The Italian and Croatian vessels considered in this study usually do not change gear during the year, and it was the assumption applied. Each bottom trawling vessel (OTB and TBB) 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). Therefore, the generally observed trip pattern was reproduced in the model for the trawlers. In reality, the subdivision of time at sea per day might vary among harbors. Usually, gillnetters go fishing every day, but less frequently on the weekends, releasing their nets in the afternoon and pulling them in the morning of the following day. Thus, in the model, these vessels were considered to work 5 d/week, with an average daily fishing time of 12 h. On the other side, the small pelagic fishery (PTM and PS) had different configurations reflecting the real behavior of fishers. PS were assumed to work during the dark hours, namely from 10 p.m. to 4 a.m., while PTM only during the light hours, from 3 a.m. to 3 p.m..

Since the Case Study accounted for a total number of vessels equal to 5962, to speed up the simulation process, in the harbors having more than 6 vessels doing the same activity, they were grouped into 1 single “super-individuals”, resulting in a total of 1183 “agents” to be simulated. The specifications for each agent, which included the individual catch rates, hourly fuel consumption rate (deduced from the vessel engine power), fuel tank capacity, and fish storage capacity, were therefore multiplied by four to obtain values for each of the “super-individuals.”

3.2.2 Stock dynamics

The model was configured to simulate the spatial population dynamics of 7 commercially important different species: European hake (*Merluccius merluccius*), Common sole (*Solea solea*), Red mullet (*Mullus barbatus*), Spottail mantis shrimp (*Squilla mantis)*, Caramote prawn (*Penaeus kerathurus*), European Anchovy (*Engraulis encrasicolus*) and European sardine (*Sardina pilchardus*). The fish body size-population structure (using total length for fish) was discretized into 3-cm bins for all species (3 mm carapace length for the shrimp and the prawn); growth parameters were the same used in the last stock assessments officially accepted for these species. The population spatial distributions were obtained from data collected during different scientific surveys (averaged), using the correspondence between survey type and target species (Tab. 1).

Table 1 – Resume of the data used to inform the model on the species population at sea and reference years (Ref. y).

MTS	SOL	HKE	MUT	TGS	ANE	PIL
Biological parameters and stock abundance at age						
GFCM assessment Ref. y. 2021	GFCM-STECF assessment Ref. y. 2021	GFCM-STECF assessment Ref. y. 2021	STECF assessment Ref. y. 2020	Personal estimation, no abun/age	GFCM assessment Ref. y. 2021	GFCM assessment Ref. y. 2019
Survey data						
SoleMon 2015-2020	SoleMon 2015-2020	MEDITS 2015-2020	MEDITS 2015-2020	SoleMon 2015-2020	MEDIAS 2015-2020	MEDIAS 2015-2020

By applying geostatistics and modeling to the survey data, interpolated levels of stock abundance were obtained by the categories of fish sizes. For each single species, the spatial distribution was described according to three size groups based on commercial categories (small, medium, and large individuals) as reported in Table 2.

Table 2 – Resume of the size categories by species.

Species	Small	Medium	Large	Measure	Unit
SOL	0-20	21-25	>26	TL	cm
MTS	0-26	27-31	>32	CL	mm
TGS	0-24	25-39	>40	CL	mm
HKE	0-20	21-29	>30	TL	cm
MUT	0-14	15-19	>20	TL	cm

3.3 Scenario selection

During the different meetings organized with the stakeholders of the fishery sector in the context of ARGOS project, different suggestions on possible management measures to be tested using DISPLACE model were collected. All the suggestions were resumed, presented, and summed up with the academic proposals arisen by the scientific partners involved in the project (namely PP12 and PP13) and discussed within the AAC (Tab. 3).

However, due to time constraints and DISPLACE model configuration scheme, not all of these were considered worth exploring in the sumulation phase (details in Tab. 3).

- **Gradual return to fish starting at 3nm from the Italian coast after summer fishing ban**

As presented in the previous chapter, is actually in place in Italian waters the summer fishing ban to all bottom trawling activities. The Italian Ministry of Agricultural, Food, Forestry, and Tourism Policies (MIPAAFT) regulates the temporary closure of fishing activities for the bottom (OTB and TBB) trawlers in the Adriatic Sea (August-July). Since 2012 such Regulation includes temporary spatial restrictions: 1) vessels enabled to the coastal fishery (<6 nm from the coast) or having LOA <15 m cannot operate inside the 4 nm from the beginning of the temporary closure until 31st October; 2) vessels having LOA >15 m cannot operate inside the 6 nm from the beginning of the temporary closure until 31st October. In this case, fishers requested to simulate the effects of a gradual return to the 3nm, independently from the LOA. The progression of the management should be modeled as follows: 40 days fishing from 6nm -> 30 days fishing from 5nm -> 30 days fishing from 4nm -> normal from 3nm. This scenario was included between the DISPLACE model simulations.

- **170 fishing days for Purse Seine and Pelagic Midwater Trawl (PS & PTM)**
  Since at present Mediterranean fisheries are mainly managed through effort reduction, in the provision of a plausible next decrease enforced for pelagic fisheries, the relative stakeholders required to simulate the effects of a 10 days reduction. The actual number of allowed fishing days is 180, so they asked to simulate the effects of a decrease equal to 170. This scenario was excluded from the DISPLACE model simulations.

- **72h/5gg casually selected for trawlers (now fixed)**
  From what is actually in place, bottom trawlers are allowed to fish for 72 hours per week, to be compulsory spent in the first 5 days, namely excluding weekends. Fishers asked for a simulation taking into account the chance for these days to be randomly selected by each single fisher autonomously. This scenario was excluded from the DISPLACE model simulations.

- **Reduce Fishing Effort in Jabuka/Pomo Zone B**
  Jabuka/Pomo Zone B corresponds to the Italian fishable area of the FRA existing in GSA 17. Only certain vessels are allowed to fish there for 2 days per week. However, in the corresponding Croatian area (Zone C), those 2 fishing days are fixed on the weekend. One proposal that arose was to test the same management in both areas/countries. This scenario was excluded from the DISPLACE model simulations.

- **Spatial closure of Croatian inner sea (channels) to Purse Seine activity**

Croatian fishing sea consists of three parts: the inner fishing sea with an area of 12,461 km2, encompassing the inner sea from the coastland to the baseline, and the outer sea consisting of the territorial sea within 12nm off the baseline (area of 19,267 km2) and exclusive economic zone– IGP/EEZ (area of about 25,000 km2).

Since 2016 Croatia is implementing specific spatio-temporal regulations in the inner sea: in 2019 more than 50% of this area was closed for 7 months for the entire pelagic fleet above 12m; in 2020 it lasted 8 months, while in 2021 it lasted over 9 months. In the context of ARGOS project, it was asked to test the possible effects of a permanent closure (12 months) of the entire area of the inner sea to the small pelagic fishery. This scenario was selected to be included between the DISPLACE model simulations.

- **Discard ban effect (EU Landing obligation application)**

  The introduction of the obligation to land all catches in the recent reform of the Common Fisheries Policy (CFP) represents a fundamental shift in the management approach to EU fisheries switching the focus from the regulation of landings to catches. The landing obligation included under Article 15 of the new CFP basic regulation prohibits the discarding of species subject to catch limits (i.e. TAC and quota species) as well as those subject to minimum size limits in the Mediterranean. It contains several exemptions namely species not covered by catch limits; species where high survivability can be demonstrated; prohibited species, limited volumes of permissible discards which can be triggered under certain conditions, the so-called de minimis exemptions, as well as inter-species and interannual quota flexibility mechanisms.

  Until 2023 the Adriatic fisheries received, due to specific derogations applied to European Member States, no restrictions related to the effects of the introduction of this regulation.

  In the context of ARGOS project, it was asked to mimic the possible consequences of the implementation of this law, thus excluding the effects of the derogations. This scenario was excluded from the DISPLACE model simulations due to the difficult configuration in its application and the time constraint of the project.

- **Half NatMort of small pelagics due to the tuna removal**

  Atlantic Bluefin tuna (Thunnus thynnus) is the main species of tuna found in the Mediterranean Sea, and in the Adriatic. With the oldest specimens being more than 50 years old and weighing more than 300 kg, this fish is one of the greatest predators. In the Adriatic Sea it is known that one of its favourites prays are small pelagics. As a European Union Member country, Croatian fishery is under the CFP, and the legal framework governing Croatian marine fisheries includes special regulations on European BFT catches as well as on farming. The minimum size for ABFT caught in the Adriatic Sea for farming purposes was set at 8 kg or 75 cm fork length based on historical data on the size composition of Croatian ABFT catches. This tuna removal for farming purposes was considered as having a possible positive effect in decreasing the natural mortality of small pelagic species due to the exclusion of their predator activity on the stocks. It was asked to try to half the natural mortality vectors for Anchovy and Sardine in a DISPLACE scenario. However, this chance was excluded from the model simulations, but it will be taken into account for future works.

- **Sole sanctuary**
  Have been noted that the "Sole Sanctuary" described in Scarcella et al. (2014) corresponds to the area with >75% temporal persistency of the adult sole. This area included a narrow coastal portion (in front of Venice lagoon) and a wide portion extending from the Po River mouth to Ancona. It was asked to test the effects of the exclusion of all fishing activities from a part of this area to try to protect the spawning stock biomass of common sole. This scenario was excluded from the DISPLACE model simulations.

- **TAC for small pelagics**
  In the Adriatic fisheries, a significant component consists of small pelagics (i.e. species living in the water column, as contrasted to demersal species, living close to the bottom). The vast majority of these fisheries target anchovy and sardine, with small amounts of mackerel and horse mackerel mainly forming by-catches. Italy and Croatia account for almost all catches of small pelagics in the Adriatic Sea, while Slovenia, along with Albania and Montenegro, take a minor part of the catches. Anchovy and sardine stocks have been overfished and are far from sustainable fishing levels. Management at EU and national level complements international measures adopted by the General Fisheries Commission for the Mediterranean (GFCM), in an overall framework evaluated at that time as complex and ineffective. On 24 February 2017, the European Commission tabled a proposal for a multiannual plan covering certain pelagic fisheries (in particular anchovy and sardine) in the Adriatic Sea. This multiannual plan was the first to be proposed in the Mediterranean area. The idea of introducing a permanent system of fishing opportunities for small pelagic stocks in the Adriatic, through the setting of total allowable catches (TAC) and quotas, represented an important shift in the way most fisheries have been traditionally managed in this area. However, until now no official TAC has been set.
  Since the introduction of this measoure could happen in the next future, this scenario was included between the DISPLACE model simulations.

- **6nm closed to italian trawlers all year long**
  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 3nm 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 in the Adriatic Sea. Based on this evidence, the implementation of the spatial management measure currently in force (3nm) with an extension to 6nm would have the potential to substantially improve current fisheries exploitation patterns. This scenario was included between the DISPLACE model simulations.

Table 3 – Complete list of the management scenarios proposed by stakeholders and the main reasons related to their eventual exclusion from the DISPLACE test.

PROPOSED SCENARIO	INCLUSION IN THE CASE STUDY
Gradual return to fish at 3nm after Italian summer fishing ban	ACCEPTED
170fd PTM & PS (now 180fd)	REJECTED: the reduction was considered too low to have a detectable effect and justify the addiction of another scenario
72h/5gg casually selected for trawlers (now fixed)	REJECTED: In DISPLACE it is possible to distinguish between the days in a month or week in numerical terms, but it is not possible to differentiate weekdays (namely Monday from Tuesday, they are only numbers)
Reduce Feffort in Pomo Zone B	REJECTED: In DISPLACE it is possible to distinguish between the days in a month or week in numerical terms, but it is not possible to differentiate weekdays (namely Monday from Tuesday, they are only numbers)
Spatial closure of Croatian inner sea (channels) to PS	ACCEPTED
Discard ban effect	REJECTED: huge additional effort is needed to simulate a special tank on each vessel to be dedicated to discards, not feasible due to time constrains
Half NatMort of small pelagics due to the tuna removal to be put into cages	REJECTED: small pelagics dynamic difficult to be modeled, not feasible due to time constrains
Sole sanctuary	REJECTED: the same scenario was already tested in the context of other European Interreg Projects (e.g. DORY)
TAC for small pelagics	ACCEPTED
6nm closed to italian trawlers all year long	ACCEPTED

The final selection, spatially presented in Figure 4, accounted for 4 management scenarios plus the *status quo*. Considering the stochasticity property of DISPLACE MODEL, each scenario was simulated 20 times, and every single run was projected on a 10 years' timeline.

This bottom-up approach will allow, in case of positive results resulting from the projections, to be able to propose the implementation of the measure in question, already having the favorable opinion of the stakeholders.

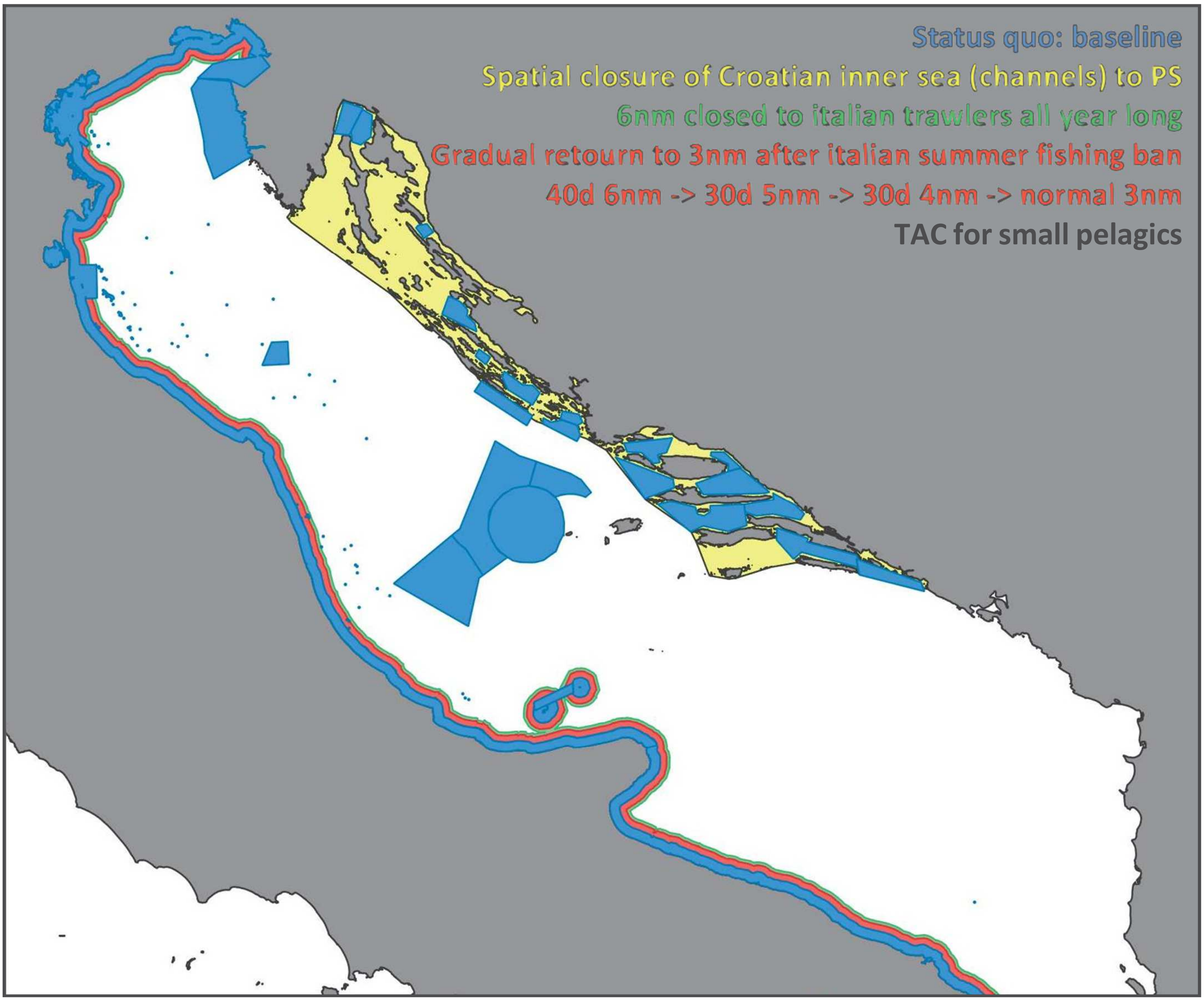

Figure 4 – Case study area with the spatial management scenarios in different colours. Since the scenario testing TAC on small pelagics missed any spatial regulation there is no representation for it in the figure.

3.4 Model results

All the results from DISPLACE model projection will be presented and discussed in the form of % ratio of performance indicators estimated in comparison to the baseline scenario.

3.4.1 Spatial closure of Croatian inner sea (channels) to PS

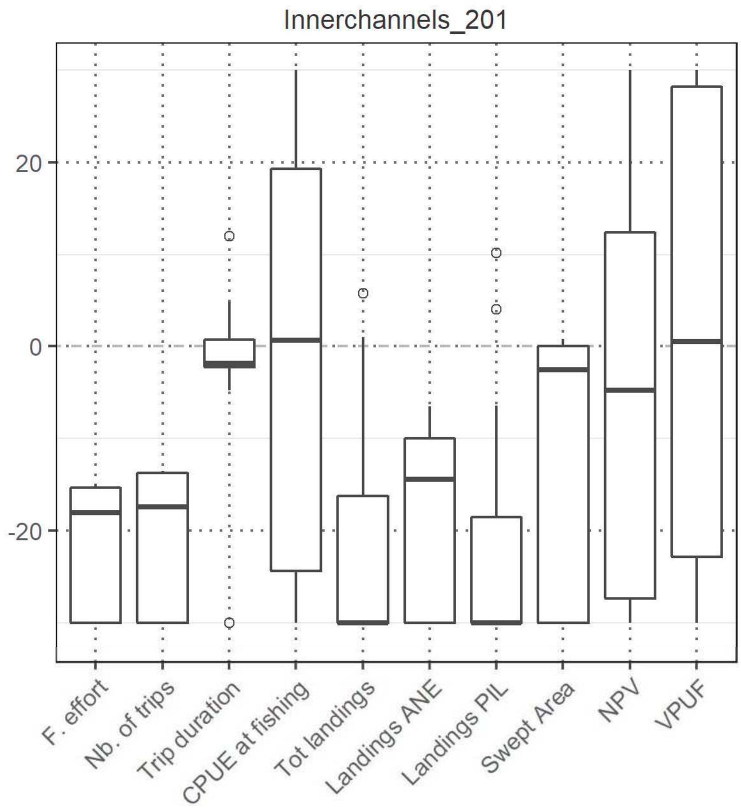

Figure 5 – Simulated effect on PS and PTM of this scenario expressed as % ratio over the baseline with respect to different indicators.

As can be seen from Figure 5, the introduction of complete spatial closure of PS to Croatian Inner channels could cause small effects. In fact, from an economic point of view, compared to the baseline, a very stable effect on the VPUF (Value Per Unit of Fuel), as well as CPUE, is projected. On the other hand, a decrease in fishing effort due to spatial interdictions could induce a decrease in the small pelagic species catches, more evident for PIL than for ANE.

Based on DISPLACE model results, the introduction of this management measure could influence not only the specific fishery (pelagic) for which it has been simulated but also the other fleets.

As can be seen from Figure 6-8, the results of the simulations for OTB, NET, and TBB are quite unstable. It is evident from the huge confidence intervals for each indicator in the plots.

For all the demersal fisheries it is evident a general decrease in all the species landings, even if quite never over 10% reduction. At the same time, it is worthy of note that for NETS and TBB it is estimated a possible positive economic effect in VPUF. It means that with the introduction of this measure specific to the pelagic fishery, the fishing efficiency of some demersal fleets could increase.

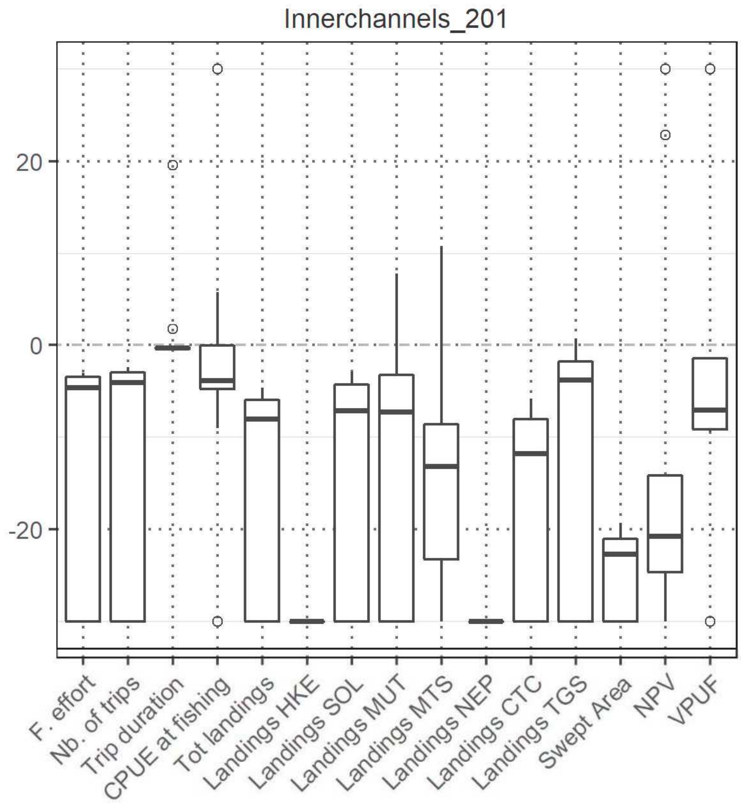

Figure 6 – Simulated effect on OTB of this scenario expressed as % ratio over the baseline with respect to different indicators.

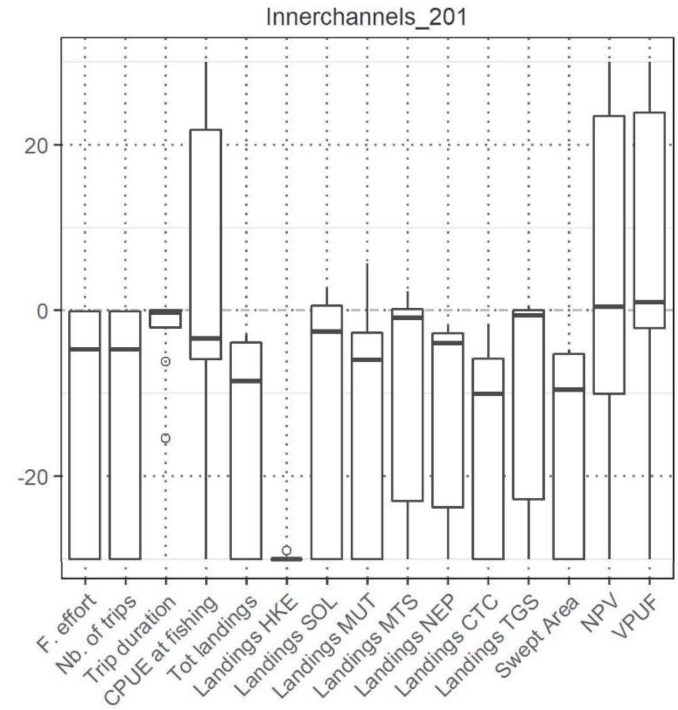

Figure 7 − Simulated effect on NETS of this scenario expressed as % ratio over the baseline with respect to different indicators.

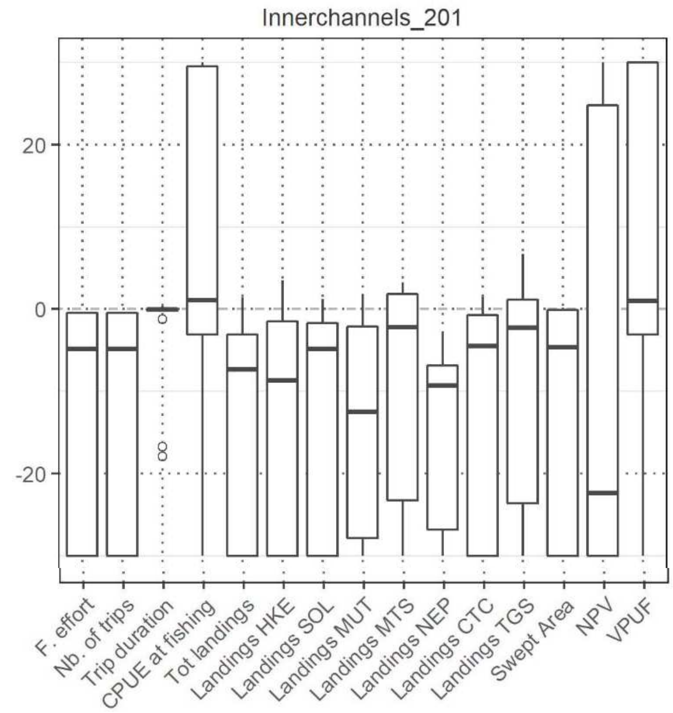

Figure 8 − Simulated effect on TBB of this scenario expressed as % ratio over the baseline with respect to different indicators.

3.4.2 6nm closed to Italian trawlers all year long

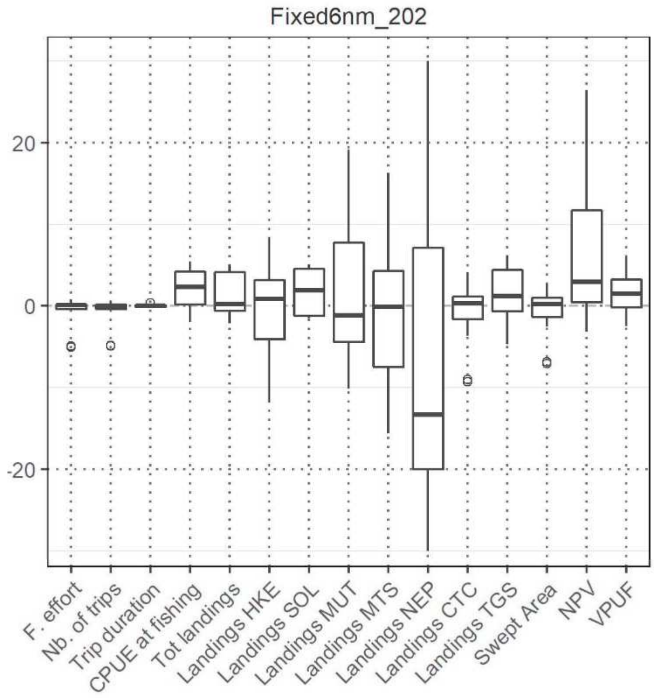

Figure 9 – Simulated effect on OTB of this scenario expressed as % ratio over the baseline with respect to different indicators.

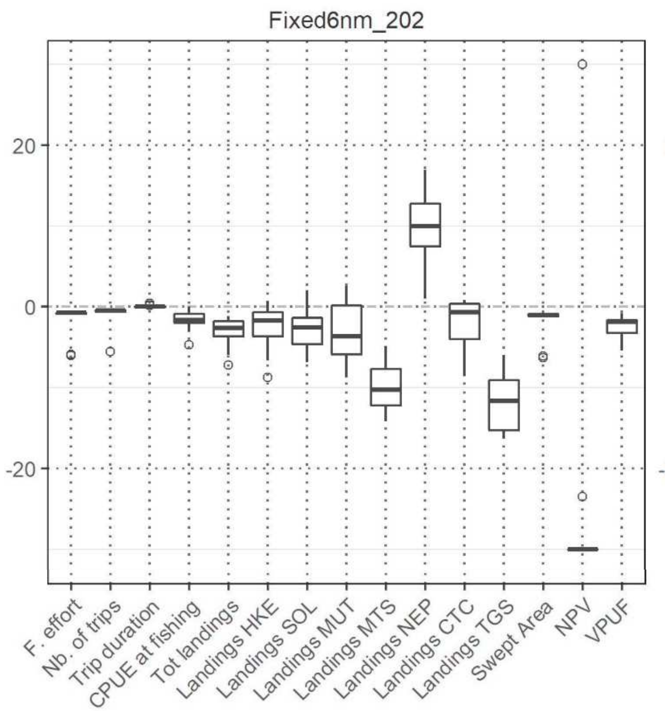

Figure 10 – Simulated effect on TBB of this scenario expressed as % ratio over the baseline with respect to different indicators.

Figures 9 and 10 represent the result for the specific fisheries targeted by this management measure, namely OTB and TBB (bottom trawlers). The effect of this measure, compared to the previous scenario, seems more reliable due to the reduced confidence intervals (all 20 simulations show very similar results). However, the measure seems to have a different possible effect on OTB and TBB. While for OTB it is estimated a positive effect on all the indicators, apart from NEP landings, for TBB it is the opposite. This measure could more negatively affect rapido trawl fishery even if the % ratio of variation compared to baseline is very low.

It should be mentioned that the proposed management scenario may generate conflicts between small-scale trawlers and large-scale trawlers. Currently, Italian small-scale trawlers (e.g. IV category fishing license "coastal fishery") operate between 3 and 6 nautical miles. Large-scale OTB generally exploits offshore fishing grounds, except for large-scale TBB, which usually operates in shallow water fishing grounds (depth < 50 m). The exclusion of small-scale trawlers from the 6 nautical miles would generate spatial conflicts along with potential socio-economic issues for this fleet segment.

Regarding the results for NETS fishery reported in Figure 11, the introduction of the closure of the 6nm from the Italian coast to all the bottom trawling activity seems to have possible positive effects. Apart from MUT and CTC, from the DISPLACE results it seems that this management measure could increase revenues for NETS fishery.

From Figure 12 it is evident that this demersal measure could induce negative effects on the pelagic fishery.

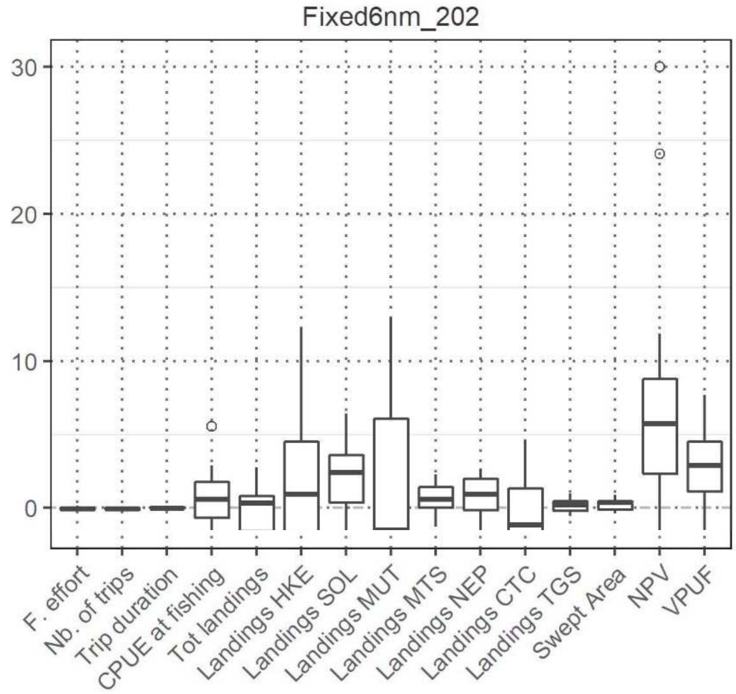

Figure 11 − Simulated effect on NETS of this scenario expressed as % ratio over the baseline with respect to different indicators.

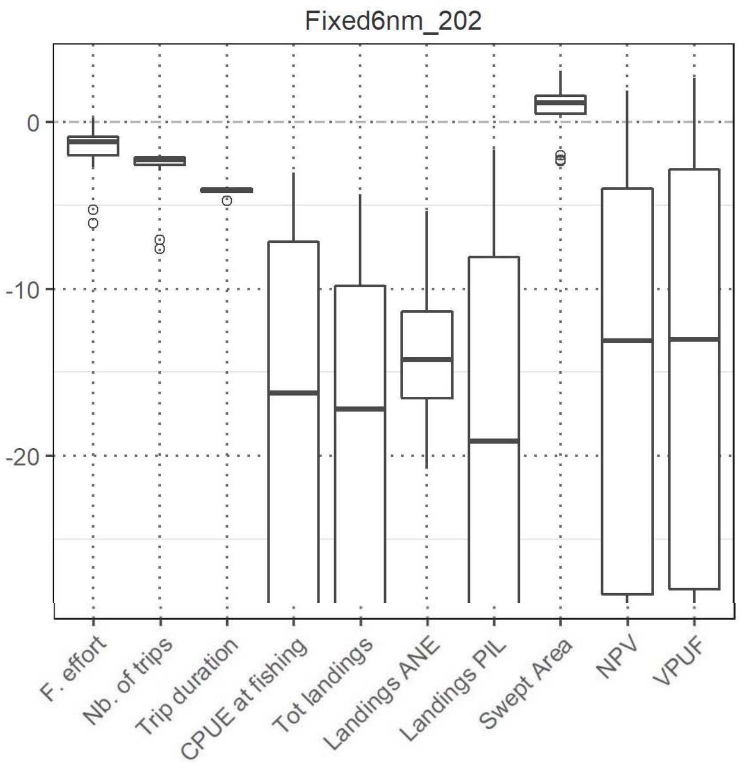

Figure 12 − Simulated effect on PS and PTM of this scenario expressed as % ratio over the baseline with respect to different indicators.

3.4.3 Gradual return to fish at 3nm after Italian summer fishing ban

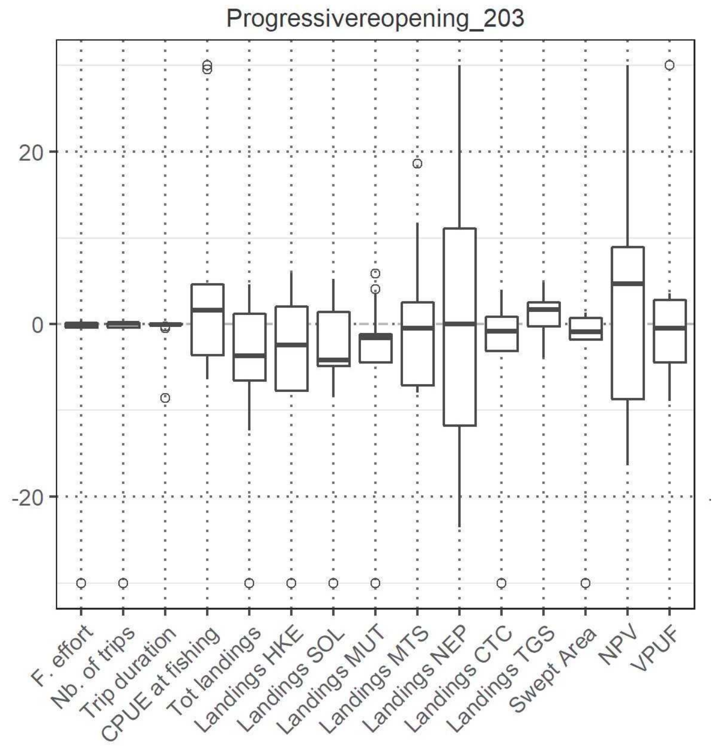

Figure 13 – Simulated effect on OTB of this scenario expressed as % ratio over the baseline in respect to different indicators.

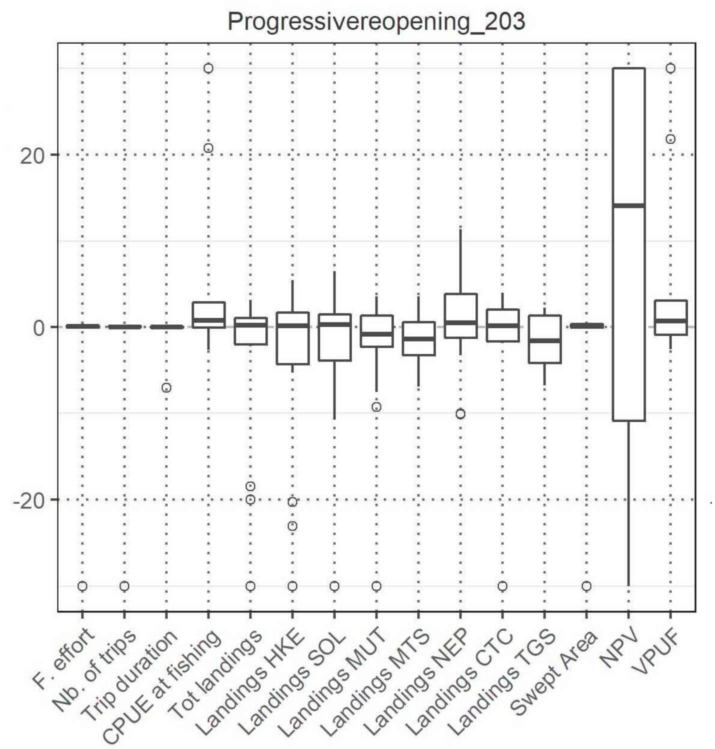

Figure 14 – Simulated effect on TBB of this scenario expressed as % ratio over the baseline in respect to different indicators.

Figures 13 and 14 represent the result for the specific fisheries targeted by this management measure, namely OTB and TBB (bottom trawlers). Also, the results of this scenario show very low variability between runs.

From DISPLACE results of this scenario, OTB appears positively affected on the indicators regarding CPUE and TGS landing, on the other side, total landing seems to decrease, mainly driven by HKE and SOL species.

For TBB the simulations are quite in line with respect to the baseline; for this fishery is also estimated a slight increase in VPUF.

In respect to the other fishery not specifically targeted from the possible introduction of the gradual return to fish at 3nm after the Italian summer fishing ban, from Figure 15 it is evident that, apart from some possible decrease estimated for HKE landings, NETS fishery seems not affected by this measure.

Even the small pelagic fishery seems not to be affected in this scenario, however, in this case, the simulations are more unstable. Even if it estimated a little decrease in total landings, mainly driven by PIL catches, the VPUF for this fishery seems to increase.

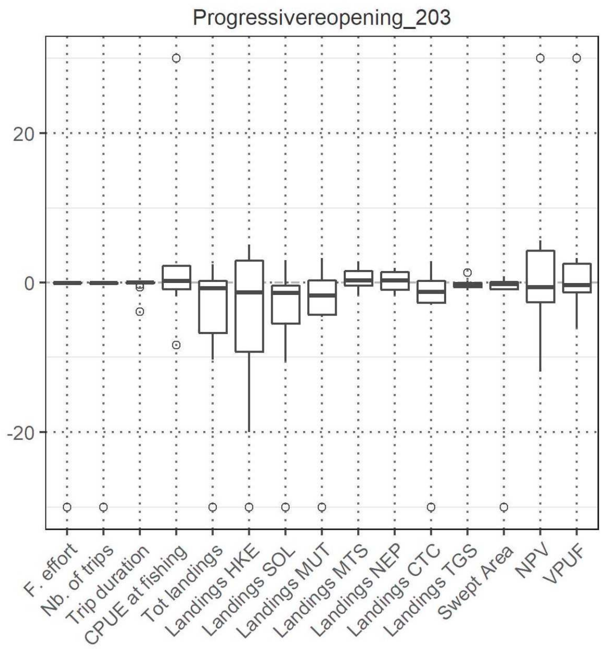

Figure 15 – Simulated effect on NETS of this scenario expressed as % ratio over the baseline in respect to different indicators.

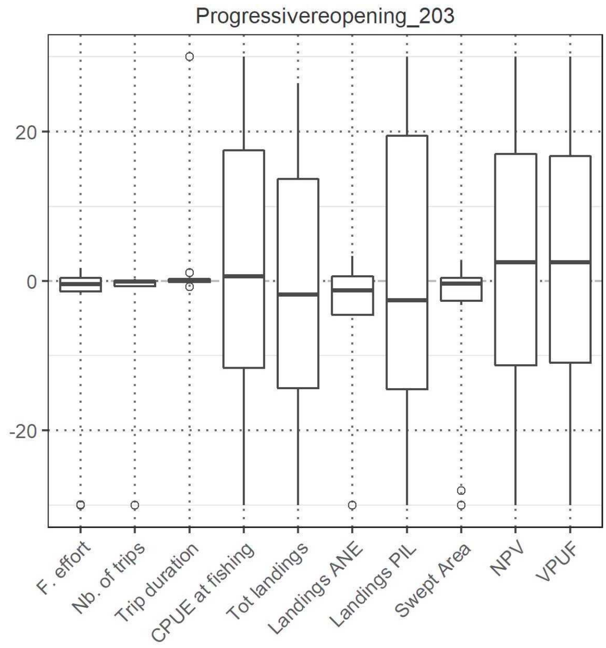

Figure 16 – Simulated effect on PS and PTM of this scenario expressed as % ratio over the baseline in respect to different indicators.

3.4.4 TAC on small pelagics

It has to be specified that DISPLACE is not the best instrument to test the effect of a management measure like the imposition of TACs. In addition, due to time constrain in the project development, this was the more difficult scenario to be modeled. On those bases, the results will be presented even if they are considered not totally reliable.

From Figure 17-20 it is evident that the management measure tested seems to negatively affect the pelagic fishery, while positive effects could be verified on all the other fleets.

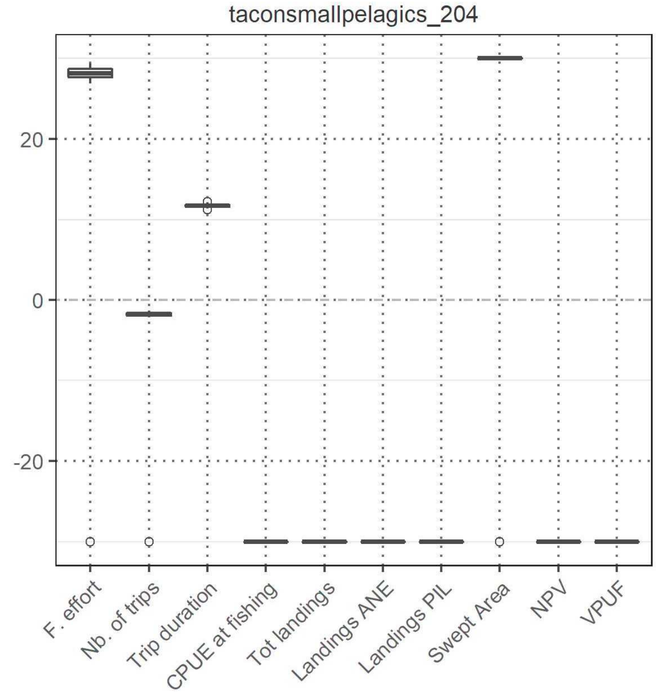

Figure 17 – Simulated effect on PS and PTM of this scenario expressed as % ratio over the baseline in respect to different indicators.

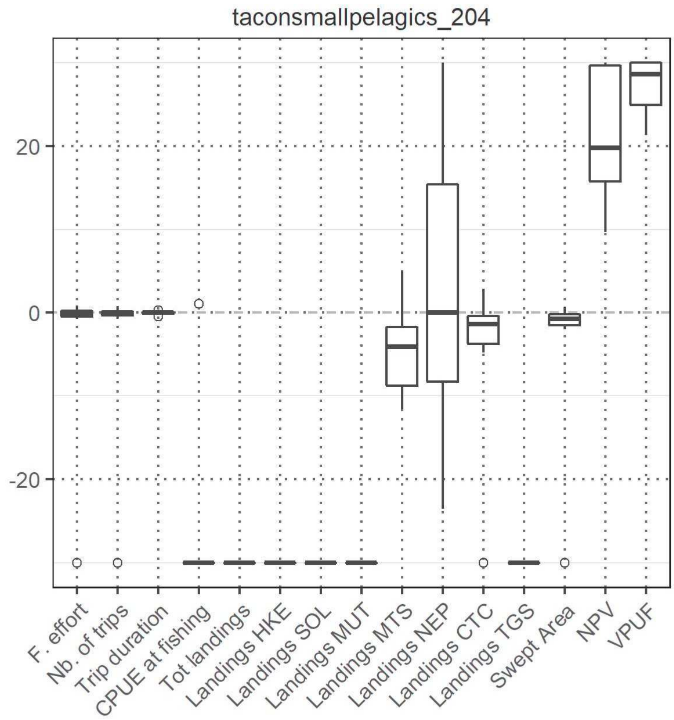

Figure 18 – Simulated effect on OTB of this scenario expressed as % ratio over the baseline in respect to different indicators.

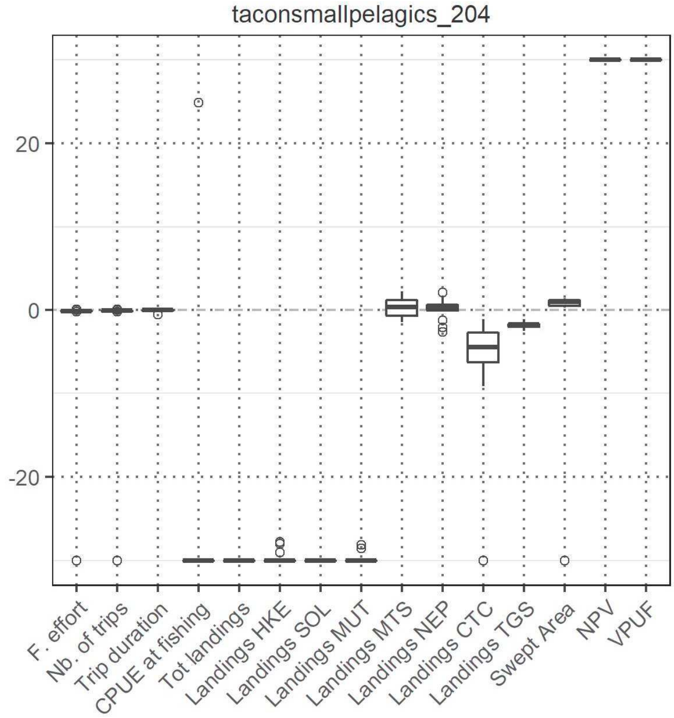

Figure 19 – Simulated effect on NETS of this scenario expressed as % ratio over the baseline in respect to different indicators.

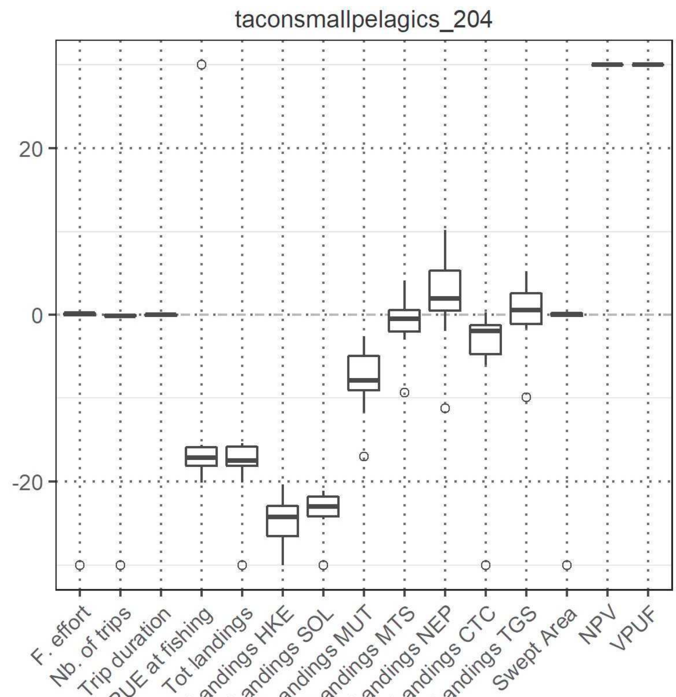

Figure 20 – Simulated effect on TBB of this scenario expressed as % ratio over the baseline in respect to different indicators.

4. CONCLUSION

Mediterranean Sea is generally managed through fishing effort reduction, however, this type of management seems not to directly improve the status of fishery resources (Cardinale et al., 2017). Other possible technical measures that could complement the fishing time reduction are the implementation of permanent and seasonal closures, selectivity improvements, and local co-management plans (Sánchez Lizaso et al., 2020).

In the context of ARGOS project, 4 different management scenarios were tested and showed difficult direct and indirect effects on fisheries. All the scenarios focused on the spatial closure of some specific area (Croatian inner channels and Italian coastal areas) seem to have positive effects both at the biological and economic level, even if some minor negative effect is present.

In many cases, a decrease in F combined with increased selectivity is needed to see large changes in SSB. However, an increase in SSB has a multitude of positive effects, both for the fisheries through an increase in CPUE and average individual size of the fish caught, for the stock as it increases its resilience to climate change and for the ecosystem as larger biomass and size diversity in general increase ecosystem functionality, resilience, and services.

Although overall exploitation patterns may be improved, gear modifications generally make net construction more expensive, and modified gears are often more difficult to operate and maintain. In mixed-fishery situations, technical measures are often compromises that tend to increase short-term costs for the industry, through short-term losses, re-designing of vessels and/or equipment costs. Although this may cause reluctance among fishers to commit to such regulations, the short-term economic losses associated with selective fishing gears are a more important concern from the fishers' point of view (Suuronen & Sardà, 2007), and it could correspond to stakeholders being not prone to these changes.

Another concern related to technical measures is that gear-related conservation measures are based traditionally on the assumption that fish escaping from fishing gears survive and live on to support the exploited population. For many commercially important fish species, there are currently no reliable estimates of post-capture survival, but the information collected indicates that escape-induced mortality may not always be negligible.

However, any improvement in the stock situation depends ultimately on enforcement, and compliance with existing rules has to improve dramatically.

In conclusion, simultaneously increasing the selectivity and decreasing F would demand smaller changes compared to only manipulating only one parameter. This may increase the incentive (or rather decrease the disincentive) for change.

5. REFERENCES

Caddy, J. F. (1999). Fisheries management in the twenty-first century: will new paradigms apply. *Fish Biology and Fisheries*, *9*, 1–43.

Cardinale, M., Osio, G. C., & Scarcella, G. (2017). Mediterranean Sea: A Failure of the European Fisheries Management System. *Frontiers in Marine Science*, *4*(March), 72. https://doi.org/10.3389/fmars.2017.00072

Colloca, F., Garofalo, G., Bitetto, I., Facchini, M. T., Grati, F., Martiradonna, A., Mastrantonio, G., Nikolioudakis, N., Ordinas, F., Scarcella, G., Tserpes, G., Tugores, M. P., Valavanis, V., Carlucci, R., Fiorentino, F., Follesa, M. C., Iglesias, M., Knittweis, L., Lefkaditou, E., … Spedicato, M. T. (2015). The seascape of demersal fish nursery areas in the North Mediterranean Sea, a first step towards the implementation of spatial planning for trawl fisheries. *PLoS ONE*, *10*(3). https://doi.org/10.1371/journal.pone.0119590

Colloca, F., Scarcella, G., & Libralato, S. (2017). Recent Trends and Impacts of Fisheries Exploitation on Mediterranean Stocks and Ecosystems. *Frontiers in Marine Science*, *4*(AUG). https://doi.org/10.3389/fmars.2017.00244

European Environment Agency. (2021). *Europe's seas and selected characteristics of EU marine protected area networks*. https://www.eea.europa.eu/data-and-maps/figures/regional-seas-surrounding-europe-and-2

Grati, F., ALADZUZ, A., AZZURRO, E., BOLOGNINI, L., CARBONARA, P., ÇOBANI, M., DOMENICHETTI, F., DRAGICEVIC, B., DULCIC, J., ĐUROVIC, M., IKICA, Z., JOKSIMOVIC, A., KOLITARI, J., MARCETA, B., MATIC-SKOKO, S., VRDOLJAK, D., LEMBO, G., SANTOJANNI, A., SPEDICATO, M. T., … MILONE, N. (2018). Seasonal dynamics of small-scale fisheries in the Adriatic Sea. *Mediterranean Marine Science*, *19*(1), 21. https://doi.org/10.12681/mms.2153

Grati, F., Azzurro, E., Scanu, M., Tassetti, A. N., Bolognini, L., Guicciardi, S., Vitale, S., Scannella, D., Carbonara, P., Dragičević, B., Ikica, Z., Palluqi, A., Marčeta, B., Ghmati, H., Turki, A., Cherif, M., Bdioui, M., Jarboui, O., Benhadjhamida, N., … Arneri, E. (2022a). Mapping small-scale fisheries through a coordinated participatory strategy. *Fish and Fisheries*, *23*(4), 773–785. https://doi.org/10.1111/FAF.12644

Grati, F., Azzurro, E., Scanu, M., Tassetti, A. N., Bolognini, L., Guicciardi, S., Vitale, S., Scannella, D., Carbonara, P., Dragičević, B., Ikica, Z., Palluqi, A., Marčeta, B., Ghmati, H., Turki, A., Cherif, M., Bdioui, M., Jarboui, O., Benhadjhamida, N., … Arneri, E. (2022b). Mapping small-scale fisheries through a coordinated participatory strategy. *Fish and Fisheries*, *23*(4), 773–785. https://doi.org/10.1111/faf.12644

R Core Team. (2021). *R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.* https://www.r-project.org/.

Sánchez Lizaso, J. L., Sola, I., Guijarro-García, E., Bellido, J. M., & Franquesa, R. (2020). A new management framework for western Mediterranean demersal fisheries. *Marine Policy*, *112*.

https://doi.org/10.1016/j.marpol.2019.103772

Scarcella, G., Grati, F., Raicevich, S., Russo, T., Gramolini, R., Scott, R. D., Polidori, P., Domenichetti, F., Bolognini, L., Giovanardi, O., Celić, I., Sabatini, L., Vrgoč, N., Isajlović, I., Marčeta, B., & Fabi, G. (2014). Common sole in the northern and central Adriatic Sea: Spatial management scenarios to rebuild the stock. *Journal of Sea Research*, *89*, 12–22. https://doi.org/10.1016/j.seares.2014.02.002

STECF, S. T. and E. C. for F. (2021). *Review of technical measures Regulation (STECF-21-07)*. https://doi.org/10.2760/790781

Suuronen, P., & Sardà, F. (2007). The role of technical measures in European fisheries management and how to make them work better. *ICES Journal of Marine Science*, *64*(4), 751–756. https://doi.org/10.1093/icesjms/fsm049