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"Fisheries in the AdriatIc Region - a Shared Ecosystem Approach"

D5.3.1 Report on the results from the application of scenarios for fisheries management in the Adriatic Region

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Report on the results from the application of scenarios for fisheries management in the Adriatic Region

FAIRSEA – Fisheries in the Adriatic Region – a shared Ecosystem Approach

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List of Acronyms used

AIS	Automatic Identification System
ALB	Albania
BFM	Biogeochemical Flux Model
BIH	Bosnia and Hercegovina
CL	Carapace Length
CPCs	Cooperating non-Contracting Parties
DRB	Dredge
EAF	Ecosystem Approach to Fisheries
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAIRSEA	Fisheries in the Adrlatic Region – a Shared Ecosystem Approach
FRA	Fishery Restricted Area
GFCM	General Fisheries Commission for the Mediterranean
GNX	Set nets
GSA	Geographical Sub Areas
GT	Gross Tonnage
GRT	Gross Registered Tonnage
HRV	Croatia
IT/ITA	Italy
LL/LLX	Longline
LP	Leader Partner
LPUE	Landings Per Unit of Effort
MAP	Multi Annual Plan
MEY	Maximum Economic Yield
MSY	Maximum Sustainable Yield
MCRS	Minimum Conservation Reference Size

MFS	Mediterranean Forecasting System
MIX	Mixed gears/fishery such as seine, traps, small-scale fishery
ML	Mantle Length
MNT	Montenegro
MS	Member States
OGS	Istituto Nazionale di Oceanografia e di Geofisica Sperimentale
OGSTM	OGS - Transport Model
OTB	Bottom Otter Trawl
OTT	Otter Twin Trawls
PP	Project Partner
PS	Purse Seine
PTB	Bottom Pair Trawls
PTM	Mid-water Pair Trawl
SAC	Scientific Advisory Committee
SDM	Species Distribution Model
SRC-AS	Subregional Committee-Adriatic Sea
TAC	Total Allowable Catches
TL	Total Length
TBB	Beam Trawl
VL	Vessel Length
VMS	Vessel Monitoring System
WP	Work packages

About FAIRSEA Project

The FAIRSEA is a European Territory Cooperation project financed under the priority 1 “Blue innovation”, Specific Objective 1.1 “Enhance the framework conditions for innovation in the relevant sectors of the blue economy within the cooperation area” of the INTERREG V-A Italy –Croatia Programme 2014-2020. The project focuses on the fisheries sector, key driver for the blue growth of the Adriatic communities, towards a sustainable co-management of resources and marine ecosystem protection. The transboundary nature of marine resources requires a cross-border cooperation and a shared “Vision” to properly tackle and address the different socio-economic and environmental challenges related to fisheries activities management. In this context, FAIRSEA Project aims at enhancing transnational capacity and cooperation in order to promote the sharing of knowledge and good practices between regional and transnational key actors in the sector of sustainable fisheries management in the Adriatic Sea as well as to implement innovative approaches adopting an ecosystem approach to fisheries (EAF). Coordinated by the OGS of Trieste (IT), the project involves a consortium of 12 strategic and operational partners from Italy and Croatia that will make to best use of their complementary expertise to address and support the application of the EAF ensuring a strong and interactive engagement of institutional, technical and socio-economic stakeholder in project activities.

The main result of the FAIRSEA Project will be the development of an integrated platform for a quantitative ecosystem approach to fisheries that goes across territorial boundaries and across several disciplines. The platform will integrate biological/ecological processes (i.e. considering water mass circulation, physical-chemical properties, plankton productivity and dynamics of resources including their interactions) and fisheries bio-economic dynamics (including fisheries displacement). This high technological and innovative platform will be used as a planning tool to implement demonstrative testing of applicable fisheries policies both at local (subareas) and Adriatic scales. It will provide a scientific basis for formulating and evaluating the shared management advice in the local and international participatory processes, involving management authorities, experts and stakeholders. The Project will also provide an answer to the need of reference points, best practices and guidelines for the optimisation between ecological and socio-economical sustainability of fisheries in the Adriatic Sea.

Executive summary

The Deliverable 5.3.1 is focused to summarize in a single text methodologies and results partially detailed in other Deliverables of FAIRSEA project, integrating information deriving from multiple sources and providing indication about possible management scenarios of fisheries at the Adriatic basin level in an EBM approach, taking into consideration the ecological and environmental needs of the fishing system as well as the economic and social ones.

To this purpose different analysis tools and different skills were applied and integrated each other to provide indication about the possible implications and evolutions of the fishing system. This was carried out taking into consideration both the current and future recommendations of the GFCM and the suggestions received from the stakeholders during dedicated meetings.

In particular, drivers implemented in different tools used to provide future management scenarios of fishery in the Adriatic Sea were climate changes in terms of changes in environmental and oceanographic variables and changes in fishing effort, including spatial and temporal ban of several fishing grounds and reduction of the fishing effort.

Concerning climate change, two future projections of the hydrodynamic and biogeochemical conditions of the Adriatic-Ionian system have been produced considering the emission scenarios RCP4.5 and RCP8.5 over the entire Mediterranean Sea. The scenario simulations covered the period 2005-2100 (subdivided in PRESENT 2005-2020; NEAR-FUTURE 2021-2040; MID-FUTURE 2040-2059 and FAR-FUTURE 2080-2099) and are based on the offline coupling between the physical model MFS16 and the transport-biogeochemical reactor OGSTM-BFM. The results of the scenario analysis show that the Adriatic and Ionian Seas will be affected by significant long-term trends for several key physical and biogeochemical variables.

For the definition of possible future scenarios of the Adriatic fishery system, in the FAIRSEA project were applied different modelling approaches:

1. the spatial distribution modelling approach, allowing the possibility to provide information about spatial distribution of target species over time including changes in biogeochemical and oceanographic variables;
2. the Spatial MAnagement of demersal Resources for Trawl fisheries bio-economic model (SMART), devised to estimate the potential effect of whatever management actions on the effort (including reduction of fishing capacity, effort, or spatial closures) instead of directly setting a desired value of F for the target stocks and evaluate the related effects of this new exploitation pattern;

3. the bio-economic model (BEMTOOL) to evaluate effects of changes in fishery-driven impacts (e.g. fishing effort, fleet selectivity) and management or fishing strategies (e.g. closed season/areas, changes in fishing opportunity) on the stock and fisheries dynamics in terms of Stock Spawning Biomass, landings, discards and economic performance;
4. The Ecopath with Ecosim and Ecospace approach (ECOSPACE in the following) that consider all the relationships among functional groups characterizing the food web of the Adriatic Sea and among those and fishery.

1 INTRODUCTION

The Activity 5.3 is one of task included in WP5 which has been focused to the full development of a participatory process for the definition of management scenarios and pilot actions, shaped accounting for the multiple processes embedded in the integrated platform developed in WP4, and for the delineation of best practices and guidelines emerging from obtained results. In particular the Activity 5.3 regarded the application of the different tools to explore management scenarios of fisheries at the Adriatic basin level for selected stocks in an EBM approach, taking into account the complexity of species as well as ecological effects and gear interactions in the spatial and temporal dimension. Moreover, the application of scenarios for fisheries management took into consideration, as much as possible, the current and forthcoming measures in the area according to the International Multiannual Plan in force in the Adriatic Sea.

The legislative framework in place until 2018 is available in the STECF report of the EWG 19-02: "MAP for the fisheries exploiting demersal stocks in the Adriatic Sea1 (Annex V)". The provided information shows the areas and the temporal closures of the fishing activities applied at national level. The first Fishery Restricted Area (FRA) agreed between Italy and Croatia has been the Jabuka/Pomo Pit, as the result of a proactive collaboration between Croatian and Italian scientist, fishers and managers. The FRA is established by the Recommendation GFCM/41/2017/3 and the monitoring activities carried out in the area shown the positive effects of the closure.

Furthermore, the available information related to the management measures in place and forthcoming includes the Recommendation GFCM/43/2019/5 "On a multiannual management plan for sustainable demersal fisheries in the Adriatic Sea (geographical subareas 17 and 18)" and some relevant outcomes of the 5th meeting of the Subregional Committee for the Adriatic Sea (SRC-AS) which was held from 20 to 23 April 2021. Although the management advice of the SRC-AS has to be still validated by the Scientific Advisory Committee and adopted by the Commission (GFCM), the suggestions coming by the scientific advice have been taken into account as much as possible in the scenarios in order to provide the results related to the most likely management measures.

Below, there are listed information on the common rules for Italy and Croatia in place (2020-2021) and expected (in 2022) in the framework of GFCM:

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1 Scientific, Technical and Economic Committee for Fisheries (STECF) – Multiannual Plan for the fisheries exploiting demersal stocks in the Adriatic Sea (STECF-19-02). Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-04009-5, doi:10.2760/026674, JRC116731

- Fleet segments: Otter-trawling (OTB), Beam-trawling (TBB), Bottom Pair Trawling (PTB), and Otter Twin Trawling (OTT). The effort groups are defined for the combination of gear type and vessel length class ("fleet segment") accounting for at least 5% of the landings in 2017.
- "Actively fishing" is defined as any trawler targeting the key species: European hake (*Merluccius merluccius*), Norway lobster (*Nephrops norvegicus*), common sole (*Solea solea*), deep-water rose shrimp (*Parapenaeus longirostris*) and red mullet (*Mullus barbatus*).
- No measure provides for Total Allowable Catches (TAC) by now.
- Transitional Fishing Effort Regime in 2020 and 2021: The overall fishing effort (number of fishing days) deployed by fleets actively fishing for key demersal stocks using bottom otter trawls (OTB), beam trawls (TBB), bottom pair trawls (PTB) and otter twin trawls (OTT) in GSAs 17 and 18, reduced by at least 12% for OTB and 16% for TBB with respect to the annual effort exerted in 2015 or to the 3-year average within the2015–2018 period. Proportion between CPCs: [CPCa reduction = Overall reduction* ($CPCa^2$/ ($CPCa^2$+$CPCb^2$+ $CPCc^2$+$CPCd^2$+$CPCe^2$))].
  The transitional fishing effort regime is not applied to national fleets operating with OTB and fishing for less than 1000 days during the reference period (not exceed the effort limit of 3000 fishing days per year). Then, in view of 2022, the SRC-AS considered that a linear reduction over time, based on yearly advice of stock status, could be a solution to explore.
- Closure of the coastal zone, irrespective of depth, out to six nautical miles, or four nautical miles for vessels not allowed to fish beyond six nautical miles, to towed gear targeting demersal stocks, for a continuous period of at least 8 weeks. Or a closure can be set of at least 30 continuous days and covering at least 20% of territorial sea for fishing activities with OTB, PTB, OTT and TBB irrespective of their overall length in the areas and periods recognized as important for the protection of juveniles of demersal key stocks.
- The overall fleet capacity of the fleets operating with OTB, TBB, PTB and OTT and actively fishing for key demersal stocks, in terms of gross tonnage (GT) and/or gross registered tonnage (GRT), engine power (kW) and number of vessels, does not exceed the fleet capacity for demersal fisheries in 2015 or its average over 2015–2017. This measure is not applied to national fleets operating with OTB and fishing for less than 1000 days during the reference period. The fishing capacity of such active fleets operating with OTB shall not increase by more than 50% with respect to the reference period.

- The Minimum Conservation Reference Size (MCRS) of the key species: European hake, *M. merluccius*, 20 cm TL; deep-water rose shrimp, *P. longirostris*, at 20 mm CL; for Norway lobster, *N. norvegicus*, at 20 mm CL or 70 mm TL; for common sole, *S. solea*, at 20 cm TL; for red mullet, *M. barbatus*, at 11cm TL.
- Jabuka/Pomo Pit rules (GFCM Recommendation GFCM/41/2017/3):
    - **Zone A** - Prohibition of any professional fishing activity with bottom-set nets, bottom trawls, set longlines and traps, recreational fishing.
    - **Zone B** - Fishing activities with bottom-set nets, bottom trawls, set longlines and traps shall be prohibited in zone B, from 1 September to 31 October each year and starting from 2017. Authorized fishing vessels shall not be entitled to fish for more than two fishing days per week. Authorized otter tein trawl gear no more than one fishing day per week.
    - **Zone C** - Fishing activities with bottom-set nets, bottom trawls, set longlines and traps and recreational fisheries shall be prohibited in zone C, from 1 September to 31 October each year and starting from 2017. Authorized vessels fishing with bottom trawls shall be entitled to fish on Saturdays and Sundays only, from 05.00 hours till 22.00 hours. Authorized vessels fishing with bottom-set nets, set longlines and traps shall be allowed to fish from Monday 05.00 hours till Thursday 22.00 hours.
- The SRC-AS proposed the Jabuka/Pomo Pit as permanent closure maintaining management measures for both small-pelagic and demersal fisheries.
- Additional FRAs in the Adriatic will have to be defined, other than Jabuka/Pomo Pit, where any fishing activity with OTB, PTB, OTT and TBB has to be prohibited unless differently provided for by a specific recommendation setting management rules for any of these areas. The SRC-AS in 2021 proposed Bari Canyon to be considered as a potential new FRA. Other proposals to be further investigated: Otranto channel in southern Adriatic Sea and an area of the northern Adriatic Sea known as “sole sanctuary” – to protect sole spawners; great Mediterranean scallop and the peculiar macrobenthos of the area which comprises a vulnerable marine Ecosystem.

2 SCENARIOS PROPOSED

In this chapter were reported methods applied and results obtained in order to provide possible management scenarios for target stock of fisheries in the Adriatic and Ionian Sea. The idea is to detail objectives and reasons for the choice of the proposed scenarios, highlighting biological, economic and social indicators useful to evaluate the proposed scenario and to compare the scenario with similar scenarios tested by other tools. Moreover, management implications of each scenarios tested should be discussed.

2.1.1 Study area

The study area is located in the Central-eastern Mediterranean Sea and encompass the Adriatic and the northern part of the Ionian Sea (including the Gulf of Taranto), corresponding to GSAs 17, 18 and 19, as defined by the FAO-GFCM. In particular, the countries included in the GSA 17 are Croatia, Bosnia-Herzegovina, Italy and Slovenia (Northern and the central Adriatic Sea), those included in the GSA 18 are Albania, Italy, Serbia, and Montenegro. The GSA 19 encompasses the southern part of Italy (south Apulia, east Calabria and east Sicily).

The northern Adriatic Sea is the shallower part of the Adriatic epi-continental shelf, with a mean depth of 30 m and maximum depths less than 70 m, with large seasonal variation in temperature and salinity conditions especially related to the Po river discharge in the western part of the basin (Boldrin et al., 2005). The central part of the Adriatic basin is characterized by a meso-Adriatic depression, called Pomo pit, reaching 260 m depth that was recently included in restricted fisheries recommendations (GFCM/41/2017/3). The meteorological conditions of the Adriatic Sea are characterized by two principal winds, Bora and Scirocco, involving the occurrence of two main cyclonic gyres in the northern and the southern part of the basin, respectively. Bora is a strong north-eastern cold wind that, generating waves especially in the north part of the Adriatic Sea, cause free sea surface to rise close to the coast enhancing the West Adriatic Current. Scirocco blows from the southeast to the northwest (Pomaro et al., 2017) and lead the flood events in the shallow lagoons along the coast (Marini et al., 2008).

The southern part of the basin (GSA 18) is characterized by a steep continental slope and depth reaches 1250 m. Its circulation is characterized by a cyclonic gyre. The dynamics of the Southern Adriatic and the Ionian Sea have been linked through the Bimodal Oscillating System (BiOS) mechanism (Civitarese et al. 2010).

The Adriatic coasts, especially along the Italian side, are characterized by many marine activities as fishing, shipping traffic, tourist industries and fish farming (Italy and Croatia) which contribute to intense coastal urbanization and anthropic pressure occurring in the basin (Punzo et al., 2017, Pranovi et al. 2016).

2.2 CLIMATE SCENARIOS

2.2.1 Summary of climate scenarios developed

As reported in deliverables D.4.1.2 and D.4.2.2 already provided in WP4, two future projections of the hydrodynamic and biogeochemical conditions of the Adriatic-Ionian system have been produced considering the emission scenarios RCP4.5 and RCP8.5 over the entire Mediterranean Sea. The scenario simulations covered the period 2005-2100 and are based on the offline coupling between the physical model MFS16 (Oddo et al., 2009; Cavicchia et al., 2011) and the transport-biogeochemical reactor OGSTM-BFM (Lazzari et al., 2012, 2016; Cossarini et al., 2015). The spatial resolution of the coupled model is 1/16° in the horizontal direction, while the vertical discretization considers 70 unevenly-spaced levels. The results are provided in the form of two datasets composed of fourteen 3D variables and three 2D variables extracted for the Adriatic and Ionian Seas (GSA17-19). The 3D variables are: temperature, salinity, meridional and zonal currents, chlorophyll-a, nitrate, phosphate, dissolved oxygen, phytoplankton carbon biomass, pCO_2, alkalinity, pH and net primary production. The 2D variables are sea surface height, bottom values of temperature and bottom values of oxygen. The modeling system and the domain used in the scenario simulations are the same as those used to build the CMEMS reanalysis dataset (version 2020). This assures the consistency of the comparison between the present and future state of the Adriatic-Ionian system. A specific protocol has been implemented during the analysis of both datasets (RCP4.5 and RCP8.5) to disentangle the climate signal from the internal drifts and errors derived from the model settings. In particular, the scenario analysis consists of the comparison between two 100-year-long simulations: a control simulation and the two RCP4.5 and RCP8.5 scenario simulations. The results of the scenario analysis show that the Adriatic and Ionian Seas will be affected by significant long-term trends for several key physical and biogeochemical variables. In particular, the Adriatic-Ionian system shows an overall warming of the water column both in the top and bottom layers, both in the inshore and offshore areas. While the warming in the first part of the 21st century in two basins is comparable in both emission scenarios (RCP4.5 and RCP8.5), at the end of the 21st century (Far-Future 2080-2099), the increase of the temperature will be stronger in the RCP8.5 scenario, with anomalies greater than 4°C at the bottom of the Adriatic Sea (Fig. 2.2.1.A). The overall increase of the water column temperature will result in an overall decrease of the oxygen solubility on the order of 20 mmol/m^3 (and more) in the shallow Northern Adriatic at the end of the 21st century (Fig. 2.2.1.A). Also the salinity will be characterized by an increase at the end of the 21st century, stronger in the RCP8.5 scenario and in particular in the Adriatic Sea (not shown).

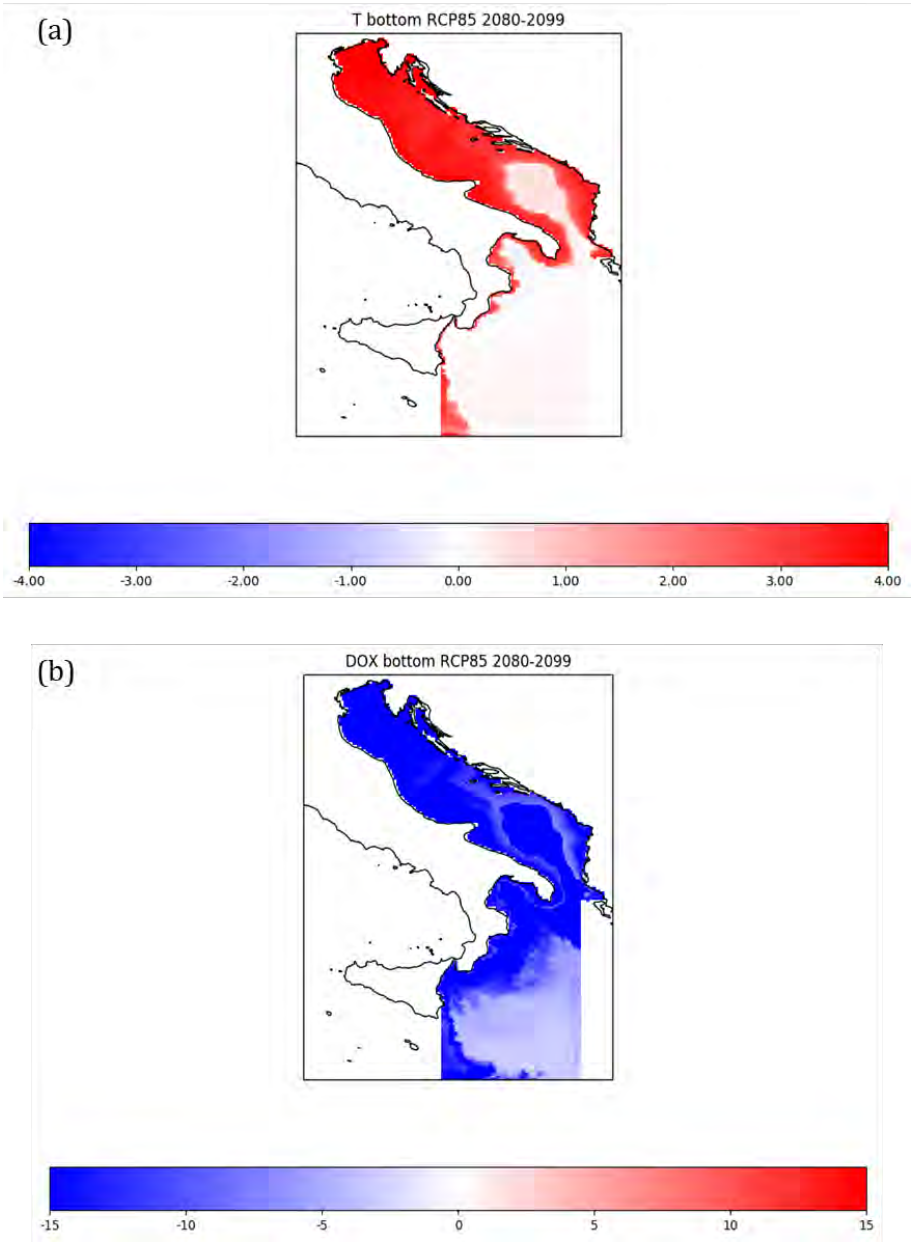

Figure 2.2.1.A - (a) Mean temperature anomaly (T, °C), (b) Dissolved oxygen (DOX, mmol/m^3) at the bottom in the Far-Future period of the RCP8.5 scenario.

As regards the biogeochemical variables, the RCP8.5 scenario shows an increase of both nitrogen and phosphorus concentration (stronger in the former parameter, weaker in the latter) in the relatively shallow Northern Adriatic and along the Italian coast, and a general decrease in all the off-shore areas of the Adriatic and Ionian Seas at the end of the 21st century (Fig. 2.2.1.B, a,b).

Moreover, both scenarios (RCP4.5 and RCP8.5) show a negative anomaly of nitrogen and phosphorus in the Southern Adriatic Sea and an increase in the concentration of both nutrients below 500 m due to a less efficient upward transport by the vertical winter mixing processes. The phytoplankton biomass (and chlorophyll-a, which is tightly correlated with the carbon biomass, Fig. 2.2.1.B, c) will decline in the surface (0-50 m) and subsurface (50-100 m) layers. Two small spotty areas with positive anomalies at the surface are identified in the northernmost part of the Adriatic and in the south-western part of GSA 19. A slight increase in the concentration of phytoplankton biomass is also depicted in the 100-200 m layer of the Ionian Sea, and it is associated with a change in the location of the deep chlorophyll-a maximum. Furthermore, the overall decrease in phytoplankton biomass is due to the increase of the ecosystem metabolism induced by the warming of the water column.

An overall decreasing trend of pH is simulated during the 21st century and at the end of it. Negative anomalies are higher in the surface rather than subsurface layers, following the vertical pattern of temperature increase and the absorption of atmospheric CO_2 from the surface and the diffusion toward the subsurface layers (Fig. 2.2.1.B, d). The decrease of pH at the surface in the RCP8.5 scenario, which is much stronger than in RCP4.5, reaches values down to -0.3 by the end of the century.

Full description of scenarios implemented with the physical-biogeochemical coupled models are described in detail in deliverables of activities 4.1 and 4.2: “D4.1.2 Scenario analysis of future circulation” and “D4.2.2 Future scenario of production patterns”.

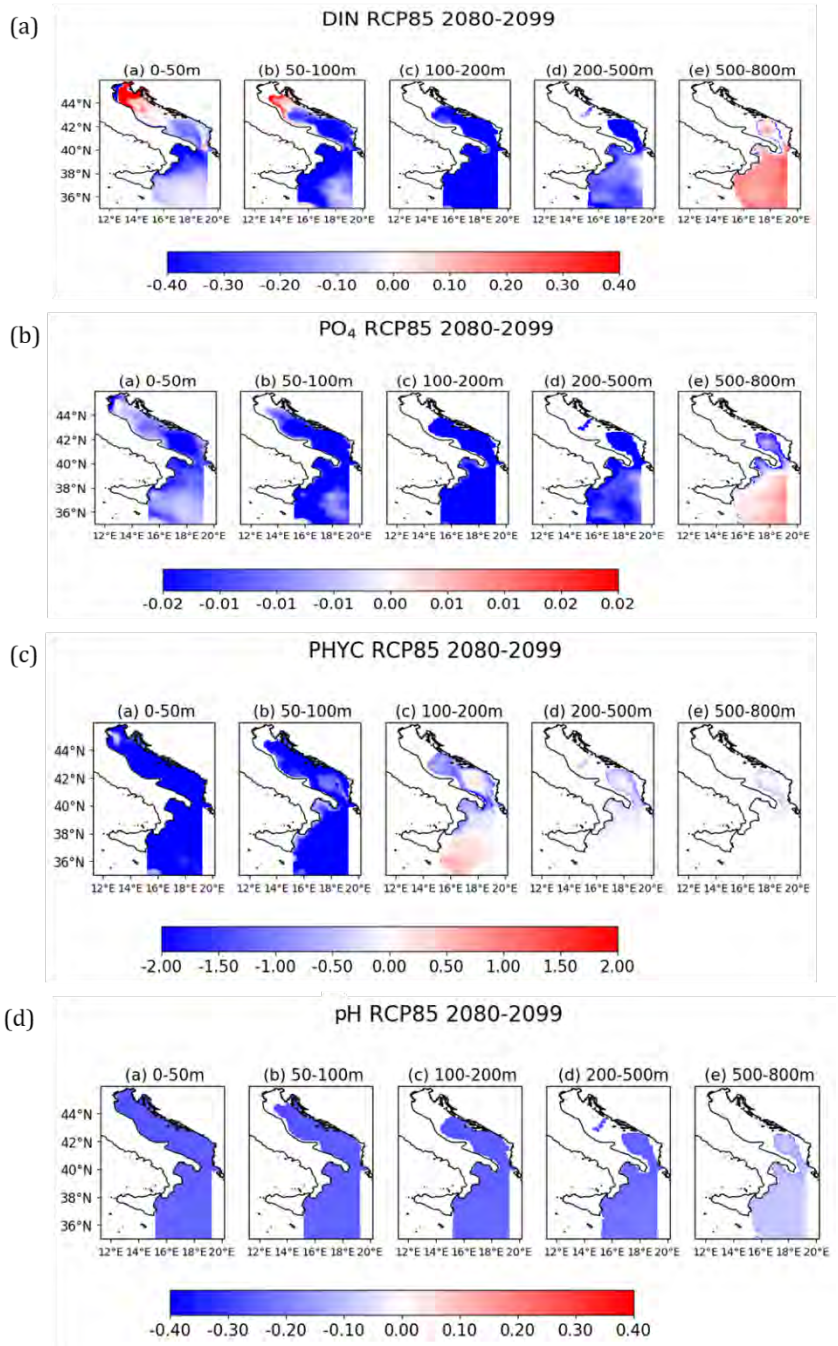

Figure 2.2.1.B - (a) Mean Dissolved Nitrogen anomaly (DIN, mmol/m^3), (b) Phosphate (PO_4, mmol/m^3), (c) phytoplankton biomass (PHYC, mgC/m^3) and (d) pH in the Far-Future period of the RCP8.5 scenario.

2.3 SPECIES DISTRIBUTION MODELS

A method adopted for the identification in the GSAs 17, 18 and 19 of the present and future areas characterized by a high biomass density (n/km^2) or hot-spot areas of different target species is those of Spatial Distribution Model (SDM). In particular, this modelling approach allowed to identify any spatial and temporal changes of hot-spot areas based on the variation of environmental variables over time.

Target species selected for the application of this modelling approach were: the European hake (*Merluccius merluccius*, bone fish), the red mullet (*Mullus barbatus*, bone fish), Norway lobster (*Nephrops norvegicus*, crustacean), the deep-water rose shrimp (*Parapenaeus longirostris,* crustacean), the blackbellied angler *(Lophius budegassa,* bone fish), the southern shortfin squid (*Illex coindetii,* mollusc) and the Atlantic horse mackerel (*Trachurus trachurus,* bone fish), from MEDITS dataset; the common sole (*Solea solea*), the spottail mantis shrimp (*Squilla mantis*, crustacean), and the common cuttlefish (*Sepia officinalis*, mollusc), from the SOLEMON dataset.

2.3.1 METHODOLOGICAL APPROACH

To develop predictive SDMs of selected target species, the fitted models derived from the application of three different approaches or an ensemble model of them, as detailed described in the deliverable D.4.8.1 "First analysis of layers of information", were used.

Three different approaches applied include: Generalized Additive Models (GAM), Random Forest model (RF) and Gradient Boosted Machine (GBM).

As a prediction grid, it was adopted the CMEMS grid with a resolution of 1/16° already used for the forecasting of the hydrodynamic and biogeochemical conditions in the basin (see paragraph 2.2), which cover the study area extended from 39°05'00''N, 12°00'00"E to 46°00'00''N, 20°00'00"). The range of bathymetry considered varied from 10 to 800 m for MEDITS survey, and from 10 to 100 m for SOLEMON survey (Fig. 2.3.1.A).

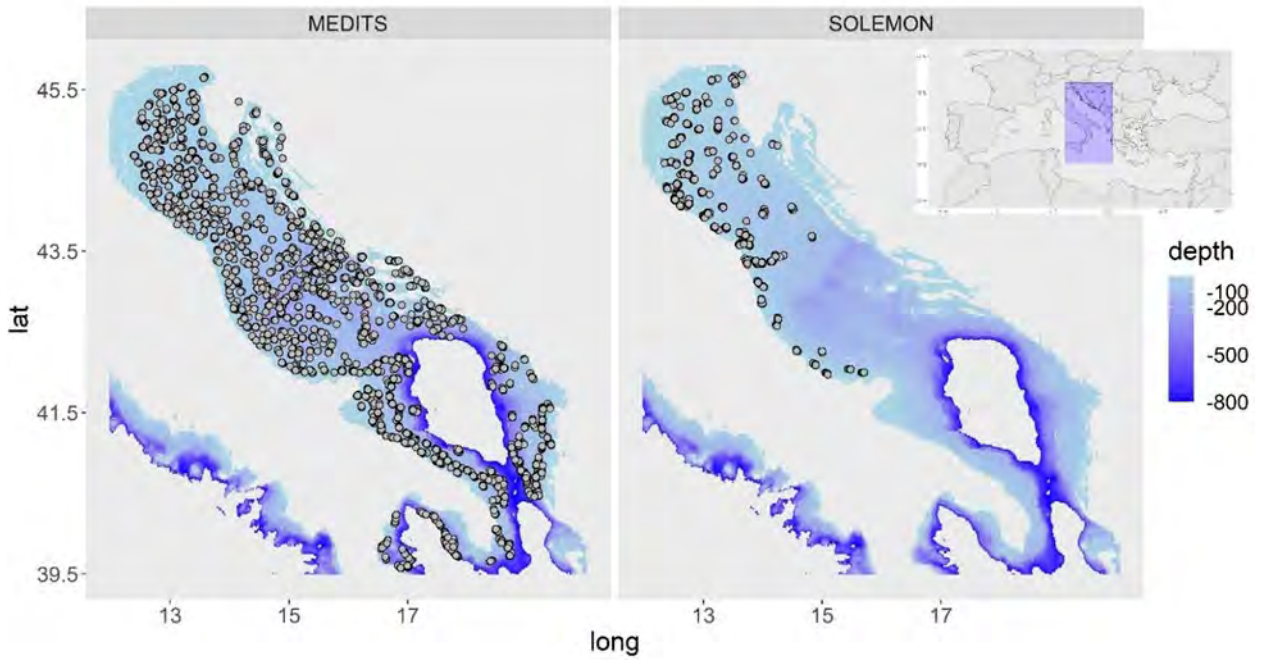

Figure 2.3.1.A - Hauls position (from 2008-2018) for MEDITS, left panel, and SOLEMON surveys, right panel. In the upper right corner, it is represented the Mediterranean Sea and the study area in a shade blue box.

In particular, three grids were used: grid 2014-2018, for present data, grid 2031-2035 and grid 2046-2050, for predicted future data. For each grid, the variables involved are: geographical position variables (latitude and longitude), additional oceanographic variables, derived from the climate scenarios (see paragraph 2.2) and fishing effort considering only data for TBB or OTB.

Among all the variables available from the 3D monthly CMEMS Mediterranean scenario fields (deliverables D.4.1.1 "Connectivity and main circulation patterns in the Adriatic Sea" and D.4.2.1 "Production patterns in the Adriatic Sea"), the relevant oceanographic variables considered were: the water temperature (C°) and dissolved oxygen (mmol/m^3) at the sea surface and bottom, water column averages of nitrate and phosphate concentration (mmol/m^3), chlorophyll-a (mg/m^3), particulate organic carbon (mg/m^3), pH at the sea bottom and surface salinity. These variables were selected based on known ecological importance for chosen demersal species (Carlucci et al., 2018; Bitetto et al., 2019) as well as proxies for productivity and favourable environments.

Effort data, including both the Italian and Croatian fleets, were estimated by VMS/AIS data for the period 2014-2018 and analysed according to the methodology reported in the deliverable D4.5.1 "Fishing effort map distribution" (Russo et al., 2014a). Effort data are expressed as

trawling time (kW/hours) per year at the spatial resolution of 1/16° and for demersal species selected in this study, only OTB and TBB data has been used in the modelling approach, with OTB data for the species collected by MEDITS, and TBB data for the species collected by SOLEMON. This selection depends on the respective and different fishing technic used in the two surveys.
Indices of demersal species density (n/km^2, n=number of individual) were retrieved from the MEDITS and SOLEMON dataset. For some species were considered also the life stage, in particular adult and juvenile one, depending on the respective biology (Table 2.3.1.a).

Table 2.3.1.a - Table of split size for each species. Column size indicates the threshold between adult and juvenile. CL is carapace length; ML is mantle length.

Species	Size (cm)	Source
M. merluccius	14	Flamigni, 1983.
M. barbatus	9-10	Haidar, 1970, Jukić and Piccinetti, 1981.
N. norvegicus	2.5 CL	Froglia and Gramitto, 1979.
P. longirostris	1.5	https://www.faoadriamed.org/html/Species
L. budegassa	33	Jardas, 1987.
I. coindetii	15	FAO MedSudMed & FAO AdriaMed
T. trachurus	14	https://www.faoadriamed.org/html/Species
S. solea	19	Colloca et al., 2015.
S. mantis	2.5 CL	Colella et al., 2016
S. officinalis	10 ML	https://www.faoadriamed.org/html/Species/SepiaOfficinalis.html

Regarding the prediction of species density in both future scenarios (2031-2035 and 2046-2050), values of the oceanographic variables were derived from the CMEMS future scenario dataset that covers those periods considering both emission scenarios RCP4.5 and RCP8.5 (see paragraph 2.2); those of fishing effort correspond to values recorded in 2018. Considering that the forthcoming MAPs in the Adriatic have not yet adopted, the fishing effort is not predictable for the future years, so in this way, it is assumed that it will not change over time.
Hence, taking into account the best models fitting density data for each species (derived from the training and test routine already described in the deliverable D.4.8.1), these were applied to obtain maps of the density distribution (n/km^2), that allow identifying areas of high biomass density (hot-spots) in the GSAs 17, 18, and 19. After prediction, the mean of density over years for each of the three periods (present 2014-2018, future 2031-2035 and 2046-2050) were

calculated. To identify the hot spot areas, the Getis index (Getis and Ord, 1992) were applied on the average of the density distribution over years of the best model for each approach and prediction grid, considering 8 cells around the cell in analysis.
Finally, an ensemble model (for each prediction grid) was obtained weighting on the respective R^2 derived from the validation process on the 3 approaches. To obtain this, the results of Getis index analysis are multiplied for the value of the R^2 of the respective approach (see Deliverable 4.8.1) of the best model with environmental variable (ST+ENV) and spatio-temporal model (ST). Furthermore, the anomaly between the density distribution (N/km^2) of the present (mean over years 2014-2018) and future scenarios (means over years 2031-2035 and 2046-2050) were calculated for the models with environmental variables (ST+ENV). The equation for the anomaly is:

$$\frac{p_{j,2018} - p_{j,20xx}}{\frac{(p_{j,20xx} + p_{j,2018})}{2}}$$

Where p is the n/km^2, j is the j-th cell in analysis, 20xx is the future years' scenario (2035 or 2050).

2.3.2 RESULTS

The methodological approach adopted and described in previous paragraph led to the realization of prediction maps of density distribution of the selected species for the present (2014-2018) and both future scenarios (years 2031-2035 and 2046-2050). Some examples are showed in subsequently paragraphs 2.3.2.1 and 2.3.2.2. In particular, prediction maps of density for future scenarios showed values of density as anomalies or as difference between values modelled for the present (2018) and predicted from the future (2035 or 2050) divided by the mean of two values. Moreover, prediction maps of the present showed also the center of gravity of hot spot areas for present and future years, according to ST and ST+ENV models. All results about coordinates of the center of gravity, for both ensemble models (ST and ST+ENV) for each species and life stage, are visible in Table 2.3.2a. The center of gravity in models ST does not change position over time, due to the application of the model at the same covariate: depth, latitude, longitude and year of the grid in analysis. Quite the opposite, the center of gravity for the hot spot of the models ST+ENV (including also environmental and effort variables) changes its position over time and space as a consequence of the climate change variables', from the two IPCC scenarios (RPC4.5 and RPC8.5).

Table 2.3.2.a - Coordinates of the center of gravity (longitude and latitude), for life cycle stage (adult and juvenile) of selected species, for emission scenario (RPC4.5 and RPC8.5), considering models with (ST+ ENV) and without environmental variables and effort (ST).

RPC4.5	ADULT				RPC4.5	JUVENILE			
	x ST	y ST	x ST+ENV	y ST+ENV		x ST	y ST	x ST+ENV	y ST+ENV
European hake					**European hake**				
2018	17.23	42.19	17.18	42.26	2018	16.2	42.6	16.46	42.49
2035	17.23	42.19	16.08	42.75	2035	16.2	42.6	16.77	42.37
2050	17.23	42.19	16.16	42.68	2050	16.2	42.6	16.59	42.45
Red mullet					**Red mullet**				
2018	16.85	42.77	17.12	42.55	2018	16.2	42.42	16.71	42.02
2035	16.85	42.77	16.96	42.65	2035	16.2	42.42	17.51	41.94
2050	16.85	42.77	16.89	42.69	2050	16.2	42.42	17.35	42.05
Norway lobster					**Norway lobster**				
2018	16.81	42.04	16.65	42.2	2018	17.04	41.86	16.11	42.44
2035	16.81	42.04	16.45	42.35	2035	17.04	41.86	16.04	42.52
2050	16.81	42.04	16.41	42.39	2050	17.04	41.86	16.29	42.29
Deep-water rose shrimp					**Deep-water rose shrimp**				
2018	18.02	40.55	18	40.53	2018	18.11	40.71	18.04	40.61
2035	18.02	40.55	18.36	40.81	2035	18.11	40.71	18.42	40.88
2050	18.02	40.55	18.41	40.81	2050	18.11	40.71	18.41	40.89
Blackbellied angler					**Blackbellied angler**				
2018	18.14	41.31	18.09	41.35	2018	16.49	41.78	16.42	41.88
2035	18.14	41.31	16.6	42.33	2035	16.49	41.78	15.50	42.46
2050	18.14	41.31	16.64	42.36	2050	16.49	41.78	15.54	42.42
Southern shortfin squid					**Southern shortfin squid**				
2018	16.75	42.43	16.56	42.54	2018	16.93	42.16	17.25	42.01
2035	16.75	42.43	16.77	42.50	2035	16.93	42.16	18.08	41.7
2050	16.75	42.43	17.01	42.36	2050	16.93	42.16	18.07	41.73
Atlantic horse mackerel					**Atlantic horse mackerel**				
2018	17.05	41.93	17.1	41.87	2018	15.17	43.05	15.47	42.93
2035	17.05	41.93	16.66	42.45	2035	15.17	43.05	16.73	42.08
2050	17.05	41.93	16.48	42.60	2050	15.17	43.05	16.56	42.29
Common sole					**Common sole**				
2018	13.03	44.91	13.05	44.94	2018	12.53	44.72	12.57	44.67
2035	13.03	44.91	13.29	44.82	2035	12.53	44.72	12.67	44.50
2050	13.03	44.91	13.25	44.82	2050	12.53	44.72	12.67	44.58
Spottail mantis shrimp					**Spottail mantis shrimp**				
2018	15.19	42.92	13.7	43.89	2018	13.66	43.78	13.32	43.98

2035	15.19	42.92	13.54	43.94	2035	13.66	43.78	13.38	43.85
2050	15.19	42.92	13.64	43.93	2050	13.66	43.78	13.23	44.02
Common cuttlefish					**Common cuttlefish**				
2018	15.74	42.65	15.06	43.34	2018	13.32	44.93	13.25	45.03
2035	15.74	42.65	15.42	43.02	2035	13.32	44.93	13.33	44.93
2050	15.74	42.65	15.43	42.93	2050	13.32	44.93	13.33	44.91

RPC8.5	ADULT				RPC8.5	JUVENILE			
	x ST	y ST	x ST+ENV	y ST+ENV		x ST	y ST	x ST+ENV	y ST+ENV
European hake					**European hake**				
2018	17.23	42.19	17.18	42.26	2018	16.2	42.6	16.46	42.49
2035	17.23	42.19	15.97	42.80	2035	16.2	42.6	16.67	42.42
2050	17.23	42.19	16.05	42.77	2050	16.2	42.6	16.57	42.46
Red mullet					**Red mullet**				
2018	16.85	42.77	17.12	42.55	2018	16.2	42.42	16.71	42.02
2035	16.85	42.77	16.94	42.67	2035	16.2	42.42	17.15	41.08
2050	16.85	42.77	16.88	42.69	2050	16.2	42.42	17.13	42.10
Norway lobster					**Norway lobster**				
2018	16.81	42.04	16.65	42.2	2018	17.04	41.86	16.11	42.44
2035	16.81	42.04	16.49	42.27	2035	17.04	41.86	16.14	42.42
2050	16.81	42.04	16.29	42.40	2050	17.04	41.86	16.08	42.42
Deep-water rose shrimp					**Deep-water rose shrimp**				
2018	18.02	40.55	18	40.53	2018	18.11	40.71	18.04	40.61
2035	18.02	40.55	18.38	40.85	2035	18.11	40.71	18.42	40.89
2050	18.02	40.55	18.40	40.81	2050	18.11	40.71	18.35	40.86
Blackbellied angler					**Blackbellied angler**				
2018	18.14	41.31	18.09	41.35	2018	16.49	41.78	16.42	41.88
2035	18.14	41.31	16.56	42.38	2035	16.49	41.78	15.49	42.44
2050	18.14	41.31	16.64	42.35	2050	16.49	41.78	15.52	42.48
Southern shortfin squid					**Southern shortfin squid**				
2018	16.75	42.43	16.56	42.54	2018	16.93	42.16	17.25	42.01
2035	16.75	42.43	16.98	42.39	2035	16.93	42.16	18.06	41.7
2050	16.75	42.43	17.05	42.32	2050	16.93	42.16	18.06	41.73
Atlantic horse mackerel					**Atlantic horse mackerel**				
2018	17.05	41.93	17.1	41.87	2018	15.17	43.05	15.47	42.93
2035	17.05	41.93	16.51	42.44	2035	15.17	43.05	16.64	42.21
2050	17.05	41.93	16.42	42.53	2050	15.17	43.05	16.56	42.29
Common sole					**Common sole**				
2018	13.03	44.91	13.05	44.94	2018	12.53	44.72	12.57	44.67
2035	13.03	44.91	13.25	44.81	2035	12.53	44.72	12.64	44.50

2050	13.03	44.91	13.24	44.83	2050	12.53	44.72	12.64	44.50
Spottail mantis shrimp					**Spottail mantis shrimp**				
2018	15.19	42.92	13.7	43.89	2018	13.66	43.78	13.32	43.98
2035	15.19	42.92	13.51	43.99	2035	13.66	43.78	13.20	43.97
2050	15.19	42.92	13.60	43.96	2050	13.66	43.78	13.17	44.06
Common cuttlefish					**Common cuttlefish**				
2018	15.74	42.65	15.06	43.34	2018	13.32	44.93	13.25	45.03
2035	15.74	42.65	15.38	43.01	2035	13.32	44.93	13.33	44.89
2050	15.74	42.65	15.44	42.95	2050	13.32	44.93	13.33	44.89

2.3.2.1 Results obtained considering emission scenario RPC4.5

Examples of maps of density distribution for adults and juveniles of different species were reported, considering the emission scenario RPC4.5. Specifically, there are reported spatial distribution of adult individual of the European hake, the blackbellied angler fish and the spottail mantis shrimp (Fig. 2.3.2.1.A÷2.3.2.1.C) and juvenile individuals of the Norway lobster, the deep-water rose shrimp and the spottail mantis shrimp (Fig. 2.3.2.1.D÷2.3.2.1.F).

The center of gravity of distribution of adults of the European hake in both future scenarios (2035 and 2050), considering the model ST+ENV, changed position towards the central part of the Adriatic Sea. The anomalies showed an increased density distribution (blue shades) along the coastline and in the central part of the basin and a decrease (red shades) in some coastal and in mid waters.

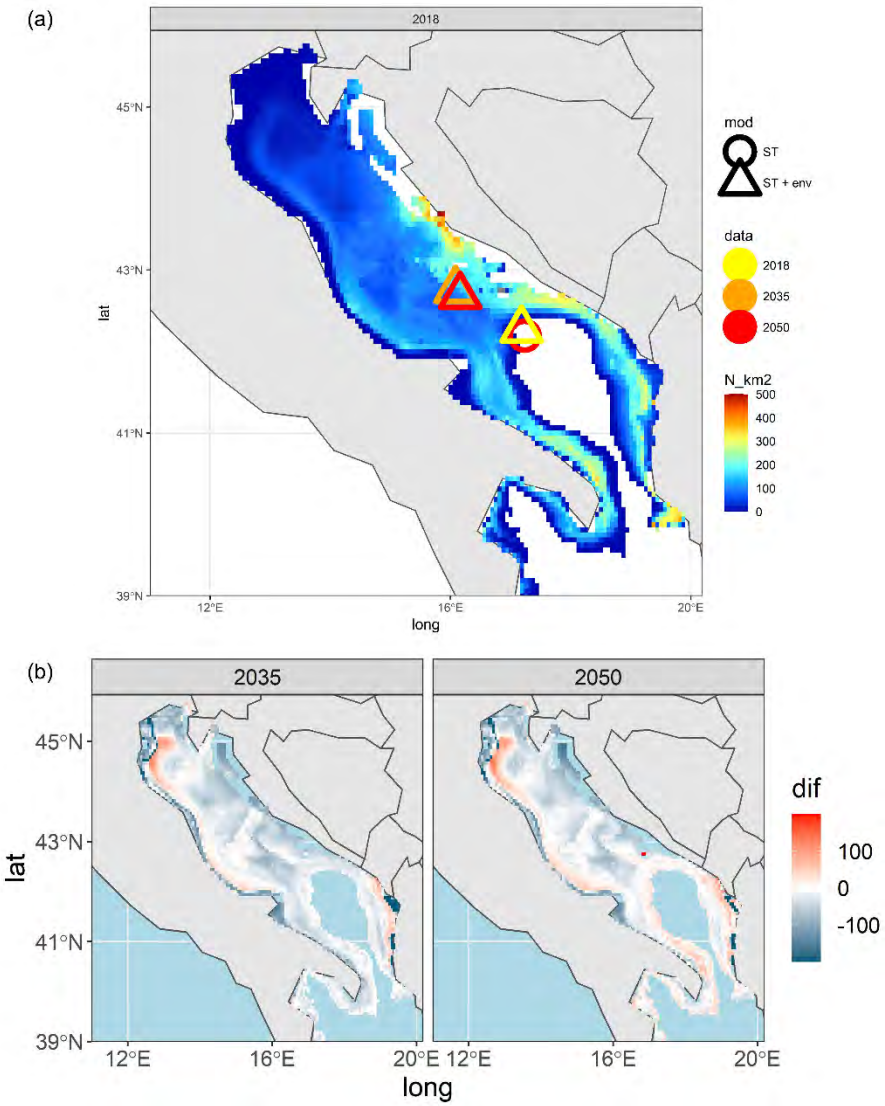

Figure 2.3.2.1.A – Density distribution of the adult individuals of the European hake: (a) prediction map for the present (2014-2018) with indication of center of gravity of distribution considering the model ST (circle) and ST+ENV (triangle) for the three periods (2018, 2035, and 2050 in yellow, orange and red, respectively), considering emission scenarios RPC4.5; (b) maps of anomalies observed in future scenarios compared with the present one. Red shades indicates decreasing values of density, while blue shades indicates an increase in density respect to present.

A similar situation was observed for the centre of gravity of the distribution of adults of the blackbellied angler fish, even if in this case a greater intensification of distribution was observed (blue shades) in the entire basin with a decreasing of density in the hot spot area in front of Montenegro (in red).

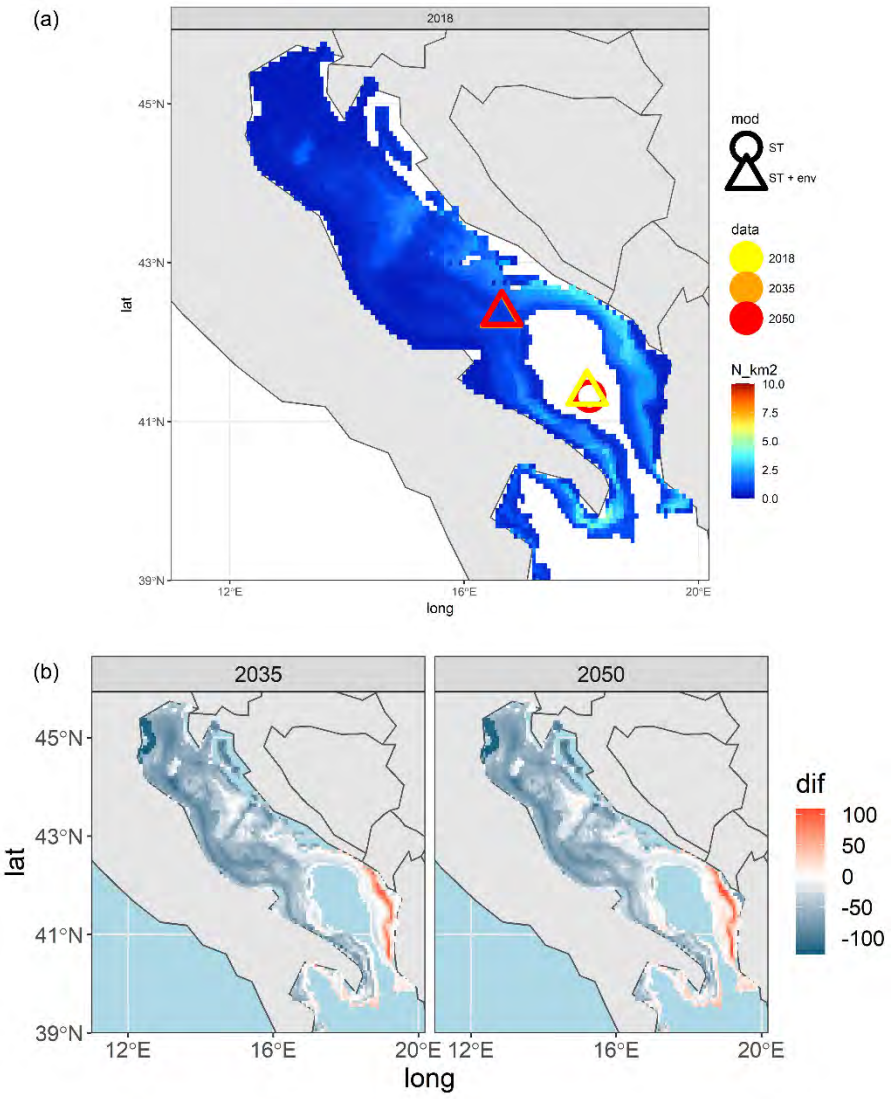

Figure 2.3.2.1.B – Density distribution of the adult individuals of the blackbellied angler: (a) prediction map for the present (2014-2018) with indication of center of gravity of distribution considering the model ST (circle) and ST+ENV (triangle) for the three periods (2018, 2035, and 2050 in yellow, orange and red, respectively), considering emission scenarios RPC4.5; (b) maps of anomalies observed in future scenarios compared with the present one. Red shades indicates decreasing values of density, while blue shades indicates an increase in density respect to present.

In the case of adult individuals of the spottail mantis shrimp, the three centers of gravity (triangle) are located in the same position and near the hot spot area (close to the mouth of Po River). However, the anomalies showed a decrease of the density distribution (red shades) in the entire basin, especially in the year 2050.

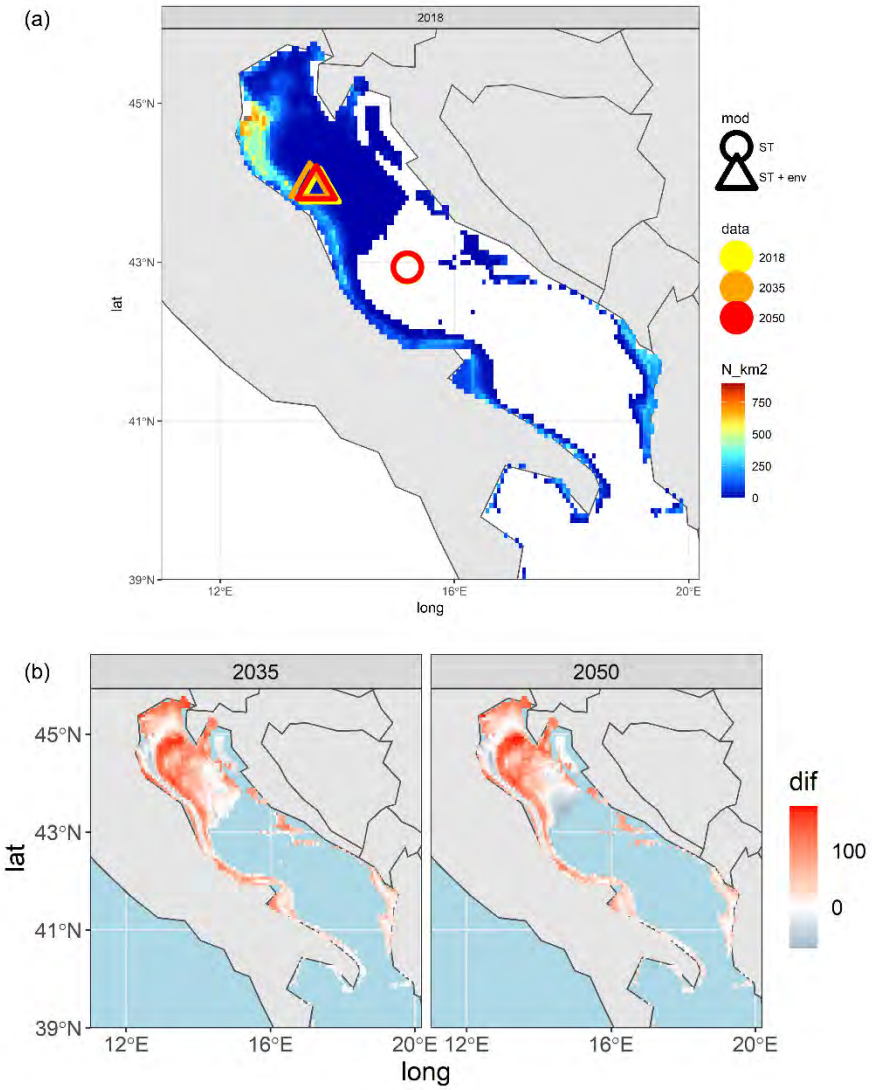

Figure 2.3.2.1.C – Density distribution of the adult individuals of the spottail mantis shrimp: (a) prediction map for the present (2014-2018) with indication of center of gravity of distribution considering the model ST (circle) and ST+ENV (triangle) for the three periods (2018, 2035, and 2050 in yellow, orange and red, respectively), considering emission scenarios RPC4.5; (b) maps of anomalies observed in future scenarios compared with the present one. Red shades indicates decreasing values of density, while blue shades indicates an increase in density respect to present.

The specific case of juvenile of the Norway lobster is more complex, due to survey data not specifically targeting this life stage. Considering the model ST+ENV, the centers of gravity for the three periods are located further north than those resulted considering ST model. In any

case, future scenarios showed a decreasing density distribution of this species in the central part of the basin and a little increase near Venice lagoon and in FRA of Pomo area.

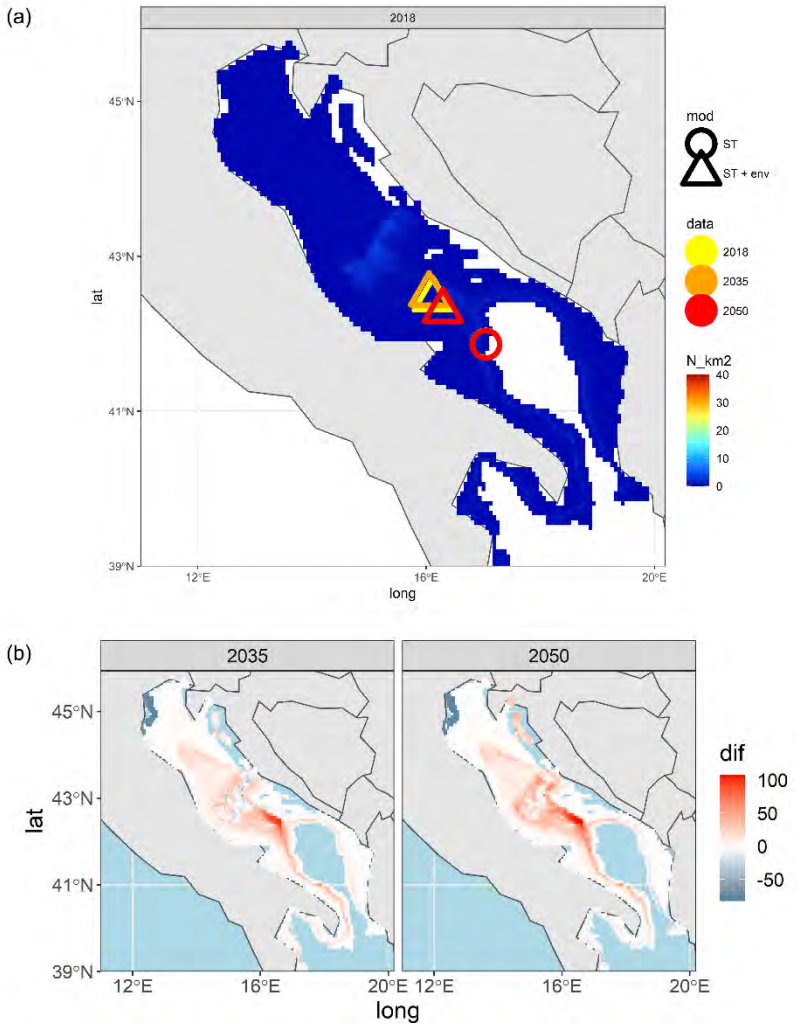

Figure 2.3.2.1.D – Density distribution of the juvenile individuals of the Norway lobster: (a) prediction map for the present (2014-2018) with indication of center of gravity of distribution considering the model ST (circle) and ST+ENV (triangle) for the three periods (2018, 2035, and 2050 in yellow, orange and red, respectively), considering emission scenarios RPC4.5; (b) maps of anomalies observed in future scenarios compared with the present one. Red shades indicate decreasing values of density, while blue shades indicates an increase in density respect to present.

In the case of the juveniles of the deep-water rose shrimp, no big changes in the center of gravity for both models ST and ST+ENV are recorded. However, differences in the anomalies

distribution are observed, and in particular, an increase in the northern part of the basin and a decrease in the central-southern one, corresponding to the current hot spots.

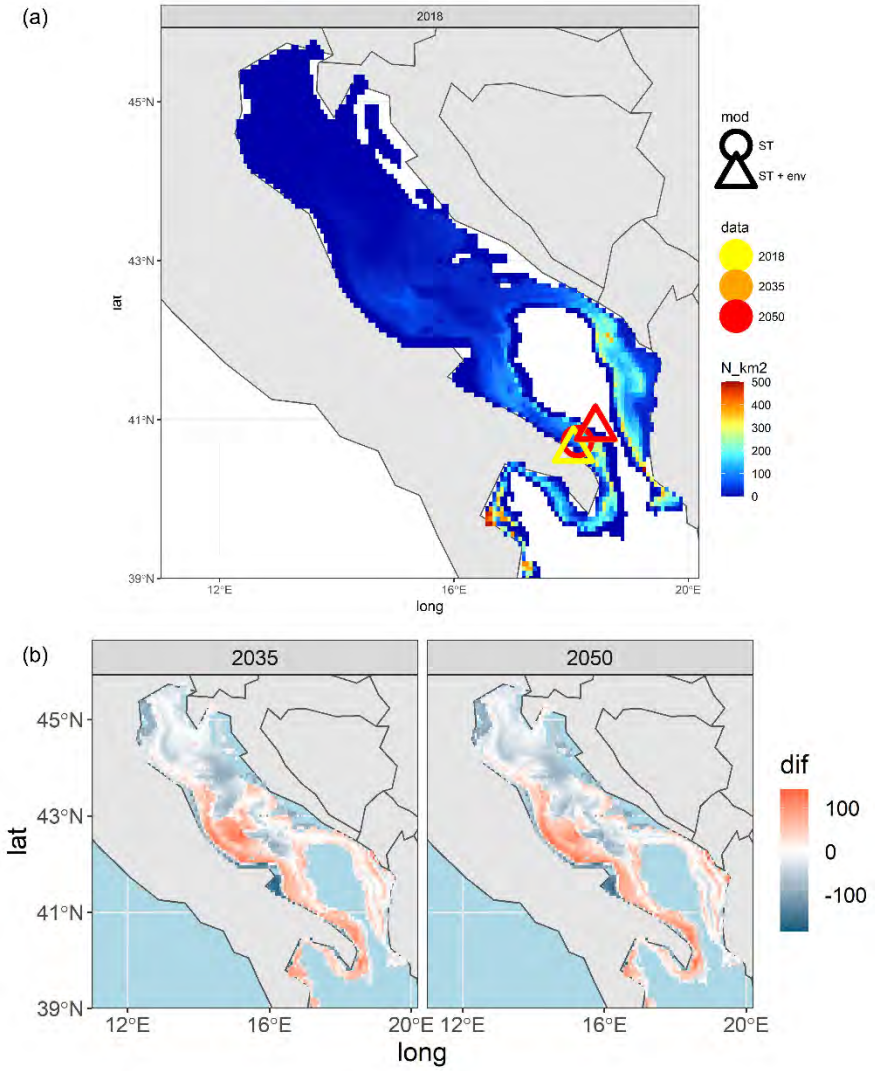

Figure 2.3.2.1.E – Density distribution of the juvenile individuals of the deep-water rose shrimp: (a) prediction map for the present (2014-2018) with indication of center of gravity of distribution considering the model ST (circle) and ST+ENV (triangle) for the three periods (2018, 2035, and 2050 in yellow, orange and red, respectively), considering emission scenarios RPC4.5; (b) maps of anomalies observed in future scenarios compared with the present one. Red shades indicates decreasing values of density, while blue shades indicates an increase in density respect to present.

Similarly to previous case, also the centers of gravity of the spottail mantis shrimp juveniles do not change very much in their position between ST and ST+ENV models. However, some strange anomalies were observed. In particular, it is visible a huge increase of density in deeper part of the northern Adriatic Sea and a decreasing in the hot spot area close to the mouth of Po River.

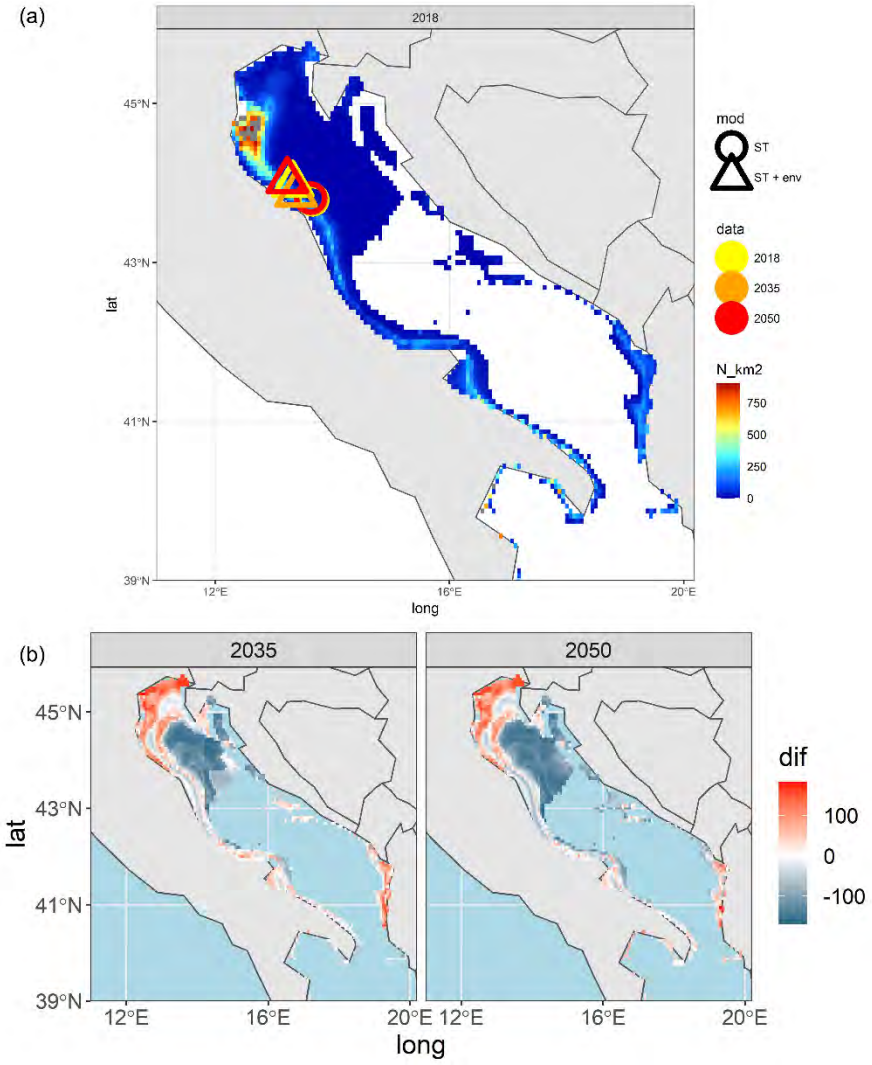

Figure 2.3.2.1.F – Density distribution of the juvenile individuals of the spottail mantis shrimp: (a) prediction map for the present (2014-2018) with indication of center of gravity of distribution considering the model ST (circle) and ST+ENV (triangle) for the three periods (2018, 2035, and 2050 in yellow, orange and red, respectively), considering emission scenarios RPC4.5; (b) maps of anomalies observed in future scenarios compared with the present one. Red shades indicates decreasing values of density, while blue shades indicates an increase in density respect to present.

2.3.2.2 Results obtained considering emission scenario RPC8.5

Examples of maps of density distribution for adults and juveniles of different species were reported, considering the emission scenario RPC8.5. Specifically, there are reported spatial distribution of adult individual of the shortfin squid, the red mullet and the common sole (Fig. 2.3.2.2.A÷2.3.2.2.C) and juvenile individuals of the blackbellied angler, the Atlantic horse mackerel and the spottail mantis shrimp (Fig. 2.3.2.2.D÷2.3.2.2.F).

The centers of gravity of distributions of the southern shortfin squid adults in the present and in the future considering both models (ST and ST+ENV) are located, more or less, in the same area. However, the distribution of anomalies shows a strong decreasing of values in the central-southern part of the basin and an increase in the northernmost one in the future years.

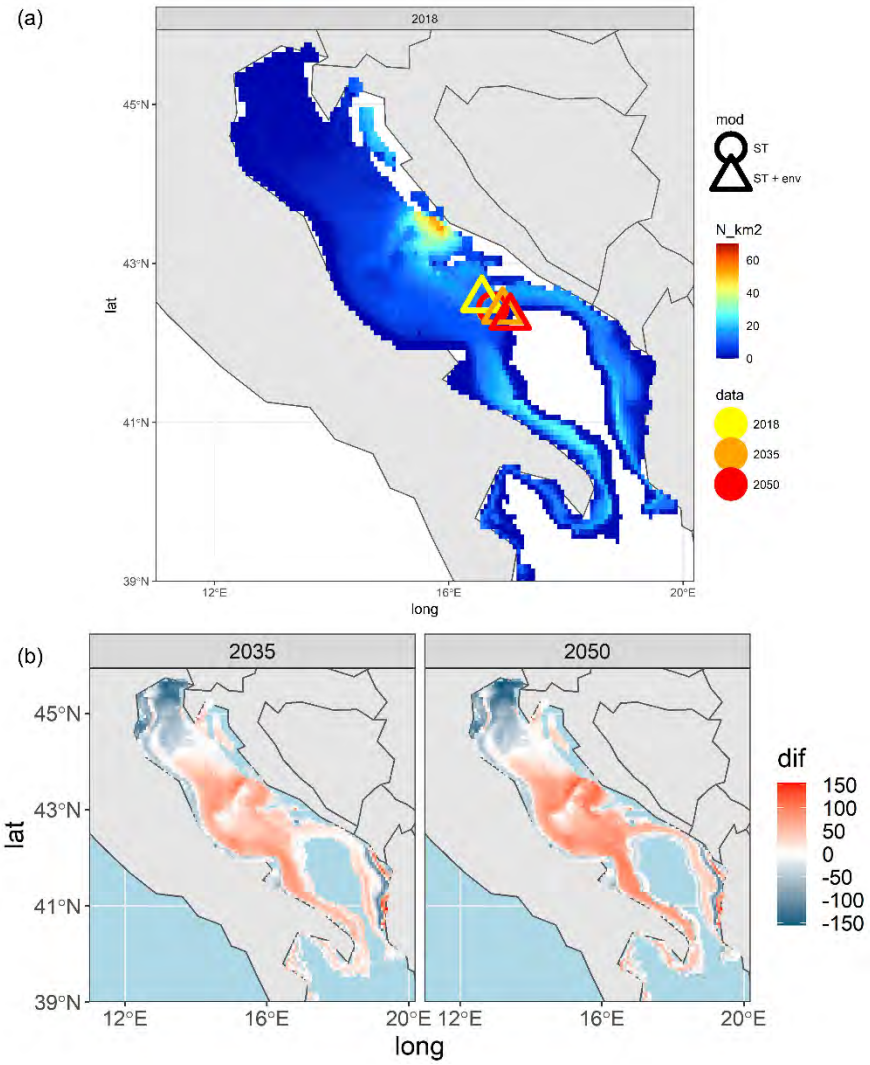

Figure 2.3.2.2.A – Density distribution of the adult individuals of the southern shortfin squid: (a) prediction map for the present (2014-2018) with indication of center of gravity of distribution considering the model ST (circle) and ST+ENV (triangle) for the three periods (2018, 2035, and 2050 in yellow, orange and red, respectively), considering emission scenarios RPC8.5; (b) maps of anomalies observed in future scenarios compared with the present one. Red shades indicates decreasing values of density, while blue shades indicates an increase in density respect to present.

Similarly to previous species, also the distribution of the centers of gravity for adults of the red mullet does not showed particularly differences in their location. However, an increasing in values of the density distribution (blue colour) in the basin is visible, except for some coastal area in the norther and southern Adriatic Sea.

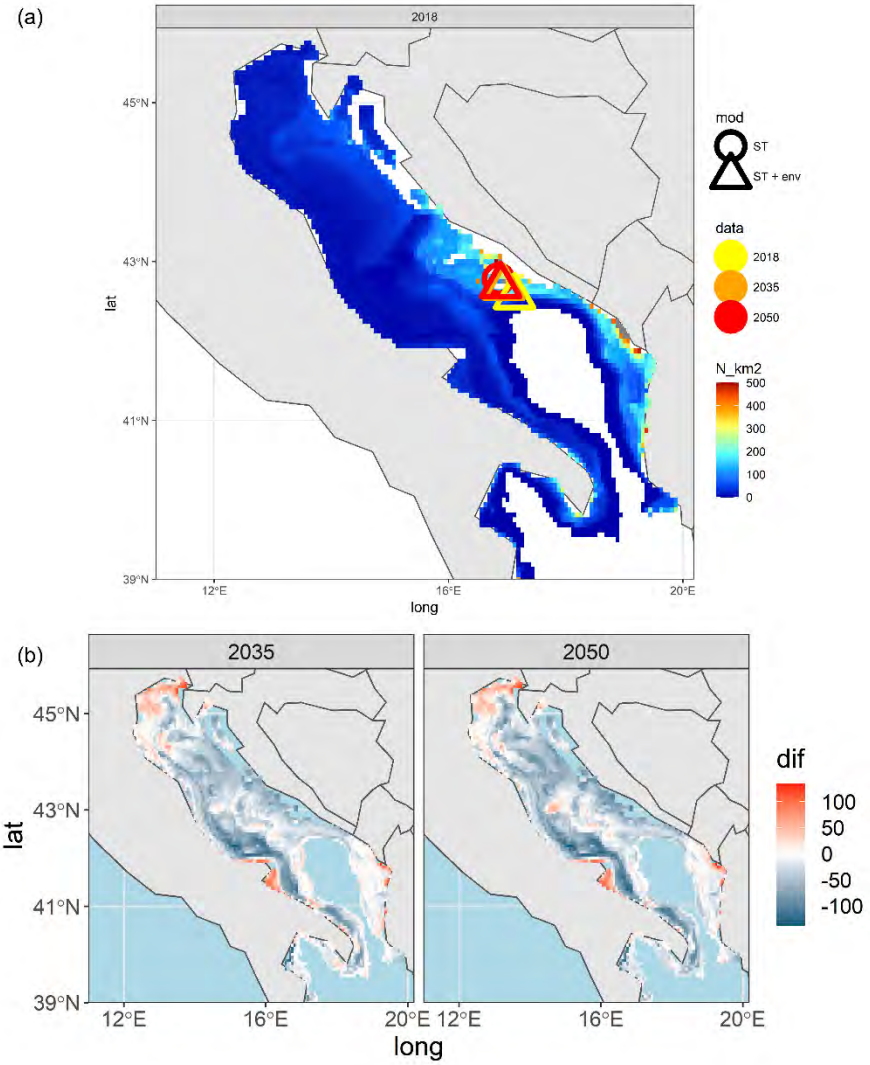

Figure 2.3.2.2.B – Density distribution of the adult individuals of the red mullet: (a) prediction map for the present (2014-2018) with indication of center of gravity of distribution considering the model ST (circle) and ST+ENV (triangle) for the three periods (2018, 2035, and 2050 in yellow, orange and red, respectively), considering emission scenarios RPC8.5; (b) maps of anomalies observed in future scenarios compared with the present one. Red shades indicates decreasing values of density, while blue shades indicates an increase in density respect to present.

In the case of distribution of adults of the common sole, a little southward shift of the center of gravity for the future scenarios for ST+ENV model was observed. This resulted in a strong decrease of the density of the species, especially in the year 2050, in the hot spot areas near Venice lagoon and close to the mouth of Po River.

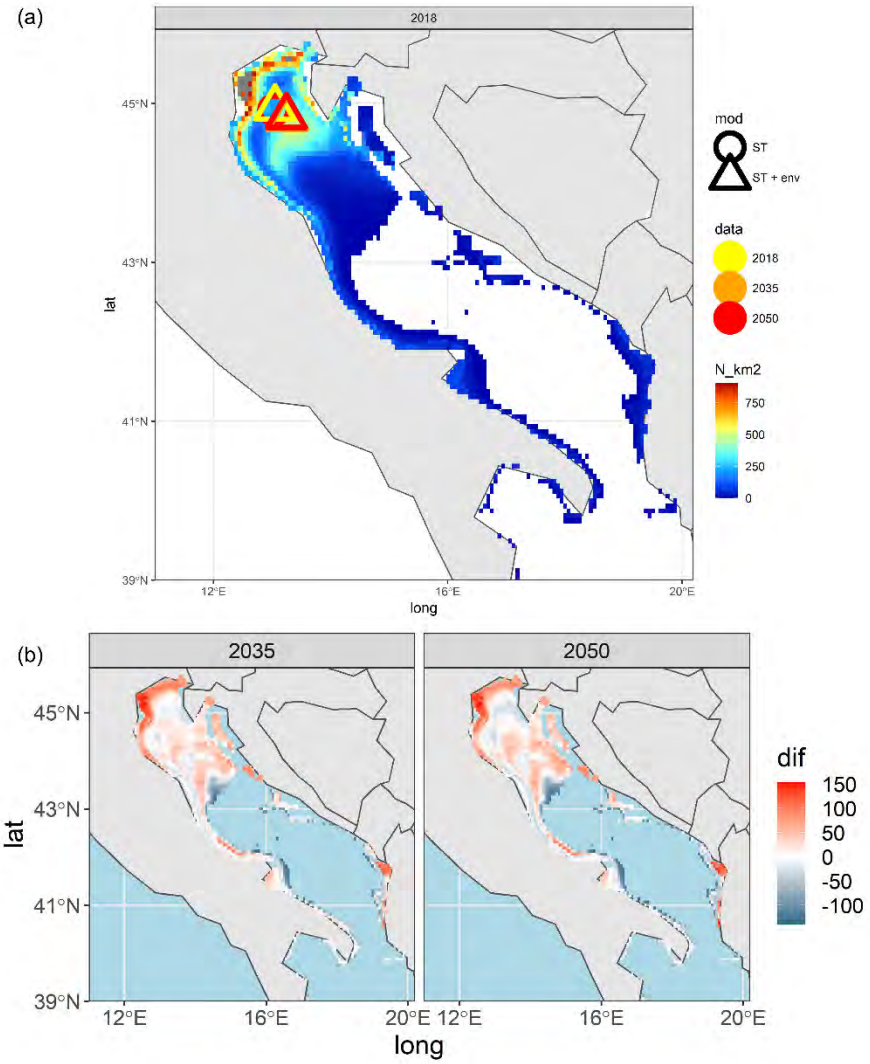

Figure 2.3.2.2.C – Density distribution of the adult individuals of the common sole: (a) prediction map for the present (2014-2018) with indication of center of gravity of distribution considering the model ST (circle) and ST+ENV (triangle) for the three periods (2018, 2035, and 2050 in yellow, orange and red, respectively), considering emission scenarios RPC8.5; (b) maps of anomalies observed in future scenarios compared with the present one. Red shades indicates decreasing values of density, while blue shades indicates an increase in density respect to present.

In the case of the spatial distribution of juveniles of the blackbellied angler, a northernmost shift of the center of gravity in 2050, considering the ST+ENV model, was observed. Moreover, an increase in the density values along the coast and a decrease in the central part of the basin was observed in both future scenarios (2035 and 2050).

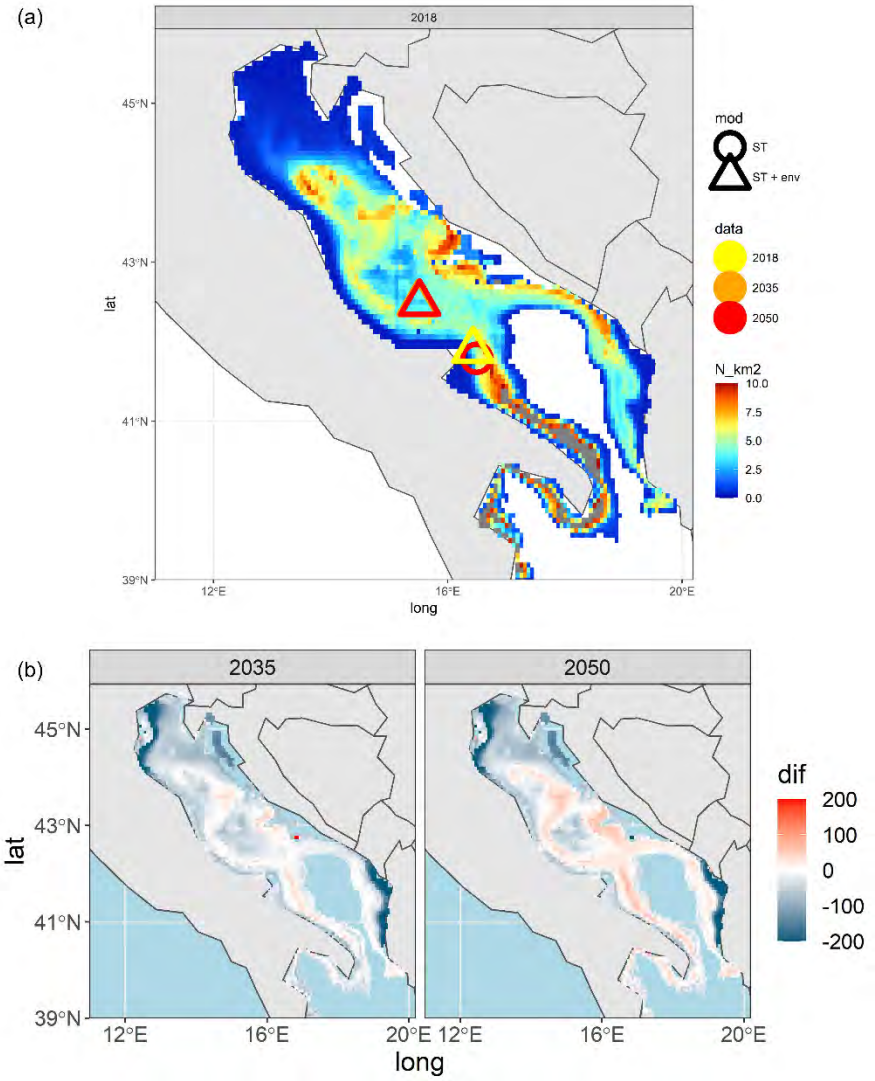

Figure 2.3.2.2.D – Density distribution of the juvenile individuals of the blackbellied angler: (a) prediction map for the present (2014-2018) with indication of center of gravity of distribution considering the model ST (circle) and ST+ENV (triangle) for the three periods (2018, 2035, and 2050 in yellow, orange and red, respectively), considering emission scenarios RPC8.5; (b) maps of anomalies observed in future scenarios compared with the present one. Red shades indicates decreasing values of density, while blue shades indicates an increase in density respect to present.

In this case, the position of center of gravity of juveniles of Atlantic horse mackerel showed differences considering both model ST and ST+ENV and different scenarios (present vs. future) applying the model ST+ENV. In addition, the anomalies distribution in future scenarios showed a strong decrease in the entire basin with a strong increase in some coastal areas, especially along the northernmost part of Italian coasts.

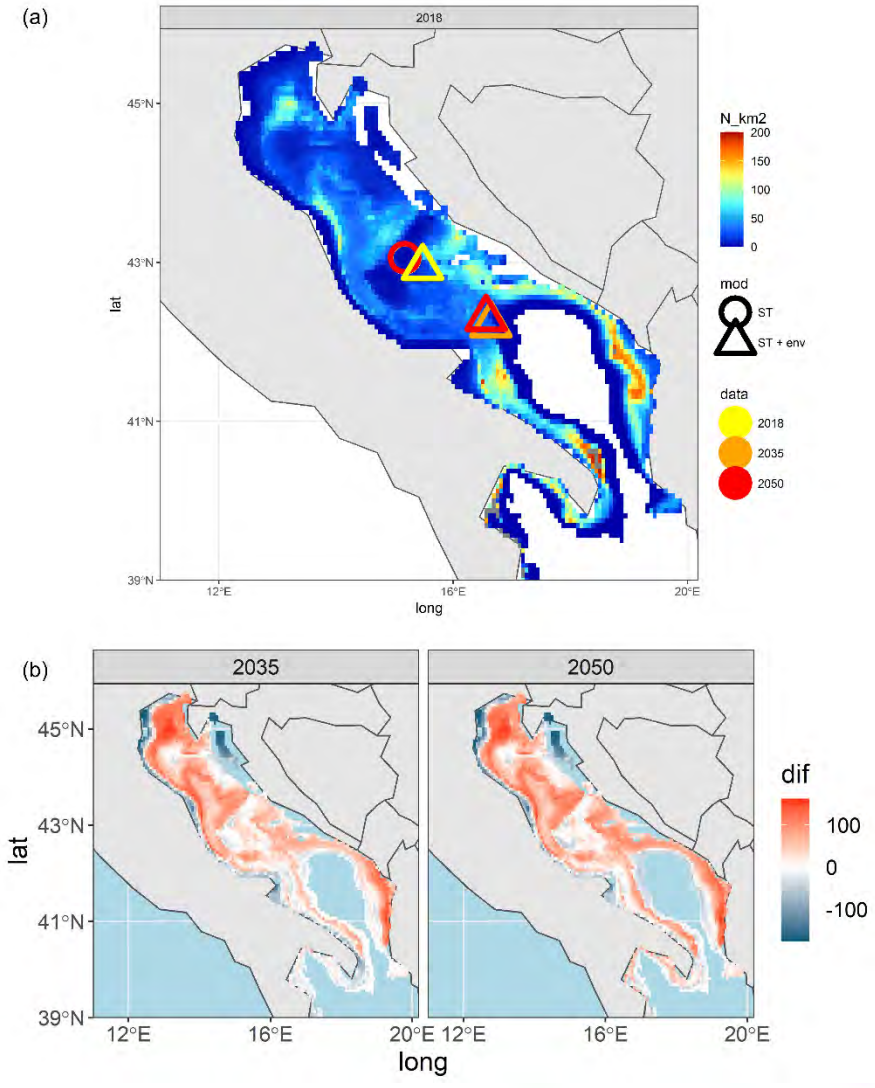

Figure 2.3.2.2.E – Density distribution of the juvenile individuals of Atlantic horse mackerel: (a) prediction map for the present (2014-2018) with indication of center of gravity of distribution considering the model ST (circle) and ST+ENV (triangle) for the three periods (2018, 2035, and 2050 in yellow, orange and red, respectively), considering emission scenarios RPC8.5; (b) maps of anomalies observed in future scenarios compared with the present one. Red shades indicates decreasing values of density, while blue shades indicates an increase in density respect to present.

In the case of distribution of juvenile individuals of the spottail mantis shrimp, the position of centres of gravity in different scenarios was more or less the same. However, an increase in of density were estimated in the deeper part of the Adriatic Sea and an increase was observed in the coastal part of the basin, both in the northern Adriatic that along Albanian coasts.

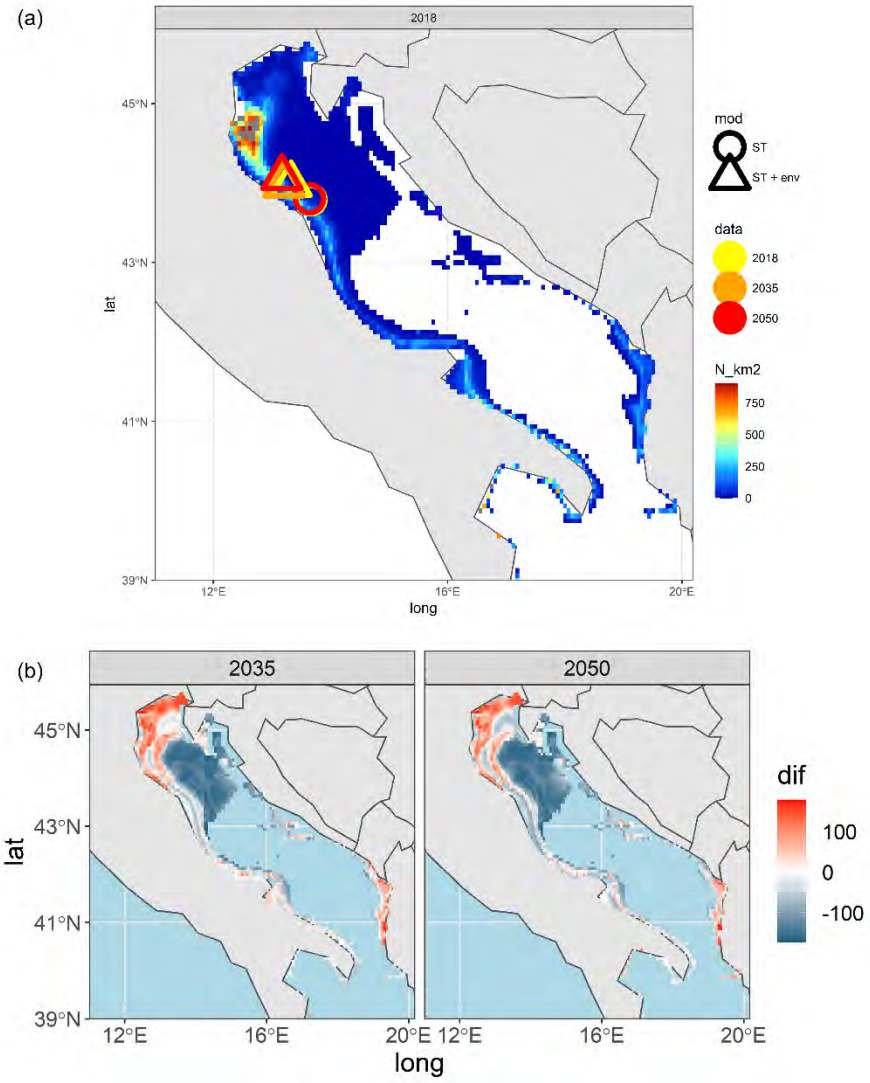

Figure 2.3.2.2.F – Density distribution of the juvenile individuals of the spottail mantis shrimp: (a) prediction map for the present (2014-2018) with indication of center of gravity of distribution considering the model ST (circle) and ST+ENV (triangle) for the three periods (2018, 2035, and 2050 in yellow, orange and red, respectively), considering emission scenarios RPC8.5; (b) maps of anomalies observed in future scenarios compared with the present one. Red shades indicates decreasing values of density, while blue shades indicates an increase in density respect to present.

2.3.3 MANAGEMENT IMPLICATIONS

The application of future scenario analysis based on species distribution model approaches can be a useful indicator of the possible evolution of essential fish habitats in the Adriatic Sea considering the evolution of climate change. The multiple statistical approaches used and a final ensemble model used resulted in a robust statistical analysis on this type of data. Results indicate that the center of gravity is not expected to move too much under future climatic conditions for most of the adults of investigated species. The most relevant shift expected is for European hake adults with the center of gravity moving toward northern part of the basin. Conversely for juveniles it is estimated a southern movement of the center of gravity for horse mackerel.

The implications in the adoption of this statistical approach to data analysis are different: the possibility to provide maps of hot spots distribution, maps of density in different years as well as maps of anomalies considering different future scenarios. These outputs are useful in a cross validation process of results provided by other types of models (e.g. Ecospace). Moreover, this type of approach can be very useful for management purposes of the fishery in the Adriatic Sea, because they can provide reference points to understand how change, over time and space, the distribution of target species in an optical of climate change scenario.

2.4 SMART TOOL

Another tool adopted in the FAIRSEA project for the identification of future management scenarios of fisheries in the Adriatic and Ionian region is the SMART bioeconomic model (Spatial MAnagement of demersal Resources for Trawl fisheries) (D'Andrea et al., 2020).

The rationale of the SMART model, as well as the workflow of the "smartR" R add-on package, can be summarized in the following logical steps:

1. Use landings and catch data, combined with VMS data, to estimate the spatial/temporal productivity in each cell of the spatial domain selected, in terms of aggregated LPUE by species;
2. Use catch data to estimate the Length-Frequency Distribution (LFD) and the Age-Frequency Distribution (AFD), by species, for each cell/time;
3. Use VMS data to assess the fishing effort by vessel/cell/time;
4. Combine LPUE, LFD/AFD and VMS data to model the landings by vessel/species/length class/time;
5. Estimate the cost by vessel/time associated to a given effort pattern and the related revenues, which are a function of the landings by vessel/species/length class/time (step 4);
6. Combine costs and revenues by vessel, at the yearly scale, to obtain the incomes, which are the proxy of the vessel performance. Incomes could be aggregated at the fleet level to estimate the overall performance;
7. Use estimated landings by species/age, together with survey data, to run MICE model for the selected case of study in order to obtain a biological evaluation of the fisheries.

Each of these steps corresponds to a different module of the package. Within SMART, the key aspect is represented by the optimization, at the scale of each vessel, of the fishing effort pattern at the monthly temporal scale. This is done through the iterative exploration of alternative vessel-specific effort patterns and evaluation of the corresponding catch converted in revenues and compared with the total costs to estimate the gains.
A detailed description of the method is available in D'Andrea et al. (2020).

2.4.1 METHODOLOGICAL APPROACH

Input datasets for landings of Italian and Croatian trawlers, effort (by VMS and AIS), economic parameters (fuel prices, price at the market of resources by species/ size class), and resources status (i.e. abundance indexes from MEDITS survey) were processed for the period 2016-2020.

The spatial productivity (monthly CPUE/LPUE[2] as grams of catch per meter of LOA and hour of fishing) was estimated using landings and VMS data, according to the procedure described in Russo et al. (2018, 2019). At the same time, the economic parameters needed to model the relationships between: 1) fishing effort and its related costs (crew salaries, fixed costs, etc.); 2) spatial fishing footprint and its related costs (i.e. fuel consumption); 3) yield and production costs (i.e. commercialization); 4) yield and revenues (using the prices at market of the different species by size class) were collected and integrated into the model.

2.4.1.1 Economic parameters

Market prices by species and length class, together with the price of fuel, were reconstructed using multiple sources of information:

- the public databases provided by the "Istituto di servizi per il mercato agricolo alimentare" (ISMEA http://www.ismea.it/flex/FixedPages/IT/WizardPescaMercati.php/L/IT) and by the Ministry of Economic Development (https://dgsaie.mise.gov.it/prezzi_carburanti_mensili.php).
- The EU fish market - 2020 edition (https://op.europa.eu/en/publication-detail/-/publication/7b4e4859-7004-11eb-9ac9-01aa75ed71a1);
- Carvalho and Guillen, 2021. Economic Impact of Eliminating the Fuel Tax Exemption in the EU Fishing Fleet. Sustainability 2021, 13(5), 2719; https://doi.org/10.3390/su13052719;
- FAO 2020. European price report. http://www.fao.org/3/cb0946en/cb0946en.pdf;
- GLOBEFISH - European Price Report - Jan 2021. https://issuu.com/globefish/docs/globefish_-_european_price_report_-_jan_2021.

2.4.1.2 Spatial domain and resolution

For this application of SMART to the case study of whole Adriatic and Ionian region (GSAs 17, 18, and 19), a 5 by 5 km square grid, coherent with the Copernicus statistical grid (https://land.copernicus.eu/eagle/files/documents-and-reports/t42-grid-approach), was used (Fig. 2.4.1.2.A). The cells covering areas deeper than 800 m in depth were excluded to reduce complexity and computational time required for the simulations, and also because biomass data derived from experimental surveys were carried out within 800 m in depth.

[2] In this work, considering the list of species selected, we assumed that the by-catch and the discards are negligible and so CPUE ~ LPUE

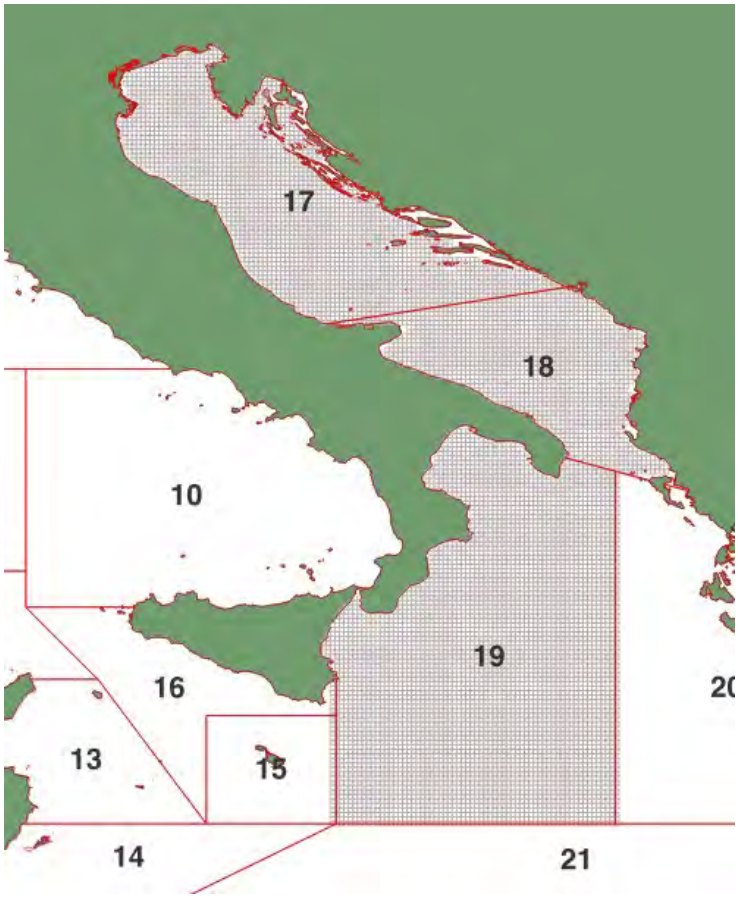

Figure 2.4.1.2.A – Area of study considered in the FAIRSEA project with indication of square grid of about 5x5 km used for the implementation of SMART on the GSAs 17, 18, and 19.

Temporal series of CPUE and AFD (proportion of age classes/length by species) were estimated for the cells of the grid, together with accessory economic models. These represent the basis for the simulation of different effort scenarios, including the *status quo*.

2.4.1.3 Fleets

The fleet included in the analyses is composed by the Italian and Croatian trawlers with LOA equal or larger than 15 m that is essentially the portion of the fleet equipped with VMS and/or AIS. The native VMS and AIS pings were pre-processed using the VMSbase platform (Russo et al., 2014) and coupled, at the level of single vessels and at a monthly scale, with logbook, landings and economic data (fuel consumption, etc.). The Figure 2.4.1.3.A shows the average hours of fishing across the time series (2016-2020) by cell for different fleet segments and

country (notice that fleet segments were used only for graphical purposes but not considered in the model, since SMART is an IBM in which the actual LOA of each unit is considered).

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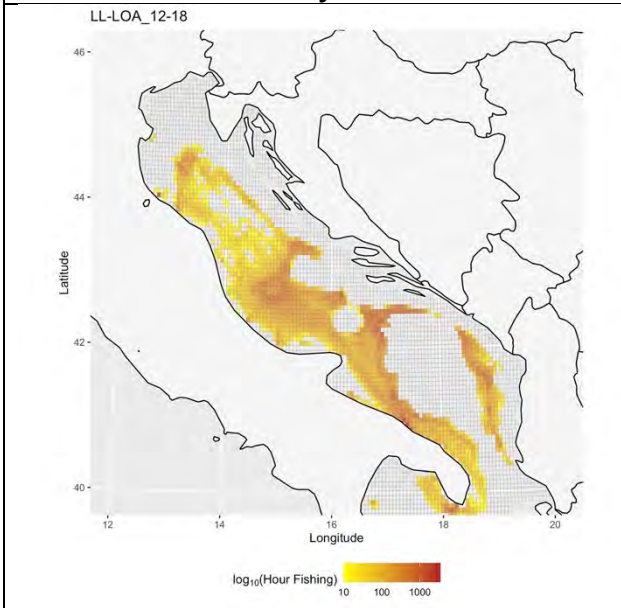	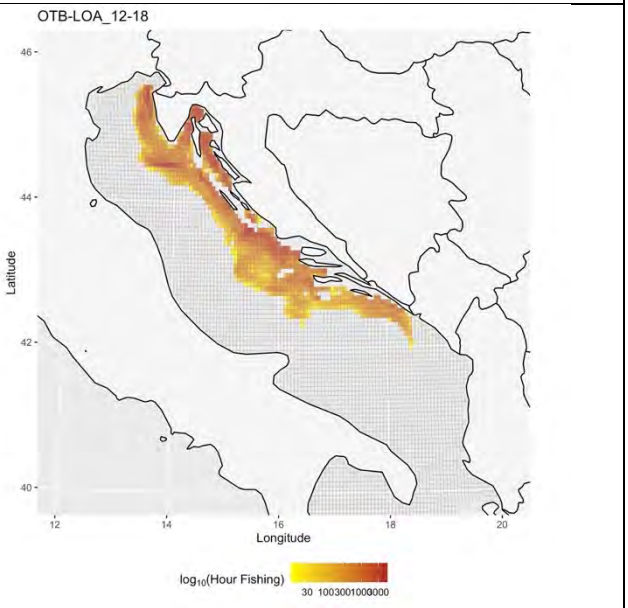
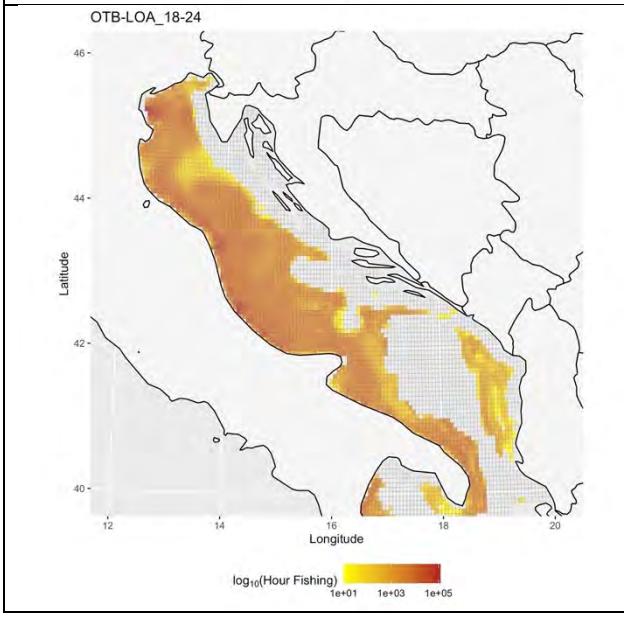	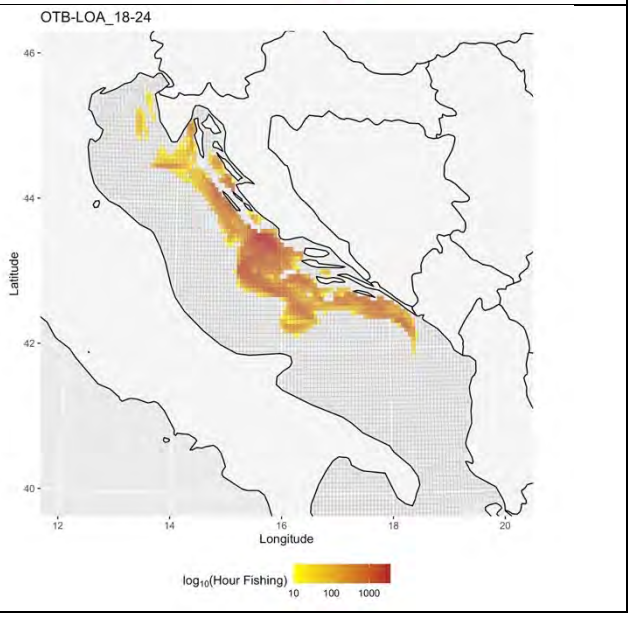

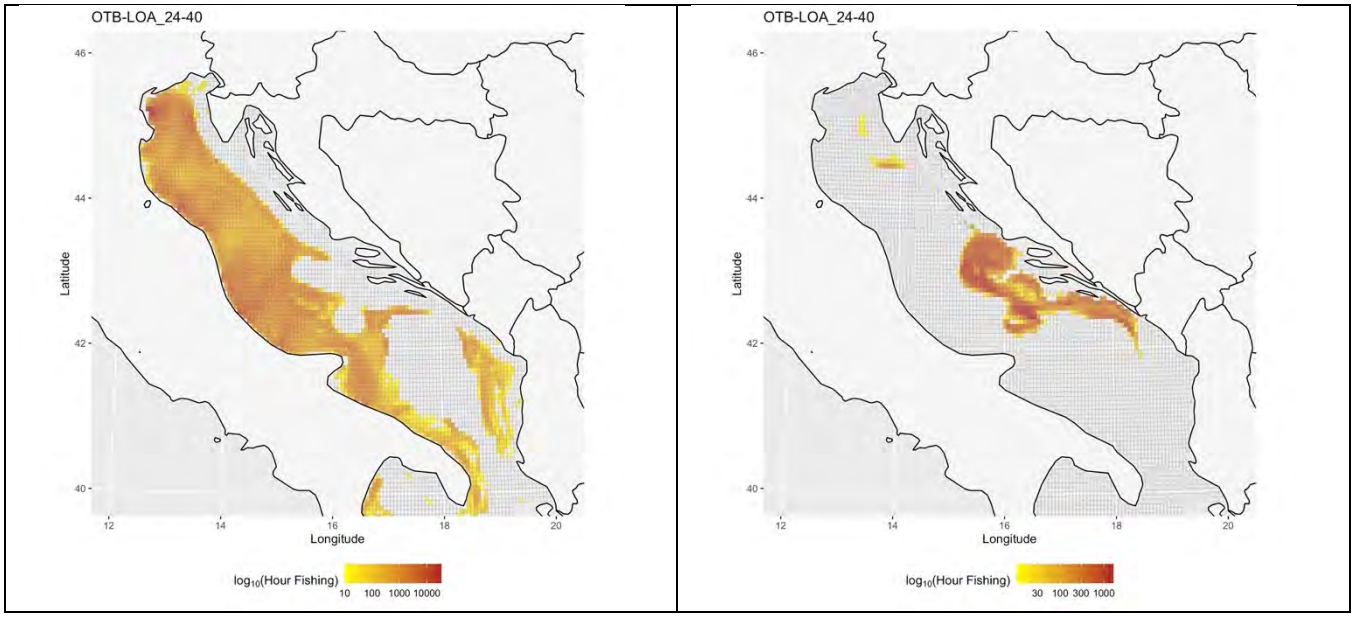

Figure 2.4.1.3.A – Map of the total yearly trawl fishing hours averaged over the years 2016-2020 and represented in logarithmic base 10 with a colour scale from yellow (low values) to red (high values).

2.4.1.4 Stocks

In the framework of this project, there were considered the following species:

- the giant red shrimp (*Aristaeomorpha foliacea* - ARS);
- the blue and violet shrimp (*Aristeus antennatus* - ARA);
- the deep-water rose shrimp (*Parapenaeus longirostris* – DPS);
- the European hake (*Merluccius merluccius* – HKE);
- the red mullet (*Mullus barbatus* – MUT);
- the surmullet (*Mullus surmuletus* – MUR);
- the Norway lobster (*Nephrops norvegicus* – NEP).

The main fishing grounds for these species are represented, by country, in Figure 2.4.1.4.A.

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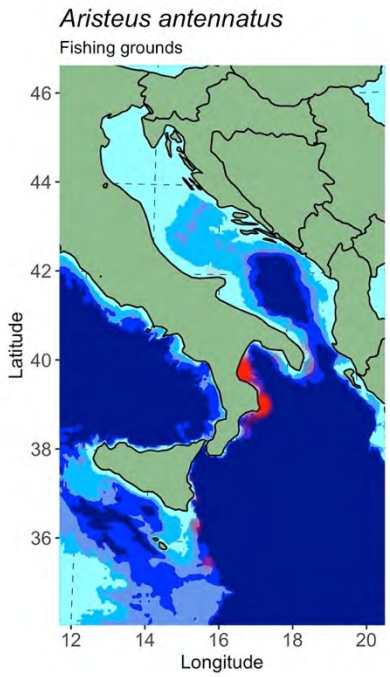	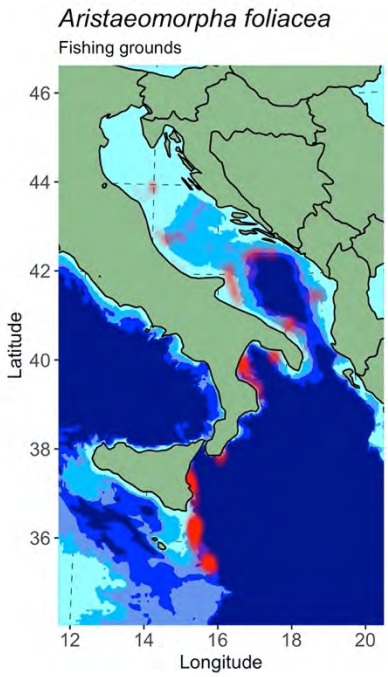
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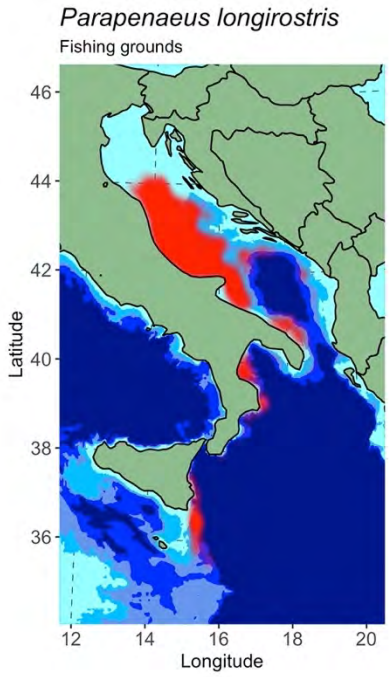	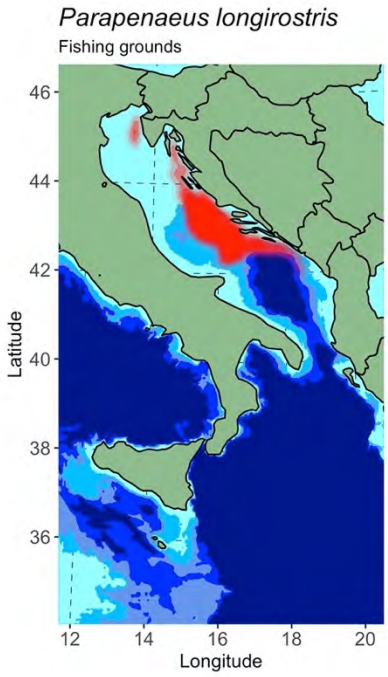
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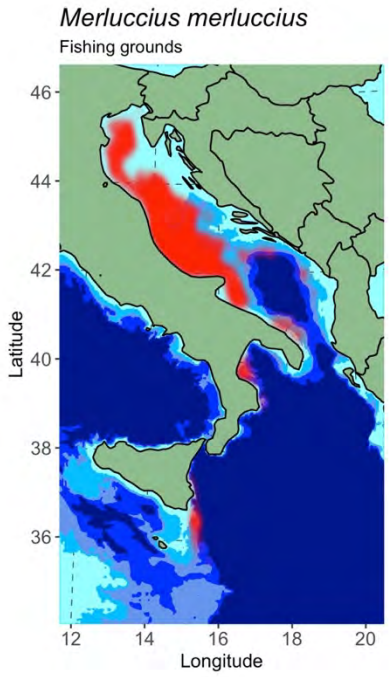	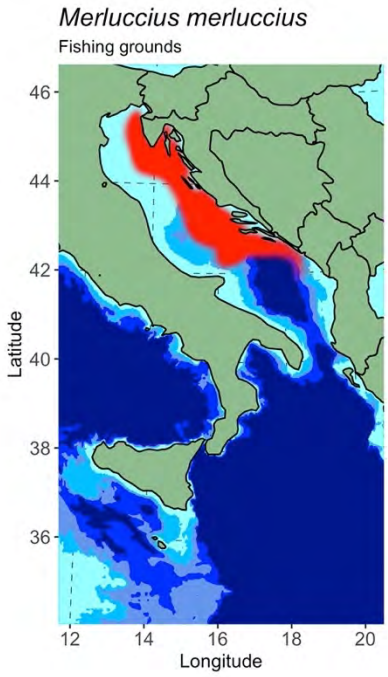
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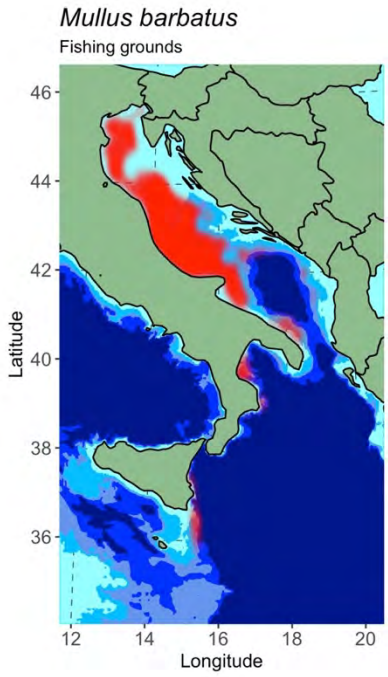	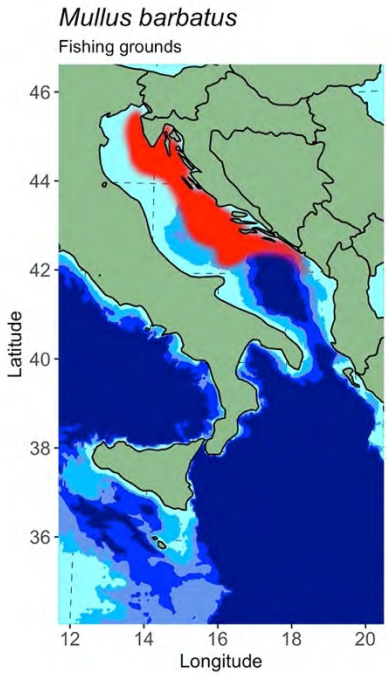
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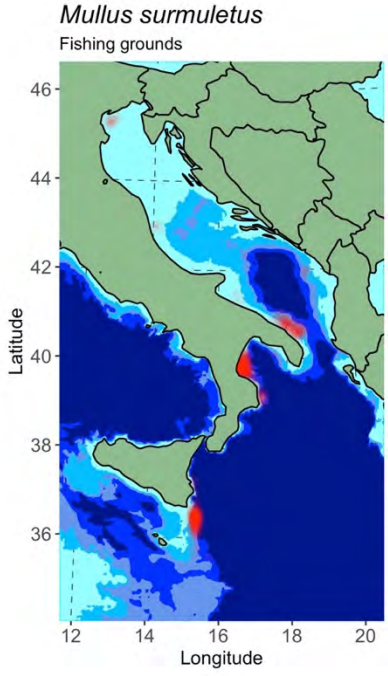	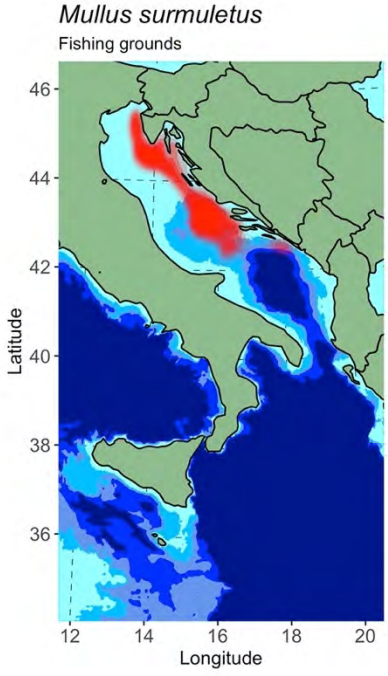
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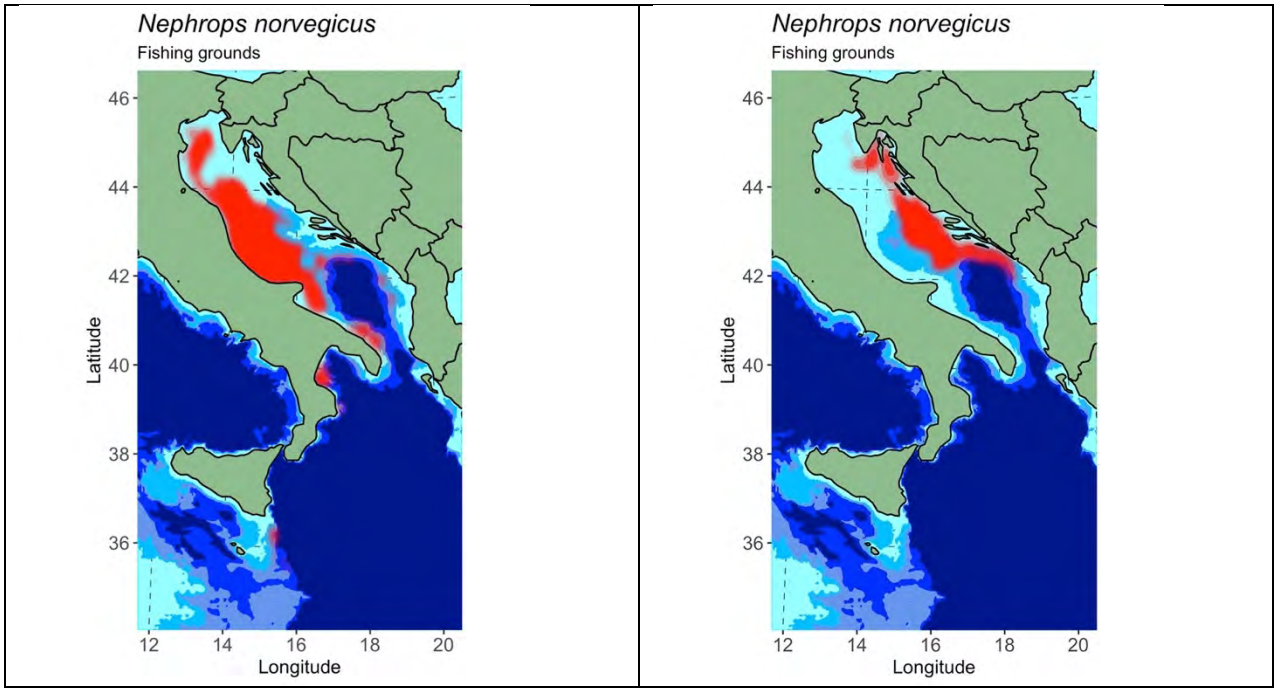

Figure 2.4.1.4.A – Spatial distribution of fishing grounds by species and country, for the period 2016-2020.

The average CPUE by species, month and depth are represented, by country, in Figure 2.4.1.4.B.

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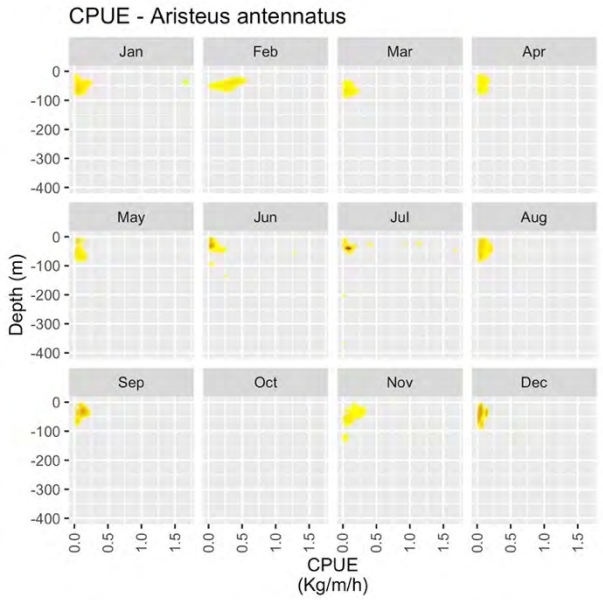	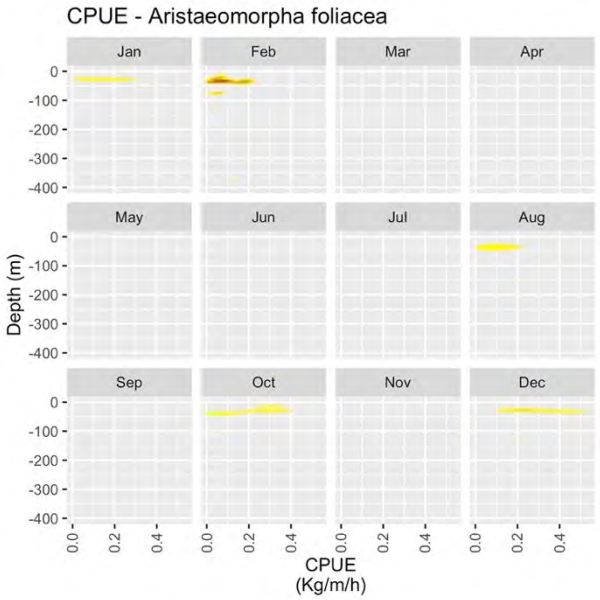
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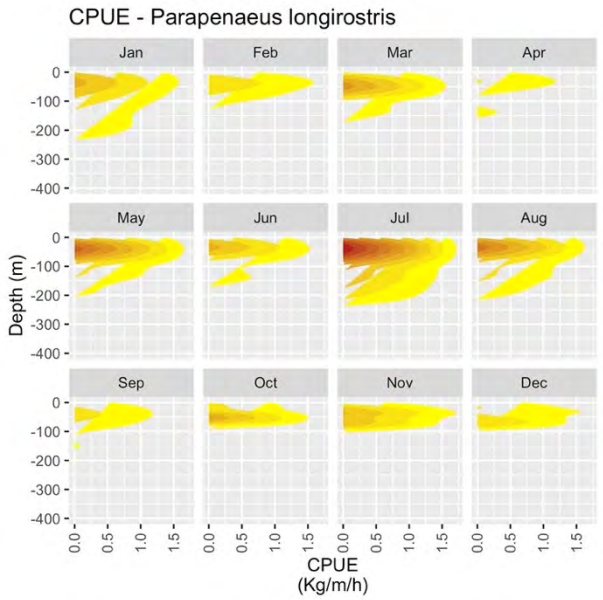	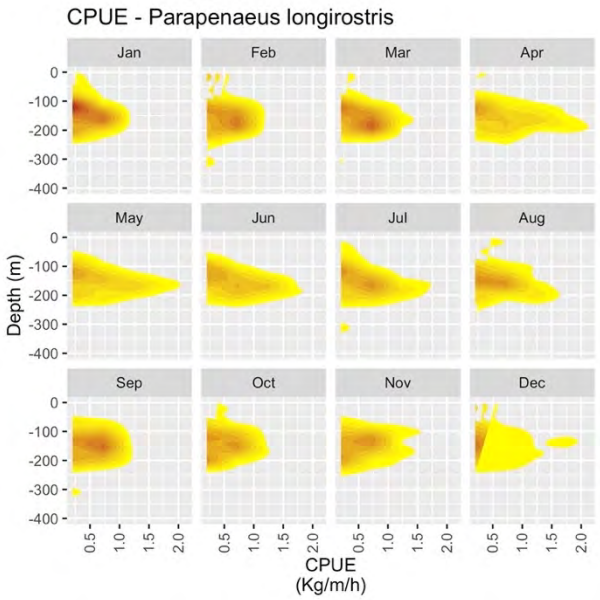
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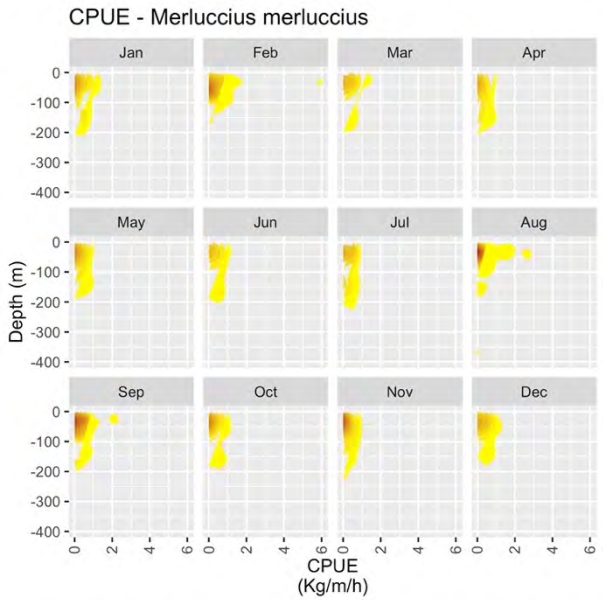

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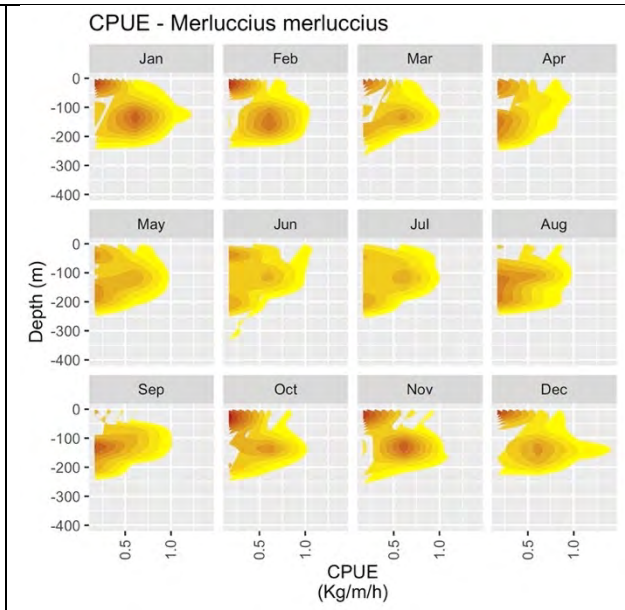

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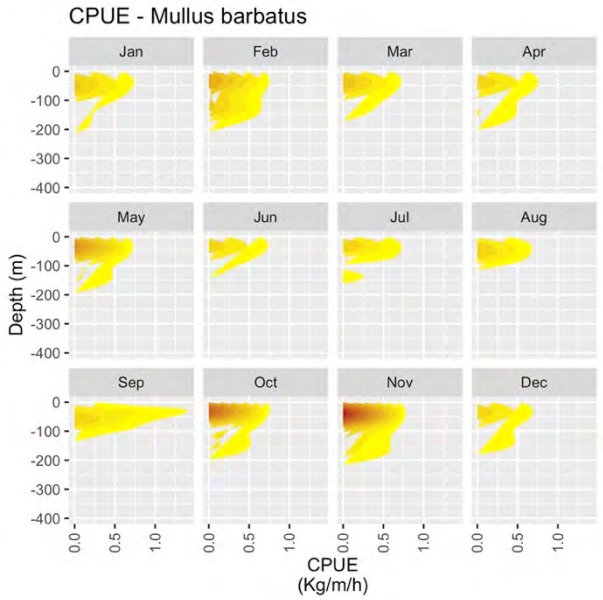

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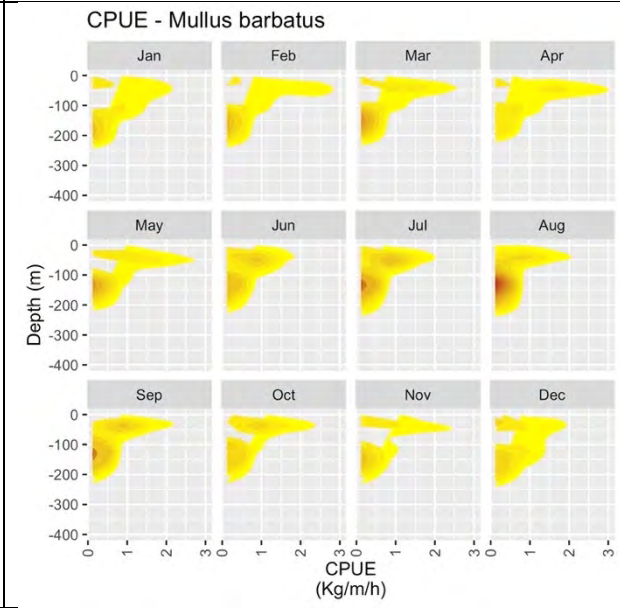

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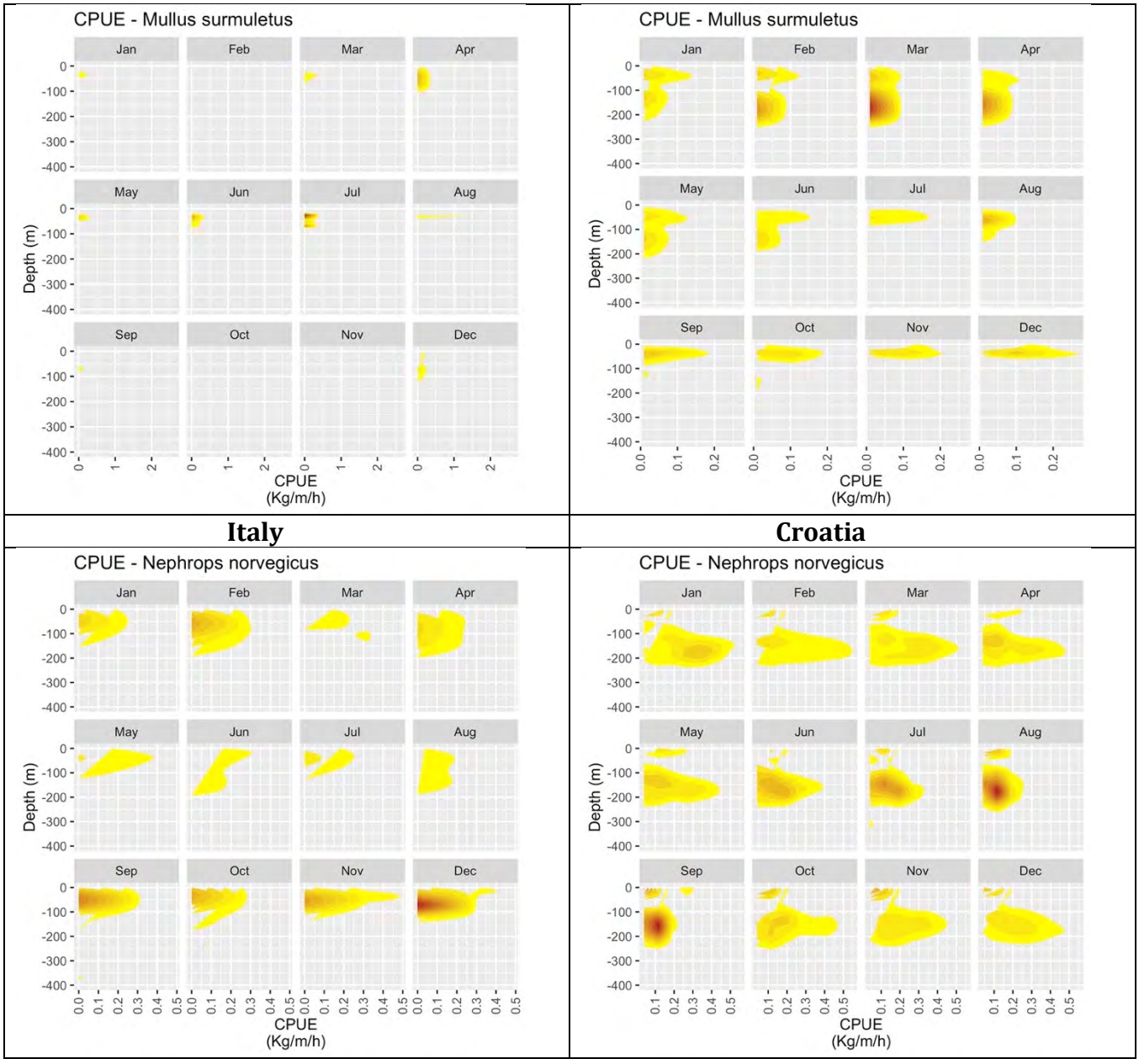

Figure 2.3.5 –CPUE by species, depth, month and country. The CPUE is inter-calibrated among vessels according to their LOA and represented with a colorscale describing the density of the observations (yellow-low, red-high).

2.4.2 SIMULATED SCENARIOS

The SMART model is devised to estimate the potential effect of whatever management actions on the effort (including reduction of fishing capacity, effort, or spatial closures) instead of directly setting a desired value of F for the target stocks and evaluate the related effects of this

new exploitation pattern. Thus, the SMART model was used to assess the potential effect of different management scenarios including:

- **Scenario #1:** *Status quo* (including the presence of the Pomo Fisheries Restricted Area);
- **Scenario #2:** Scenario #1 + closure of the 6 nautical miles zone (coastal area);
- **Scenario #3:** Scenario #1 + effort reduction up to 30% in 3 years;
- **Scenario #4:** Scenario #1 + Extended late summer ban (total stop in September/October, -40% of the normal effort in November).

In the SMART modelling approach, the effort displacement resulting from the scenario simulation is obtained according to an individual based optimization of the observed pattern of effort of each fishing vessel following a strategy of profit maximization. When the adaptation of each vessel to the simulated scenario is obtained, it is possible to aggregate effort and catches to obtain a new set of predicted effects on fisheries. Then, the new exploitation pattern is used to simulate the impacts on the stocks. The effects on the stocks are summarized by mid and long-term trends of the Spawning Stock Biomass, an acknowledged index of stock condition.

2.4.3 RESULTS

The distribution of the trawling effort by country and depth range (Fig. 2.4.3.A) indicates that coastal closure is likely to largely impact on both Italian and Croatian fleet, which deploy a relevant portion of their effort in this area. However, the Italian fleet also operates on deeper fishing grounds. This scenario actually is the one associated with the largest changes in the fishing footprint. Conversely, the Scenarios 2 to 4 returned small differences in the overall fishing footprint of the two fleets with respect to the *status quo* of Scenario 1.

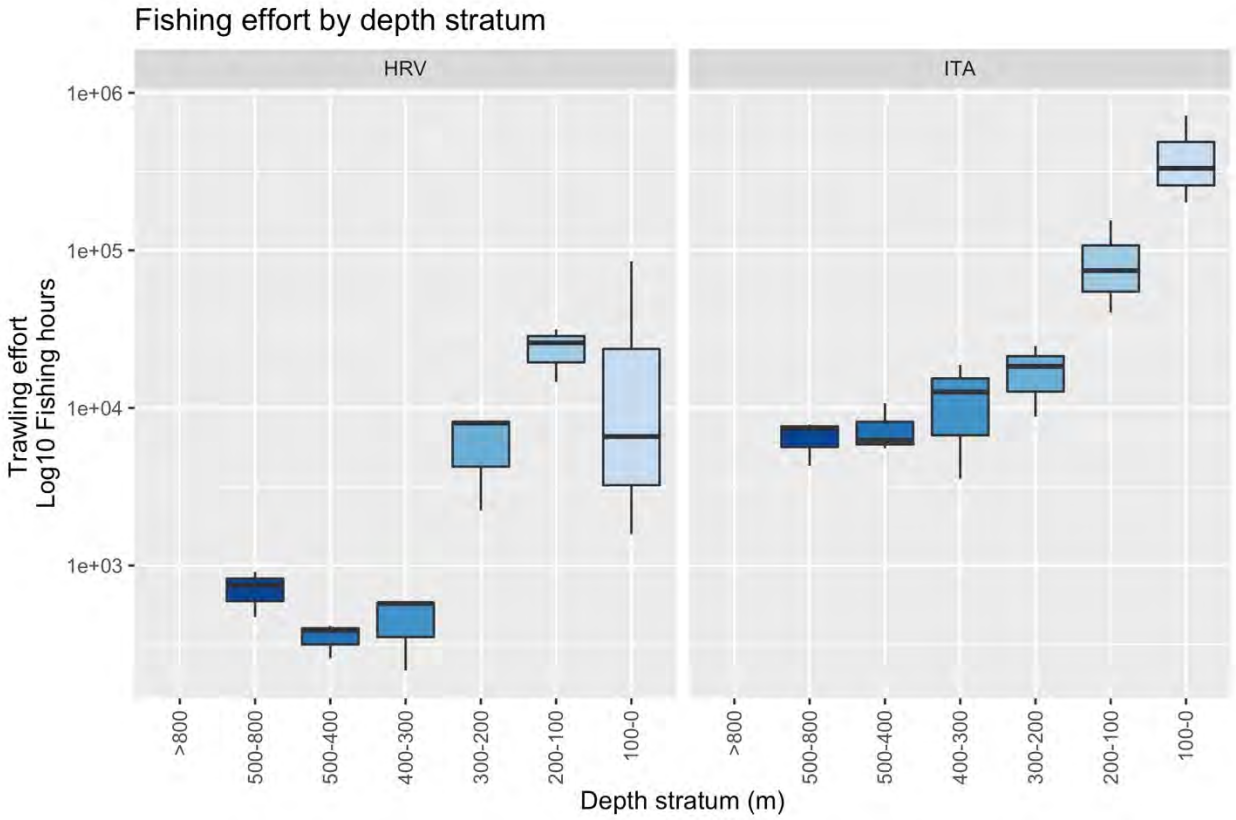

Figure 2.4.3.A – Boxplot of the average fishing effort by depth stratum and country.

The Scenario #2 that consider the Scenario #1 + closure of the 6 nautical miles zone (coastal area) clearly shows the complete elimination of fishing effort around the coasts and the subsequent redistribution of the lost fishing time into the more distant fishing areas. It is also noticeable the attractiveness of some particular area with a high revenue potential with a large increase of effort. The other three scenarios which entail a general reduction of total effort, mainly highlight the general decrease across all the regions, except for some small areas affected by a net increase of fishing pressure.

From an economical point of view, the different scenarios are expected to determine different mid-term consequences for the fleets and are associated to largely different impacts at their entry into force (Fig. 2.4.3.B).

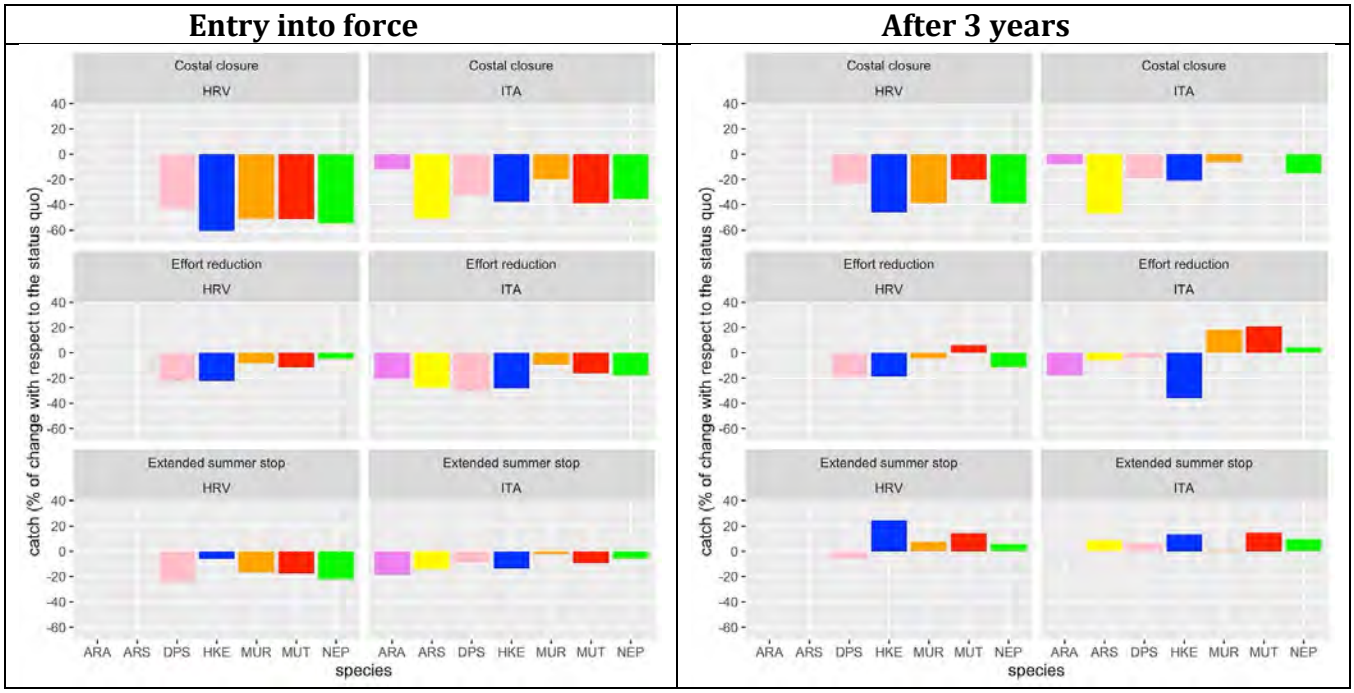

Figure 2.4.3.B – Simulated consequences, in terms of variation in percentage of catches with respect to the *status quo*, associated to each scenario at its entry into force and after 3 years of implementation.

The potential effects of the coastal closure (when compared to the *Status quo*) at its entry into force can be summarized in a drastic decrease of catches for both fleets, and in particular for the Croatian one. After 3 years, this decrease is still present although it is smaller. In contrast, the other scenarios are associated with less impacting decreases at the entry into force and, moreover, are likely to determine an increase of catches after 3 years, for some or all stocks considered. The extended summer ban, in particular, is expected to determine an increase of catches for almost all the stocks.

The biological consequences for the stocks also vary across the different scenarios (Fig. 2.4.3.C).
It is interesting to notice that the *status quo* is expected to determine positive results for the European hake and the Norway lobster, two species largely distributed also in deeper fishing grounds. For NEP, the Scenario1 is the best one and for HKE it is the second. Conversely, more coastal species such as MUT show benefit only in association with the Coastal closure.

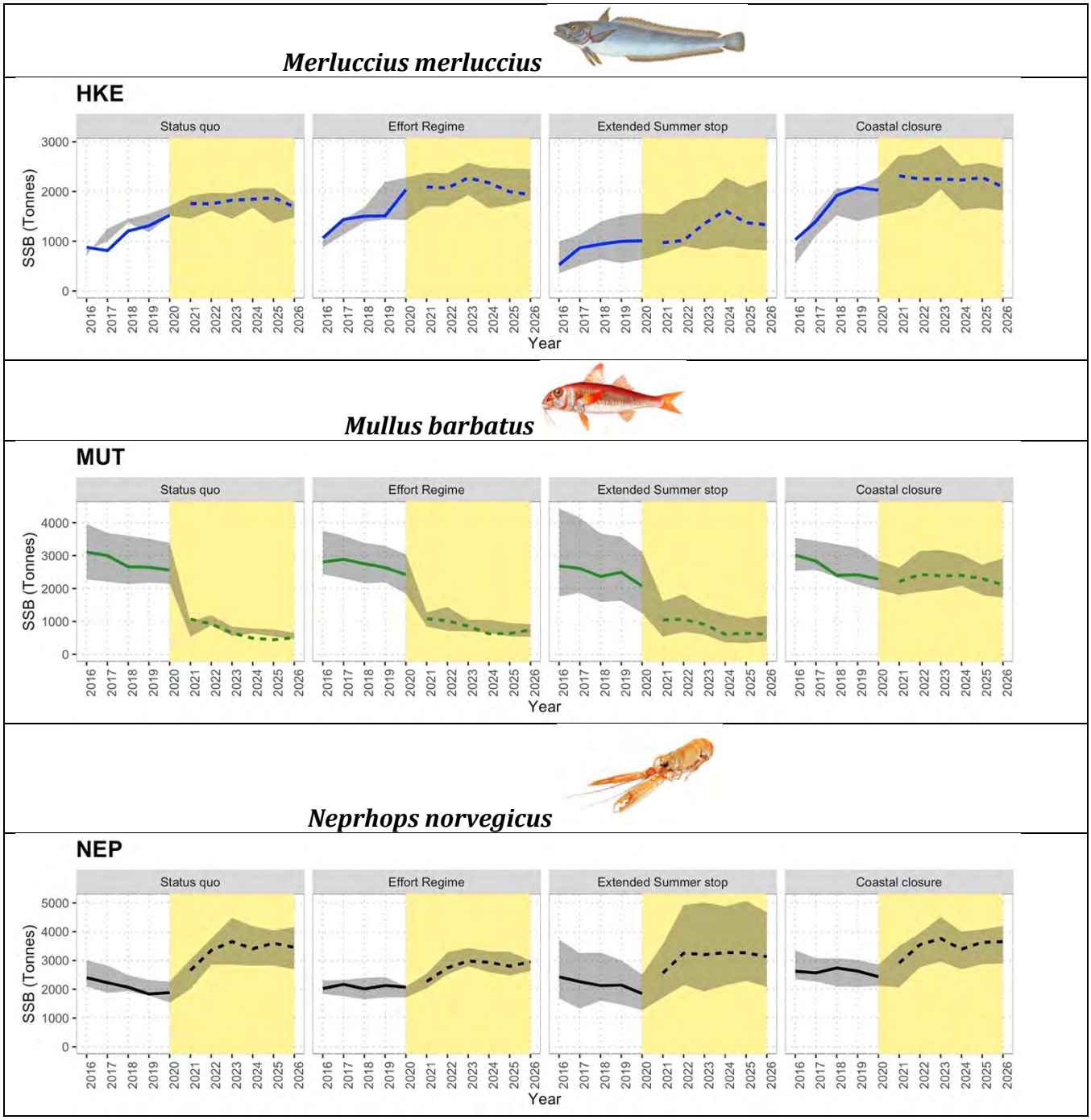

Figure 2.4.3.C – Predicted trends of the Spawning Stock Biomass for some key stocks by scenarios. The prediction is limited to the next five years.

2.4.4 MANAGEMENT IMPLICATIONS

The Adriatic Sea is a "closed" system in which the trawl fishing fleets operate exploiting an array of resources that are almost completely accessible (there are not no fishing zone with the exception of the Pomo pit Fisheries Restricted Area and the 3 nautical miles coastal buffer). The Adriatic Sea is also one of the most fished basins worldwide. In this way, we have high levels of fishing effort combined with stocks without refugees. In this context, the consequences of different management measures should be investigated considering the redistribution of the effort determined by actions such as the establishment of Fisheries Restricted Area or temporal closures. Actually, this application of SMART testifies that some largely spatially impacting actions such the closure of the 6 nautical miles coastal buffer not only implies the loss of most fishing grounds (with obvious consequences for the fishers) but could also determine an increase of the effort in the remaining fishing grounds. Considering also that, from an environmental point of view, the Adriatic Sea is an "oriented" system in which most of the species use the western and the eastern subareas during different life stages, it is clear that appropriate management actions should be identified considering all these aspects.

Some of the previous considerations apply also for the Ionian Sea, where the topology of the system limits the fishing grounds in the coastal areas.

The scenarios evaluated in this section of the FAIRSEA project using the SMART platform scored differently with respect to economic and biological consequences. Given that the safe conditions of stocks are the priority, it seems that protecting some critical areas in the deeper grounds is not enough to guarantee a sustainable exploitation of demersal resources. While the recent introduction of the Pomo pit Fisheries Restricted Area is showing interesting and promising results, some stocks in the coastal areas are still overexploited and associated with worsening trends. Here, we suggest that some integrated scenarios such as the progressive decrease of the trawling effort and/or an extended late summer temporal ban could significantly improve the situation, also leading to positive effects for the fleet after some years.

2.5 BEMTOOL

The application of the bio-economic model BEMTOOL is fully described in the D4.6.2 of the FAIRSEA project. It was applied to evaluate how changes in fishery-driven impacts (e.g. fishing effort, gear selectivity) and management or fishing strategies (e.g. closed season/areas, changes in fishing opportunity, change in selectivity), affect stock of target species and fisheries dynamics in terms of SSB, landings, discards and economic performance.

2.5.1 METHODOLOGICAL APPROACH

The BEMTOOL tool is a multi-fleet and multiple species bio-economic platform in R language, mimicking the effects of management on stocks and mixed fisheries (Ulrich et al. 2012; Sanchez-Lizaso et al., 2020), at a monthly time scale. It allows to understand length/age-specific selection effects as well as effects of compliance with landing obligation; to estimate discard and its survivability, economic and social performances as well as reference points such as FMSY, MSY, MEY and the ones linked to the SSB.

It consists of six operational modules characterized by different components: biological (age/length structured dynamic model, Lembo et al., 2009), Impact, Economic, Behavioural, Policy and Multi Criteria Decision Analysis (MCDA) (Rossetto et al, 2014; Spedicato et al., 2016; Russo et.al, 2017). This last combines two multi-criteria techniques: the multi-attribute utility theory (MAUT) and the Analytic Hierarchy Process (AHP) (Rossetto et al., 2014). Further details about the modelling process of different variables (discard, growth, natural mortality, economic indicators, etc…) are reported in Deliverable 4.6.2.

BEMTOOL mimics stock assessments based on age-structured (analytical) or global assessment methods. In this application the key stocks are the ones regulated by the Recommendation GFCM/43/2019/5, i.e. common sole (GSA 17), European hake (GSA 17-18), red mullet (GSA 17-18 and 19), Norway lobster (GSA 17-18), and deep-water pink shrimp (GSA 17-18-19). In the simulations also European hake and red mullet stocks in the GSA19 were considered. In addition, this tool uses official time series of transversal variables such as i) landings and effort from Annual Economic Report (AER) and Fisheries Dependent Information (FDI)Data Call; ii) official time series of socio-economic variables (e.g variable/fixed/capital costs, etc…) by fleet segment from National Statistics (this data were obtained by the FAIRSEA Data Call for Italy). and AER.

Concerning the fleets considered, the model included 28 fleets, trawlers and small scale, from small (<12 m LOA) to large scale (>24 m LOA), among which 16 Italian, 2 Slovenian, 4 Croatian, 1 Albanian and 4 Montenegrin.

The price dynamic has been modelled as a function of the variation of landing (modified from Salz et al., 2011) through an elasticity coefficient; the variable costs have been simulated as a function annual fishing activity, while the fixed or non-variable costs are based on the annual

GT; the capital costs depend on the annual GT (Saltz et al., 2011; Frost et al., 2013) and finally, labour costs have been modelled according to the crew share system.
According to the last endorsed stock assessment (SAC, 2019 and STECF EWG 20-15), the stocks of common sole (GSA17) and Norway lobster (GSA17-18) are close to a sustainable state (Table 2.5.1.a, Figure 2.5.1.A). On the contrary deep water rose shrimp (GSA17-18-19), European hake (GSA17-18) and red mullet (GSA17-18) are overexploited ($F_{current}/F_{0.1}$ between 3.0 and 2.0), while red mullet in GSA 19 appears in a less severe overexploitation status. The available stock assessments cover different time periods.

Table 2.5.1.a - Current status (updated to the latest available assessment) of the target stocks.

Stock	F_{curr}	F_{low}	F_{upper}	F_{MSY}	F_{curr}/F_{MSY}	Biomass	Assessment
Sole 17	0.50	0.33	0.67	0.49	1.0	↓	GFCM WGSAD 2019
European hake GSA17-18	0.41	0.12	0.25	0.18	2.3	↑	STECF_EWG 20-15
Red mullet 17-18	0.69	0.23	0.47	0.34	2.0	↑	STECF_EWG 20-15
Norway lobster 17-18	0.40	0.24	0.49	0.36	1.1	↓	STECF_EWG 20-15
Deep-water rose shrimp GSA17-18-19	1.49	0.33	0.68	0.50	3.0	↑	STECF_EWG 20-15
Red mullet 19	0.60	0.27	0.55	0.40	1.5	↔	STECF_EWG 20-15
European hake 19	0.32	0.10	0.20	0.14	2.2	↑	STECF_EWG 20-15

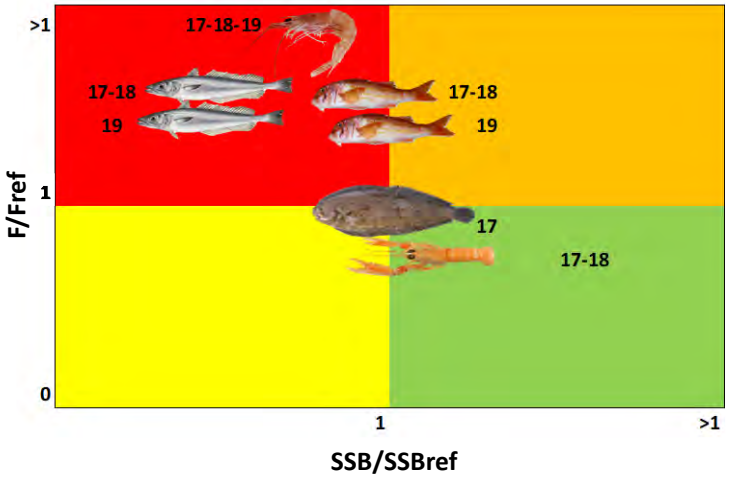

Figure 2.5.1.A - Kobe plot representing the status of the stocks in relation to the reference points.

The rationale behind the selection of future scenarios to be tested followed the Recommendation of GFCM/43/2019/5 and its management targets. In addition, it was taken into consideration also the concept of mitigating species underutilization under scenario of fishing effort reduction for those stocks considered sustainably exploited.
All the scenarios incorporated a transition phase 2020-2021 that includes the effort reductions that have been already implemented according to the Recommendation GFCM/43/2019/5, i.e. 12% reduction for OTB and 16 % for TBB in respect to the annual effort exerted in 2015 or on average in the period 2015–2018.
Specifications of the scenarios tested are:

- **S0 *status quo***: characterized by no variation compared with 2021. Thus, all the measures already in place(seasonal fishing ban, existing closed areas such as Pomo FRA) are included;
- **S1 effort reduction:** linear reduction of effort of 40% until 2026 for trawlers and beam trawlers (rapido) toward the $F_{MSY,\ combined}$ equal to 0.35. This value of $F_{MSY,\ combined}$ was estimated considering the landing value of each stock and its F_{MSY} proxy according to formula below:

$$F_{MSY,combined} = \frac{\sum_{s=1}^{S}(ValueLand_s * F_{MSY,s})}{\sum_{s=1}^{S} ValueLand_s}$$

  This strategy was adopted to mitigate possible underutilization of certain stocks, given that reductions of fishing effort would have affected a mixed fisheries, in which stocks with a different level of exploitation are the targets, and in our case some stocks are even heavily overexploited, while other are close to a sustainable exploitation.
- **S2 composite scenario**: this scenario is characterized by a combination of measures that are:
  - fleet selectivity improvements;
  - spatial closure areas (within 6 nautical miles, until December) taking into account the presence of nurseries of the main target species in the same areas and the fishing footprints in the area from AIS (global fishing watch) ;
  - 2 months of fishing bans for other gears (PGP 17-18 and DFN Croatia fishing ban in February and May; HOK GSA 18 in March and May);
  - linear reduction of 25% in Fishing Days (FD) for trawlers and rapido fleets.

All the future scenarios tested were run until 2030. Indicators used to evaluate the performance of scenarios were the SSB, fishing mortality, overall catches by stock, total landing, total revenues, profits, wages, employment and current revenues to break-even revenues (CR/BER), considering both the Maximum Economic Yield (MEY) and the F_{MSY} value

and its range (F_{low} and F_{upper}). All setting are detailed in the second deliverable of activity 4.6 ("D4.6.2 Management scenarios of policy using BEMTOOL outputs").

2.5.2 RESULTS

The two scenarios, S1 and S2, analysed and compared with the *status quo* S0 showed pros and cons. In S1, the fishing mortality would get closer to the reference points for certain stocks such as European hake in all three GSAs, red mullet in GSA19 (Figure 2.5.2.A), but for other ones it would be even higher (as shown for deep water rose shrimp in D.4.6.2) or lower with a risk of underutilization of the stock productivity as showed in Figure 2.5.2.B for Norway lobster in GSA17-18 and the common sole in GSA17.

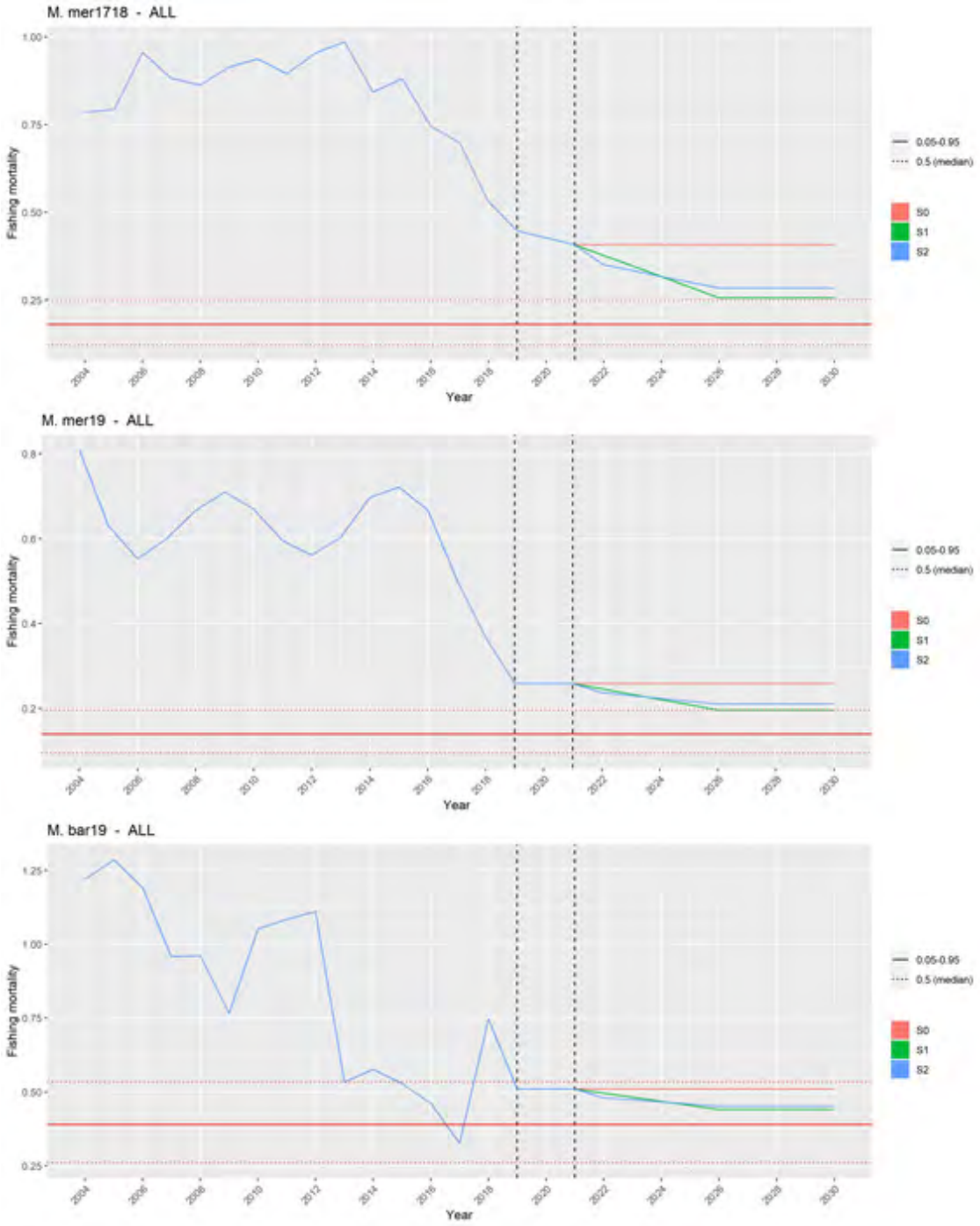

Figure 2.5.2.A - Effects of the scenarios on the fishing mortality of stocks of European hake and red mullet.

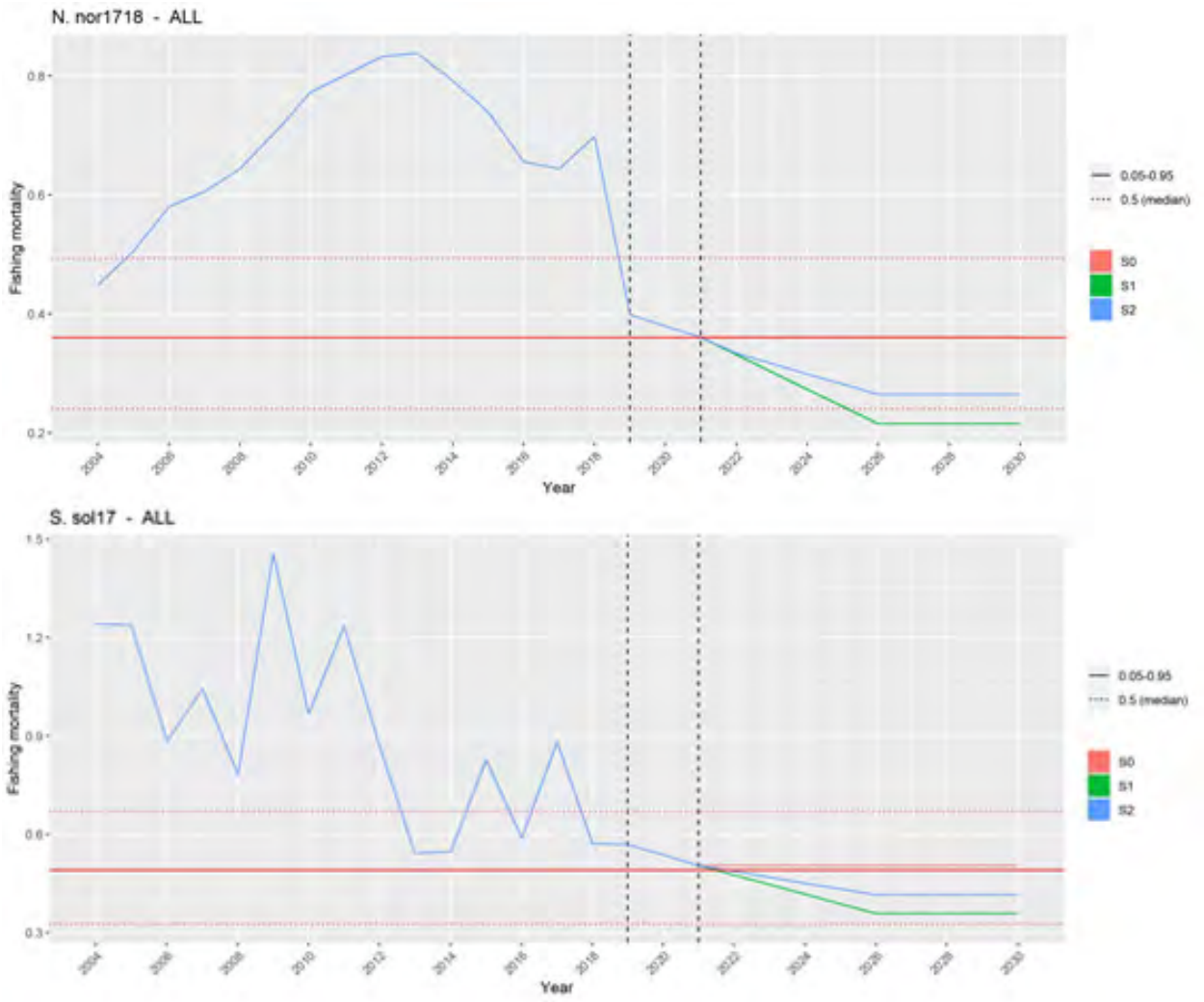

Figure 2.5.2.B - Effects of the scenarios on the fishing mortality of stocks of Norway lobster and common sole.

Both scenarios S1 and S2 improved SSB in comparison with S0 with similar performance for all the stocks except for those of red mullets in GSA17-18 in which the scenario S2 seems to be more effective than S1 in mid-term (Figure 2.5.2.C).

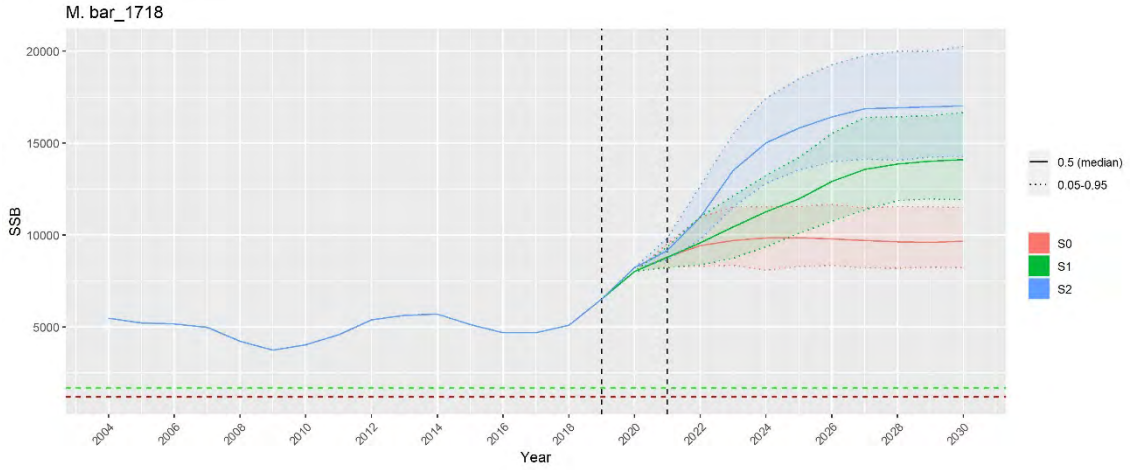

Figure 2.5.2.C - Effects of the scenarios on the SSB of red mullet stock in GSA17 and 18.

Regarding the economic indicators the situation is different according to the fleet and the species, but for most of the indicators scenario S2 performs better than scenario S1. This is true especially for the trawlers, as S1 is often better for fleets using nets or longlines. These latter fleets, in fact, would take higher advantage by the trawler limitation in S1 as in S2 the fishing activity of the small scale fisheries is also limited for two months by year. This overall effect is due to the mixed fisheries and it is evident for species like European hake and red mullet.

A sharp decrease of the economic indicators, such as revenues and profits was observed for trawler fleets in some species. In particular, the losses in the short term are more pronounced for the red mullets in GSA17 and 18 especially for Italian trawler fleets even if the recovery is expected since the second year from the implementation of the measures, and in the medium term such decrease is mitigated by the increase of stock productivity due to the stock recovery. Sole, instead, is fished sustainably and consequently the fisheries by beam trawlers would be more negatively impacted by the management measures compared to the other fleets for underutilization issues. In this case, both for S1 and S2, the situation would deteriorate compared to the status quo, though S2 performs better than S1 and R/BER would not fall below 1, as for scenario 1, though the uncertainty is high.

Overall the predictions highlight that the situation of the wages could be not negatively impacted by the management measures except for beam trawlers and it would be possible to see some improvements in the future under the current crew share system of wage. The forecasts of the employment highlights a possible deterioration of the situation mostly due to the losses in the short term, determined by limitations in job opportunities, also in this case the scenario S2 would have a mitigated impact compared to scenario S1.

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2.5.3 MANAGEMENT IMPLICATIONS

All the results provided from BEMTOOL modelling approach highlight that the integrated scenarios could provide more wise solutions under the economic perspective, not compromising the biological objectives. Indeed, the fishing mortality of European hake, the most exploited species, would get close to F_{upper}, likewise under scenario S1, in which, however, the economic impact would be higher. A strategy based on the improvement of the exploitation pattern, increasing selectivity and protecting the nursery areas, combined with a reasonable reduction of fishing activity could represent a trade-off toward the objectives of a biological and economic sustainability. This is also close to the indications provided by the stakeholders for the implementation of management scenarios in BEMTOOL. In fact, inputs stressed to avoid the lone limitation of the fishing activity as a mid-term management strategy, giving more weight to the economic component as summarised in the results of the Multi Criteria Decision Analysis (Figure 2.5.3.A) under different weighing of the biological, impact and economic indicators.

The results, management implications and discussion are fully reported in the second deliverable of activity 4.6 ("D4.6.2 Management scenarios of policy using BEMTOOL outputs").

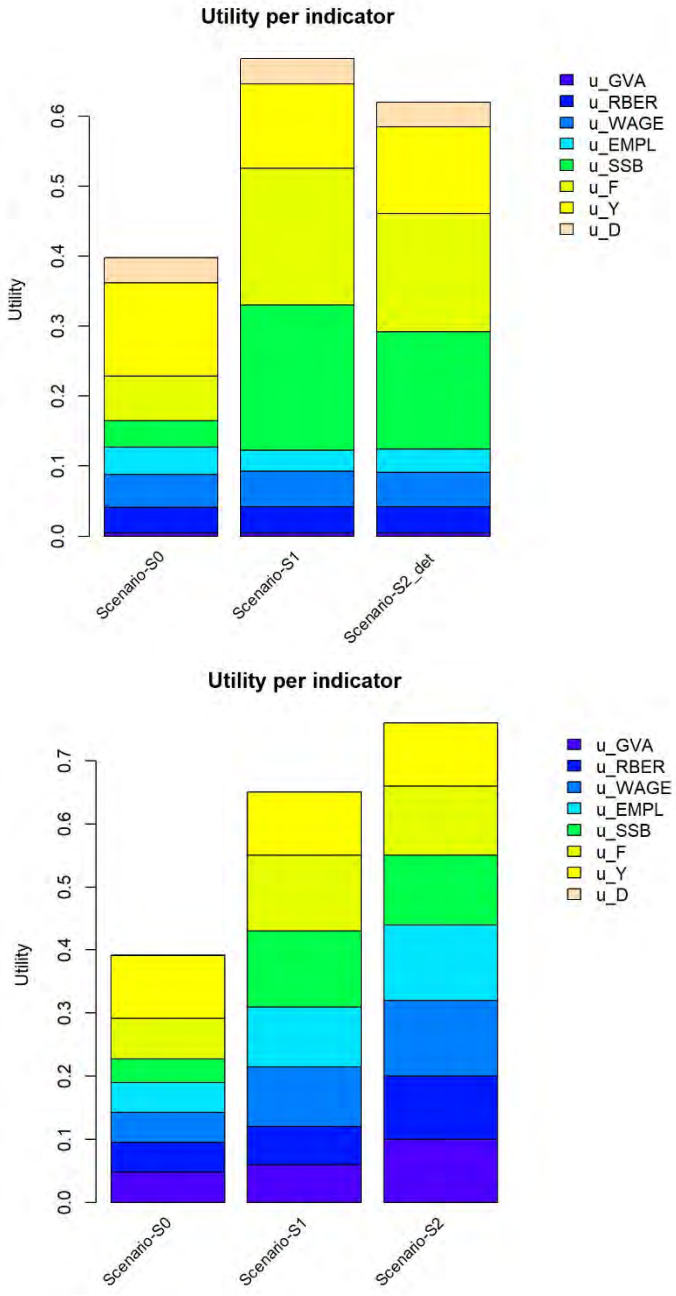

Figure 2.5.3.A - Results from the Multi Criteria Decision Analysis.

2.6 ECOSPACE

Another modelling approach considered one of the most suitable tools for evaluating the direct and indirect effects of anthropogenic pressures on spatial scale ecosystem dynamics is those built in the Ecopath with Ecosim and Ecospace (EwE) (Adebola and Mutsert, 2019; Couce Montero et al., 2021; Puts et al., 2020; Serpetti et al., 2021; Steenbeek et al., 2020). Ecopath is a mass balance food-web model representing a snapshot of the ecosystem in a given year; Ecosim models the temporal dynamics and Ecosim provides simulations of implemented model through the use of foraging arena theory (Ahrens et al., 2012) where each predator/prey interaction is defined by vulnerability parameters that, assessing the vulnerability of a prey to its predators, affect the strength of the trophic interactions: top-down for vulnerabilities values greater than 2, or bottom-up for vulnerabilities values between 1-2.

2.6.1 METHODOLOGICAL APPROACH

The model considered in the framework of FAIRSEA project was built in Ecopath with Ecosim and Ecospace (EwE) version 6.6.6. For detailed information regarding the Ecopath with Ecosim model that defines the predator/preys species interactions please refer to Deliverable 4.7.1 ("D 4.7.1 Calibrated Ecopath with Ecosim model for the Adriatic region").

To summarise here some information: the model built for the GSA 17&18 includes 33 fishing segments (across a combination of fishing gears by vessel sizes and country of origin) and a total of 73 functional groups including mammals (4), sea turtle (1), seabirds (1), finfish (33), jellyfish (1), crustacean invertebrates (15), mollusc invertebrate (7), zooplankton (3), primary producers plankton (2), primary producers seagrass and seaweed (2), bacteria (1), detritus (3).

The Ecopath with Ecosim temporal changes are driven by primary productivity, changes of phytoplankton group (2) (offline coupling in Ecosim through forcing functions) and changes of fishing efforts (33) (Deliverable 4.7.1). The Ecopath with Ecosim model was fitted to time-series observations (15-year period) of biomasses (44) and catches (53).

The fitting was performed using different settings:

- fitting by predator (stepwise fitting);
  - M01_PR_w01_S;
  - M01_PR_w20_S;
- fitting by predator/prey (stepwise fitting);
  - M01_PP_w01_S;
  - M01_PP_w20_S;

- fitting using manual settings to estimate the vulnerabilities not considered by the stepwise fitting.

- M01_PR_w01_SM2;
- M01_PR_w20_SM2;
- M01_PP_w01_SM3;
- M01_PP_w20_SM3;

where M01=model 1; PP=fitting by predator/prey setting; PR=fitting by predator setting; w01=relative biomasses weight=1; w20=relative biomasses of stock assessed groups weight=20; S=stepwise fitting; SM= stepwise fitting followed by manual fittings (2-3 number of manual search).
For Ecosim fitting results please refer to supplementary material of this report (Fig. SM1).

2.6.1.1 Ecospace environmental variables

The Ecospace domain covers 121,269 km^2 encompassing GSA17&18 out to ~800 m depth (Fig. 2.6.1.1.A). The area is characterised by salinity ranges between ~34-39 ppm with fresher waters found on the Italian side due to the influence of the Po River. Depth integrated temperature (DIT, integrated over 200 m depth), with colder water located in the Northern Adriatic Sea ranging between 16 and 19 °C, whilst sea bottom temperature (SBT) varies between 11 and 19 °C, with warmer waters found in the Northern Adriatic Sea and in coastal waters. Significantly higher Net Primary Production (NPP) values were found only close to the River Po estuarine.

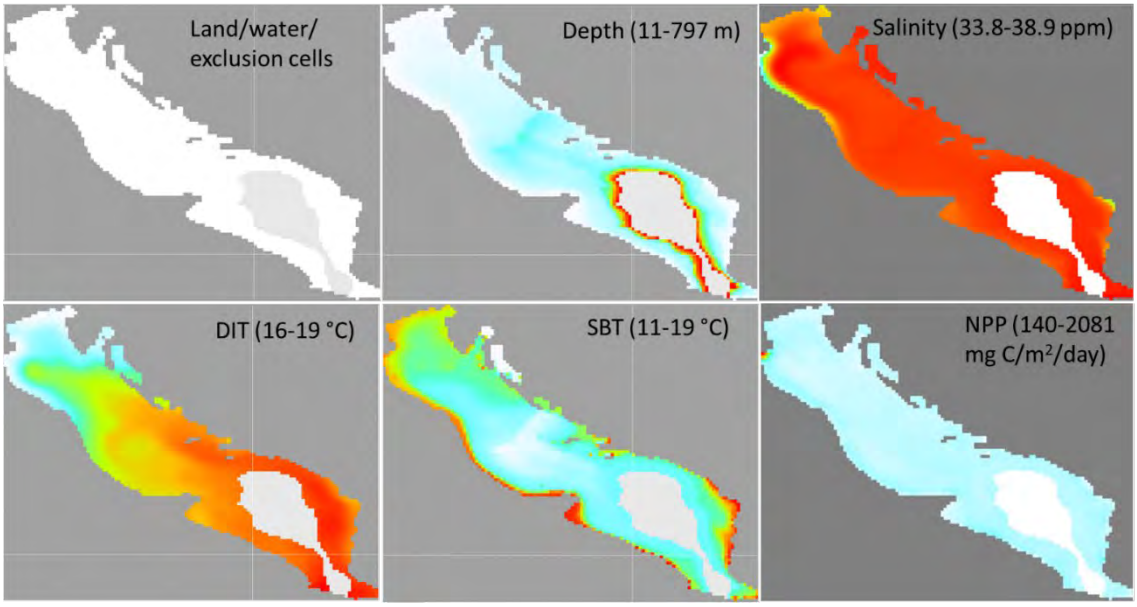

Figure 2.6.1.1.A. Environmental properties of the GSA 17&18 spatial model. (a) Cells deeper than 800m were excluded from the model; (b) depth model domain; (c) averaged salinity, (d) sea surface temperature; (e) sea bottom temperature and (f) net primary production.

The environmental variable were used to drive the species distributions in relation of their habitat preferences (niches): depth has been the main driver for many functional groups (41), whist death integrated temperature was only used for G25_SPX, "other small pelagic" dominated by *Sprattus sprattus,* for G28 and G29_PIL, sardines juvenile and adults and for all three stanzas of *Solea solea*. Distribution of sardines was also driven by salinity. Sea bottom temperature has been used only to drive the distribution of G43_CTC (*Sepia officinalis*) (for details of the response function please refer to supplementary material).
Species have unique responses to these environmental conditions. Ecospace calculates the suitability of each cell for each species: the application of multiple environmental variables in relation with their response functions is calculated in Ecospace as a multiplier factors (Figure 2.6.1.1.B) (Christensen et al., 2014), therefore we limited to use variables simultaneously in order to avoid a restriction of the habitat capacity (C).

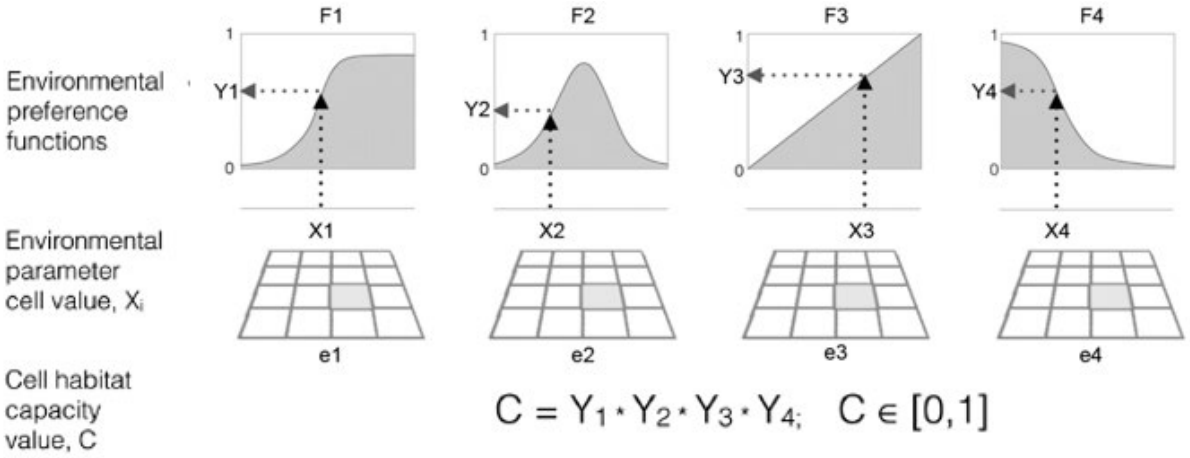

Fig. 2.6.1.1.B - Foraging arena calculation in relation of environmental condition and species preferences (adopted from Christensen et al., 2014).

In Ecospace, the vulnerable prey density Vij is represented by the foraging arena equation (1), which can be expressed as:

$$Vij = \frac{vij \cdot Bj}{2vij + aij \cdot \frac{Bj}{Crcj}} \qquad \text{(eq. 1)}$$

Where v_{ij} is prey vulnerability exchange rate, B_j is predator biomass, aij is the rate of effective search by the predator and C_{rcj} is relative habitat size or capacity of the predator. When C is small, predation activity concentrates in small areas causing a fast reduction of the vulnerable prey density when the biomass of the predator increases. When C is small, therefore, might instabilities of the temporal-spatial biomass distributions (Coll et al., 2019).

Environmental variables, in Ecospace, as well as primary productivity data derived from the biogeochemical model outputs (Deliverable 4.1.2 and D.4.2.2.), were coupled in time and space using the spatial-temporal framework (Steenbeek et al., 2016). Monthly data of biomasses of small and large zooplankton (G69_PDM and G70_PDF), DIT, SBT and salinity were coupled from 2000 to 2049. It is worth noting that the simulation period 2000-2004 is the model spinoff, then simulated years 2004-2018 represent the actual model calibration range, whilst 2018-2049 in the model baseline for future simulations. In the future baseline scenario fishing and environmental changes are fixed at values as in the 2018, i.e., fishing efforts and monthly environmental drivers (DIT, SBT, salinity and biomasses of phytoplankton groups) for 2018 are repeated constantly every year up to the end of temporal simulations.

2.6.1.2 Ecospace fisheries

Regions were created to represent different administrative areas were the different fisheries are allowed to be active (Supplementary material, table S1). In Ecospace, fisheries can be allocate to be active in specific "regions" that represent administrative areas. Regions were created as a combination of territorial waters per country, international waters and distance to coast per country (e.g. 3-4-6 nautical miles) (Figure 2.6.1.2.A). For Italy, four more region were created in Ecospace only for allocating "Rapido trawlers" north of the Gargano area (not showed in Figure 2.6.1.2.A). Fifty-five regions were created: Albania (4), Bosnia and Hercegovina (1), Italy (9), Montenegro (5), Slovenia (4) and Croatia (31).

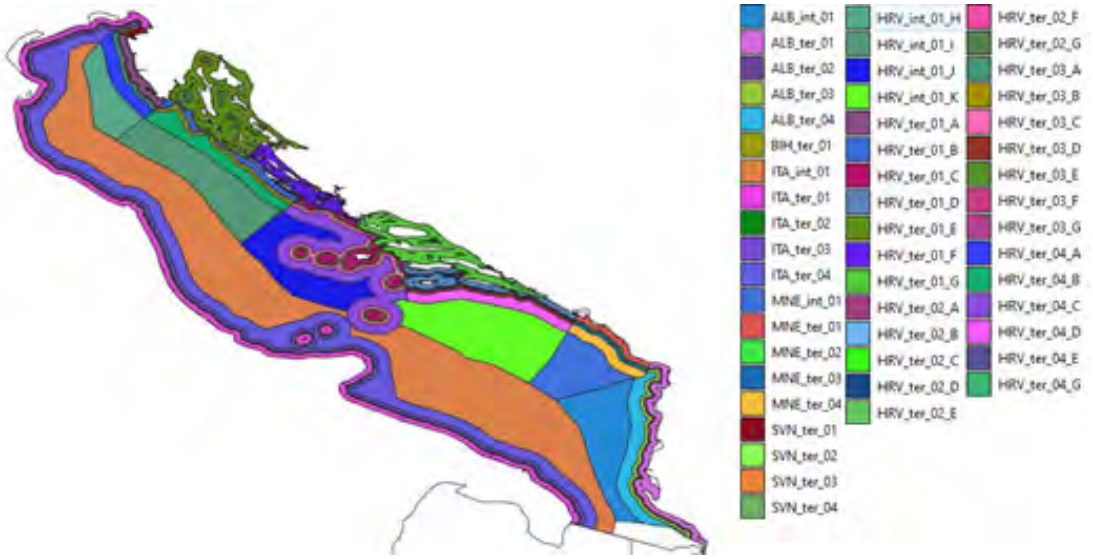

Figure 2.6.1.2.A - Ecospace administrative areas set for fishery allocations. Int=international waters; ter=territorial waters; ITA=Italy; BIH=Bosnia and Hercegovina; HRV=Croatia; MNT=Montenegro; SLO

and SVN= Slovenia; 01=3 nautical miles; 02=4 nautical miles; 03=6 nautical miles; 04=up to the midline.

Each species has an allocated value in Euros per kilogram that differs across countries and fleets (Supplementary material Table SM3). In the FAIRSEA project, fleets are set to have fixed and equal cost with a fixed profit of 20% (Fixed cost 20%, effort related cost 40%, sailing related cost 20%) this need to be updated in the future considering local characteristics of the fisheries section. In Ecospace, fishing fleets move in a 2D in order to follow the centre of gravity of their resources (target species per fishing gear) within the permitted administrative areas, also aiming to reduce the sailing costs and maximising their profits: their movements is in fact, also regulated by the distance to coast in relation to species value. Based on all these variable Ecospace predict the relative spatial-temporal fishing effort for each fleet (Figures 2.6.1.2.B-C).

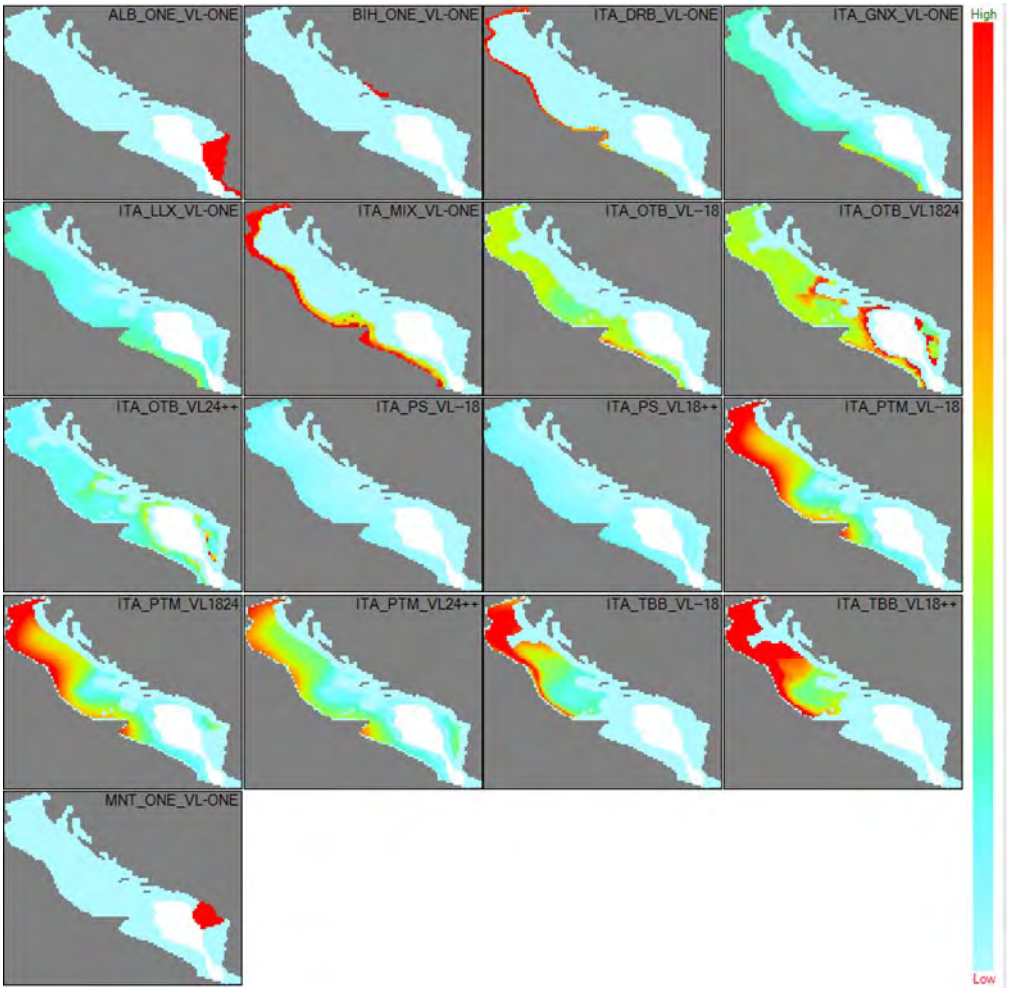

Figure 2.6.1.2.B - Ecospace relative predicted effort (for May/2011). ALB=Albania; BIH=Bosnia and Hercegovina; ITA=Italy; MNT=Montenegro. OTB= Bottom otter trawls; PTM= Pelagic pair trawls; PS=Purse seine; TBB= Beam trawls; DRB=dredges; GNX=set nets; LLX= long lines; MIX (seine, traps, small-scale fishery); VL=vessel length.

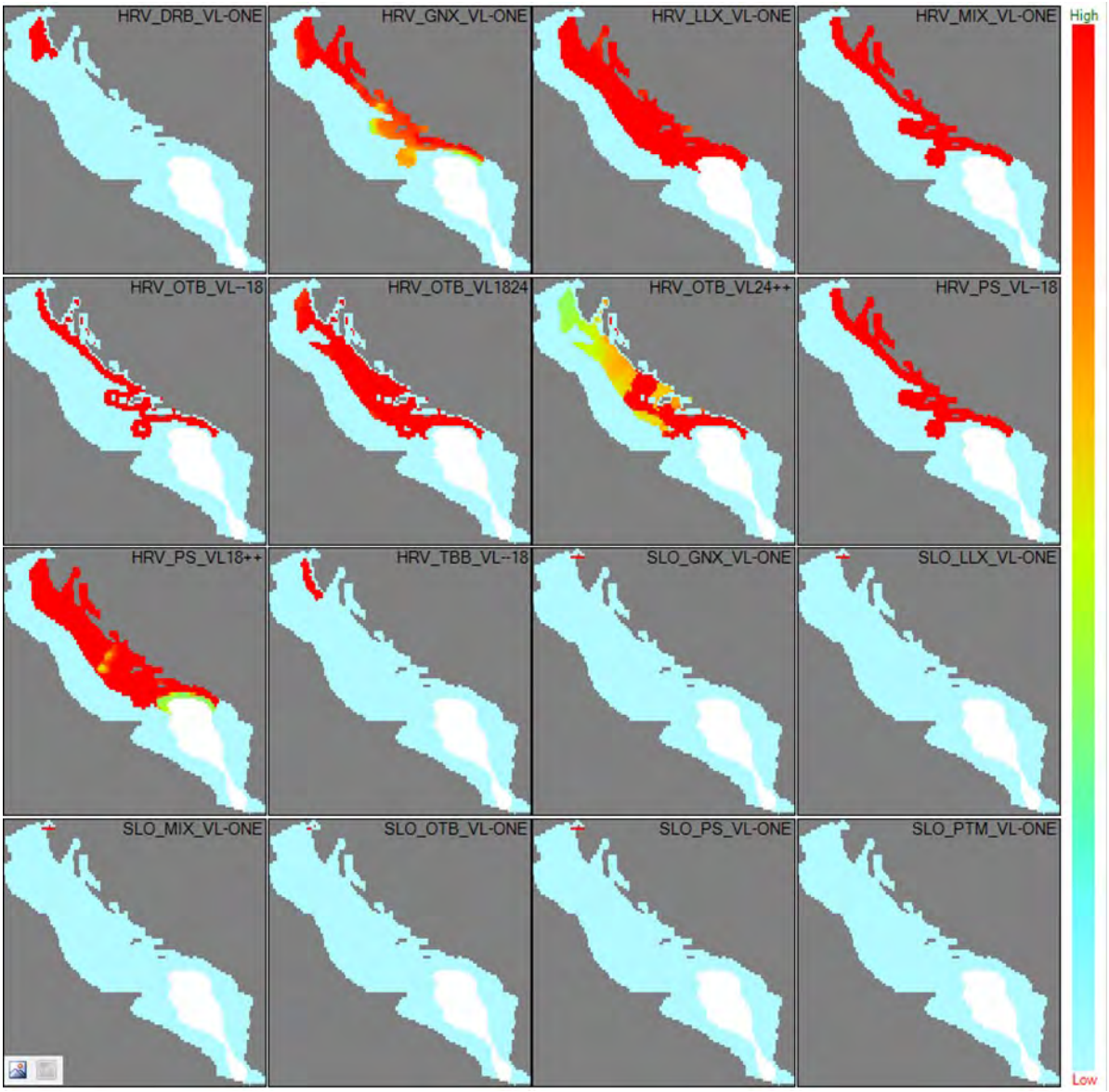

Figure 2.6.1.2.C - Ecospace relative predicted effort (for August/2011). HRV=Croatia; SLO and SVN= Slovenia. OTB= Bottom otter trawls; PTM= Pelagic pair trawls; PS=Purse seine; TBB= Beam trawls; DRB=dredges; GNX=set nets; LLX= long lines; MIX (seine, traps, small-scale fishery); VL=vessel length.

2.6.1.3 Ecospace scenarios

For Ecospace analysis the best fitted model using predator/prey setting were chosen and two approaches were tested. The first consisted in a sensitivity test, in which the implementation of each FRAs (Figure 2.6.1.3.A) were activated one at time to assess the ecosystem responses to each restricted area. The second one consisted in the evaluation of the impact of Ecospace management scenarios tested. All scenarios were run up to 2050.

Concerning the Fishery Restricted Areas, the natural zones are identified as "Sporco area", characterised by coarse-gravel substrate not suitable for DRB, OTB, and TBB; and "deep-water area", also this not suitable for the same gears (Figure 2.6.1.3.A). The managed areas include all zones within 3, 4 and 6 nautical miles, the FRA of Pomo, of Bari canyon and North Adriatic sanctuary.

FRAs were activated in different time with the spatial-temporal framework (Steenbeek et al., 2016), whilst the effort changes are implemented in Ecosim temporal drivers. These management implementations remain active in the future simulations.

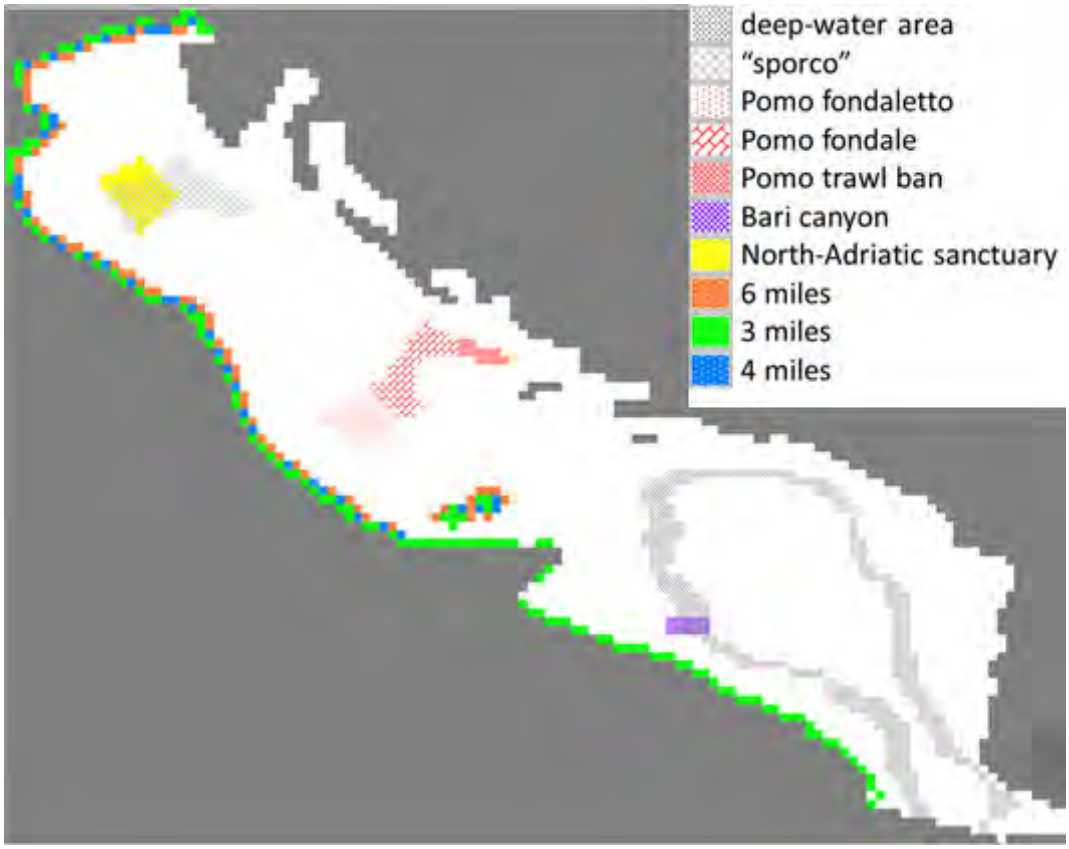

Figure 2.6.1.3.A – Maps of natural and managed restricted areas as well as rules in force or proposed in the framework of GFCM to manage the fisheries in the Adriatic Sea.

The baseline scenario (S0) is based on 2021 conditions that includes:

i. natural fishery restricted areas, including Sporco area and deep-water area;
ii. management restricted areas:
   - 3 nautical miles from Italian coastline for OTBs, PTMs, TBBs (active all year from 2010);
   - Pomo Pit (active from 2017) characterized by three sub-regions:
     - "fondale": restricted all year for all fleets;
     - "fondaletto": restricted in September and October for all bentho-demersal fleets;
     - "trawl-ban": restricted in September and October for all bentho-demersal fleets.
iii. Implementation fishing effort management already in place in 2021:
   - transition phase of effort reduction for TBB of 16% and OTB of 12% (in respect to 2015 effort value) from 2020 to 2021; the reference scenario is developed by considering constant the effort at the level reached in 2021.

Ecospace FRAs sensitivity

In Ecospace, single regions were set for each fishery restricted area and coastal zone, allowing to assess the changes in biomass at sea of the entire Adriatic domain and also inside each restricted areas and coastal zone. In order to test the efficacy of each single management area in place or foreseen a sensitivity analysis was done, in which a single managed area is applied each time.

Management fishery restricted areas (Figure 2.6.1.3.A) were dynamically activated/deactivated (in the case of Pomo Pit area) for assessing their impact on the ecosystem in comparison to the baseline:

1) Pomo Pit all sub-regions (active from 2017) therefore to assess theirs impacts these areas were deactivated when comparing to the baseline;

2) Bari canyon (active from 2021): restricted all year for all fleets;

3) North Adriatic sanctuary (active from 2021): restricted for all OTBs and TTBs;

Although activated in different moment the effects of each individual FRA is comparable because evaluated far in the future and always compared with the baseline scenario.

Ecospace management scenario

The Ecospace management scenarios tested in this project were established with stakeholders during numerous meetings (see deliverables of Activity 5.1: D5.1.1 First international stakeholder meeting, D 5.1.2 Second international stakeholder meeting, D5.1.3. Final

international stakeholder meeting) under GFCM/43/2019/5 recommendation and consisted in:

S1) coastal closure: up to 4 nautical miles from Italy coastline (active from 2021), restricted all year for OTBs, PTMs, TBBs and up to 6 nautical miles from Italy coastline restricted from August to November for OTB_VL24++, PTM_VL24++, TBBs (active from 2021).

S2) Implementation of a gradual five-years (2022-2026) further effort reduction as foreseen in the Multiannual Management Plan. Each year, on the basis of SAC advice, the GFCM shall establish yearly effort quotas that contribute on reaching F_{msy} for selected species. This will approximatively lead to a cumulative fishing effort reduction in relation of 2021 of 29% (5.5% ITA_OTB_VL--18, 9.2% ITA_OTB_VL1824, 0.5% ITA_OTB_VL24++, 0.6% ITA_TBB_VL18++, 9% HRV_OTB_VL--18, 0.1% HRV_OTB_VL1824, 2.4% HRV_TBB_VL--18).

S3) Effort reduction as applied in S2 and implementation of new FRAs. Thus other than Pomo Pit as in the baseline, also the Bari Canyon and the North Adriatic sanctuary were activated.

S4) Climate changes: driven by changes of primary productivity simulated as changes of biomasses of small and large zooplankton derived by the biogeochemical model outputs.

2.6.2 RESULTS

Ecospace output predicted the temporal-spatial distributions of all 73 functional groups defined in the Ecopath model (see "D 4.7.1 Calibrated Ecopath with Ecosim model for the Adriatic region"). Here we are presenting the output of target species that were considered commercially important for the Adriatic Sea ecosystem: *Sardina pilchardus* (PIL), *Engraulis encrasicolus* (ANE), *Solea solea* (SOL), *Mullus spp*. (MUT), *Merluccius merluccius* (HKE), *Squilla mantis* (MTS), *Nephrops norvegicus* (NEP) and *Parapeneus longirostris* (DPS). Although scenarios are basically devoted to analyse effects of measures on demersal resources, outputs for small pelagic species are reported because they are main target species in the Adriatic sea that are influenced indirectly by management on demersal resources through fishing technical interactions and ecological trophic interactions which are represented in the model. Figure 2.6.2.A shows the Ecospace baseline spatial distributions of selected species at 2021 temporal snapshot. All scenarios were then presented in this report as a relative changes from the baseline run. Results could have been presented considering immediate, mid-term and prolonged effects, but for the sake of simplicity results are presented as the average proportional change in the period 2021-2050 between scenario and baseline run.

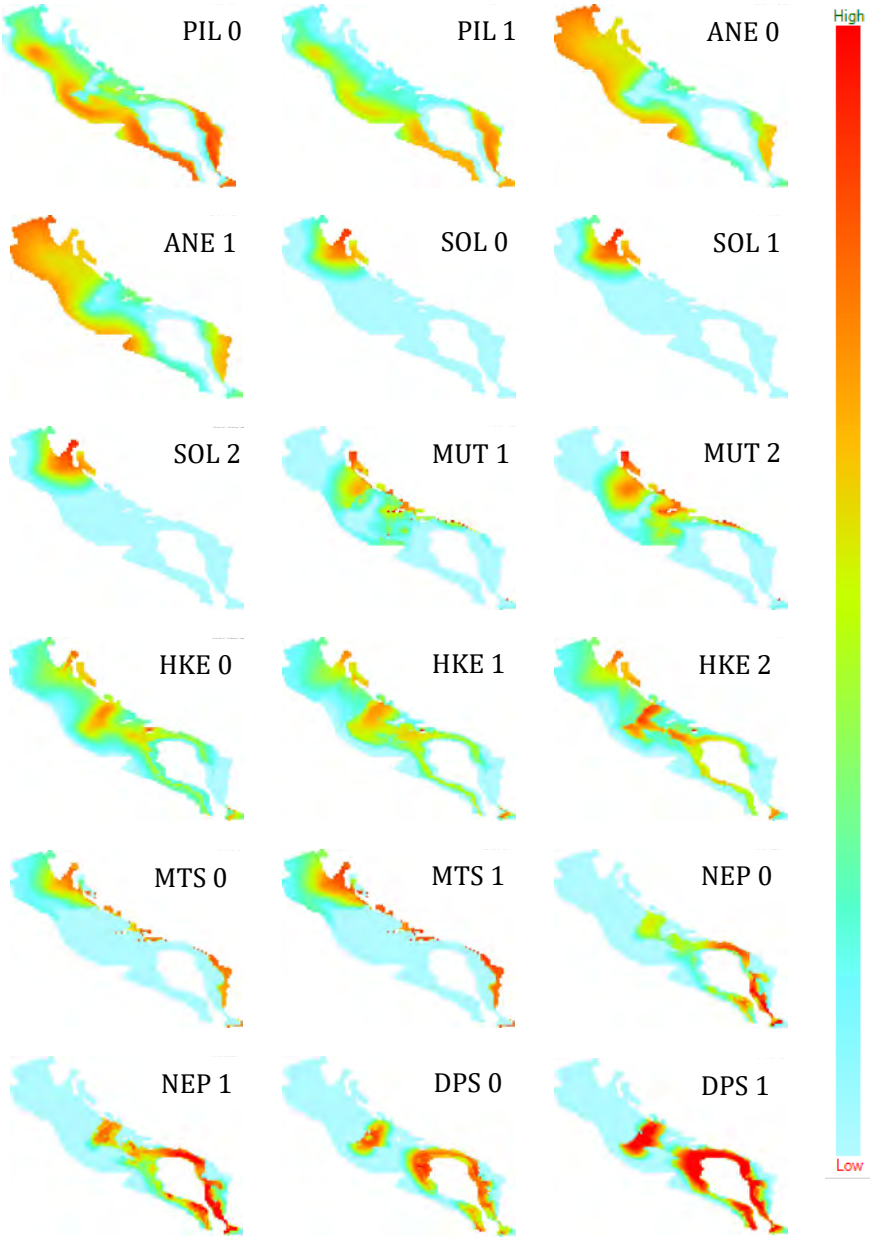

Figure 2.6.2.A – Spatial distributions of biomasses of selected functional groups in the 2021 baseline run. Please refer to table SM1 for functional group codes. Colours are relative changes to the baseline per each species "red" high change (*10log), "blue" low change (-10log).

2.6.2.1 *Results of sensitivity tests: Ecospace FRAs sensitivity*

The magnitude of impacts of each restricted area was depending on their dimension and location (Figure 2.6.2.1.A). The implementation of Pomo Pit area showed the highest impact on the biomass of European hake (HKE) with increases of 12.3%±8.7%. Norway lobster (NEP) also showed increases (5.8%±2.9%), whilst red mullet (MUT) decreased (-2.6%±1.3%). Deep-water rose shrimp (DPS) showed an overall small change with high variability (0.5%±4.8%). The highest impacts are of course expected for species with high biomasses spatially distributed around the Pomo Pit area such as European hake and Norway lobster (Figure 2.6.2.A), whilst the decrease of red mullet biomass was caused both by increased predation by predator (i.e., European hake) and by fishery dislocation towards areas where this species is abundant when Pomo Pit restricted area is implemented. Similarly, the implementation of the Bari canyon FRA showed an increase of biomass of European hake (up to 1.4±0.7%) with a smaller magnitude due to a small size of this area.

The implementation of the North-Adriatic sanctuary FRA showed very small increases of mantis shrimp (MTS, up 0.4%±0.2%), anchovy (ANE, 0.1%±0.07%) and sole (SOL, 0.1%±0.06%): the implementation of this management areas however dislocated the fishery in other areas where resources are more abundant causing a reduction of biomasses at sea for red mullet (-0.3%±0.2%), European hake (-0.2%±0.12%) and sardines (-0.1±0.07%).

Overall, changes of relative catches (Figure 2.6.2.1.B) followed the biomass changes (Figure 2.6.2.1.A), because of the inherent assumption of the model in which fishing mortality is proportional to biomass. Closing specific areas to fisheries determined an initial decreases of catches. Subsequently, catches will start to increase with time, due to the rebuilding of biomasses at sea of target species as a response to the effective protection of restricted areas: this is represented by a larger standard deviation in the Figure 2.6.2.1.B. Notably, preys of target species benefiting of the management measure resulted depleted because of predation effect (e.g., when European hake increase, red mullet tend to decrease in the long term). These temporal changes are more evident looking at the temporal relative changes. Figure 2.6.2.1.C showed, as an example, the strong temporal increases of biomass for HKE (1 year old) when Pomo Pit was implemented, this significant increase quickly overcome the reduction of catches registered just after 2017 due to the area closure to otter trawls. Similar findings were obtained for NEP. Different situation was found for DPS that showed high variability of temporal biomass, but not significant increases (Figure 2.6.2.1.A), therefore the catches did not show any increases by 2050.

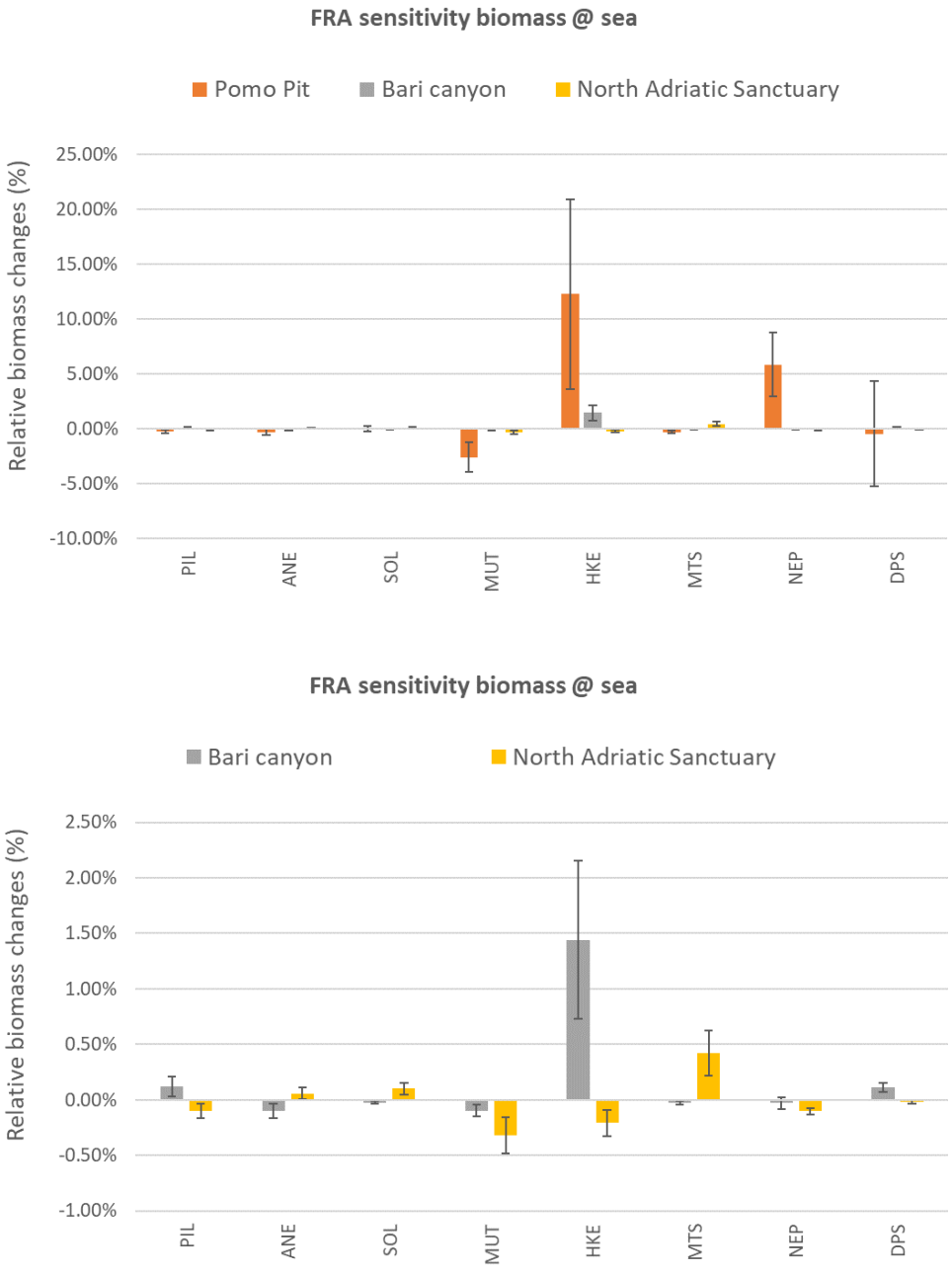

Figure 2.6.2.1.A - Fishery restricted areas, assessing the impact of their single implementation on the biomass at sea for selected species. Please refer to table SM1 for functional group codes.

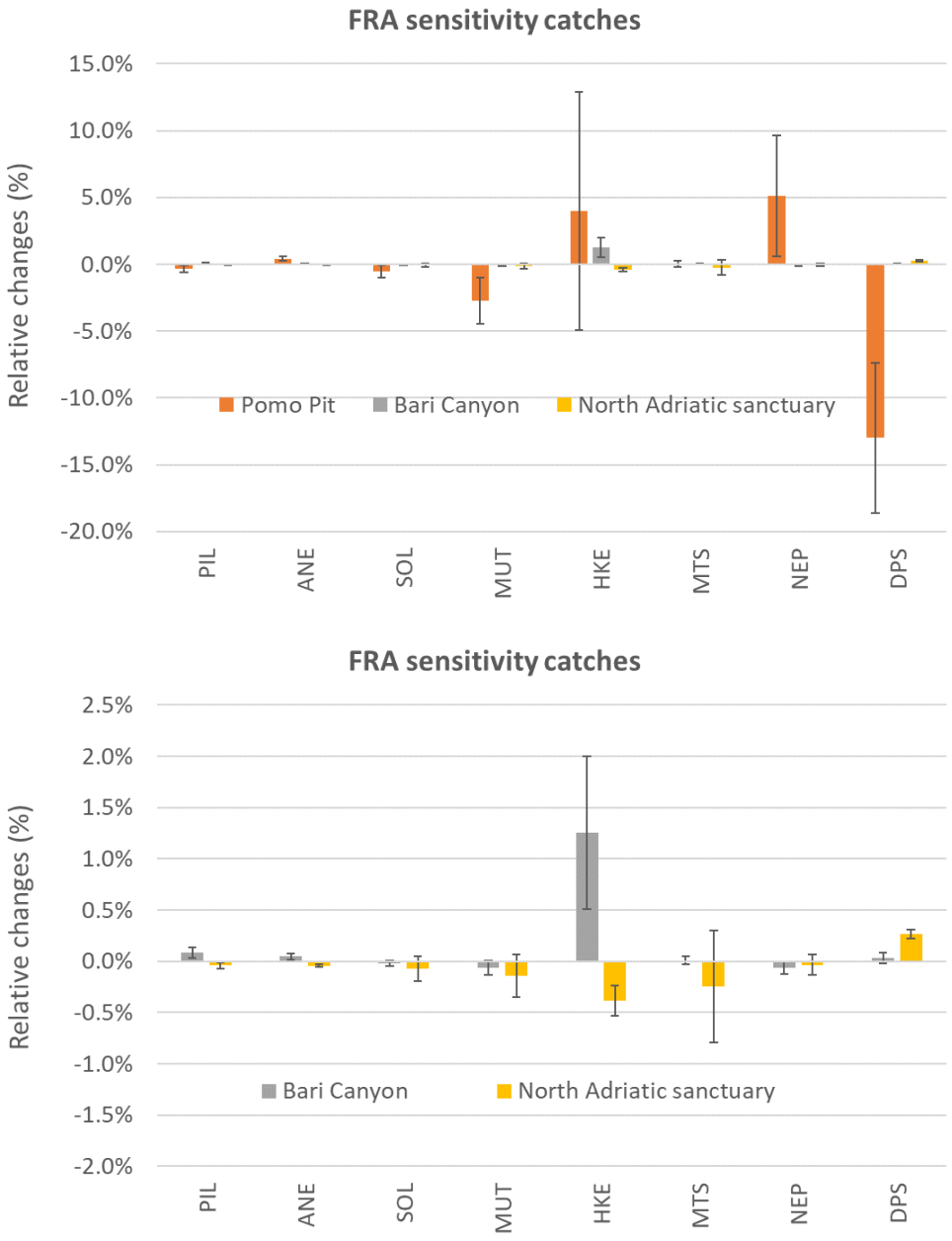

Figure 2.6.2.1.B - Fishery restricted areas, assessing the impact of their single implementation on the total catches for selected target species. Please refer to table SM1 for functional group codes. Note the different y-axis scale in the two graphs.

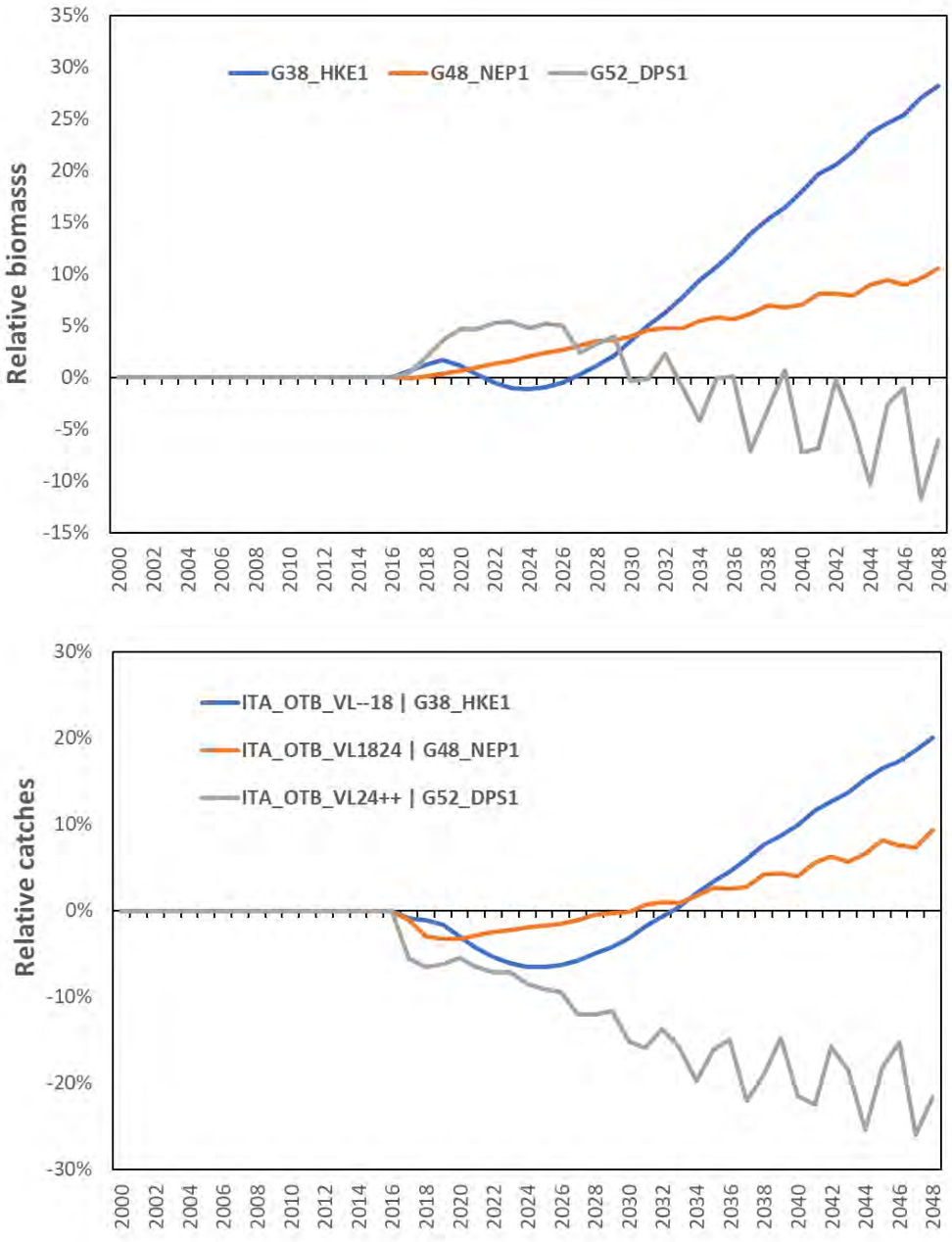

Figure 2.6.2.1.C - Temporal changes showing the impact of Pomo Pit FRA on biomass and catches for selected species (HKE and DPS) and fishing activity (Italian otter trawls). Please refer to table SM1 for functional group codes.

Ecospace allows also estimating the local effects, permitting estimation of biomasses at sea within the boundaries of defined FRA (this is done by setting each FRA as a region, and in this way we were able to also assess the changes of biomasses inside the FRA regions).

Figure 2.6.2.1.D showed the increases of biomasses (as ton/km^2) up to 372%±142% and 56%±18% for Norway lobster and 102%±19% and 25%±9% for hake inside Pomo Pit "fondale" and Bari canyon respectively. Smaller biomass changes were found in the North-Adriatic sanctuary with increases of 8%±2%, 8%±2% and 9%±3% for the common sole, European hake and Norway lobster respectively.

Basically by considering the results within the FRAs and their effect on the wider scale, one can infer on the stocks rebuilding inside the FRA, the dispersion of this rebuilt biomass in the larger area and thus the spill over.

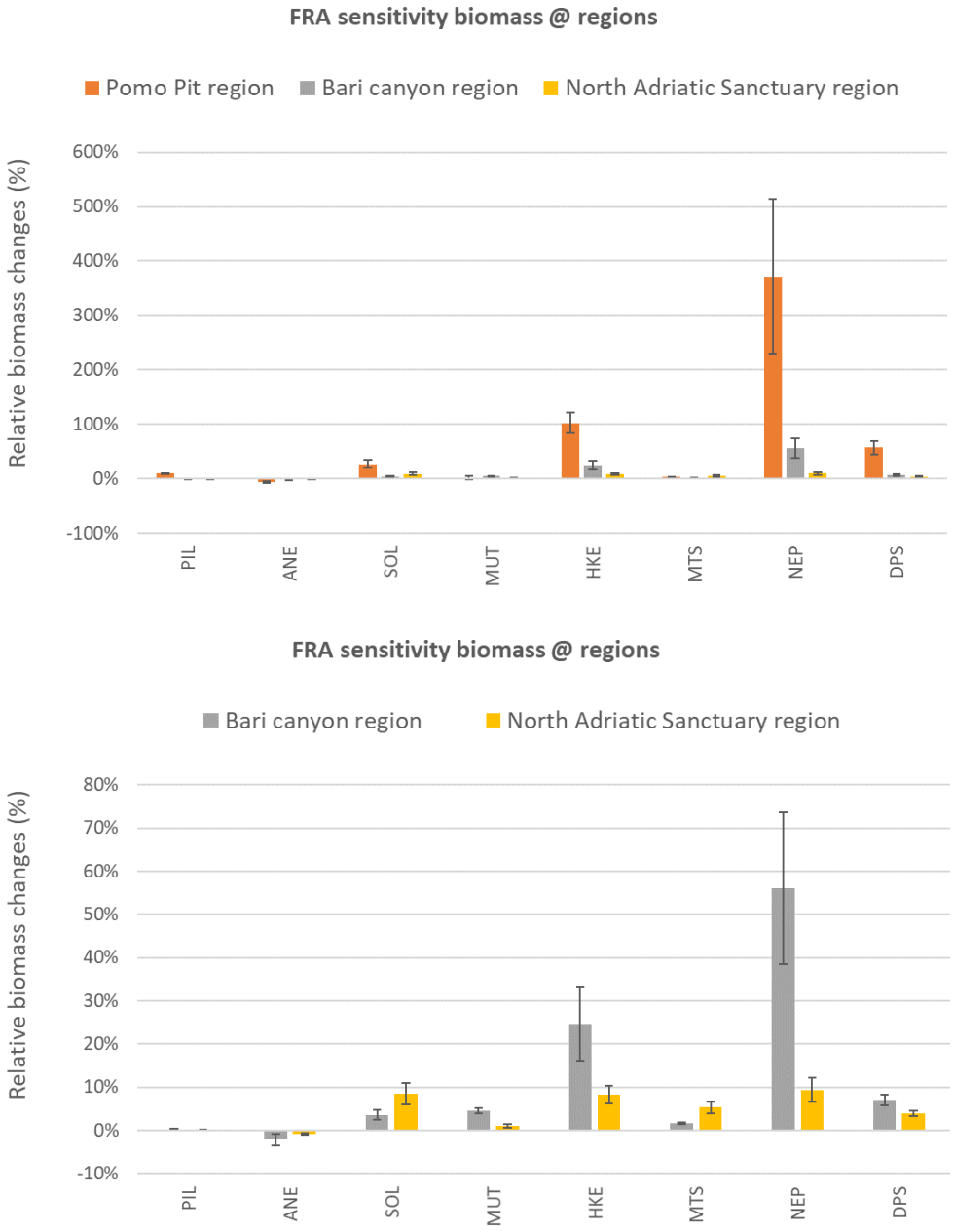

Figure 2.6.2.1.D - Fishery restricted areas, assessing the impact of their single implementation on the biomass within the single restricted area (region). Please refer to table SM1 for functional group codes.

2.6.2.2 Ecospace management scenarios

By comparing results for the selected target species biomass and catches under scenarios S0 (reference baseline), S1 (coastal closure), S2 (effort reduction), S3 (effort reduction with additional FRAs) and S4 (climatic changes), one can gain important insights on the effects of regulation.

Figure 2.6.2.2.A showed the ecosystem responses biomass changes (A) and catches (B) to the selected management scenarios tested.

The implementation of the coastal closure 4-6 miles from the Italian coastline (S1) caused a dislocation of the fishery activity towards areas with high abundances of target species causing a reduction of biomass at sea of sole (-1.67%±1.1%), European hake (-2.1±0.9%) and anchovy (-1±0.4%).

The reduction of effort 2022-2026 (S2) showed clear results with significant increases of biomass for target species of Italian OTB and TBB such as red mullet (8.6%±3.6%), European hake (11.8%±4%), common sole (1.7%±1.2%), spottail mantis shrimp (2.6%±1.1%), Norway lobster (3.2%±0.9%), anglers (G27_LOP, 6%±1%), shallow waters sharks (G10_SELh, 2%±0.5%) and black-mouth catshark (G11_SHO, 3%±1%) (for details of top predators refers to supplementary material figure SM2). The increases of these top-predators groups is also driven by the increases of biomasses of their preys.

The impact of the implementation of all FRAs (S3) applied in a scenario with reduced effort (S2) was not significant as the impacts of the FRAs is of one order of magnitude smaller in comparison to the impact of effort reduction.

In the Climate change scenario (S4), temperature, salinity and biomasses of primary producers changed accordantly with the output of Copernicus biogeochemical model simulations under IPCC RCP 8.5 scenario. These simulations predicted a reduction of -10%±11% for large phytoplankton (G69_PDM) and 5%±7% for small phytoplankton (G70_PDF) by the end of 2050. These reductions at the bottom of the food-web caused an overall reduction of biomasses in the entire ecosystem, with the highest decreases found for anchovy (-10.7%±9.4%): the only species that recorded an increase of biomass was the sardine due to a reduction of predation mortality driven by the decreases of all its predators.

The overall relative changes of catches (Figure 2.6.2.2.A) followed the biomass changes with higher variabilities under scenarios S2 and S3. Reductions of catches were in fact predicted at the beginning of the simulations (Figure 2.6.2.2.B) due to the reduction of fishing effort, catches were then increasing due to the rebuilding of species biomass at sea for selected species (e.g. HKE, MUT) target by otter trawls): species that did not show a biomass rebuilding did not show a temporal increase of catches (e.g. DPS).

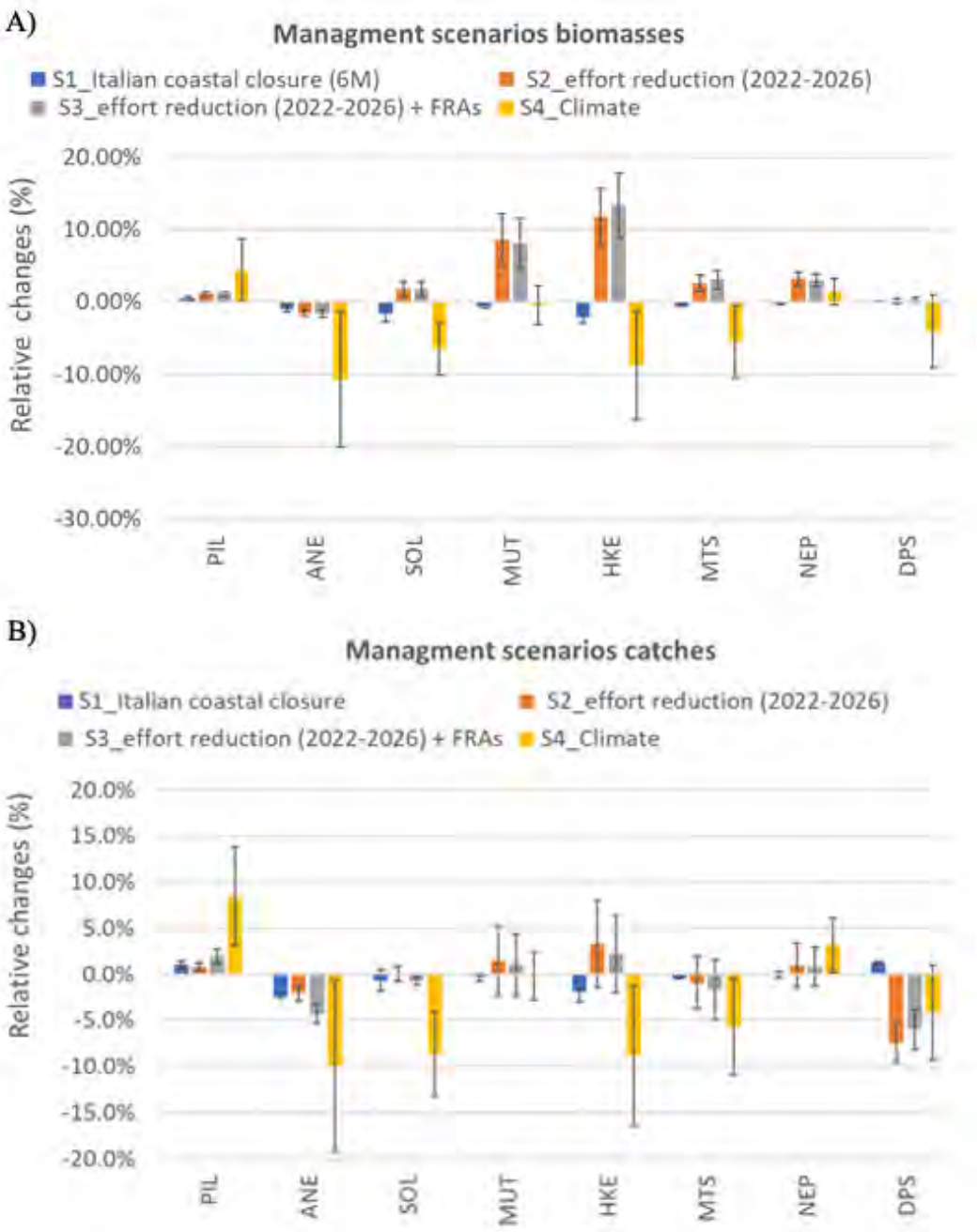

Figure 2.6.2.2.A – Biomasses (A) and catches (B) outputs under different management scenarios in comparison to S0 (reference): S1 (coastal closure), S2 (effort reduction), S3 (effort reduction with additional FRAs) and S4 (climatic changes). Please refer to table SM1 for functional group codes.

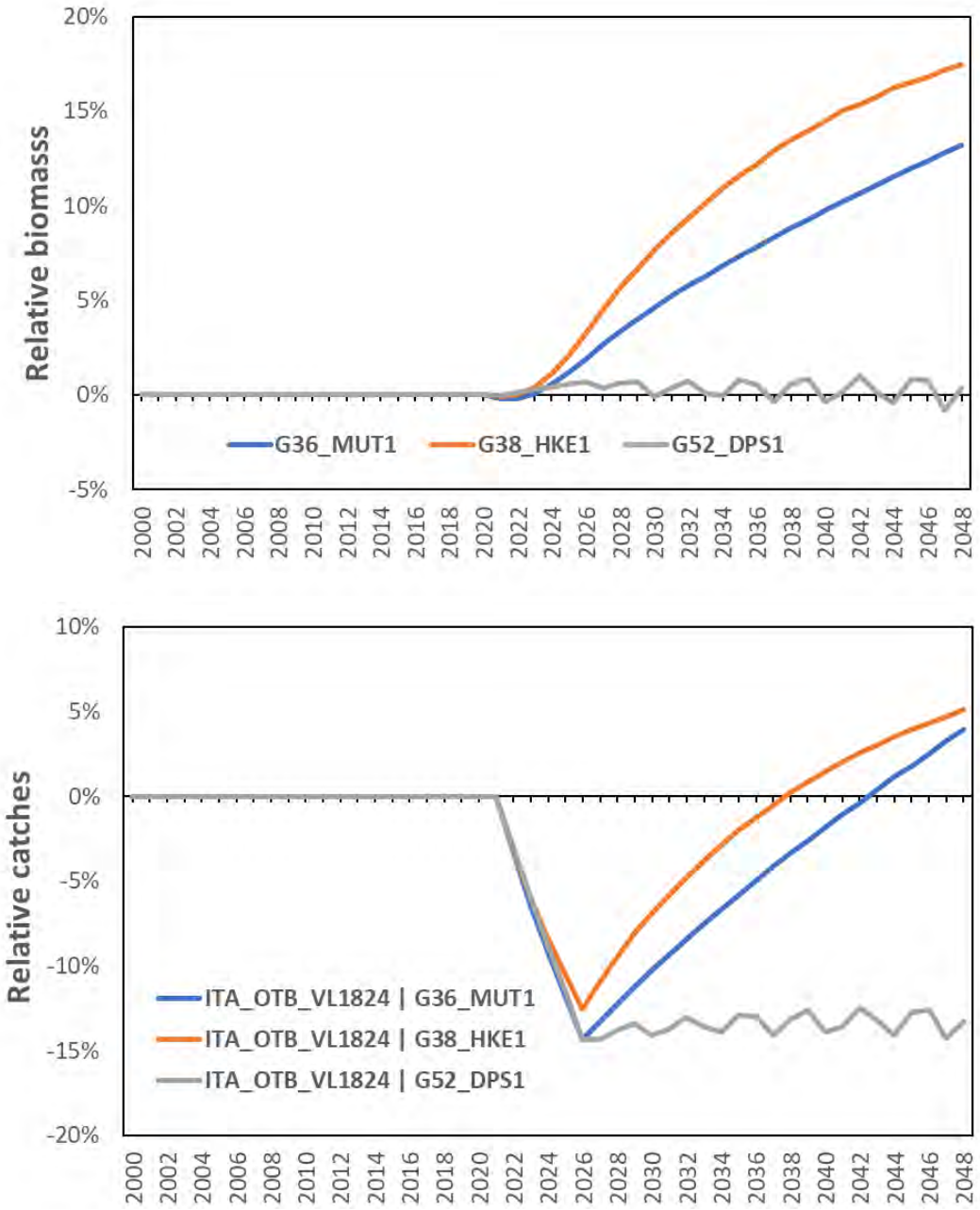

Figure 2.6.2.2.B - Temporal changes showing the impact of effort reduction on biomass and catches for selected species (MUT, HKE and DPS) and fishing activity (Italian otter trawls). Please refer to table SM1 for functional group codes.

2.6.3 MANAGEMENT IMPLICATIONS

The scenarios developed with ECOSPACE, although might be improved in accuracy, provide a set of important results that have potentially large implications.

First the dimension and position of FRA matters, and larger the area larger the effects inside and outside the managed area. Nevertheless, the trophic cascade due to protection of top predators (e.g., European hake) result in depletion of some commercially relevant preys. Notably, the rebuilding is so strong that in some instances (large key FRA such as Pomo Pit) the stock rebuilding is favouring fisheries sector in the mid-term (Figure 2.6.2.1.C).

Among management scenarios the coastal closure (S1) represents the most controversial because of reduction of catches even in the long run. This is because of the displacement of high fishing pressure from the coast. Notably the results might be affected by the relatively poor capabilities of the model to represent juveniles and distribution of them.

Scenarios S2 and S3 showed very similar results, driven by the impact of the effort reduction that was an order of magnitude higher than the implementation of the FRAs. The reduction of the fishing effort caused the expected initial decrease of catches, however the rebuilding of biomasses at sea for several species (target by otter trawls) determined a subsequent increase of theirs catches at mid-end terms (Figure 2.6.2.2.B).

Important and controversial results were found under the climate scenario (S4): the output of Copernicus biogeochemical model simulations under IPCC RCP 8.5 scenario predicted strong reductions of biomass for small and large phytoplankton groups, however they also predicted no significant temporal changes in terms of net primary production. These results are driven by rising water temperature that increased the metabolism and the overall turnover rates of the phytoplankton groups. In Ecospace we coupled the phytoplankton group biomasses to drive the climate ecosystem variations, therefore the reduced production at the bottom of the food-web caused an overall reduction of the entire ecosystem production that cascade and can be amplified through the food web (Armengol et al., 2019; Christensen, 2013; Chust et al., 2014) with the highest decreases found for anchovy. The model results showed also the importance of the food-web interactions recording an increase of sardines due to an overall reduction of its predation mortality driven by the decreases of all its predators. Future work is required to represent more comprehensively the changes observed from biogeochemical models i.e., the reduction of biomass but not reduction of net primary production. This could possibly be done by introducing a function that simulates the increase of the turnover rate (P/B) of phytoplankton groups driven by rising temperatures. However, it is clear that more efforts might be done in this direction to consolidate the results obtained.

3 THE SWOT ANALYSIS

The comparison of the advantages/disadvantages of the various management scenarios was carried out using the SWOT Analysis (Strengths, Weaknesses, Opportunities, Threats) (Table 3.a), a tool widely used in the formulation of strategies. Internal (Strengths and Weaknesses) and external (Opportunities and Threats) factors are considered prompting several variations on the theme. Although originally designed for planning, the SWOT model is also used in evaluation processes to ensure that the implemented strategy is appropriate to the situation described in the analysis. Therefore, SWOT analysis may be used in any decision-making situation when a desired objective has been defined.

In our case, when comparing management scenarios, the SWOT was structured taking into consideration the model used for the simulation and the predictions, the key indicators of sustainability and the current situation characterising the fisheries in the Adriatic-Ionian region. External factors are taken into account as potential reactions of the fishery system that can be triggered by the implementation of the simulated scenarios.

Only the scenarios simulating and forecasting the management strategies in the short, medium and long term were taken into account in the SWOT analysis. Given the characteristics of the approach, more useful in a strategic and long vision framework, the Ecospace results are considered mainly in the medium-long term framework (years 2026-2050).

Table 3.a - SWOT ANALYSIS - Strengths, Weakness, Opportunities and Threats of the different management scenarios simulated using SMART, BEMTOOL and ECOSPACE models.

Model	Scenario	Strengths	Weakness	Opportunities	Threats
SMART	**S1:** *Status quo* (including the presence of the Pomo Fisheries Restricted Area)	Expected improvements of biological conditions for some stocks (i.e. HKE and NEP) distributed on the platform and on the shelf	Expected worsening of biological conditions for some coastal stocks (i.e. MUT)	Easier approach to implement and eventually develop, since based on the control of a relatively small area	This scenario could lead to an increase of fishing effort in more coastal areas
SMART	**S2:** S1 + closure of the 6 nautical miles zone (coastal area)	Very effective for most of the stocks in terms of improvement biological conditions	Dramatic consequences for the fleets in terms of landings and profits		Collapse of the fisheries in terms of economic performance
SMART	**S3:** S1 + effort reduction up to 30% in 3 years	Expected improvements of biological conditions for some stocks (i.e. HKE and NEP) distributed on the platform and on the shelf	Not effective in protecting coastal stocks (i.e. MUT)	Could determine an improvement of fisheries performance in the mid-term, also as consequence of the improved conditions of some stocks	
SMART	**S4:** S1 + Extended late summer ban (total stop in September/October, -40% of the normal effort in November)	Expected improvements of biological conditions for some stocks (i.e. HKE and NEP) distributed on the platform and on the shelf	Not effective in protecting coastal stocks (i.e. MUT)	Could determine an improvement of fisheries performance in the mid-term, also as consequence of the improved conditions of some stocks	
Model	**Scenario**	**Strengths**	**Weakness**	**Opportunities**	**Threats**
BEMTOOL	**S0** (Status quo)	S0 benefits of the effects due to the transition	The biomass of the stocks sustainably exploited has	No opportunities.	Though not simulated in BEMTOOL, there is the

		phase, during which a reduction of the fishing effort already took place and the stocks start to recover. In S0 the stocks which fishing mortality is close to the reference point would continue to be exploited near to the optimal harvest strategy. In addition, the economic performance of the fleets, especially those (beam trawlers) targeting mainly the stocks close to a sustainable exploitation (common sole) is not perturbed.	a decreasing trend. In addition, there are at least four assessed stocks with a ratio F/F_{MSY} higher than 2 and 1 stock with a ratio at 1.5. This implies an exploitation at a suboptimal level compared to the potentials of the stocks. The MEY is currently exceeded of at least 20%. The discarding will continue as usual.		risk that external drivers, as the effects of climate change, might negatively impact the stock productivity in the medium terms (for example *via* the recruitment success), determining a further deterioration of the status of the stocks more vulnerable by such impact.
BEMTOOL	**S1** (only fishing days reduction)	Under Scenario S1, F would get or even be lower than Fupper for all the stocks except two. SSB would increase for all the stocks, positively influencing the productivity. This would positively affect the revenues of the small scale fleets in the short and	Considering the mixed fishery features, the landings, revenues and all the economic indicators of the beam trawlers, which main target is common sole, a stock in sustainable conditions, would be very negatively impacted in the short and medium terms. For these fleets all the	Subsidies for compensation and incentives to maintain more sustainable fisheries practices might be introduced with the new structural funds for fishery (FEAMPA 2021-2027). Given that the amount of landings for some fleets	The dependency analysis showed that revenues are quite dependent (>30%) by the assessed and regulated species, for almost all the trawl and beam trawl fleets. Since 2004-2010 to 2016-2018 a decrease of the employment of 10% for all the fleet has been

		medium terms. Overall the tendency of the economic performance (i.e. profits and the balance indicator R/BER) will moderately improve in the medium terms. Also the wages would improve considering the current crew share system. The discards will decrease and so the Landing Obligation would pose less management problems.	economic indicators will enter in a negative loop. Though to a lesser extent, the landing and revenues of most of the trawler fleets would be impacted too. If the exploitation pattern will not change the improvement of the stock productivity in the medium term would not be durable.	would decrease, the market might react with a premium price, beyond the dynamic of model assumptions.	observed, likely as a consequence of fishing vessel withdrawal. It has been then assumed that under much reduced fishing opportunities the employment might decrease of about 5%, because trawl fishery enterprises might not have sufficient resources for competing during a period of 2-3 years until a new equilibrium is reached. This loss has been considered as definitive. The market may react to the lower landing in the short terms with an increase of the import.
BEMTOOL	**S2** (composite scenario)	Under Scenario S2, F would get in between Flow and F_{MSY} for two stocks, while for one stock it will be in between F_{MSY} and Fupper. For European hake it will get close to Fupper.	This scenario would have an impact on the economic indicators in the short terms, given the loss of revenues consequent to the increased selectivity. In the medium terms the	Subsidies for compensation and incentives to maintain more sustainable fisheries practices might be introduced with the new structural funds for	The dependency analysis showed that revenues are quite dependent (>30%) by the assessed and regulated species, for almost all the trawl and beam trawl fleets.

		SSB would increase for all the stocks, positively influencing the productivity. This would positively affect the revenues, and such effect is more wisely (compared to S1) distributed among the different fleets and metiers. Overall the economic performance will improve in the medium terms, considering profits and the balance indicator R/BER. For certain fleets even better than in S1. Also the wages would improve, under the current crew share system. The discards will decrease and so the Landing Obligation would pose less management problems. Considering that the exploitation pattern in this scenario will improve, also the	impact will be less severe than under S1. Considering the mixed fishery features, the landings, revenues and all the economic indicators of the beam trawlers that mainly target common sole, which is in sustainable conditions, would be negatively impacted in the short and medium terms, although less than in S1.	fishery (FEAMPA 2021-2027). Use incentives for improving selectivity of the fishing gears is an opportunity. Given that the amount of landings for some fleets would decrease in the short terms, the market might react with a premium price, beyond the dynamic of model assumptions. Incentive for co-management implementing pilot actions for fishing facilitating control and improve access to the market.	Since 2004-2010 to 2016-2018 a decrease of the employment of 10% for all the fleet has been observed, likely as a consequence of fishing vessel withdrawal. It is assumed that under reduced fishing opportunities the employment might decrease of about 3%, because trawl fishery enterprises might not have sufficient resources for competing during a period of 2-3 years until a new equilibrium is reached. The market may react to the lower landing in the short terms with an increase of the import. Control might be more difficult in this scenario because of the complexity of the measures (gear selectivity and closed areas).

		improvement of the stock productivity in the medium term would be durable.			
ECOSPACE	Sensitivity of different FRAs: **Pomo Pit FRA**	Large positive effects in the medium term with increase of biomass for European hake (doubling) and Norway lobster (four times the reference) locally in the protected area.	Minimal cascading effects on other species: positive effects are concentrated on the two target species (hake and Norway lobster), because no simulated modification of effort.	Spill over of European hake and Norway lobster is having positive effects in the whole Adriatic Sea in the medium term with increased biomasses and catches by 5% even in absence of any effort regime control.	Predation by European hake might negatively affecting Deep Water Rose Shrimp (decrease by 15% in the whole area) and displacement of fisheries impact on red mullet with a decrease in both biomass and catches at sea (-3%).
ECOSPACE	Sensitivity of different FRAs: **Bari Canyon**	Effects in the medium term with increase of biomass for European hake (+25%) and Norway lobster (+50%) locally in the protected area.	The positive effects are diluted in the whole Adriatic with almost no effects on all target species, except hake.	Spill over of European hake is having minimal positive effects in the whole Adriatic Sea in the medium term with increased biomasses and catches by 1% even in absence of any effort regime control.	NA
ECOSPACE	Sensitivity of different FRAs: **Northern**	Increase of biomass (between 2-8%) inside the FRA for common sole,	The positive effects are highly diluted in the whole Adriatic	Potential indirect effects on other demersal species, but great uncertainty	Displacement of fisheries with no control of effort is affecting the resources, with small (max -0.5%)

	Adriatic Sanctuary	mantis shrimp in medium term.			but consistent reduction of catches and biomass outside the FRA in the context of constant effort regime.
ECOSPACE	**S1** (coastal closure)	Possibly easy to implement, but	Minimal positive effects on biomasses inside the 6NM. Large uncertainty from this modelling approach because recruitment and juvenile habitat dynamics might be considerably improved to be accurate.	NA	Displacement of trawling outside the 6NM strip result in small reduction of biomasses of key demersal target species (European hake, common sole,)
ECOSPACE	**S2** (effort reduction as foreseen by MAP for 2022-2026)	Rebuilding of Red mullet and European hake (+5% and +10% biomass), biomass increase also for Norway lobster, Common sole, mantis shrimp (+2/3 %) in the medium term.	Small decrease of biomass for anchovy (-2%) due to predation	In spite of effort reduction, there will be an increase of catches in the medium term (after 10 years from application of the management activity) by 3% for European hake and 1-2% for Norway lobster and Red mullet.	Short terms effects are highly negative for the fisheries sector with decrease of catches for towed gears in the order of -15% with respect to reference scenario. In the long term large decrease (-8%) decrease of catches for Deep water Rose shrimp.

ECOSPACE	**S3** (effort reduction as foreseen by MAP for 2022-2026 and implementation of Bari and Northern Adriatic FRAs	Rebuilding of Red mullet and European hake (+8% and +12% a in biomass), biomass increase also for Norway lobster, Common sole, mantis shrimp (+2/3 %) in the medium term.	Small decrease of biomass for anchovy (-2%) due to predation.	In spite of effort reduction, there will be a slight increase of catches in the medium term (after 10 years from application of the management activity) by 2% for European hake and 1% for Norway lobster and Red mullet.	Short terms effects are similar to those od scenario S2. In the long term large decrease (-6%) decrease of catches for Deep water Rose shrimp.
ECOSPACE	**S4** (climatic changes affecting biomass of phytoplankton)	First level assessment of climate change effects.	Scenario is affecting species through reduction of biomass of phytoplankton and bottom temperature changes. Other effects of climate change might be considered to increase the accuracy of estimates.	Sardine and Norway lobster benefit from climate change with an increase in biomass at sea of approximately 3% and 1% respectively. This might be an opportunity in catches	Strong reduction of biomasses at sea for Anchovy, Hake, Mantis shrimp, common sole and deep water rose shrimp species: reduction range from -5% and -10% in the medium long term.

4 DISCUSSION

This deliverable contains a synthesis of large efforts conducted during the FAIRSEA project for implementing scenarios on climatic changes and alternative fisheries management options. The effort produced by FAIRSEA are valuable because done with a series of tools: hydrodynamics and biogeochemical coupled models, species distribution models (SDM), SMART approach based on VMS analysis, BEMTOOL approach taking into account biological, impact and socio-economic factors, ECOSPACE which represents spatially explicit multispecies and multifleet interactions.
Only ECOSPACE embedded explicitly environmental changes (as obtained by HYDRO+BGC) and were used to test effects on commercially relevant species in the long term.
Yet using the inputs from climatic simulations from hydrodynamic and biogeochemical modelling approach, in ECOSPACE relevant effects in biomass for many species were estimated, essentially due to the estimated reduction of biomass of large phytoplankton in the future due to changes in water temperature. Although this result is relevant and negative it needs to be considered with caution because of the high uncertainty and because only plankton biomasses and temperature were used to drive ECOSPACE climatic scenario: therefore the model has poor capacity of representing the maintained primary production as estimated by biogeochemical models. Nevertheless, the climatic scenario reveals a potentially very critical effect of climatic changes on the Adriatic and Ionian basin resources in the long term future (see Figure 4.1), with negative effects also cascading on commercial resources and fisheries that cannot be compensated by management measures.

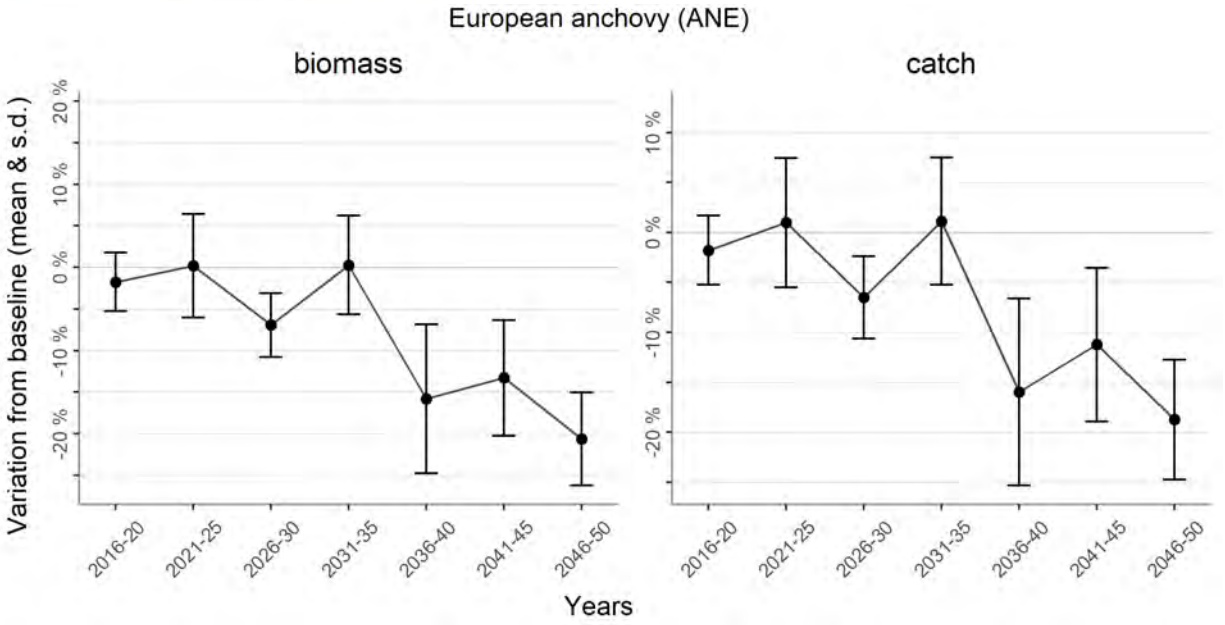

Figure 4.1 – Changes in biomass for European anchovy (ANE) in the climatic S4 scenario relative to the baseline scenario (S0) showing the high impact of climatic changes on biomass and catches.

Although future work might be required, the results report a negative effect of climate change on exploitable resources that was also obtained at global level (Tittensor et al., 2021) and highlight the need for accounting on it at least for evaluating the relative effects of management actions.

It is worth noting the potentially decoupled in temporal effects: fishing management have short and medium term effects on resources while climate changes might influence the resources on long terms. Thus management is anyway required for a more wise use of the resources, taking into account also the economic implication in terms of economic efficiency of the fishing system.

All the scenarios highlighted short terms general criticalities after the adoption of most of the alternative management actions, but a potential for recovery in economic parameters after a few years. Among the scenarios, those envisaging an improvement of selectivity and an integrated system of measures seems the most promising (see results of BEMTOOL) while the scenario most controversial resulted both for SMART and ECOSPACE in the coastal closure. Both these models that explicitly account for spatial movements of species and fleets reveal the drawbacks of the protection of the coastal zone (4NM from trawling all year round and the strip 4-6NM up to

December of each year) as the increase of effort off-shore with negative impacts on the populations.

Overall a combination of managed areas, control measures of effort and increase of selectivity seems the most indicated approach for increasing sustainability of fisheries, increasing efficiency of the sector. This was highlighted by the Multi Criteria Decision Analysis in BEMTOOL, when the weighing systems of the different indicators was reshaped considering the stakeholders inputs, and hence also evidenced using the SWOT approach on the basis of the advantages and disadvantages of the different scenarios. BEMTOOL highlighted that the situation of the wages would not be negatively impacted by the management measures and it would be possible to see some improvements in the future under the current crew share system of wages. The situation would be deteriorated only for the beam trawlers given the loss of fishing opportunities. The impact on the employment might be negative due to the losses in the short term that could determine a limitation in job opportunities. This also because a mechanism of compensation by subsidies or incentives has not been simulated. .

An analysis of the effects of single measure adopted or to be adopted (sensitivity to FRAs) highlighted the importance of size and positioning when defining FRAs. The analysis conducted with the spatially explicit multispecies model with trophic interactions, pose evidence on cascading effects of management measures. Effects of cannibalism and predation by top predators is emerging in the multispecies ECOSPACE approach: for instance the protection of large European hake might induce depletion on its preys such as Red mullet and on juveniles of hake itself due to cannibalism predation.

Overall the results obtained allowed to track a consistent and reliable summary and provided evidence of the usefulness of the approaches implemented in FAIRSEA to support to future management actions in the Adriatic and North-western Ionian regions.

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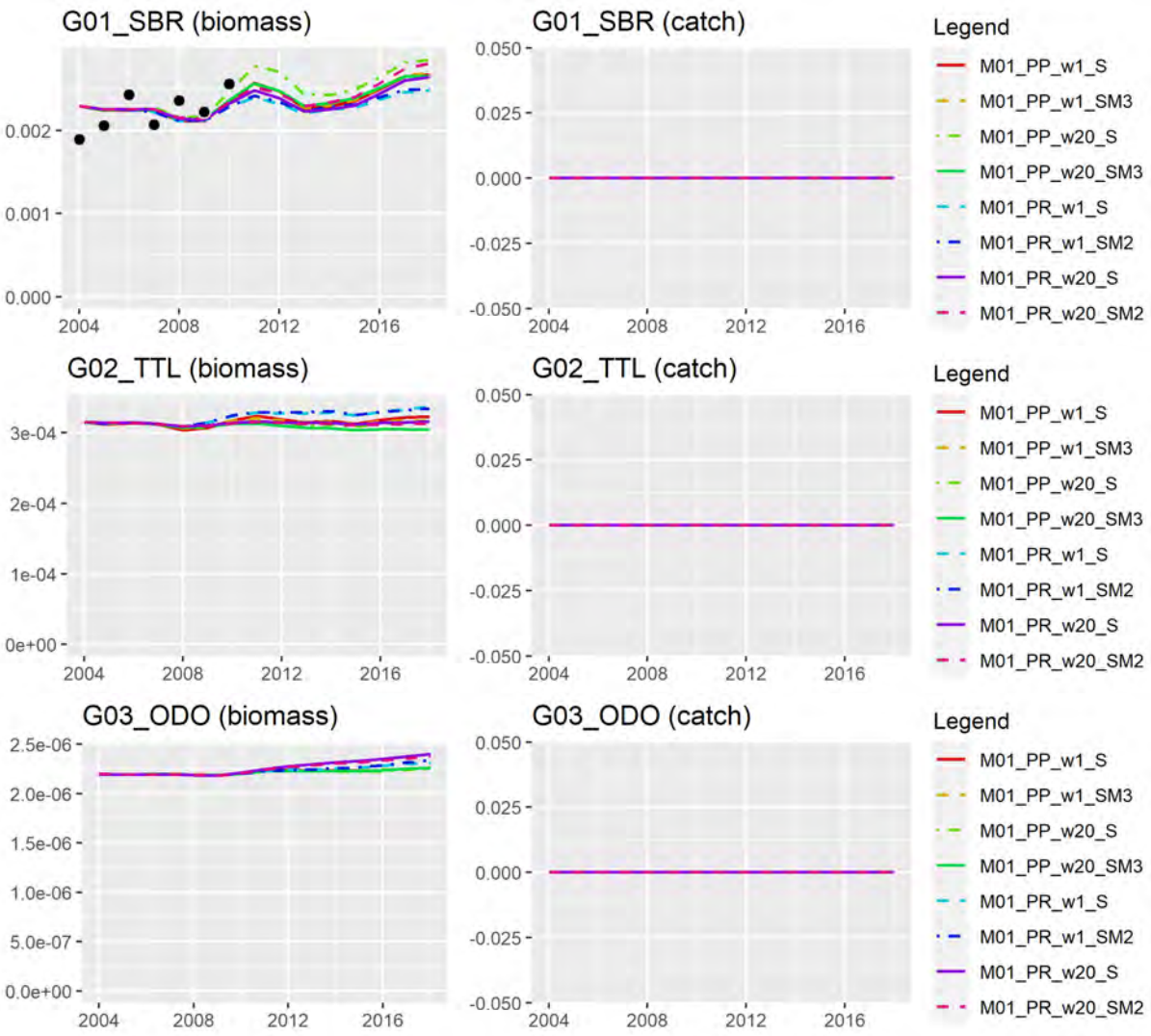
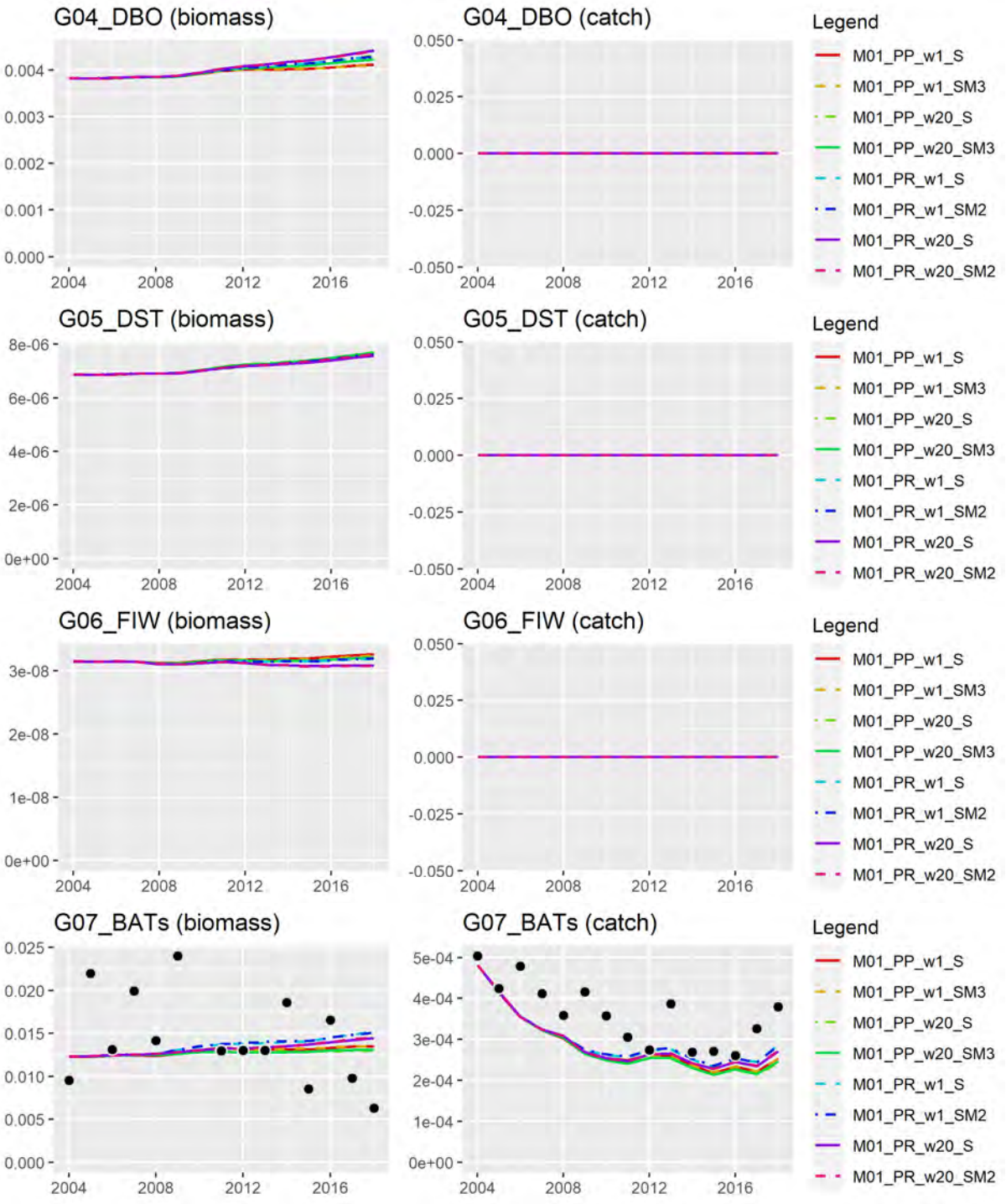
SUPPLEMENTARY MATERIAL OF SECTION 2.6

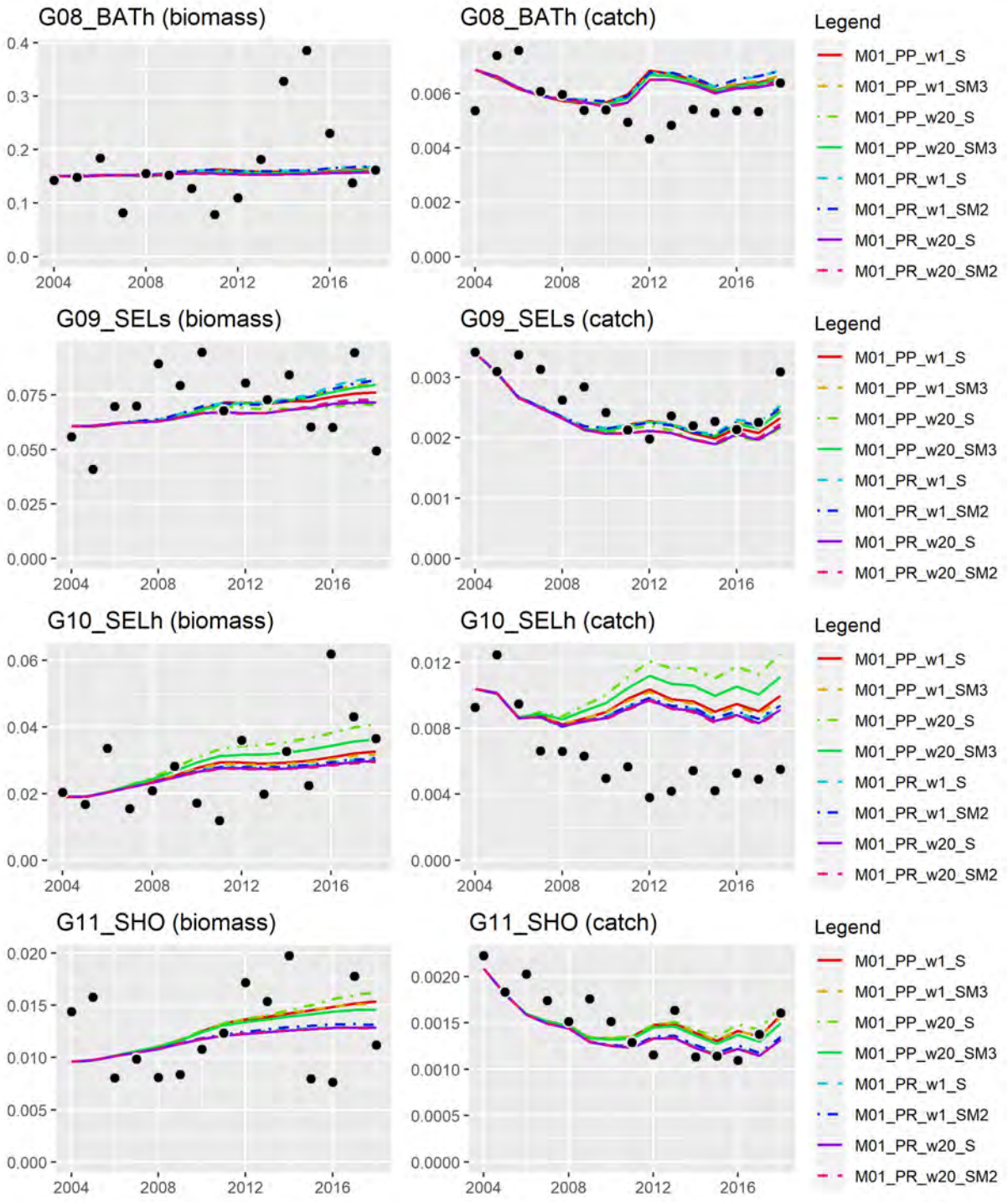
Table SM1. Functional groups (FGs) represented in the Ecopath model with their abbreviations. Shelf and Slope domains are coded as "h" and "s" in the FGs, respectively.

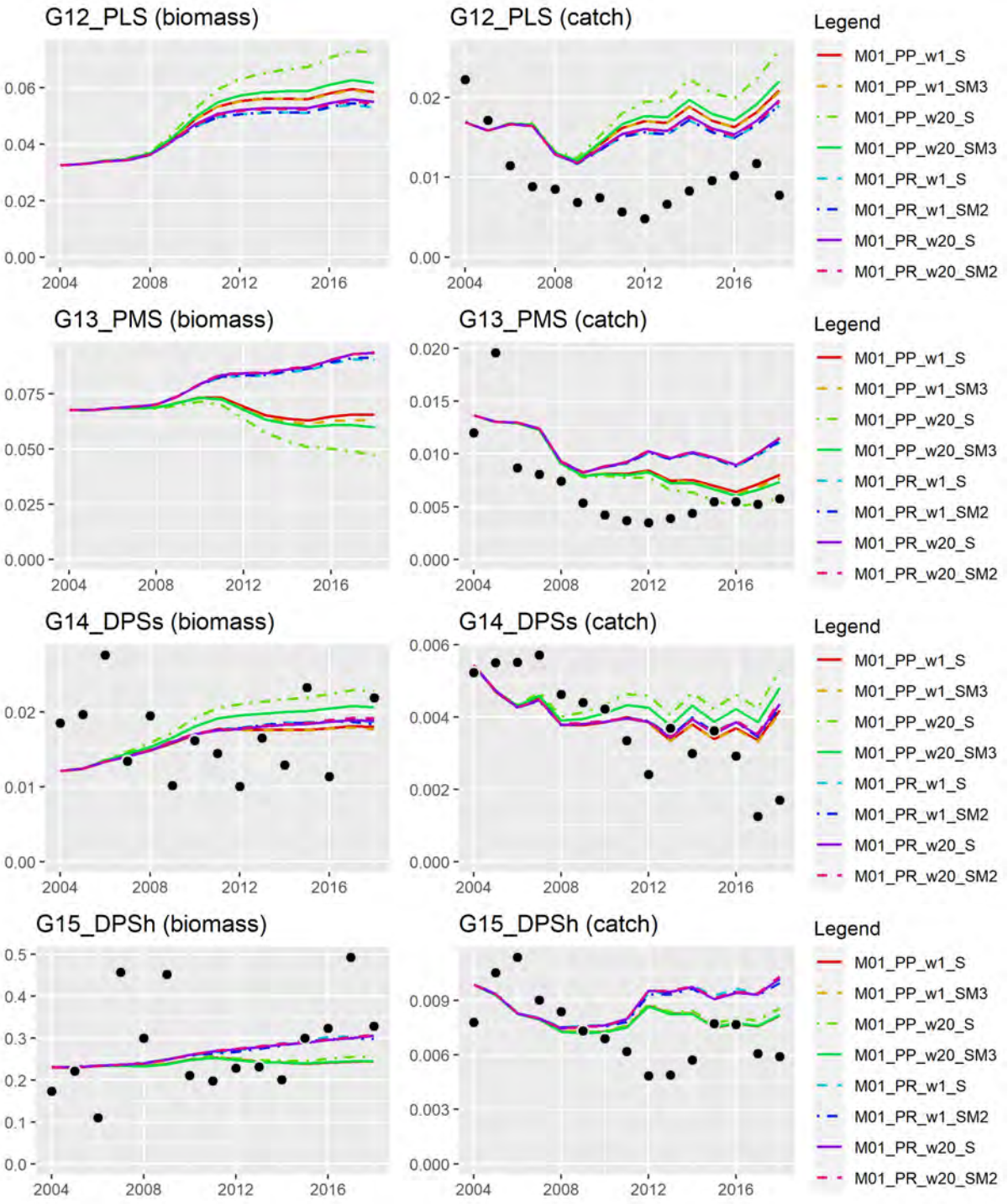
Functional Group name	Short name	Functional Group name	Short name
Seabirds	G01_SBR	Hake (age 1)	G38_HKE1
Marine turtles	G02_TTL	Hake (age 2+)	G39_HKE2
Mid-large odontocets	G03_ODO	Other cephalopods (Slope)	G40_CPXs
Common Bottlenose Dolphin	G04_DBO	Other cephalopods (Shelf)	G41_CPXh
Striped Dolphin	G05_DST	Squids	G42_SQD
Fin whale	G06_FIW	Common cuttlefish	G43_CTC
Rays skates (Slope)	G07_BATs	Musky-Horned octopus	G44_OCM
Rays skates (Shelf)	G08_BATh	Mantis shrimp (age 0)	G45_MTS0
Sharks (Slope)	G09_SELs	Mantis shrimp (age 1+)	G46_MTS1
Sharks (Shelf)	G10_SELh	Norway lobster (age 0)	G47_NEP0
Blackmouth catshark	G11_SHO	Norway lobster (age 1+)	G48_NEP1
Large pelagics fish	G12_PLS	Blue and Red Shrimp	G49_ARA
Medium pelagics fish	G13_PMS	Red Giant Shrimp	G50_ARS
Demersal piscivorous fish (Slope)	G14_DPSs	Deep-water Rose Shrimp (age 0)	G51_DPS0
Demersal piscivorous fish (Shelf)	G15_DPSh	Deep-water Rose Shrimp (age 1+)	G52_DPS1
Epipelagic fish	G16_EPI	Caramote prawn	G53_TGS
Mesopelagic crustacean feeding fish	G17_MCF	Decapods_Reptantia (Slope)	G54_REPs
Zooplancton jellyfish feeding fish	G18_ZJF	Decapods_Reptantia (Shelf)	G55_REPh
Demersal fish (Slope)	G19_DEMs	Decapods_Natantia (Slope)	G56_NATs
Demersal fish (Shelf)	G20_DEMh	Decapods_Natantia (Shelf)	G57_NATh
Other flatfishes	G21_FLX	Peracarida (suprabenthos)	G58_PER
Turbot and brill	G22_FTB	Clams	G59_CLM
Gurnads	G23_GUR	Scallops	G60_SCL
Other gadids	G24_GDX	Other Benthic invertebrates	G61_BIX
Other small pelagics	G25_SPX	Seagrasses	G62_SGR
Mackarels	G26_MCK	Seaweeds	G63_SWD
Anglers	G27_LOP	Jellyfish	G64_JLY
Sardine (age 0)	G28_PIL0	Macrozooplankton &Euphasiacea	G65_ZMA
Sardine (age 1+)	G29_PIL1	Mesozooplankton	G66_ZME
Anchovy (age 0)	G30_ANE0	Microzooplankton	G67_ZMI
Anchovy (age 1+)	G31_ANE1	Bacterioplankton	G68_BPL
Solea (age 0)	G32_SOL0	Phytoplankton - diatoms	G69_PDM
Solea (age 1)	G33_SOL1	Phytoplankton - dinoflagellates	G70_PDF

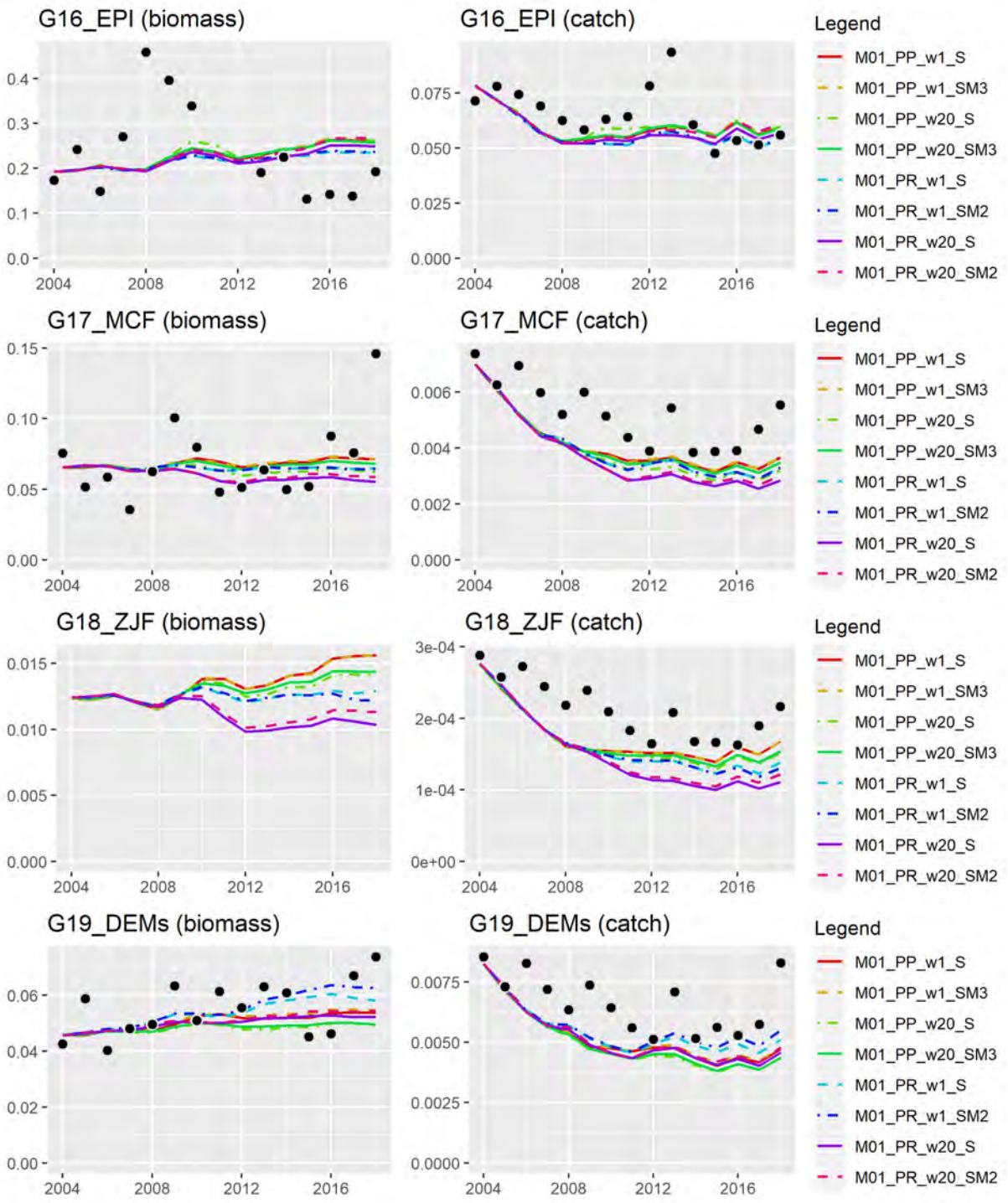
Solea (age 2+)	G34_SOL2	Discards, carrion	G71_DSC
Red mullet (age 0)	G35_MUT0	Suspended detritus	G72_POM
Red mullet (age 1+)	G36_MUT1	Bottom detritus	G73_BTD
Hake (age 0)	G37_HKE0		

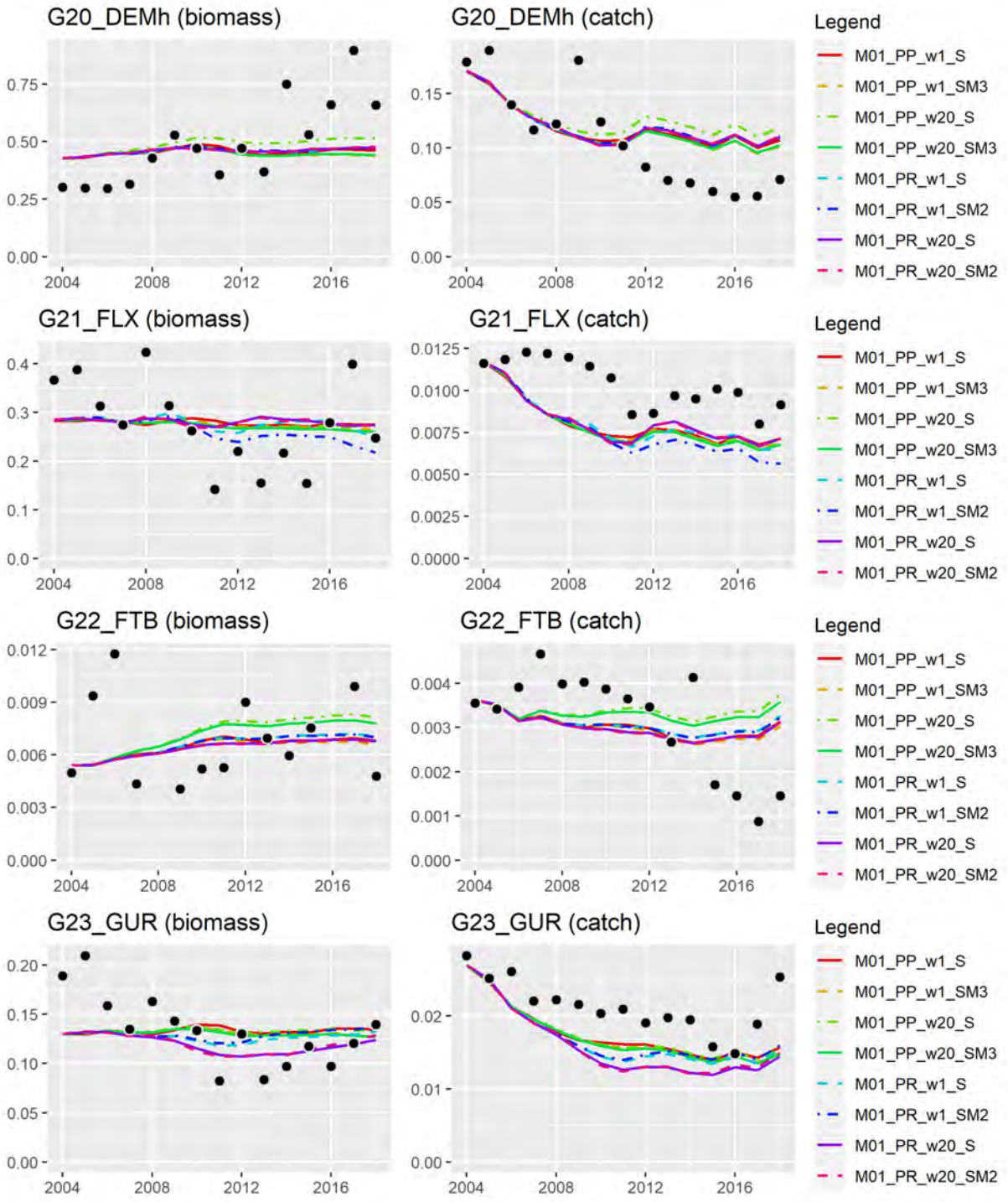



G04_DBO (biomass)
G04_DBO (catch)
G05_DST (biomass)
G05_DST (catch)
G06_FIW (biomass)
G06_FIW (catch)
G07_BATs (biomass)
G07_BATs (catch)
Legend
M01_PP_w1_S
M01_PP_w1_SM3
M01_PP_w20_S
M01_PP_w20_SM3
M01_PR_w1_S
M01_PR_w1_SM2
M01_PR_w20_S
M01_PR_w20_SM2
2004
2008
2012
2016


G08_BATh (biomass)
G08_BATh (catch)
G09_SELs (biomass)
G09_SELs (catch)
G10_SELh (biomass)
G10_SELh (catch)
G11_SHO (biomass)
G11_SHO (catch)
Legend
M01_PP_w1_S
M01_PP_w1_SM3
M01_PP_w20_S
M01_PP_w20_SM3
M01_PR_w1_S
M01_PR_w1_SM2
M01_PR_w20_S
M01_PR_w20_SM2


G12_PLS (biomass)
G12_PLS (catch)
G13_PMS (biomass)
G13_PMS (catch)
G14_DPSs (biomass)
G14_DPSs (catch)
G15_DPSh (biomass)
G15_DPSh (catch)
Legend
M01_PP_w1_S
M01_PP_w1_SM3
M01_PP_w20_S
M01_PP_w20_SM3
M01_PR_w1_S
M01_PR_w1_SM2
M01_PR_w20_S
M01_PR_w20_SM2
2004
2008
2012
2016


G16_EPI (biomass)
G16_EPI (catch)
G17_MCF (biomass)
G17_MCF (catch)
G18_ZJF (biomass)
G18_ZJF (catch)
G19_DEMs (biomass)
G19_DEMs (catch)
Legend
M01_PP_w1_S
M01_PP_w1_SM3
M01_PP_w20_S
M01_PP_w20_SM3
M01_PR_w1_S
M01_PR_w1_SM2
M01_PR_w20_S
M01_PR_w20_SM2
2004
2008
2012
2016


G20_DEMh (biomass)
G20_DEMh (catch)
G21_FLX (biomass)
G21_FLX (catch)
G22_FTB (biomass)
G22_FTB (catch)
G23_GUR (biomass)
G23_GUR (catch)
Legend
M01_PP_w1_S
M01_PP_w1_SM3
M01_PP_w20_S
M01_PP_w20_SM3
M01_PR_w1_S
M01_PR_w1_SM2
M01_PR_w20_S
M01_PR_w20_SM2
2004
2008
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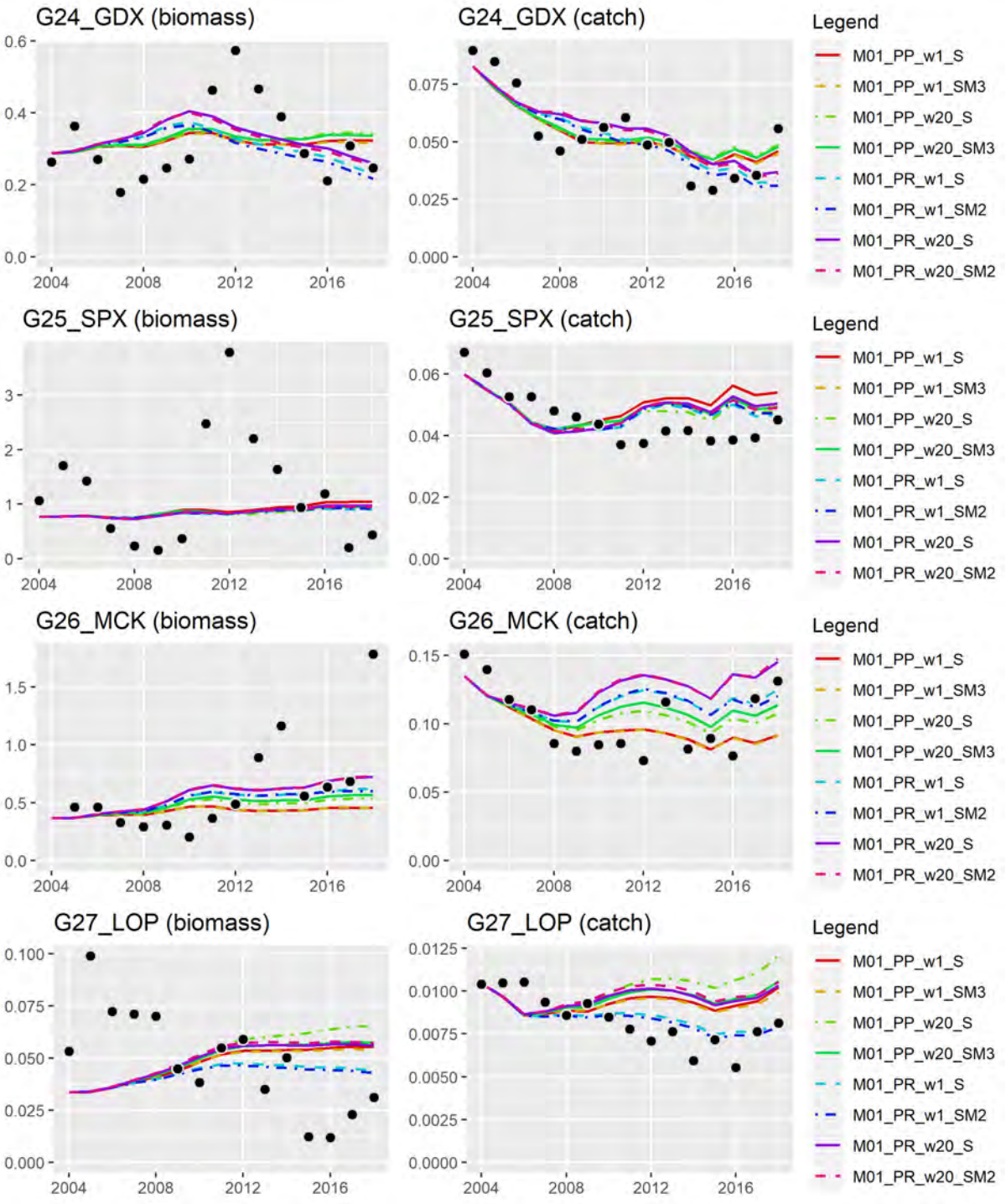
2016


G24_GDX (biomass)
G24_GDX (catch)
G25_SPX (biomass)
G25_SPX (catch)
G26_MCK (biomass)
G26_MCK (catch)
G27_LOP (biomass)
G27_LOP (catch)
Legend
M01_PP_w1_S
M01_PP_w1_SM3
M01_PP_w20_S
M01_PP_w20_SM3
M01_PR_w1_S
M01_PR_w1_SM2
M01_PR_w20_S
M01_PR_w20_SM2
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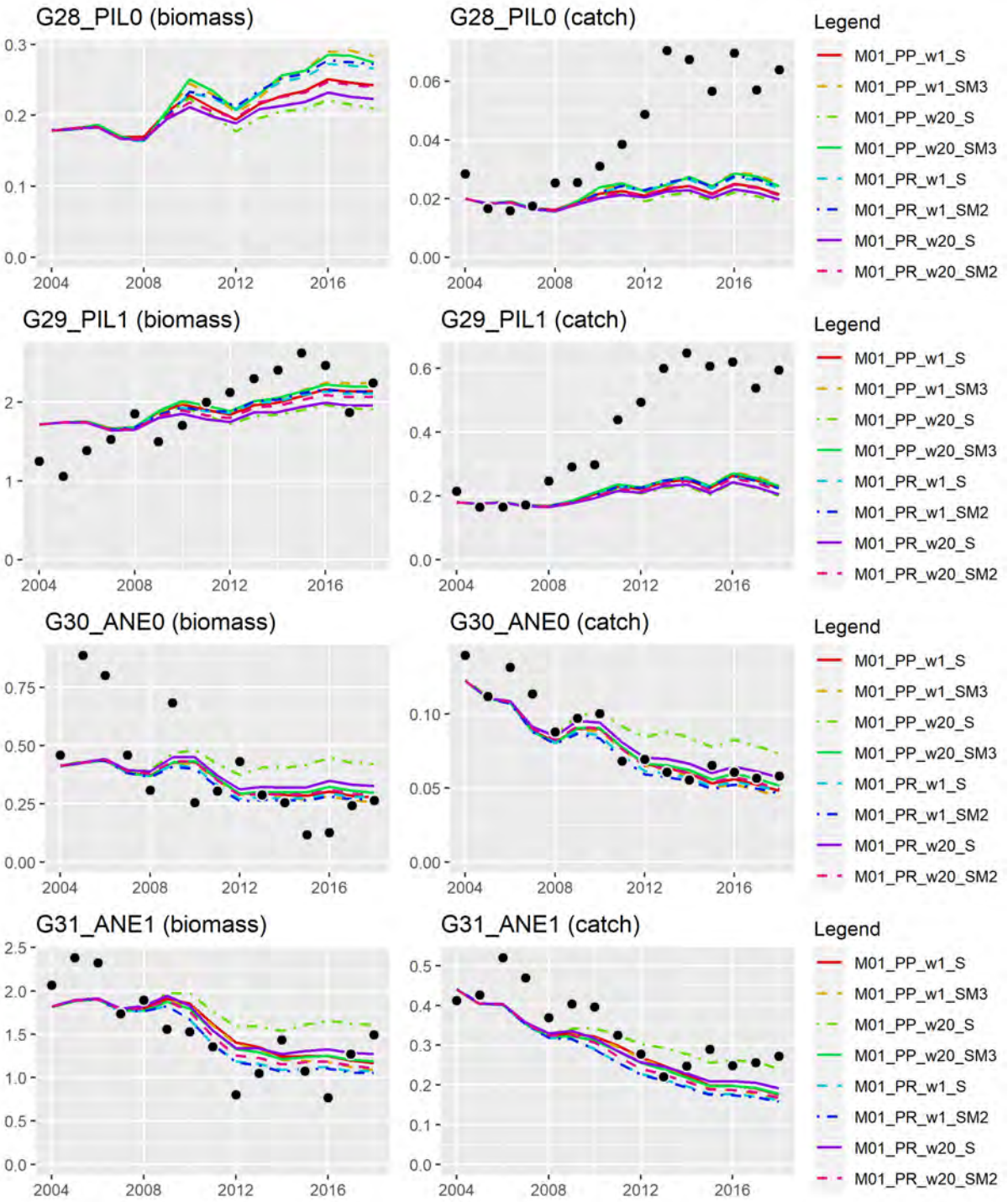
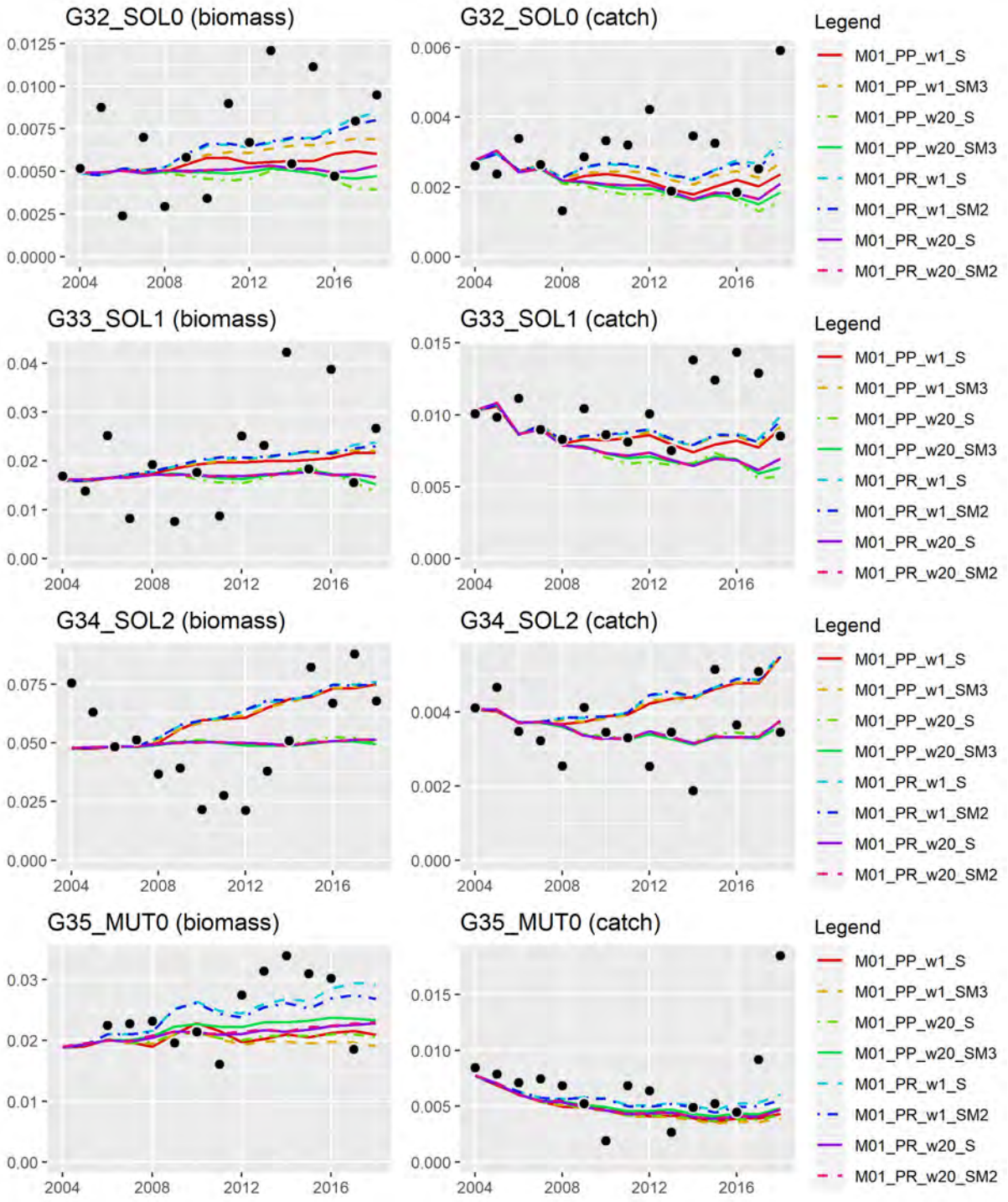

G28_PIL0 (biomass)
G28_PIL0 (catch)
G29_PIL1 (biomass)
G29_PIL1 (catch)
G30_ANE0 (biomass)
G30_ANE0 (catch)
G31_ANE1 (biomass)
G31_ANE1 (catch)
Legend
M01_PP_w1_S
M01_PP_w1_SM3
M01_PP_w20_S
M01_PP_w20_SM3
M01_PR_w1_S
M01_PR_w1_SM2
M01_PR_w20_S
M01_PR_w20_SM2


G32_SOL0 (biomass)
G32_SOL0 (catch)
G33_SOL1 (biomass)
G33_SOL1 (catch)
G34_SOL2 (biomass)
G34_SOL2 (catch)
G35_MUT0 (biomass)
G35_MUT0 (catch)
Legend
M01_PP_w1_S
M01_PP_w1_SM3
M01_PP_w20_S
M01_PP_w20_SM3
M01_PR_w1_S
M01_PR_w1_SM2
M01_PR_w20_S
M01_PR_w20_SM2
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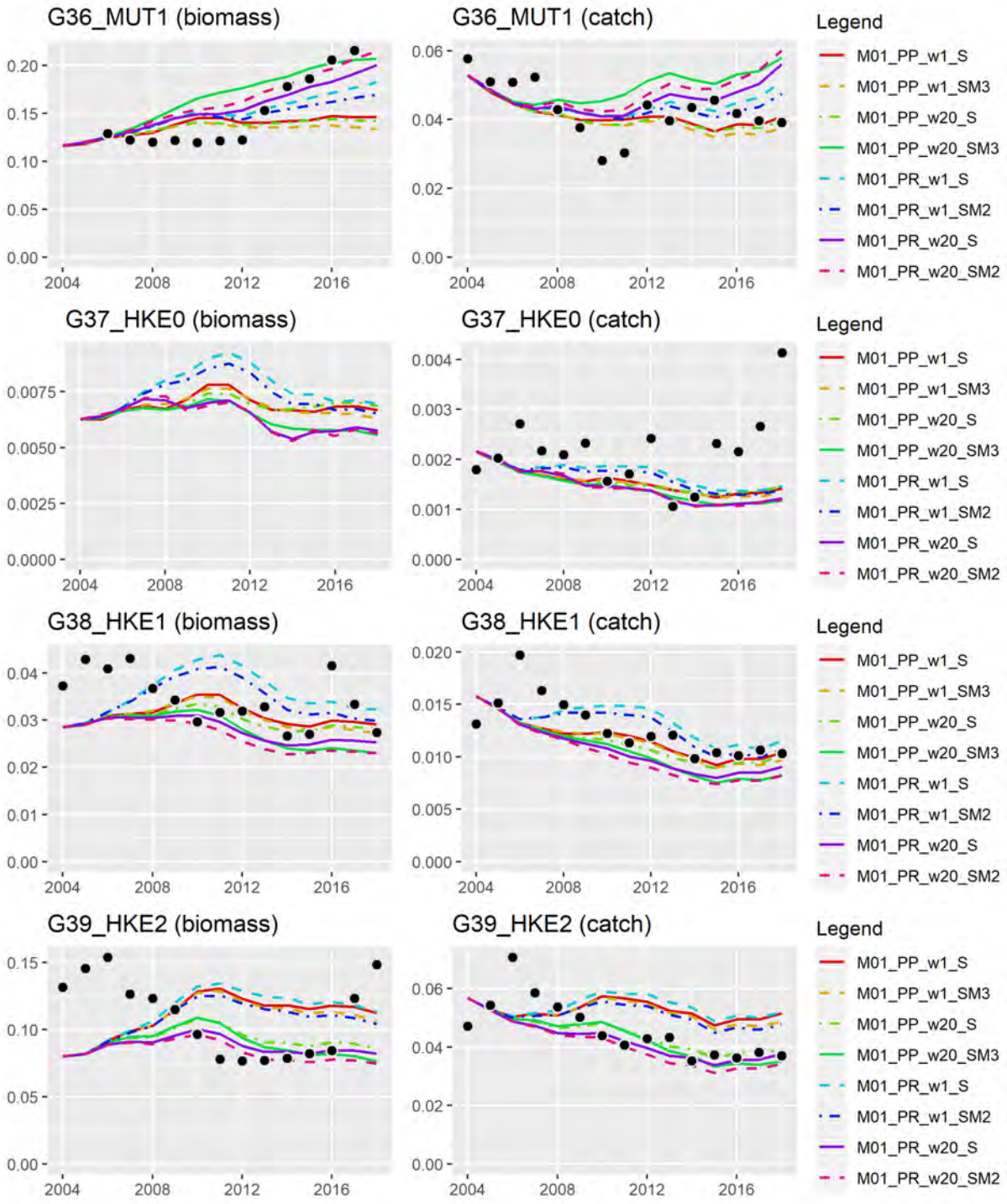
G36_MUT1 (biomass)
G36_MUT1 (catch)
G37_HKE0 (biomass)
G37_HKE0 (catch)
G38_HKE1 (biomass)
G38_HKE1 (catch)
G39_HKE2 (biomass)
G39_HKE2 (catch)
Legend
M01_PP_w1_S
M01_PP_w1_SM3
M01_PP_w20_S
M01_PP_w20_SM3
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M01_PR_w1_SM2
M01_PR_w20_S
M01_PR_w20_SM2
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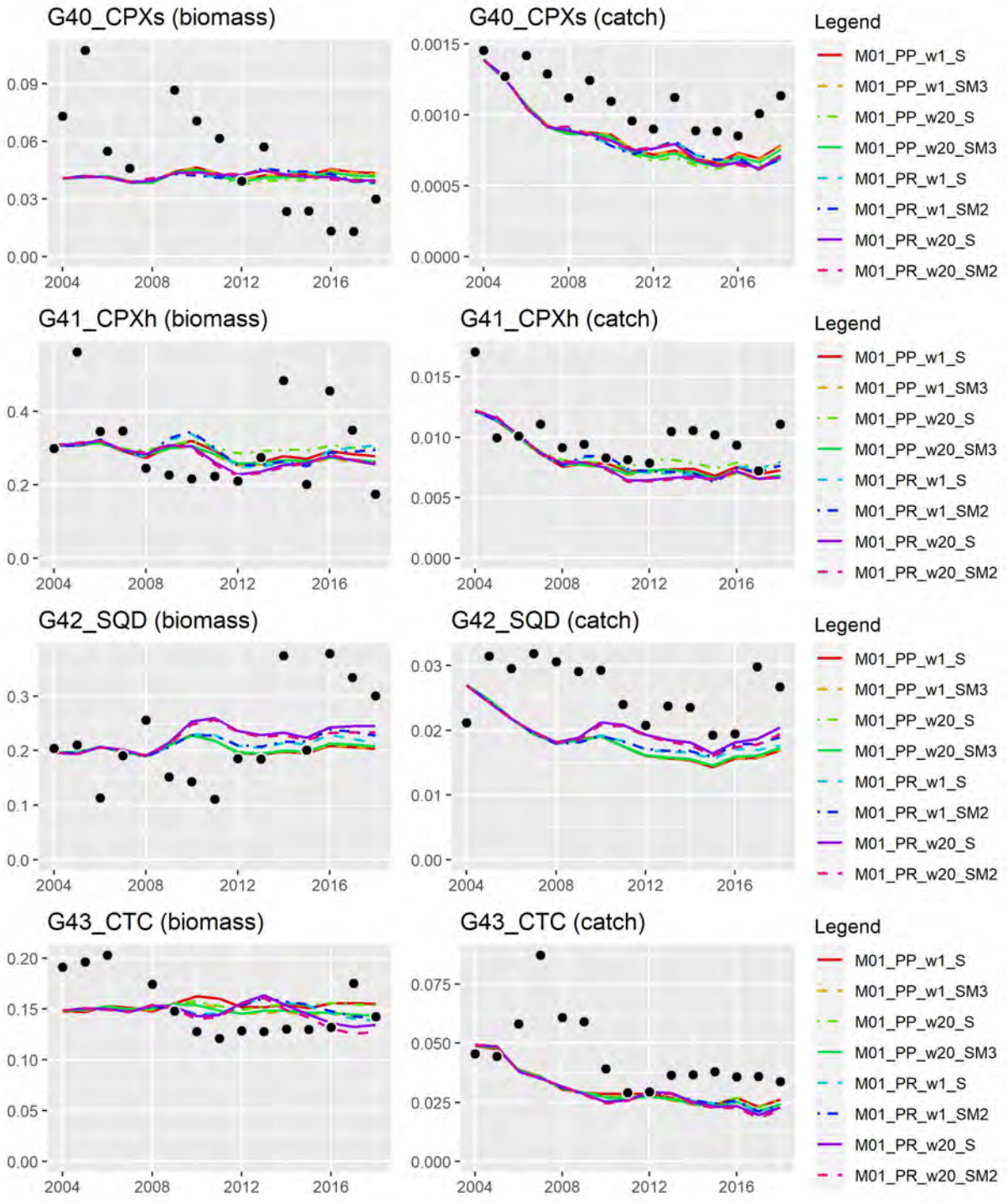
G40_CPXs (biomass)
G40_CPXs (catch)
G41_CPXh (biomass)
G41_CPXh (catch)
G42_SQD (biomass)
G42_SQD (catch)
G43_CTC (biomass)
G43_CTC (catch)
Legend
M01_PP_w1_S
M01_PP_w1_SM3
M01_PP_w20_S
M01_PP_w20_SM3
M01_PR_w1_S
M01_PR_w1_SM2
M01_PR_w20_S
M01_PR_w20_SM2
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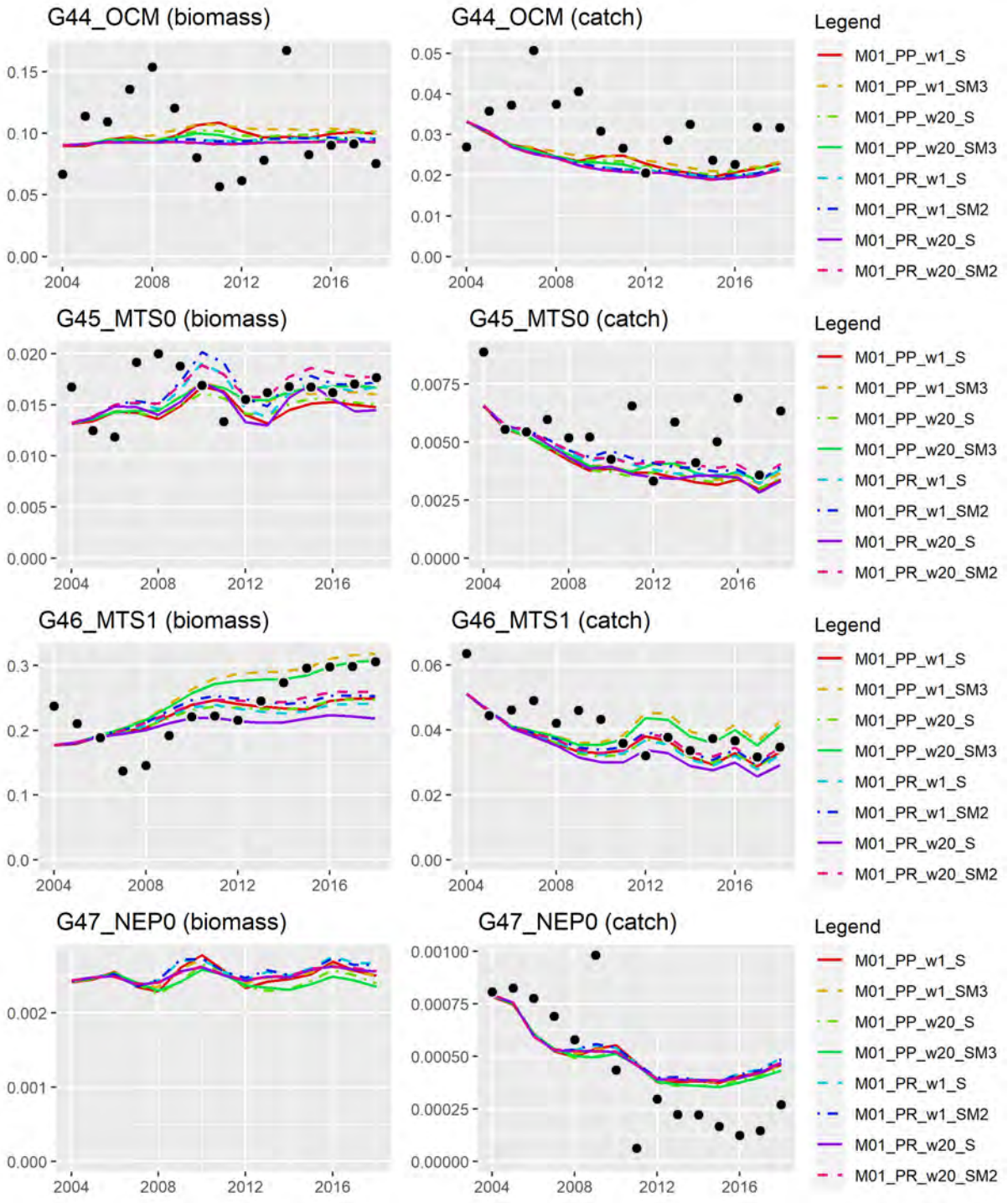
G44_OCM (biomass)
G44_OCM (catch)
G45_MTS0 (biomass)
G45_MTS0 (catch)
G46_MTS1 (biomass)
G46_MTS1 (catch)
G47_NEP0 (biomass)
G47_NEP0 (catch)
Legend
M01_PP_w1_S
M01_PP_w1_SM3
M01_PP_w20_S
M01_PP_w20_SM3
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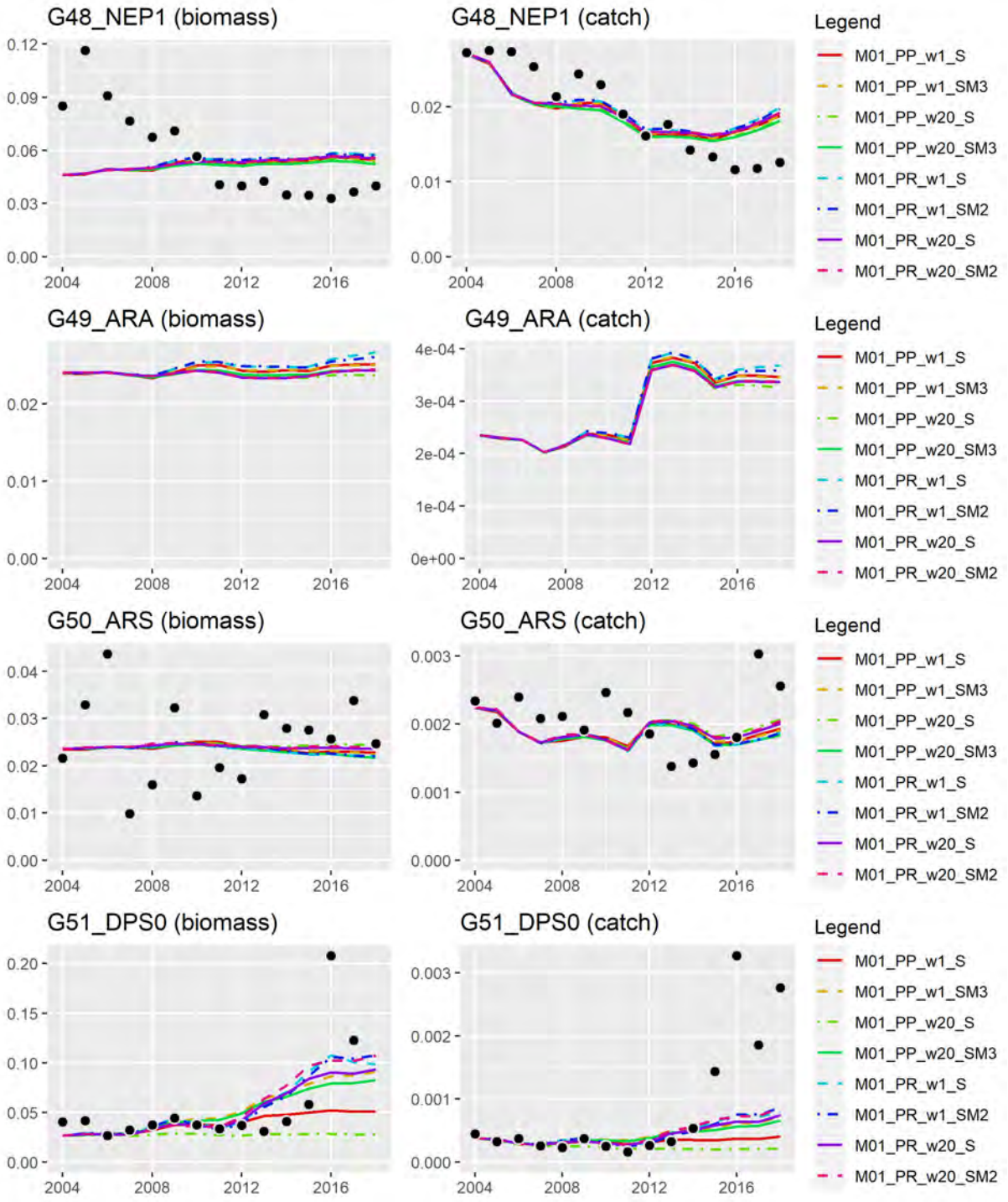
G48_NEP1 (biomass)
G48_NEP1 (catch)
G49_ARA (biomass)
G49_ARA (catch)
G50_ARS (biomass)
G50_ARS (catch)
G51_DPS0 (biomass)
G51_DPS0 (catch)
Legend
M01_PP_w1_S
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M01_PP_w20_SM3
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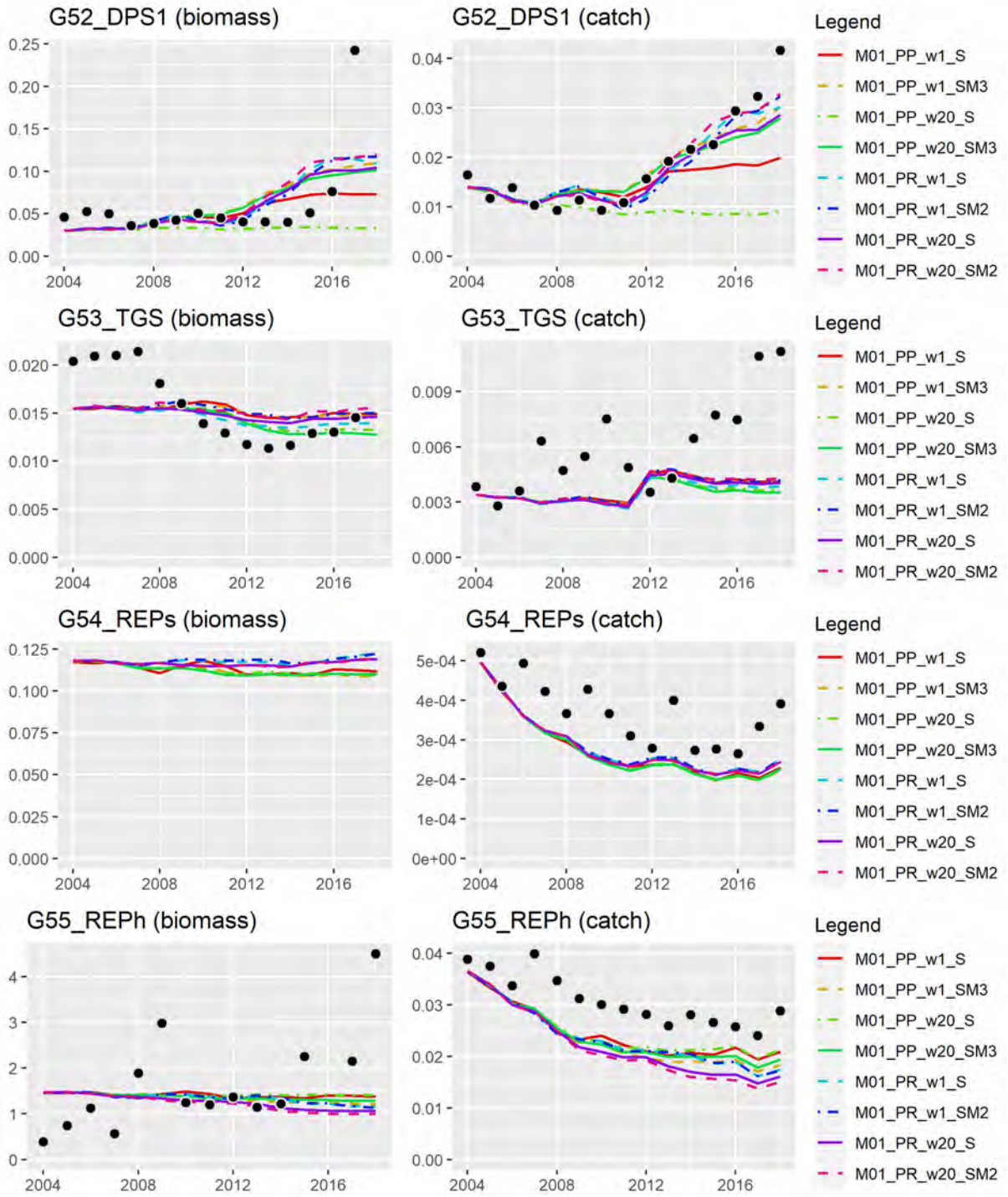
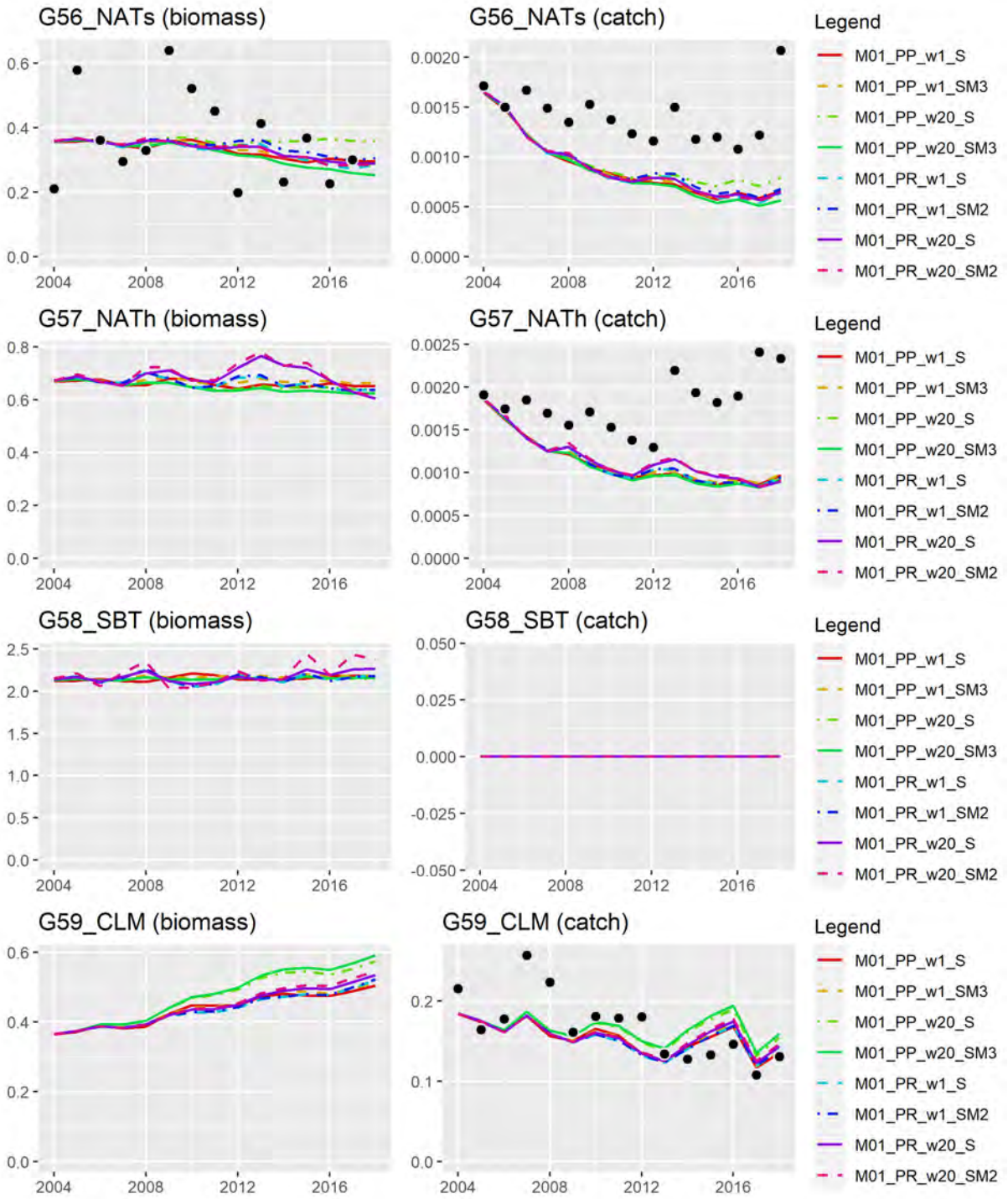
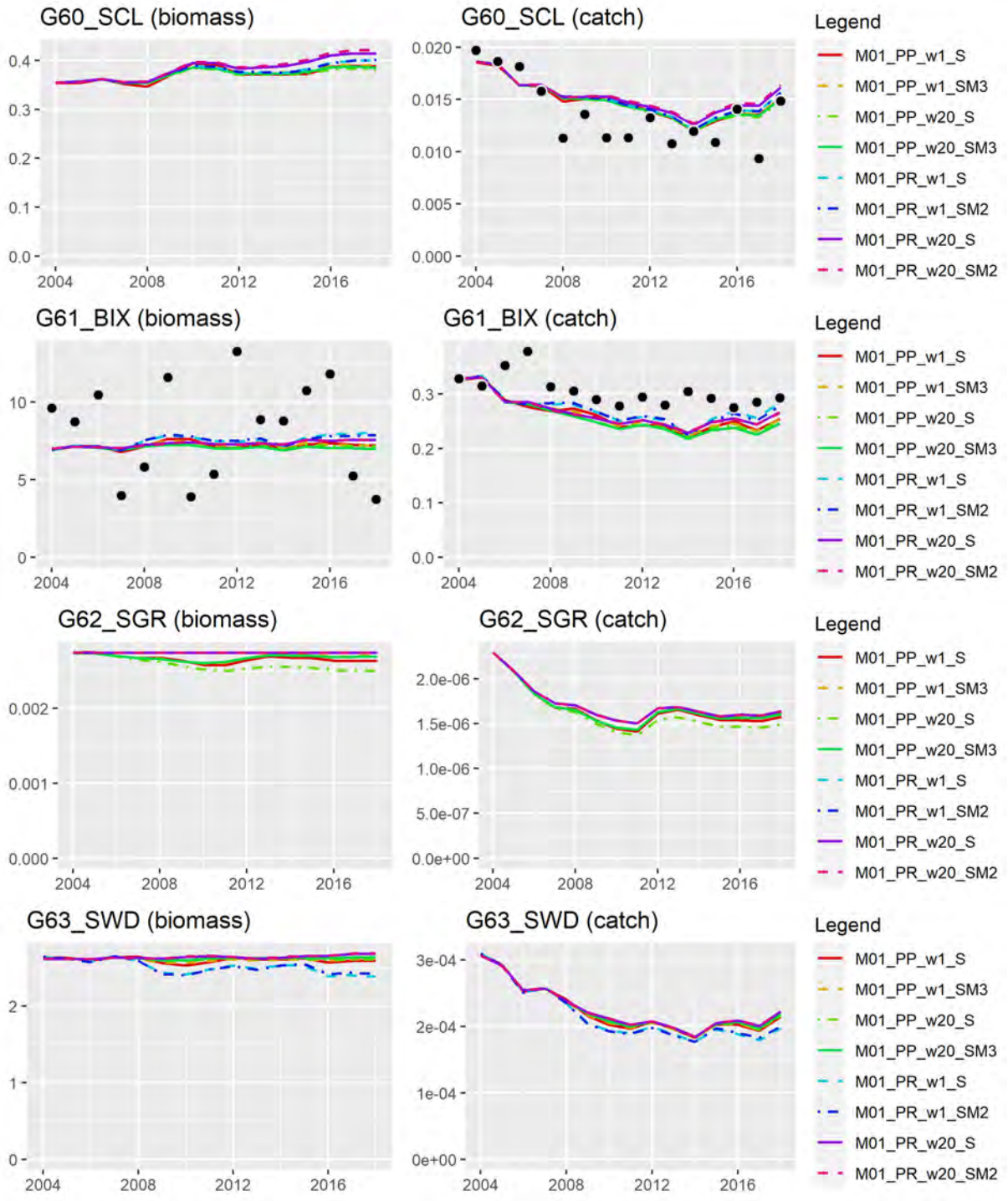
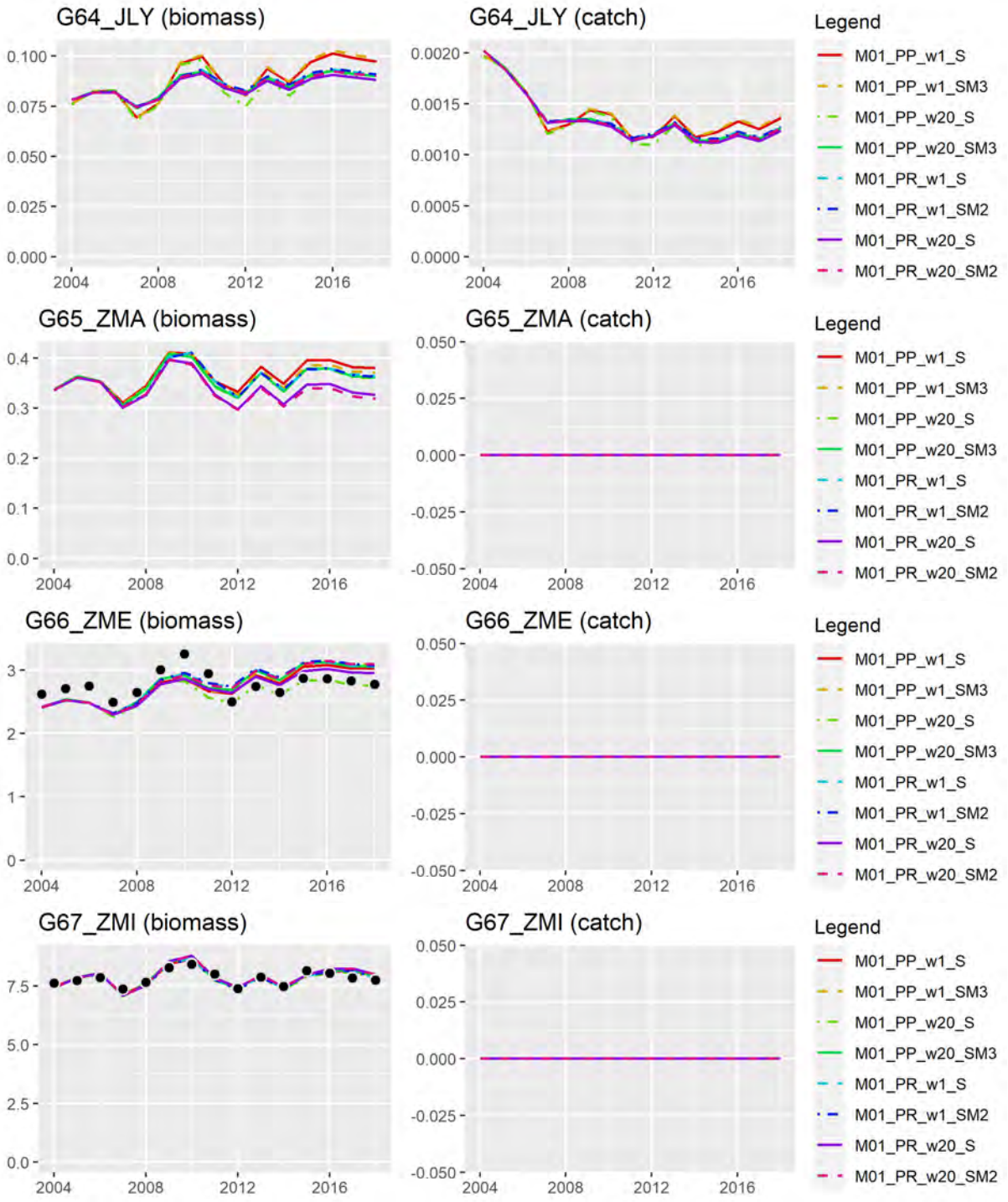

G52_DPS1 (biomass)
G52_DPS1 (catch)
G53_TGS (biomass)
G53_TGS (catch)
G54_REPs (biomass)
G54_REPs (catch)
G55_REPh (biomass)
G55_REPh (catch)
Legend
M01_PP_w1_S
M01_PP_w1_SM3
M01_PP_w20_S
M01_PP_w20_SM3
M01_PR_w1_S
M01_PR_w1_SM2
M01_PR_w20_S
M01_PR_w20_SM2
2004
2008
2012
2016


G56_NATs (biomass)
G56_NATs (catch)
G57_NATh (biomass)
G57_NATh (catch)
G58_SBT (biomass)
G58_SBT (catch)
G59_CLM (biomass)
G59_CLM (catch)
Legend
M01_PP_w1_S
M01_PP_w1_SM3
M01_PP_w20_S
M01_PP_w20_SM3
M01_PR_w1_S
M01_PR_w1_SM2
M01_PR_w20_S
M01_PR_w20_SM2


G60_SCL (biomass)
G60_SCL (catch)
G61_BIX (biomass)
G61_BIX (catch)
G62_SGR (biomass)
G62_SGR (catch)
G63_SWD (biomass)
G63_SWD (catch)
Legend
M01_PP_w1_S
M01_PP_w1_SM3
M01_PP_w20_S
M01_PP_w20_SM3
M01_PR_w1_S
M01_PR_w1_SM2
M01_PR_w20_S
M01_PR_w20_SM2
2004
2008
2012
2016


G64_JLY (biomass)
G64_JLY (catch)
G65_ZMA (biomass)
G65_ZMA (catch)
G66_ZME (biomass)
G66_ZME (catch)
G67_ZMI (biomass)
G67_ZMI (catch)
Legend
M01_PP_w1_S
M01_PP_w1_SM3
M01_PP_w20_S
M01_PP_w20_SM3
M01_PR_w1_S
M01_PR_w1_SM2
M01_PR_w20_S
M01_PR_w20_SM2
2004
2008
2012
2016

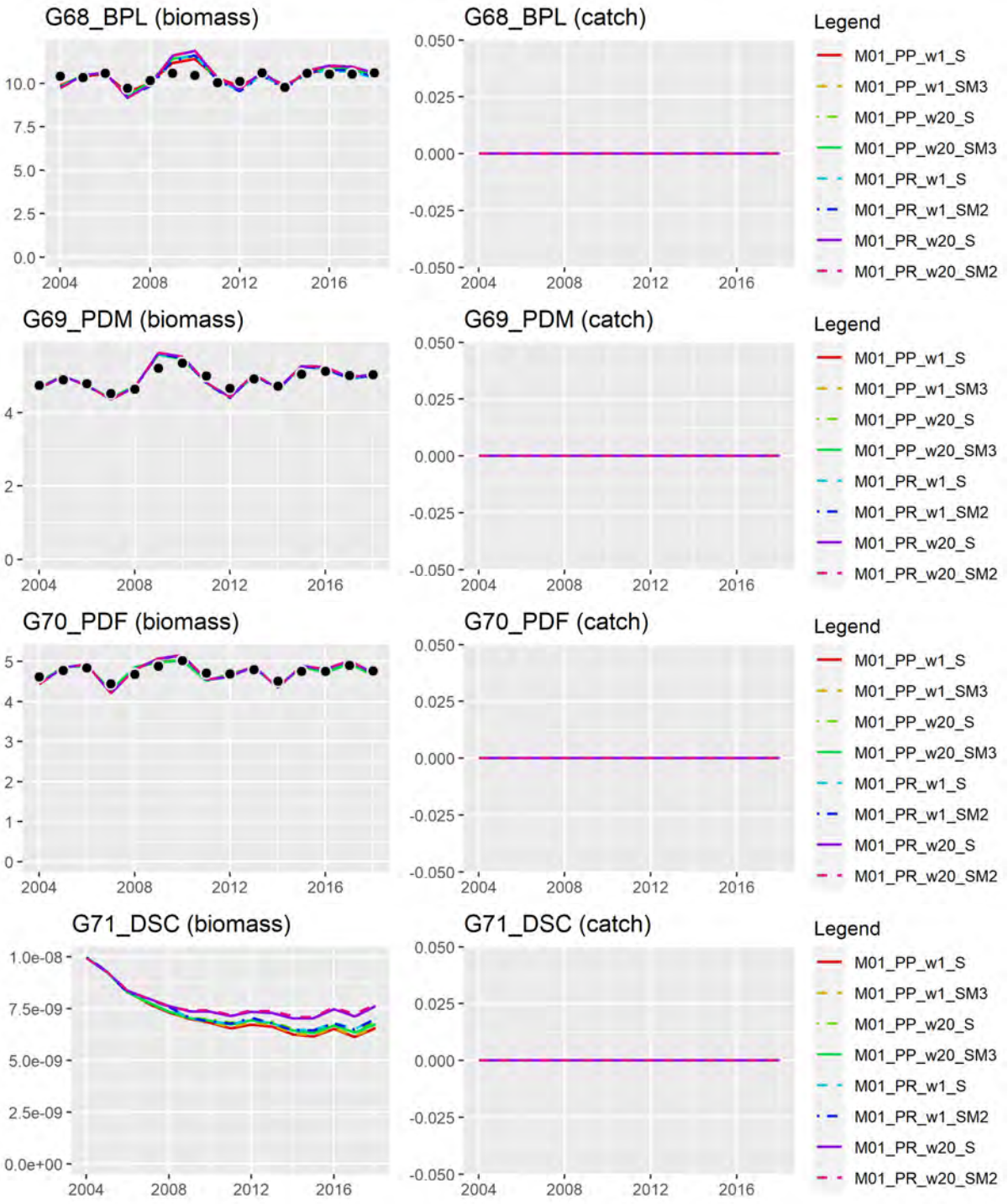

G68_BPL (biomass)
G68_BPL (catch)
G69_PDM (biomass)
G69_PDM (catch)
G70_PDF (biomass)
G70_PDF (catch)
G71_DSC (biomass)
G71_DSC (catch)
Legend
M01_PP_w1_S
M01_PP_w1_SM3
M01_PP_w20_S
M01_PP_w20_SM3
M01_PR_w1_S
M01_PR_w1_SM2
M01_PR_w20_S
M01_PR_w20_SM2
2004
2008
2012
2016



Figure SM 1. Fitting tested. For functional groups name please refer to deliverable 4.7. M01=model 1; PP=fitting by predator/prey setting; PR=fitting by predator setting; w01=relative biomasses weight=1; w20=relative biomasses of stock assessed groups weight=20; S=stepwise fitting; SM= stepwise fitting followed by manual fittings (2-3 number of manual search).

Table SM2. Fishery allocation for administrative areas. ITA=Italy; BIH=Bosnia and Hercegovina; HRV=Croatia; MNT=Montenegro; SLO and SVN= Slovenia. OTB= Bottom otter trawls; PTM= Pelagic pair trawls; PS=Purse seine; TBB= Beam trawls; DRB=dredges; GNX=set nets; LLX= long lines; MIX (seine, traps, small-scale fishery). VL=vessel length.

Fleet number	Fleet name	Region allocations in Ecospace
1	ALB_ONE_VL-ONE	all ALB waters
2	BIH_ONE_VL-ONE	HRV_ter_01_G; HRV_ter_02_G
3	HRV_DRB_VL-ONE	HRV_int_1_H; HRV_nat_2_A; HRV_nat_3_A; HRV_nat_4_A
4	HRV_GNX_VL-ONE	all territorial water HRV; HRV_int_01_H
5	HRV_LLX_VL-ONE	all HRV waters
6	HRV_MIX_VL-ONE	all territorial waters HRV
7	HRV_OTB_VL--18	all territorial waters HRV (from 4 nautical miles (02))
8	HRV_OTB_VL1824	all territorial waters HRV (from 4 nautical miles (02)); all international waters HRV
9	HRV_OTB_VL24++	all territorial waters HRV (from 4 nautical miles (02)); all international waters HRV
10	HRV_PS_VL--18	all territorial waters HRV
11	HRV_PS_VL18++	all waters HRV
12	HRV_TBB_VL--18	HRV_ter_02_A; HRV_ter_03_A; HRV_ter_04_A
13	ITA_DRB_VL-ONE	ITA_ter_01; ITA_ter_02; ITA_ter_03; HRV_int_01_H; HRV_ter_02_A; HRV_ter_03_A; HRV_ter_04_A

14	ITA_GNX_VL-ONE	all ITA waters;
15	ITA_LLX_VL-ONE	all ITA waters; all international HRV; ALB_int_01;
16	ITA_MIX_VL-ONE	all territorial waters ITA
17	ITA_OTB_VL--18	all ITA waters; HRV_int_01_H
18	ITA_OTB_VL1824	all ITA waters; ALB_int_01; MNE_int_01; HRV_int_01_H; all international HRV
19	ITA_OTB_VL24++	all ITA waters; ALB_int_01; MNE_int_01; all international HRV
20	ITA_PS_VL--18	all ITA waters; all international HRV
21	ITA_PS_VL18++	all ITA waters; ALB_int_01; MNE_int_01; all international HRV
22	ITA_PTM_VL--18	all ITA waters; all international HRV
23	ITA_PTM_VL1824	all ITA waters; MNE_int_01; all international HRV
24	ITA_PTM_VL24++	all ITA waters; ALB_int_01; MNE_int_01; all international HRV
25	ITA_TBB_VL--18	all ITA waters (North of Gargano); HRV_int_01_H; HRV_int_01_I; HRV_int_01_J
26	ITA_TBB_VL18++	all ITA waters (North of Gargano); HRV_int_01_H; HRV_int_01_I; HRV_int_01_J
27	MNT_ONE_VL-ONE	all Montenegro waters
28	SLO_GNX_VL-ONE	all SLO waters
29	SLO_LLX_VL-ONE	all SLO waters
30	SLO_MIX_VL-ONE	all SLO waters
31	SLO_OTB_VL-ONE	SVN_ter_02; SVN_ter_03
32	SLO_PS_VL-ONE	all SLO waters
33	SLO_PTM_VL-ONE	SVN_ter_02; SVN_ter_03

Table SM3. Species value across countries and fleets

Group name	G07_ BATs	G08_ BATh	G09_ SELs	G10_S ELh	G11_ SHO	G12_ PLS	G13_ PMS	G14_ DPSs	G15_ DPSh	G16_ EPI	G17_ MCF	G18_ ZJF	G19_ DEMs	G20_ DEMh	G21_ FLX	G22_ FTB	G23_ GUR	G24_ GDX	G25_ SPX	G26_ MCK	G27_ LOP	G28_ PIL0	G29_ PIL1	G30_ ANE0	G31_ ANE1	G32_ SOL0
ALB_ONE_VL-ONE		3.23		4.24		10.13	5.16	1.99	12.51	1.73				5.98	5.68	17.05	5.20	2.59	1.28	1.55	7.76	0.81	0.81	1.49	1.49	10.62
BIH_ONE_VL-ONE														5.98												
HRV_DRB_VL-ONE		2.67	3.39	4.00		10.13	2.96	2.40	2.29	1.43				1.38	8.19	12.73	4.67	1.31		0.93	6.31	0.81	0.81	1.49	1.49	8.74
HRV_GNX_VL-ONE		2.43	3.39	4.33		9.39	3.69	2.40	13.36	1.43			2.09	4.19	7.62	12.73	4.67	1.49	1.47	0.48	6.31	0.38	0.38	0.95	0.95	8.74
HRV_LLX_VL-ONE		2.41	3.39	4.32		8.72	4.16	2.40	14.59	1.35			2.09	9.28	8.21	12.73	4.67	1.38	1.51	0.40	6.31	0.38	0.38	0.95	0.95	8.74
HRV_MIX_VL-ONE		2.07	3.39	3.94		5.61	4.70	2.40	14.13	1.40			2.09	3.96	3.30	12.73	4.67	1.48	1.51	0.39	6.31	0.38	0.38	0.95	0.95	8.74
HRV_OTB_VL--18		2.49	3.39	4.10		10.51	4.40	2.40	7.74	1.13			2.09	2.75	3.53	12.73	4.67	1.29	1.21	0.43	6.31	0.38	0.38	0.95	0.95	8.74
HRV_OTB_VL1824		2.39	3.39	4.25		10.13	2.36	2.40	12.85	1.07			2.09	3.17	2.78	12.73	4.67	1.37	1.17	0.44	6.31	0.81	0.81	1.49	1.49	8.74
HRV_OTB_VL24++		2.52	3.39	3.89		11.15	2.68	2.40	11.22	1.00			6.33	4.47	2.78	12.73	4.67	1.39		0.44	6.31	0.81	0.81	0.95	0.95	8.74
HRV_PS_VL--18		2.67	3.39	4.15		8.74	5.40	2.40	4.65	1.49			2.09	3.96	5.68	17.05	5.20	1.21	1.13	0.39	6.31	0.38	0.38	0.95	0.95	8.74
HRV_PS_VL18++		3.23	3.39	4.24		11.15	1.97		2.20	1.03				3.60		17.05		1.33	0.41	0.38		0.38	0.38	0.95	0.95	
HRV_TBB_VL--18								2.40	7.35	2.53				7.83								0.81	0.81	1.49	1.49	
ITA_DRB_VL-ONE														8.54												
ITA_GNX_VL-ONE	3.23	3.84	4.65	6.16	1.00		6.31	2.07	16.02	2.27			12.37	8.96	11.46	20.71	6.07	6.67	1.71	4.09	8.11	1.57	1.57	1.39	1.39	13.04
ITA_LLX_VL-ONE	3.23	3.23	3.39	3.32	1.00	11.10	9.59	1.04	36.46	1.73		1.00	12.45	15.28	5.68		12.95	5.17		1.56	7.76					10.62
ITA_MIX_VL-ONE		3.23		4.24			8.75	2.20	23.71	5.64			6.33	8.98	12.16	24.99	3.11	4.12	1.28	1.55	7.76	0.81	0.81	1.49	1.49	13.66
ITA_OTB_VL--18	3.23	4.38	2.05	5.08	1.00	10.13	3.94	1.24	12.24	2.35	1.27	1.00	8.88	6.81	5.20	21.57	3.16	2.85	0.95	2.20	8.70	1.23	1.23	1.83	1.83	14.16
ITA_OTB_VL1824	3.23	3.82	2.15	4.79	1.00	10.13	4.34	1.42	6.02	1.19	2.96	1.00	2.67	3.20	4.91	22.12	2.95	3.04	3.06	2.87	9.85	1.23	1.23	1.57	1.57	12.32
ITA_OTB_VL24++	3.23	3.28	6.49	3.67			2.67	1.40	5.73	2.12	3.30	1.00	7.73	4.96	4.49	19.60	2.77	2.22	1.28	2.50	9.33	1.73	1.73	2.52	2.52	16.35
ITA_PS_VL--18		3.23		4.24	1.00		6.75	1.99	22.24	2.62			6.33	3.95	5.68	17.05		5.23	0.67	2.74	7.76	1.74	1.74	4.01	4.01	10.62
ITA_PS_VL18++		3.23				10.97	3.35		12.51	1.03				5.98			5.20	2.59	1.28	1.18	7.76	0.61	0.61	1.48	1.48	10.62
ITA_PTM_VL--18		2.01		3.64		14.33	6.36	1.99	18.37	0.67				6.19	1.72	17.05	2.66	3.03	0.88	3.58		0.62	0.62	1.57	1.57	12.60
ITA_PTM_VL1824		4.21		5.30		9.91	11.00	1.99	12.51	1.11		1.00		3.08		17.05	15.67	2.37	0.98	2.08		0.63	0.63	1.30	1.30	10.62
ITA_PTM_VL24++		3.23		1.97		10.02	2.12	1.99	12.51	2.11		1.00		15.26	5.68	17.05	5.20	2.59	1.28	1.23	7.76	0.54	0.54	1.49	1.49	10.62
ITA_TBB_VL--18		7.26	3.05	5.87		10.13	5.16	1.45	16.09				10.66	4.17	5.81	21.58	3.48	2.09		1.90	12.50	0.81	0.81	1.49	1.49	8.57
ITA_TBB_VL18++	3.23	3.25	1.95	3.58		10.13	10.79	1.46	2.91	1.28			14.95	3.52	2.99	18.99	2.82	2.81	1.28	2.39	9.72	0.81	0.81	1.49	1.49	9.21
MNT_ONE_VL-ONE		3.23		4.24		10.13	5.16	1.99	12.51	1.73				5.98	5.68		5.20		1.28	1.55	7.76	0.81	0.81	1.49	1.49	
SLO_GNX_VL-ONE		3.13	4.65	5.24		9.39	5.00	2.24	14.69	1.85				6.57	9.54	16.72	5.37	4.08	1.59	2.29	7.21	0.97	0.97	1.17	1.17	10.89
SLO_LLX_VL-ONE		2.41					6.88	1.72	25.53	1.35				12.28	8.21	12.73	8.81	3.28		0.98						8.74
SLO_MIX_VL-ONE		2.07					6.72	2.30	18.92	3.52				6.47	7.73	18.86	3.89	2.80		0.39		0.38	0.38	0.95	0.95	11.20
SLO_OTB_VL-ONE		3.15		4.30			3.40	1.87	9.30	1.48		1.00		4.23	3.95	16.91	3.81	2.03	1.60	1.48	7.80	1.14	1.14	1.56	1.56	11.51
SLO_PS_VL-ONE		2.67		4.15		10.29	4.37	2.40	9.70	1.54		1.00		3.84	5.68	17.05	14.42	2.59	0.74	1.17	6.31	0.78	0.78	1.84	1.84	8.74
SLO_PTM_VL-ONE		3.11		3.63		11.42	6.49		18.37	1.30				8.18		17.05	9.17	2.70	0.93	2.30		0.60	0.60	1.45	1.45	

Group name	G33_ SOL1	G34_ SOL2	G35_ MUT0	G36_ MUT1	G37_ HKE0	G38_ HKE1	G39_ HKE2	G40_ CPXs	G41_ CPXh	G42_ SQD	G43_ CTC	G44_ OCM	G45_ MTS0	G46_ MTS1	G48_ NEP1	G49_ ARA	G50_ ARS	G51_ DPS0	G52_ DPS1	G53_ TGS	G55_ REPh	G56_ NATs	G57_ NATh	G59_ CLM	G60_ SCL	G61_ BIX
ALB_ONE_VL-ONE	10.62	10.62	2.82	2.82	5.73	5.73	5.73		11.23	8.56	6.32	4.47	3.94	3.94	18.98	16.88	19.61	4.11	4.11	16.75	11.98			5.03		3.41
BIH_ONE_VL-ONE																										
HRV_DRB_VL-ONE	8.74	8.74	1.72	1.72	3.68	3.68	3.68		5.34	7.66	4.75	2.66	1.56	1.56	18.98			3.06	3.06		6.36			4.08	5.64	2.82
HRV_GNX_VL-ONE	8.74	8.74	1.72	1.72	3.68	3.68	3.68		5.41	7.43	4.76	2.66	1.56	1.56	12.65			3.06	3.06		15.14			6.13	6.49	2.14
HRV_LLX_VL-ONE	8.74	8.74	1.72	1.72	3.68	3.68	3.68		5.41	7.67	4.72	2.66	1.56	1.56	12.65			3.06	3.06		35.57			6.89	6.88	4.18
HRV_MIX_VL-ONE	8.74	8.74	1.72	1.72	3.68	3.68	3.68		5.41	7.70	4.74	2.66	1.56	1.56	12.65			3.06	3.06		37.41			7.29	5.24	2.65
HRV_OTB_VL--18	8.74	8.74	1.72	1.72	3.68	3.68	3.68		5.41	5.62	4.29	2.66	1.56	1.56	12.65			3.06	3.06		10.10			3.13	3.29	2.79
HRV_OTB_VL1824	8.74	8.74	1.72	1.72	3.68	3.68	3.68		5.41	2.74	4.31	2.66	1.56	1.56	12.65			3.06	3.06		17.57			5.03	3.10	2.55
HRV_OTB_VL24++	8.74	8.74	1.72	1.72	3.68	3.68	3.68		5.41	2.25	4.01	2.66	1.56	1.56	12.65			3.06	3.06		15.62			2.98	5.70	5.61
HRV_PS_VL--18	8.74	8.74	1.72	1.72	3.68	3.68	3.68		5.41	5.94	4.76	2.66	3.94	3.94	18.98			3.06	3.06		11.98			5.03	5.70	1.53
HRV_PS_VL18++			2.82	2.82	5.73	5.73	5.73		11.23	2.73	4.76	4.47									11.98			5.03	5.70	
HRV_TBB_VL--18			2.82	2.82	5.73	5.73	5.73		11.23	7.71	6.32	4.47									6.24					
ITA_DRB_VL-ONE											6.32													2.49	5.70	12.68
ITA_GNX_VL-ONE	13.04	13.04	4.38	4.38	7.71	7.71	7.71	8.56	8.89	5.98	8.85	4.14	9.47	9.47	18.98			4.11	4.11	19.27	10.45		15.43	5.03		1.85
ITA_LLX_VL-ONE	10.62	10.62	2.82	2.82	6.45	6.45	6.45		11.23	8.56	6.32		3.94	3.94				4.11	4.11		11.98					
ITA_MIX_VL-ONE	13.66	13.66	3.11	3.11	6.67	6.67	6.67		5.20	8.56	8.76	4.39	7.13	7.13	18.98	16.88	19.61	4.11	4.11	16.29	5.57	3.81	15.43	7.26	5.70	3.06
ITA_OTB_VL--18	14.16	14.16	5.53	5.53	7.69	7.69	7.69	8.56	15.38	8.25	9.25	6.82	5.95	5.95	22.77	15.33	20.97	5.11	5.11	14.26	3.79	3.81	15.43	5.03	7.21	2.60
ITA_OTB_VL1824	12.32	12.32	3.91	3.91	7.21	7.21	7.21	8.56	12.26	7.18	7.09	5.68	4.88	4.88	22.41	15.45	17.69	4.89	4.89	15.58	3.25	3.71	15.43	5.03	5.90	3.46
ITA_OTB_VL24++	16.35	16.35	3.90	3.90	7.92	7.92	7.92	8.56	14.14	6.48	8.53	4.51	4.64	4.64	17.19	19.86	20.18	4.07	4.07	16.95	3.62	3.91	15.43	5.03	5.70	2.87
ITA_PS_VL--18	10.62	10.62							25.24	20.89	9.48	5.97	3.94	3.94												
ITA_PS_VL18++	10.62	10.62	2.82	2.82	5.73	5.73	5.73			8.56	6.32	4.47	3.94	3.94	18.98						11.98					
ITA_PTM_VL--18	12.60	12.60	4.12	4.12	5.98	5.98	5.98		24.45	15.27	10.02	13.38	4.77	4.77						14.96	11.98					3.41
ITA_PTM_VL1824	10.62	10.62	2.36	2.36	9.64	9.64	9.64		11.23	8.56	6.32	4.47	3.94	3.94						16.75	11.98					3.41
ITA_PTM_VL24++	10.62	10.62	2.82	2.82	5.73	5.73	5.73		11.23	8.56	3.58	4.47	3.94	3.94				4.11	4.11	16.75	11.98					3.41
ITA_TBB_VL--18	8.57	8.57	3.96	3.96	7.36	7.36	7.36		26.32	20.14	7.06	5.26	6.20	6.20	41.21					19.34	5.89				4.66	2.31
ITA_TBB_VL18++	9.21	9.21	2.84	2.84	7.12	7.12	7.12	8.56	15.91	12.36	6.42	4.53	5.19	5.19	29.30		19.61	10.74	10.74	17.38	3.11	3.81			8.58	1.53
MNT_ONE_VL-ONE			2.82	2.82	5.73	5.73	5.73		11.23	8.56	6.32	4.47			18.98						11.98		15.43			3.41
SLO_GNX_VL-ONE	10.89	10.89	3.05	3.05	5.69	5.69	5.69		7.15	6.71	6.81	3.40	5.52	5.52						19.27	12.79				6.49	1.99
SLO_LLX_VL-ONE	8.74	8.74			5.06	5.06	5.06				4.72		1.56	1.56												
SLO_MIX_VL-ONE	11.20	11.20	2.42	2.42					5.30	7.70	6.75	3.53	4.35	4.35							21.49			7.27	5.24	2.86
SLO_OTB_VL-ONE	11.51	11.51	3.08	3.08	5.64	5.64	5.64		9.67	5.42	6.25	4.17	3.36	3.36						15.60	8.99			3.06	4.87	3.31
SLO_PS_VL-ONE	8.74	8.74			3.68	3.68	3.68		15.33	9.86	6.34	4.31	3.94	3.94						21.38	11.98					
SLO_PTM_VL-ONE					7.81	7.81	7.81			15.27																

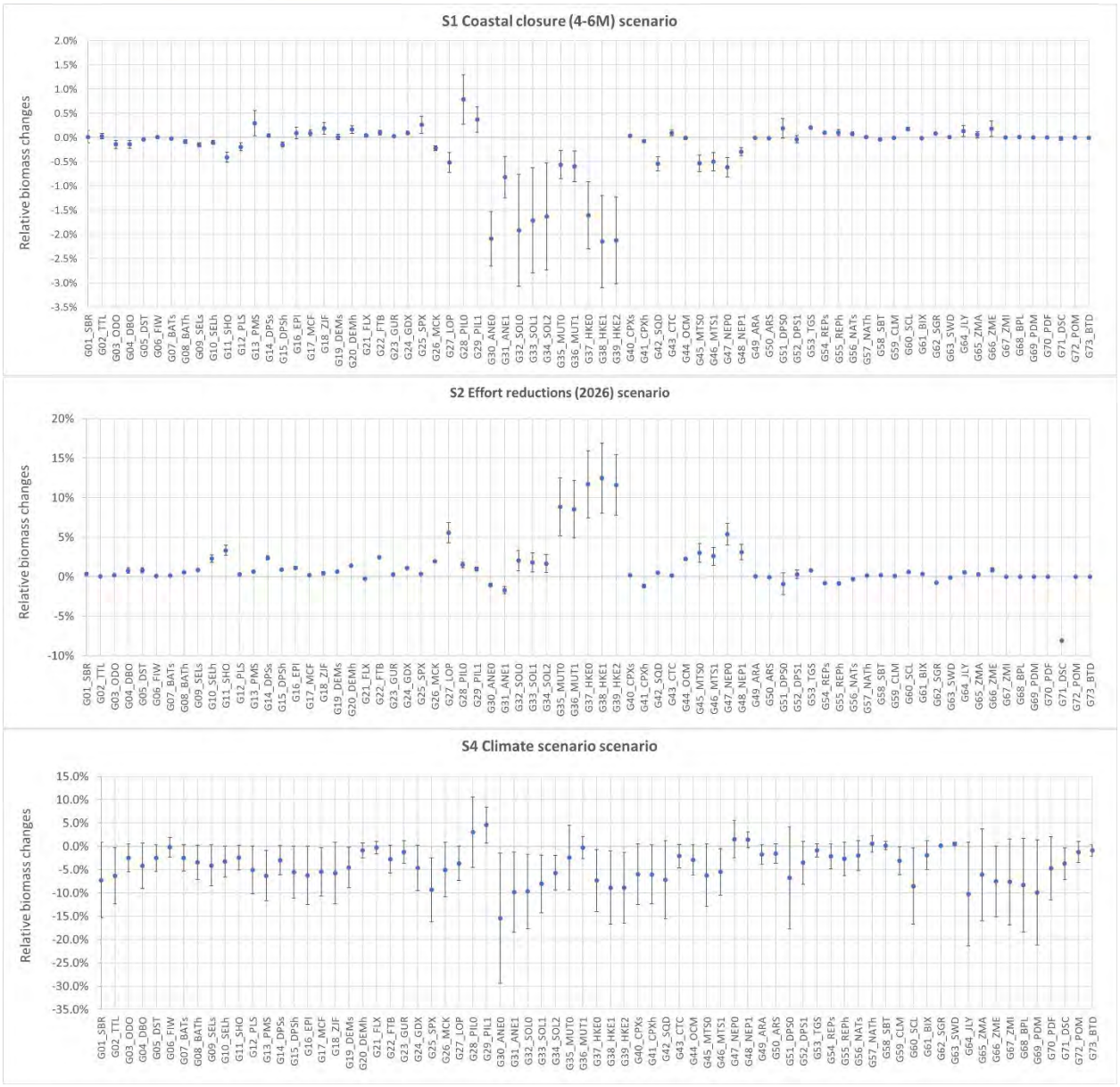


Figure SM2. Biomasses outputs under different management scenarios for all functional groups under different scenarios tested: S0 (reference): S1 (coastal closure), S2 (effort reduction), S3 (effort reduction with additional FRAs) and S4 (climatic changes).