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# Ecospace evaluation of the impact of planned conservation areas in the Israeli Exclusive Economic Zone

IOLR Report T2-2023

Submitted by

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## Summary

The “Israeli EEZ MPAs masterplan” project is a systematic conservation planning initiative led by the Society for the Protection of Nature in Israel (SPNI) in collaboration with the ministry of environment, academia and Israel Oceanographic and Limnological Research (IOLR). As part of the project, we made use of an Ecospace model in order to examine the effect of anthropogenic changes and management options on the ecosystem.

For the benefit of the project, we updated an existing Ecopath with Ecosim and Ecospace model of the Israeli EEZ. The model domain covers the Israeli continental shelf, the slope and deep sea and includes the food web for these marine regions. In the process of updating the model, we emphasized the ability to examine the effects on local, invasive and deep-sea species. This was with the intention of trying to identify alternatives that improve the biomass of local shallow and deep-sea species.

Our basic premise was that climate change is already happening and therefore we used the RCP8.5 climate change scenario in order to examine the impact on the ecosystem with and without management intervention.

This climate change scenario formed the basis for the examination of management and conservation scenarios and included two scenarios: 1) a scenario in which a network of protected areas along the coast of Israel, mainly over the continental shelf, and, 2) a scenario in which everything that happens in scenario 1 takes place and, in addition, closure of protected areas in the deep sea is carried out in the areas identified as priority conservation areas by Marxan software.

After analyzing the results, the following general conclusions can be made:

1. Due to the expected warming of the sea water, our recommendation for MPAs planned for the EEZ is to prioritize protection over the slope region, accounting for its bathymetric structure (the north is steeper) with an emphasis on the southwestern area of the bathyal area, as in this region the bathymetry is a mild continuation of the slope region.
2. From the results, it is clear that closing areas identified as priority conservation areas by Marxan over the continental slope and deep-sea regions promotes an increase in, or preservation of, the biomass of native species.

In addition, an analysis of the areas where change is expected allowed us to identify areas that can be used as climatic refuge for local species.

## Background

The deep-sea is the most extensive marine ecosystem in the Israeli exclusive economic zone (EEZ) and has in recent years attracted much human activity as fossil fuel exploration and production. In contrast, and despite the recent expansion of the national monitoring program and research in the deep-sea, very little is known about it. The recent research and monitoring efforts have resulted in numerous discoveries such as coral gardens, shark breeding sites, and more. The need to balance conservation and development is acknowledged globally and includes the 30/30 world-wide initiative to declare 30% of the marine territory within national EEZs as protected areas by the year 2030 ([Simmons et al., 2021](#)). In the Israeli exclusive economic zone in the Mediterranean Sea, conservation policy has not yet been established. The SPNI is leading a marine conservation planning process with the goal to design a MPA masterplan, that covers representative and unique habitats in 30% of the EEZ. The process included habitat classification performed using data analyses and modelling of faunal distribution.

Due to the significant existing knowledge gaps regarding habitats and fauna and flora distribution and their response to anthropogenic activities and stressors there is a need to incorporate modeling tools into the planning process. The Ecopath with Ecosim (EwE) suites of models is one of the most popular modeling tools for investigating food-web related questions in marine and freshwater ecosystems. The suite includes the ecosystem food web mass balance analysis (Ecopath), dynamic modeling capability (Ecosim), and a space-time dynamic routine (Ecospace), all of which can be used to explore past and future impacts of fishing, MPAs and environmental changes on the ecosystem ([Christensen and Walters, 2004](#)). EwE models have been used to describe ecosystems in theoretical, spatial and policy analyses ([Coll et al., 2015](#); [Heymans et al., 2012](#)). Using a set of linear equations, missing parameters can be estimated under an assumption of mass balance. The products of the models include time series of biomass, biomass dynamics of each group forward through time, changes in mortality, food consumption and diets, and numerous ecological indicators ([Coll and Steenbeek, 2017](#)). Ecospace replicates the dynamic analyses over a grid of spatial cells, and makes predictions to address policy questions such as the establishment and management of marine protected areas and changes in essential fish habitats ([Steenbeek, 2021](#); [Walters et al., 2010](#); [Walters et al., 1999](#)).

Recent improvements to the processes simulated in the software have converted Ecospace to a truly spatial-temporal dynamic model ([Steenbeek et al., 2013](#)) that also includes a habitat capacity component and physical time series. Both of these components are critical to the current study. The software further allows simulation of the ecosystem as it dynamically allocates biomass across a raster grid map, which indicates the number of habitats to which functional groups and fishing fleets are assigned. This permits alternation of trophic interaction rates, based on species habitat affinities, the location of those habitats and the regions in which the various fishing methods are utilized and the cross effects of the groups in the model on each other. In addition, it is able to import external physical data (e.g. temperature, currents) into the model ([Piroddi et al., 2022](#); [Steenbeek, 2021](#)) and examine ecosystem reactions to changes in those variables. The software structure and capabilities can be used in order to examine management options such as definitions of MPAs and applying fisheries regulations ([Vilas et al., 2020](#)) to the food-web while accounting for climate changes scenarios ([Heymans et al., 2020](#)).

In order to evaluate the possible impact of the application of priority conservation areas in Israel's EEZ, we apply an Ecospace model to the Israeli EEZ. Then, we tested the impact of the proposed MPAs on the

food web and in addition enhanced the scenario testing by introducing the projected climate change. We evaluated the impact of the proposed MPAs under climate change (RCP 8.5).

## Methods

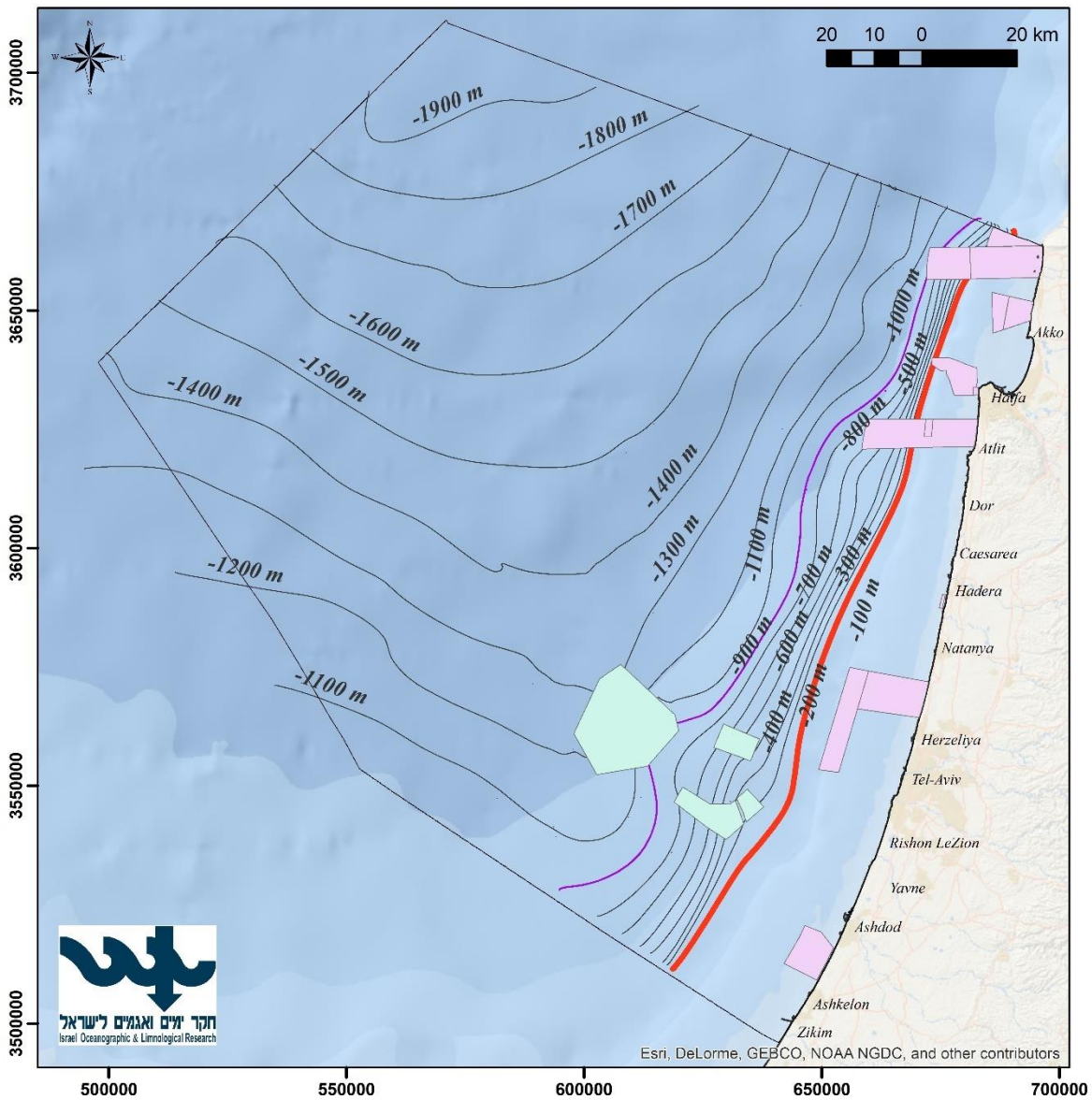
### Study area

The Israeli territorial waters and the economic waters area can be divided into three main sections (Fig. 1):

**The continental shelf-** The area is located from the shoreline down to a depth of 200 m. The slope of the continental shelf is moderate so the area is quite shallow. However, most of the fishing activity and development of the coastal area in Israel takes place within this region. The Achziv Canyon, located in its northern part, starts at the continental shelf and continues to the deep sea. The Palmahim disturbance, located in the southern portion of the continental shelf, is characterized by unique fauna. Due to its location and physical characteristics, the area is exposed to the arrival and establishment of invasive species that come mainly from the Red Sea.

**The continental slope-** An area that begins at the continental shelf and extends to depths of about 1000 meters. In the northern part it is relatively narrow because the slope is relatively steep and in the southern part it is wide because the slope is moderate. The Palmahim disturbance is located in its southern part. The slope it is characterized by a relatively high rate of biodiversity and primary productivity. Currently, no invasive species were observed in this region, possibly due to the depths and temperatures that differ from their preferable conditions.,.

**The bathyal plain –** The bathyal plain constitutes most of the area of the Israeli EEZ. The area is relatively flat with a gentle slope from south to north. The plain ranges between depths of about 1100 meters in the south to depths of about 2000 meters in the north. The area is characterized by low and fairly uniform temperatures and part of the living systems are unique to this area.



**Figure 1.** Bathymetric map of the Israeli territorial and EEZ waters. The red line represents the depth of 200 meters and the edge of the shelf. The purple line represents a depth of 900 meters and the end of the slope (the beginning of the bathyal plain). The green polygons are the Palmahim nature reserve area and the pink polygons are the areas declared or proposed MPAs in the territorial waters.

## The ecological models

### Ecopath

The Ecopath model serves as a required basis for Ecosim and Ecospace models. As a consequence, it needs to be constructed based on the requirements and objectives and the two models. The existing

Ecopath model was therefore modified to understand the distribution of the deep-sea species. The model structure was modified accordingly with a separation between groups of fish and invertebrates, groups belonging to the continental shelf, to the slope, and the deep sea and with a certain separation between invasive species and native species. The list of species in the original model was updated based on ([Shabtay et al., 2022](#)). As computational time and model uncertainty are related to model structure complexity (number of species or functional groups) there is always a need to find the correct balance between the need to reduce the number of groups and improve the working capacity of the model and the need to simulate as many species as possible. The updated model includes a total of 49 functional groups representing 460 species (Table 1).

As the original model was modified there was a need to rebalance the Ecopath model. Part of the products of the balanced model include definition of the relationships that exist within the food web. The connections, i.e. the relationships, are energy fluxes that occur between the various FGs groups and affect the size (biomass) of the groups in the system and their trophic levels (Fig 2). The constructed food web, the intensity of interactions between the various FGs and their biomass serve as the basis for the Ecosim and Ecospace models.

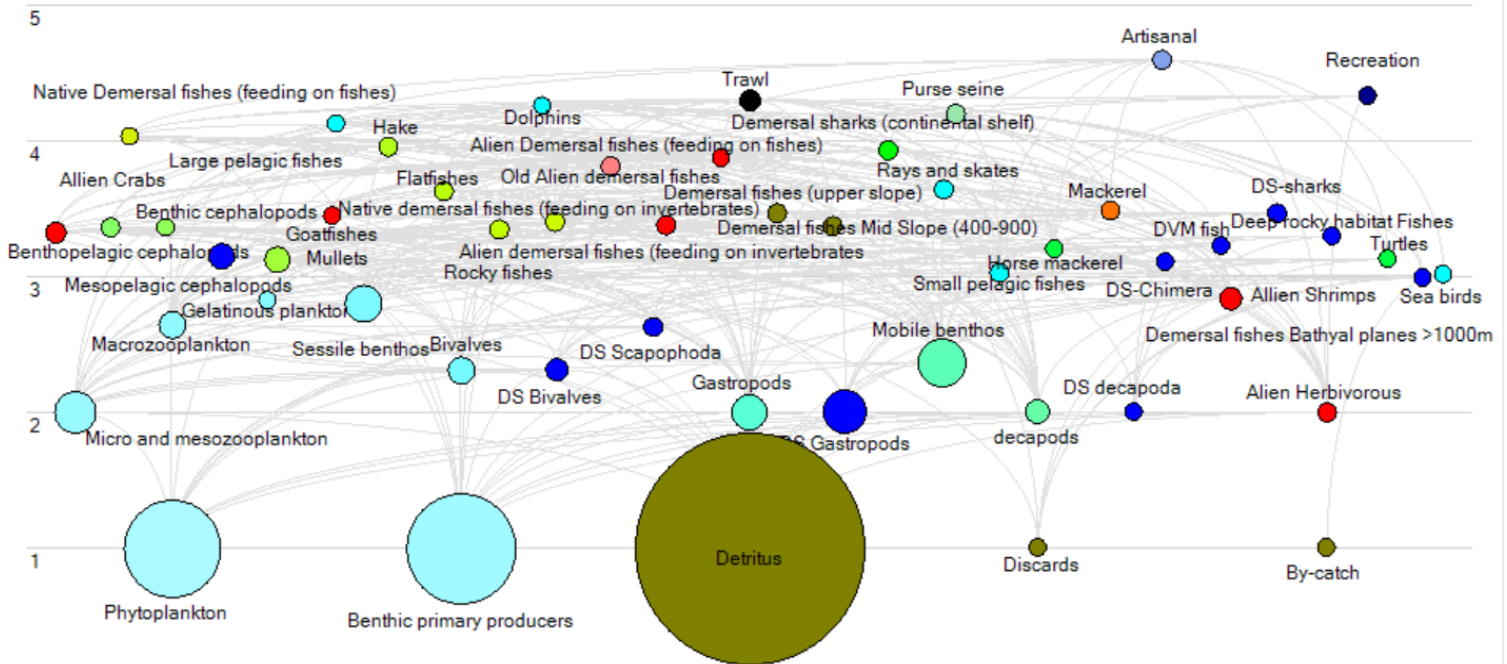
#### Model uncertainty

One of the tools available in the EwE software suite is the ability to define the uncertainty associated with the data used to construct the model. The tool called pedigree ([Christensen et al., 2000](#); [Walker et al., 2003](#)) is in essence a coded statement categorizing the origin of a given input (i.e., the type of input). The pedigree routine allows the user to mark the data origin using a pre-defined table for each type of input parameter. The key criterion used here is that input estimated from local data, i.e. from the area covered by the model in question, is as a rule better than data from elsewhere or derived from other Ecopath models. The data pedigree used to generate Ecopath input is useful as it provides a basis for the computation of an overall index of model 'quality', a model being of high quality when it is constructed mainly based on local information, parameters and species. An example of the use of the pedigree facility applies to the model's key parameters (Biomass, P/B, Q/B, Diet composition and Catches) can be seen below (Fig. 3). Based on the score given to each of the parameters, the degree of possibility to make a change in the values, during the model's computation, is also determined. As a result, values with a high level of certainty will undergo almost no change, while those with a low level of certainty a change of up to 50% can be reached. For more information about the method and its use in the model the reader is referred to the available literature ([Christensen et al., 2000](#); [Christensen et al., 2005](#); [Funtowicz and Ravetz, 1990](#)).



**Table 1** – List of the model functional groups (FGs) divided into pelagic, benthic, slope specific, deep-sea specific (DS) and others.

	Pelagic FGs	Benthic FGs	Slope specific FGs	Deep-sea specific FGs	Other FGs
<b>1</b>	Phytoplankton	Benthic primary producers	Demersal fishes (upper slope)	DS-Chimera	Sea birds
<b>2</b>	Micro and mesozooplankton	Mobile benthos	Demersal fishes Mid Slope (400-900)	DS Bivalves	Detritus
<b>3</b>	Macrozooplankton	Sessile benthos		DS Scapophoda	Discards
<b>4</b>	Gelatinous plankton	Benthic cephalopods		Mesopelagic cephalopods	By-catch
<b>5</b>	Rocky fishes	Bivalves		DS decapoda	
<b>6</b>	Native demersal fishes (feeding on invertebrates)	Gastropods		DS Gastropods	
<b>7</b>	Native Demersal fishes (feed on fishes)	Flatfishes		Demersal fishes Bathyal plains >1000m	
<b>8</b>	Mulletts	Goatfishes		DVM fish	
<b>9</b>	Alien Herbivorous	Hake		DS-sharks	
<b>10</b>	Old Alien demersal fishes (feeding on invertebrates)	Rays and skates		Deep rocky habitat Fishes	
<b>11</b>	Alien demersal fishes (feed on invertebrates)	Benthopelagic cephalopods			
<b>12</b>	Alien Demersal fishes (feed on fishes)	Decapods			
<b>13</b>	Small pelagic fishes	Invasive Shrimps			
<b>14</b>	Horse mackerel	Invasive Crabs			
<b>15</b>	Mackerel	Demersal sharks (continental shelf)			
<b>16</b>	Large pelagic fishes				
<b>17</b>	Turtles				
<b>18</b>	Dolphins				



**Figure 2** - The trophic interactions between the FGs within the food web simulated in Ecopath. The circles represent the different FGs in the model. The size of the circle indicates the relative biomass of the group in the food web and the gray lines represent the trophic interactions and hence energy fluxes between FGs. The values on the left represent the trophic level, which is determined by the model's calculations according to the relationships that occur within the food web.

Group name	Biomass in habitat area	Production / biomass	Consumption / biomass	Diet	Catch
1 Phytoplankton	5	3			
2 Benthic primary producers	1	3			
3 Micro and mesozooplankton	1	3	3	4	
4 Macrozooplankton	1	1	3	4	
5 Gelatinous plankton	1	3	3	4	
6 Sessile benthos	1	3	3	4	
7 Bivalves	1	3	3	4	
8 DS Bivalves	1	3	3	4	
9 DS Scapophoda	1	3	3	4	
10 Gastropods	1	3	3	4	
11 DS Gastropods	1	3	3	4	
12 Mobile benthos	1	3	3	4	
13 decapods	1	3	3	4	4
14 DS decapoda	1	3	3	4	
15 Allien Shrimps	1	3	3	4	4
16 Allien Crabs	1	3	3	4	4
17 Benthic cephalopods	1	3	3	4	4
18 Benthopelagic cephalopods	1	3	3	4	4
19 Mesopelagic cephalopods	5	3	3	4	4
20 Mulletts	5	3	3	4	4
21 Goatfishes	5	1	1	4	4
22 Hake	5	3	3	4	4
23 Flatfishes	5	3	3	4	4
24 Rocky fishes	5	3	3	4	
25 Native demersal fishes (feeding on invertebrates)	5	3	3	4	4
26 Native Demersal fishes (feeding on fishes)	5	3	3	4	4
27 Alien Herbivorous	1	3	1	4	4
28 Old Alien demersal fishes	5	3	3	4	4
29 Alien demersal fishes (feeding on invertebrates)	1	3	3	4	4
30 Alien Demersal fishes (feeding on fishes)	5	3	3	4	4
31 Demersal fishes (upper slope)	5	3	3	4	4
32 Demersal fishes Mid Slope (400-900)	5	1	3	4	4
33 Demersal fishes Bathyal planes >1000m	1	1	1	4	4
34 Demersal sharks (continental shelf)	5	3	1	4	4
35 Rays and skates	5	3	3	4	4
36 Small pelagic fishes	1	3	3	4	4
37 Horse mackerel	1	1	3	4	4
38 Mackerel	5	1	3	4	4
39 Large pelagic fishes	5	1	3	4	4
40 DS-Chimera	5	3	1	4	4
41 DVM fish	1	3	1	4	4
42 DS-sharks	1	3	1	4	4
43 Deep rocky habitat Fishes	1	3	1	4	4
44 Turtles	1	3	1	4	4
45 Sea birds	5	3	3	4	4
46 Dolphins	5	3	3	4	4
47 Detritus	5				
48 Discards	5				
49 By-catch	5				

**Figure 3.** – The pedigree table for the input parameters. The scale is 1-5 where 5 is the highest and based on local knowledge, 3 is data from other models (mainly for P/B and Q/B) and 1 represent values estimated by the Ecopath model. The colors correspond to the values in the table (1 is red and five is dark green).

In order to assess the validity of the model we undertook an iterative process with the relevant experts. Distribution maps and the preference functions of the depths of the various FGs were supplied to the experts whom provided comments. Following their comments, corrections and changes were made to

dispersion functions in the model. This process was repeated a number of times until a good fit between the expert's expectations and model results were aligned.

### The spatial temporal model Ecospace

The Ecospace model, was constructed based on a grid of equal cell size of 4 km<sup>2</sup>. The resulting grid was therefore 115 x 101 cells. This grid size provides a good trade-off between spatial resolution and computing costs and run-time. All spatial inputs to the model were constructed and input into the model as layers with the same spatial resolution. The range of layers included bathymetry, substrate and environmental factors namely water temperature and primary productivity. The temperature layers were divided into three depth ranges: from 0 to 150 m depth for pelagic species, an intermediate layer of 150 meters to 1 m above the bottom and temperatures adjacent to the bottom for benthic species. Primary production (PP) was vertically integrated for the upper 150 m. Time series of maps of temperature and PP were downloaded from the Copernicus website using monthly averages ([Apicella et al., 2022](#)). These maps were input into the model, at monthly time steps, via the Ecospace spatial-temporal data framework ([Steenbeek et al., 2013](#)).

In Ecospace, environmental conditions are applied to the living components through functions that express the preferences for, or tolerances to, varying environmental conditions ([Christensen et al., 2014](#)). For the most sensitive species we created these response functions using information from open sources such as AquaMaps ([Kaschner et al., 2016](#)), which were complemented with local expert knowledge. For composite functional groups, response functions were aggregated according to the relative proportion of each species' biomass in the functional group (Appendix 1).

The general limitation of spatial data and sampling at low spatial resolution and temporal frequency extremely limits the possibility to conduct a rigorous validation process of the model. This situation is not too different from other applications of spatial models. Therefore, in order to test the validity of the model results we based our examination on expert opinion and knowledge.

## Scenarios

### Climate Change

The Eastern Mediterranean Sea region has been recognized for many years as a climate change hotspot—a region in which the climate change is expected to have larger effects than other regions ([Givan et al., 2018](#); [Lejeusne et al., 2010](#); [Moullec et al., 2016](#)). According to the latest estimates of the Intergovernmental Panel on Climate Change (IPCC), the expected climate change for the Mediterranean Sea region for the period 2018–2100 with respect to the period 1986–2005, expressed by the most pessimistic RCP (Representative Concentration Pathway) 8.5 scenario, is an increase in atmospheric temperature of up to 4°C and a decrease in rainfall amounts by ca. 10–20% ([Bloomfield and Manktelow, 2021](#); [Hulme, 2016](#)). Regional data indicate a multiannual increase in temperature and reinforce projections of rising sea level and rising salinity ([Herut et al., 2021](#)). These are significant changes with far-reaching environmental consequences. For example, the increase in temperature can impact marine ecosystems via different mechanisms such as availability and distribution of species ([Wright et al., 2020](#)), and has probably already affected organism resilience, and possibly even the survival of species living at

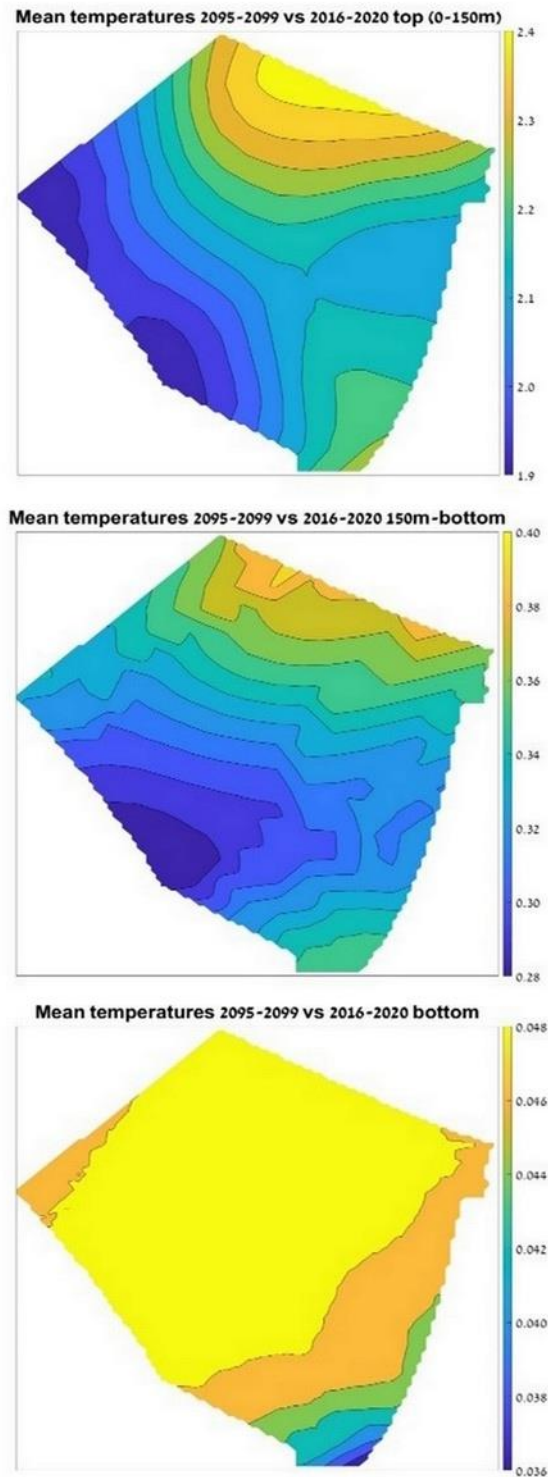
their limit to heat stress ([Edelist et al., 2013](#)). Another notable ecological impact of the rise in temperature is the improved conditions for the arrival and establishment of invasive species in habitats that until now were considered too cold for them ([Chaikin et al., 2022](#)).

To examine the future consequences of climate change and the various management alternatives we used the output from the Med-CORDEX modelling framework ([Ruti et al., 2016](#)) under the RCP8.5 scenario. Med-CORDEX is a unique framework where research communities make use of atmospheric, land surface, river and oceanic models in regional climate system models to increase the reliability of past and future regional climate information and understand the processes that are responsible for Mediterranean climate variability and trends. We obtained predictions of sea water temperature ([Ofir et al., In Review](#)). We adapted predicted water temperature for the model domain to create monthly temperature layers for the period 2006–2100 for three layers of depth: 0-150, 150 to the bottom and the bottom layer. It is evident that the change in temperature is greater in the upper part of the water column, while on the bottom the change is very small. (Fig. 4 and Appendix 2). We also used output from a coupled climate-ocean model with a biogeochemical component, the Eco3M-Med ([Baklouti et al., 2021](#)). The RCP8.5 projection simulation outcome ([Pagès et al., 2020](#)) of net primary production was used in our study.

In order to assist in understanding and analyzing the results of the different scenarios, we merged functional groups in the model into several parent groups (native species, invaders, deep sea, fish, invertebrates). In this way, it was possible to understand the trends emerging from the scenario results. In addition, in some cases we examined FG specific results in order to highlight key aspects in the results. We provide results based on the differences between the scenarios and reference period of 2016-2020. The results were therefore calculated based on the ratio of the mean of a mid-point period (2045-2050) and the end period of the scenario (2095-2099) in relation to the reference period (2016-2020) in the following way:

$$\frac{(\textit{scenario period}) - (\textit{reference period})}{(\textit{reference period}) + 1}$$

Note that in the results section we provide only a limited number of maps illustrating the trends. All other results are presented in Appendix 4.



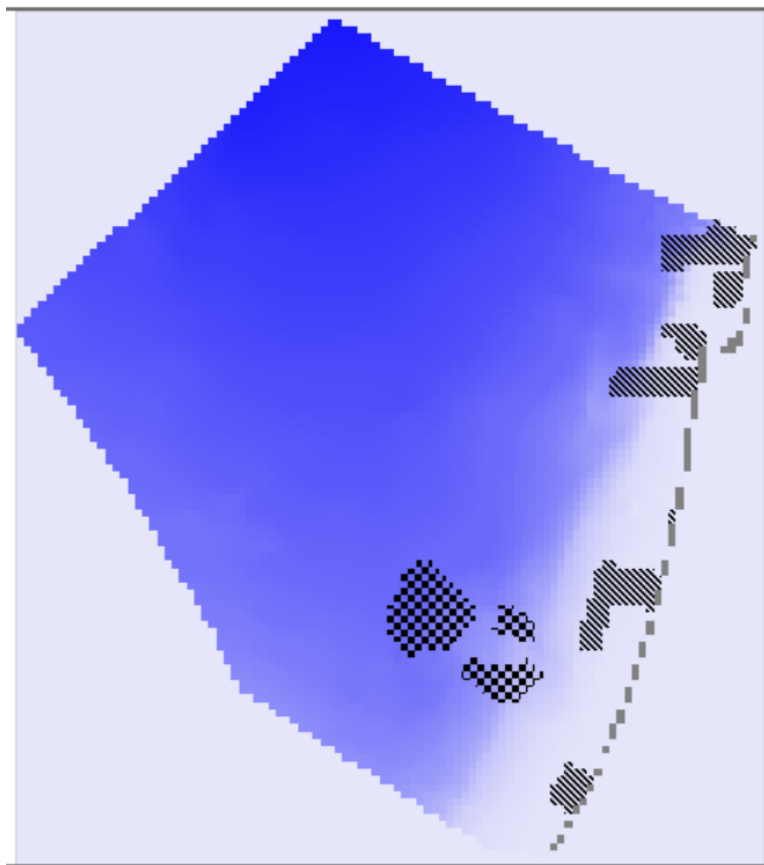
**Figure 4.** Maps of the trends of change in temperature in the three layers of the water column. The scale shows the change in temperature ( $^{\circ}\text{C}$ ) between the climate scenario and the base temperature prior to climate change. Note the differences in scale between the three panels.

## Management Scenarios under climate changes

One of the main tools available to marine resource managers and decision makers is the employment of protected areas to various activities, including fishing activities that may be impacting the ecosystem in question. We used the Ecospace model to evaluate the effectiveness and impact of various potential spatial management scenarios. There were two main assumptions underlying the scenarios we tested. The first assumption was that the defined protected areas will be enforced such that there will be no fishing activities in the protected areas. The second assumption was that the ecosystem is exposed to climate change therefore it is necessary to test management options under the influence of climate change.

## Marine protected areas

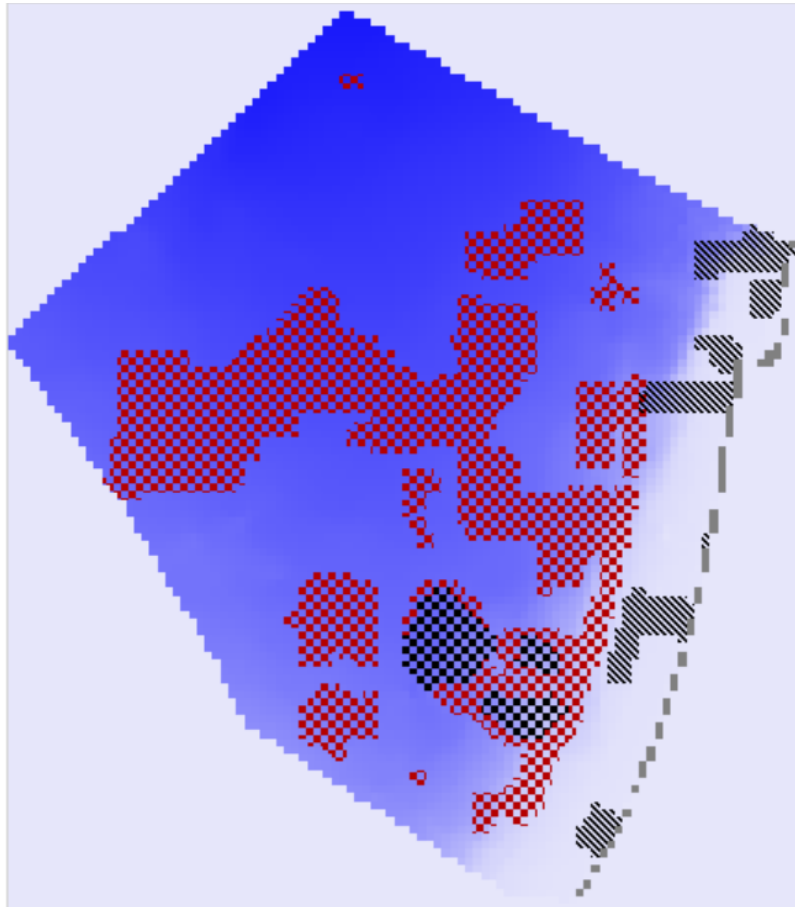
The scenario in which MPAs closed to fishing (Fig. 5) was based on the proposal of the Nature and Parks Authority which formulated a plan for the establishment of a network of nature reserves along the territorial waters of Israel. We also added the Palmahim Slide Reserve which is in the deep sea and has actually already been declared. All of the above areas were closed to fishing activity throughout the year for all fishing fleets, including fishing for pelagic species.



**Figure 5.** Map of the Israeli EEZ showing the MPAs (hatched for MPAs in the territorial waters and checkered for the Palmahim Slide Reserve in the EEZ) included in the model scenarios.

## MPAs + Marxan defined high priority areas

In the second management scenario, we included both the MPAs and additional protected areas defined by the Marxan model as high probability priority conservation areas ([Giakoumi and Ben-Lamine, 2022](#)) i.e. units selected at 80-100% in the "best cost" scenario of the eight scenarios tested (Fig. 6). All of these areas are in the EEZ.



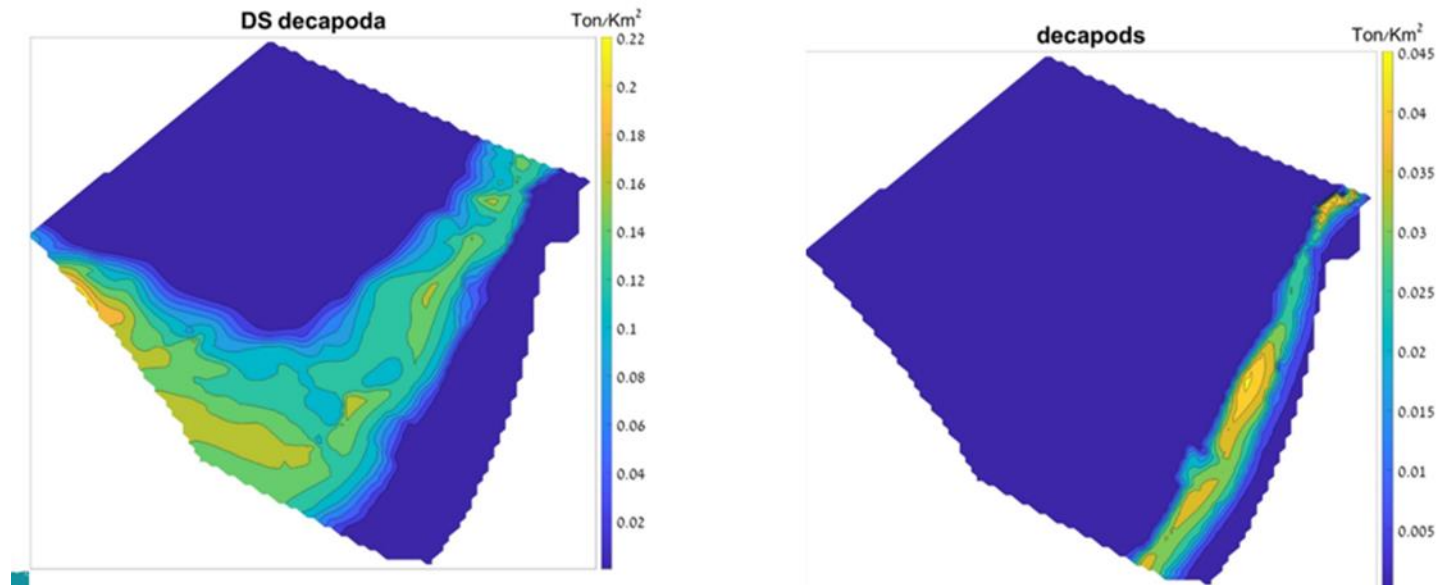
**Figure 6.** MPAs area (black) and Marxan high probability priority areas for conservation (red).



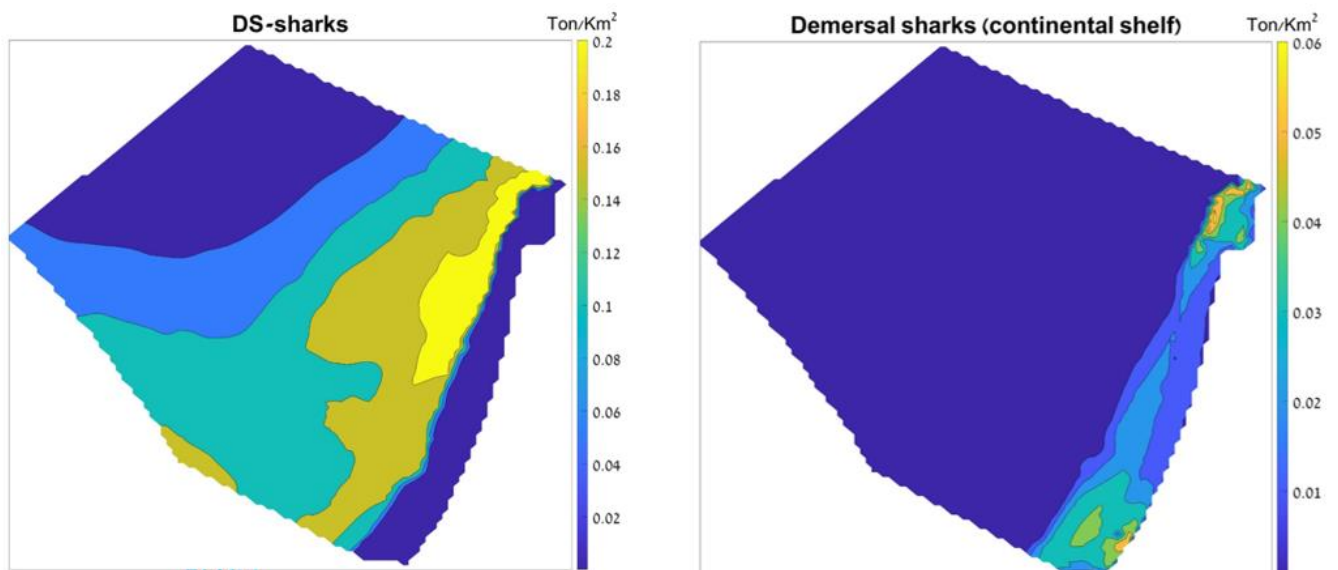
## Results

### Model validity

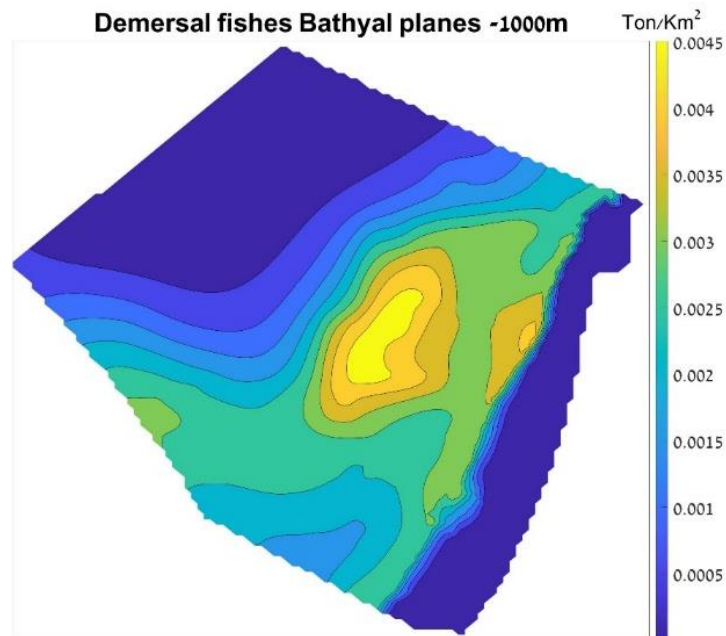
The distribution maps of the FGs highlight the difference in spatial distribution of the various groups and, as expected, of the shallow and deep-sea groups as can be seen in the case of the shallow and deep decapods (Fig. 7) and shallow and deep sharks (Fig. 8).



**Figure 7.** The simulated mean spatial distribution of shallow (right) and deep- sea (left) decapods in 2022.



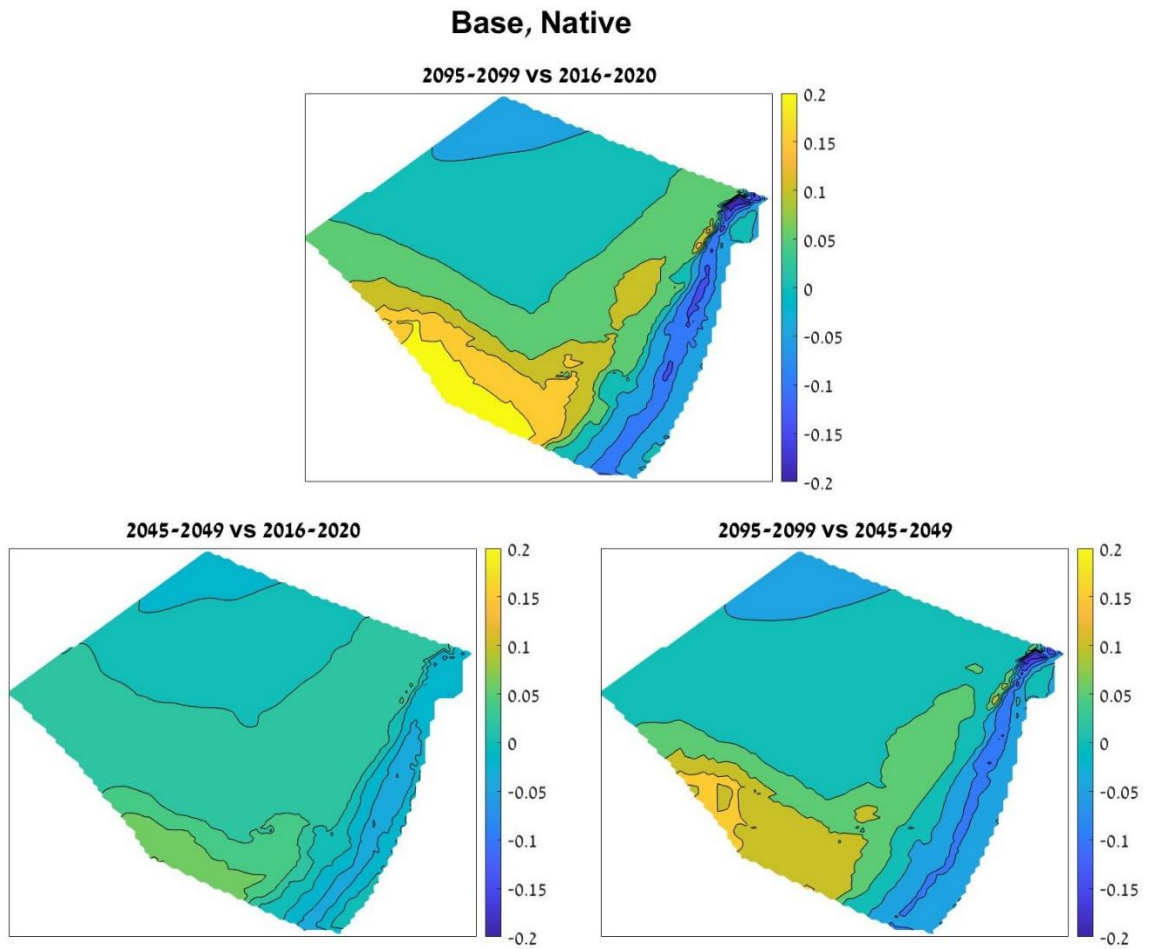
**Figure 8.** The simulated mean spatial distribution of shallow (right) and deep- sea (left) sharks in 2022.



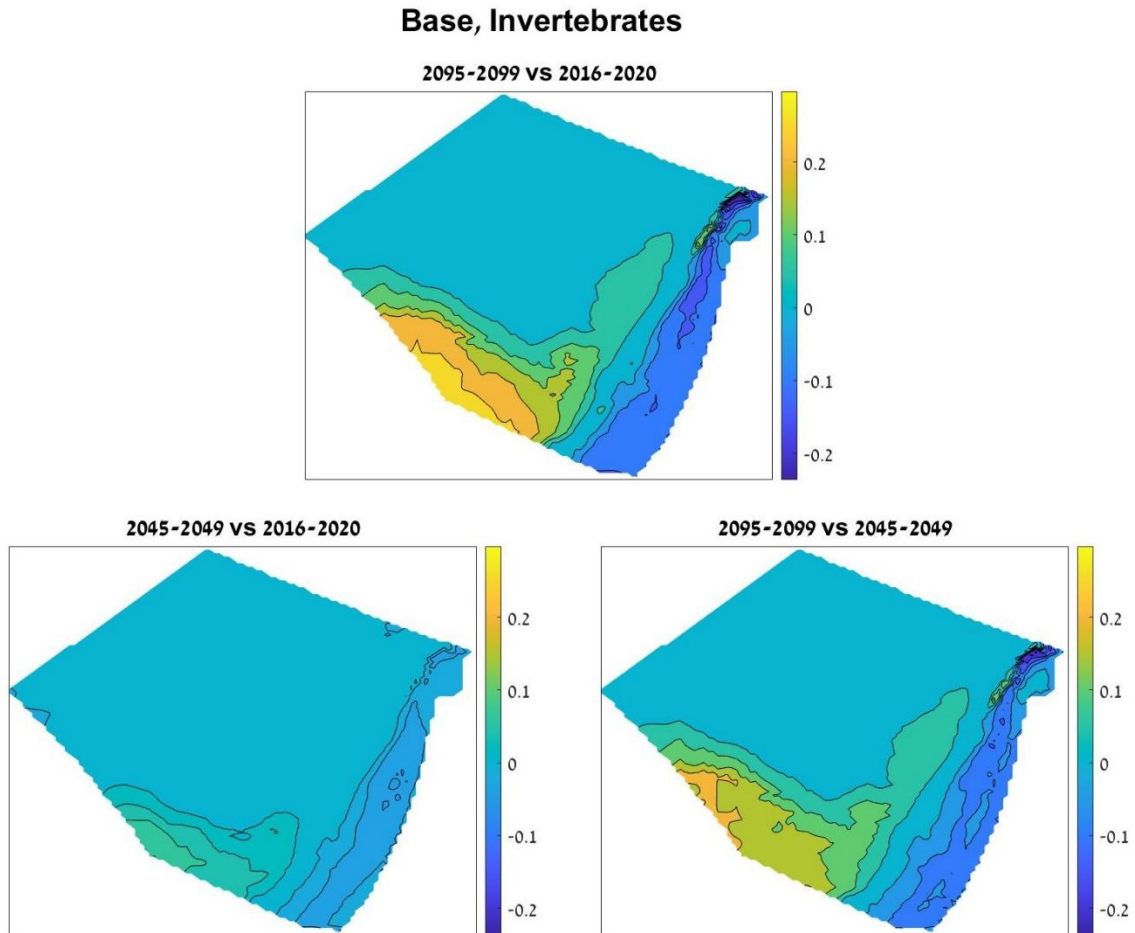
**Figure 9.** The simulated mean spatial distribution of deep-sea demersal fish in 2022.

#### Impacts of climate change

Results of the climate change scenario (Fig. 10-11, Appendix 4) were analyzed in such a way that a comparison was made between the end (2095-2100) and the middle time period (2045-2050) of the scenario and the beginning of the scenario in which the impact of climate change is minimal. The way the maps are compared is intended to emphasize the changes that have taken place with the aim of locating the areas that constitute a climatic refuge, i.e. areas more favorable in terms of water temperature, for the various groups. From the results, two regions emerge as potential climatic refuge areas. The first is the northern area of the domain within the territorial waters, adjacent to the slope and deep sea, the second larger one is in the southern part of the domain at depths of 1000 to 1200 meters.



**Figure 10.** The change in the distribution of native species under the climate change scenario. The maps shows the ratio between the reference period, prior to climate change, and at the middle and the end of the scenario when climate change is expected to be at its maximum.

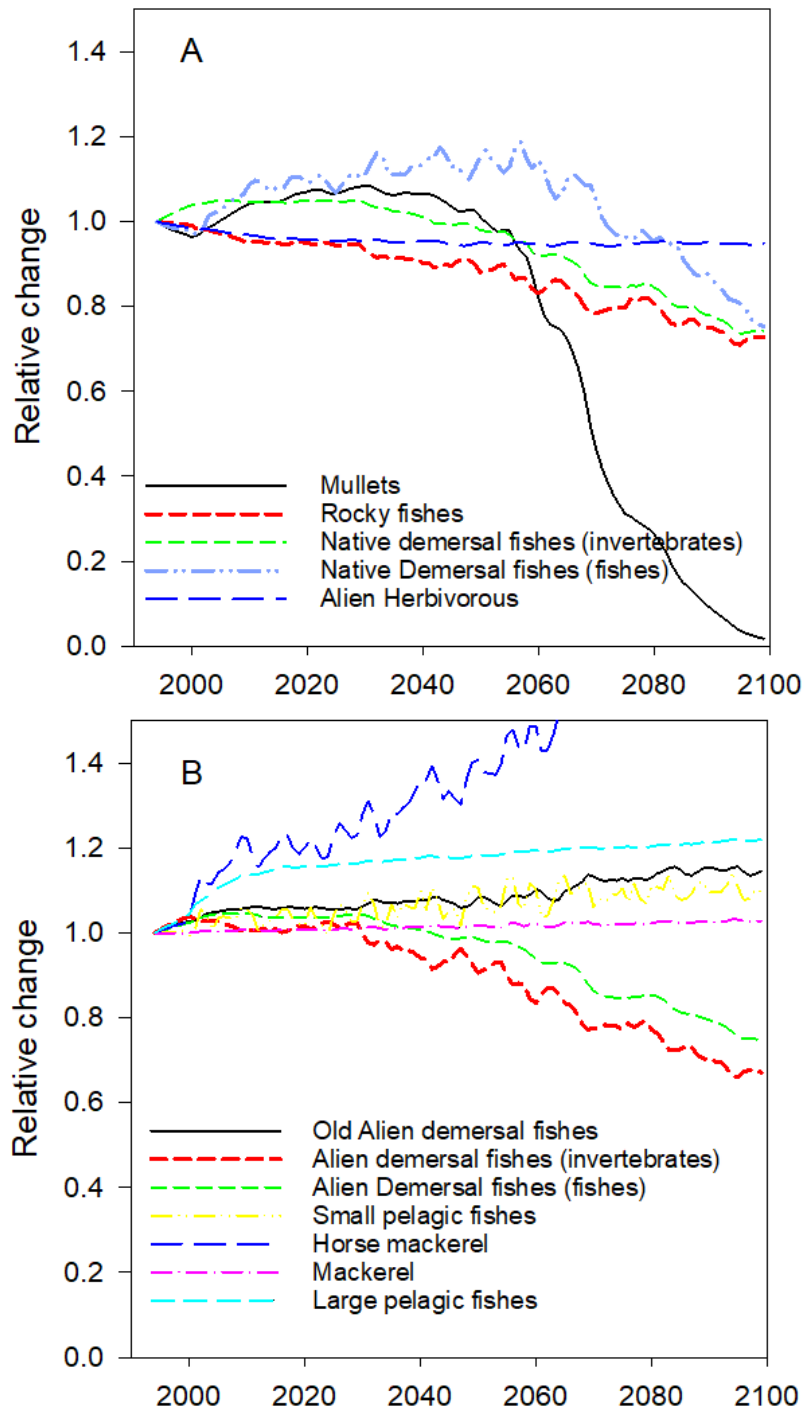


**Figure 11.** The change in the distribution of invertebrate’s species under the climate change scenario. The maps shows the ratio between the reference period, prior to climate change, and at the middle and the end of the scenario when climate change is expected to be at its maximum.

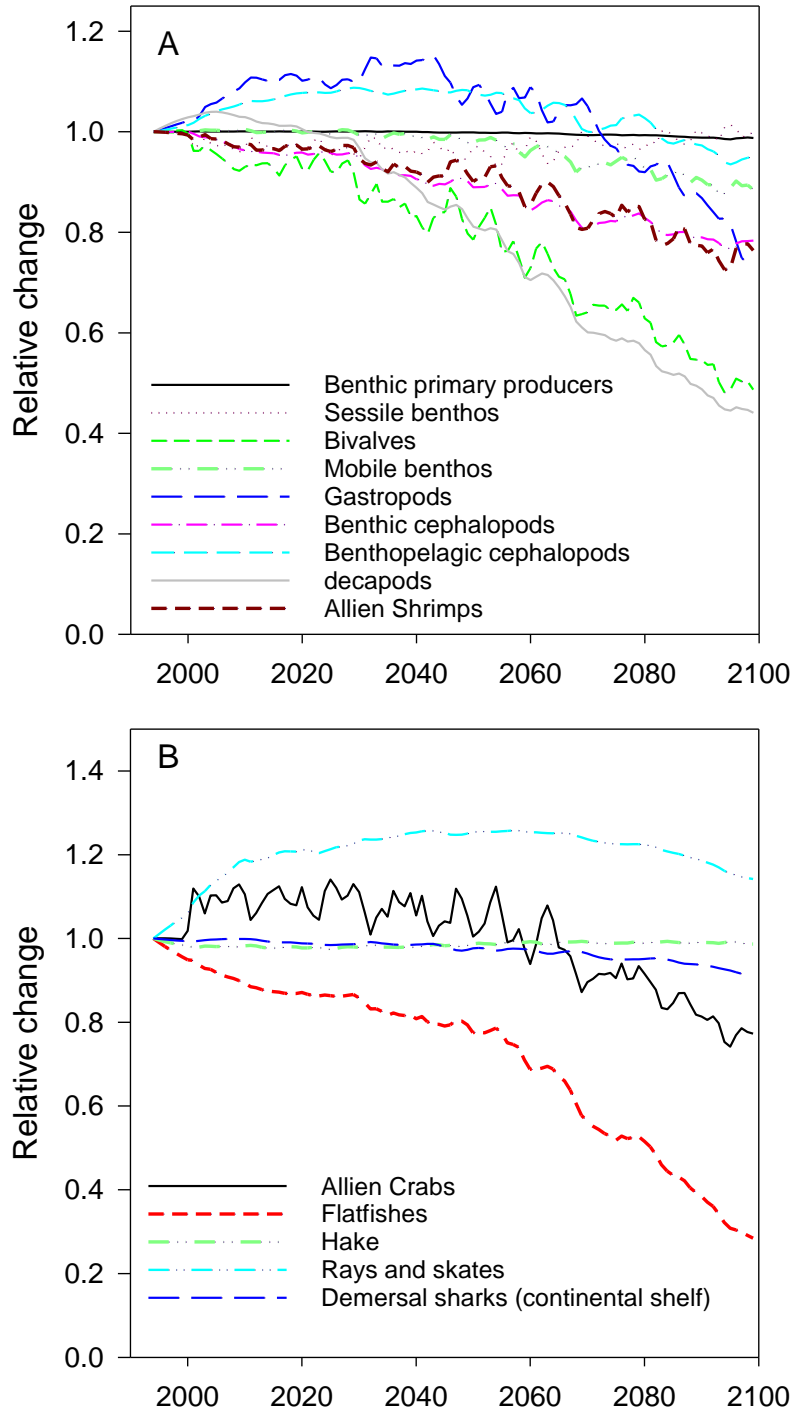
Climate change affects the distribution of the diversity of species in space to a different extent depending on their sensitivity to temperatures, the availability of food sources, their ability to move to deeper water and more. In order to be able to identify the effects on all the groups in the model, we compared the biomass of the groups at the beginning of the scenario compared to the biomass at the end (Figs. 12-14). In this way it was possible to determine the extent of the impact of the change on the FGs and to examine which groups show sensitivity to climate change. In the invertebrate groups, for example, the most significant decrease in biomass is seen in the Decapoda and Bivalvia FGs with a mean 50% decline whereas an increase of 20% was seen in the Gelatinous plankton group (Fig. 13).

There were more radical changes in the fish FGs (Figs. 12-14). Groups of local species were affected in terms of their biomass resulting in a decrease, in contrast there was an increase in invasive species biomass. The most notable cases included the mullets (local species) FG which towards the end of the scenario completely disappeared from the ecosystem and the flatfishes FG which experienced a 72% decrease in biomass. In contrast, groups of invasive species such as the Goatfishes increased to a large extent (nearly 10-fold increase), the group of Old Alien demersal fishes which exhibited an increase of

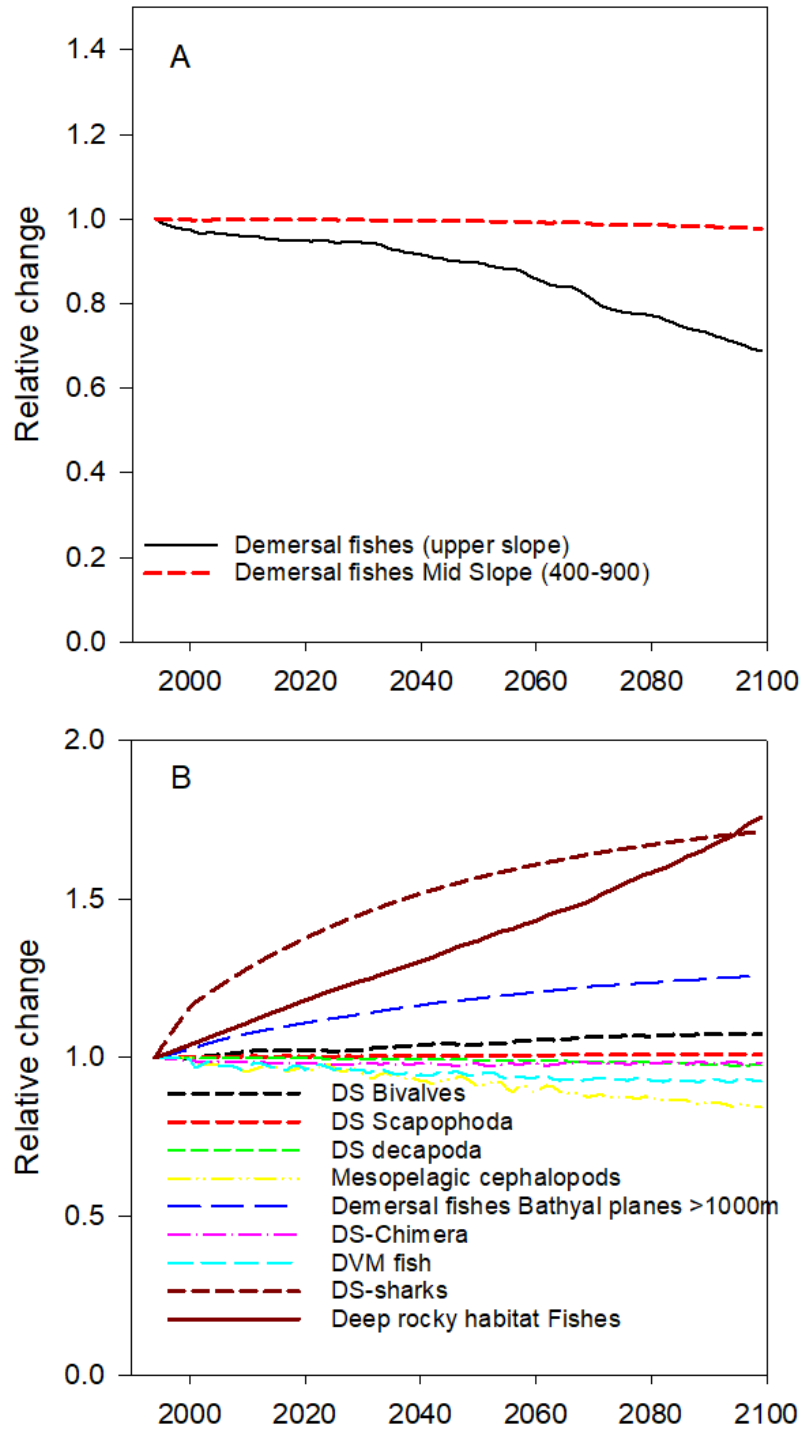
14% and the Horse mackerel FG which displayed an increase of 73%. In the deep-sea fish groups, an increase of 21% was seen in the Large pelagic fishes FG, an increase of 71% in the DS-sharks and an increase of 25% in the group termed Demersal fishes Bathyal planes >1000m.



**Figure 12.** Relative change in pelagic FGs biomass.



**Figure 13.** Relative change in benthic FGs biomass. The upper panel represents non-fish FGs and the lower panel additional benthic FGs in the model.



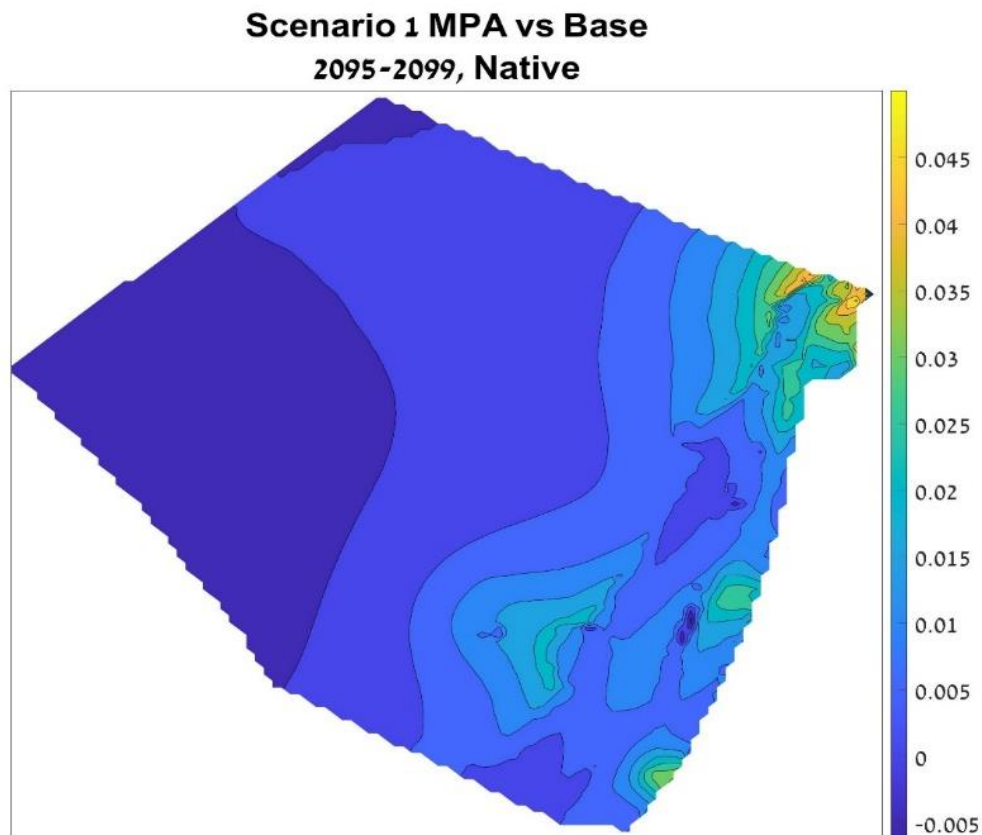
**Figure 14.** The relative change in (A) slope and (B) deep-sea FGs biomass.



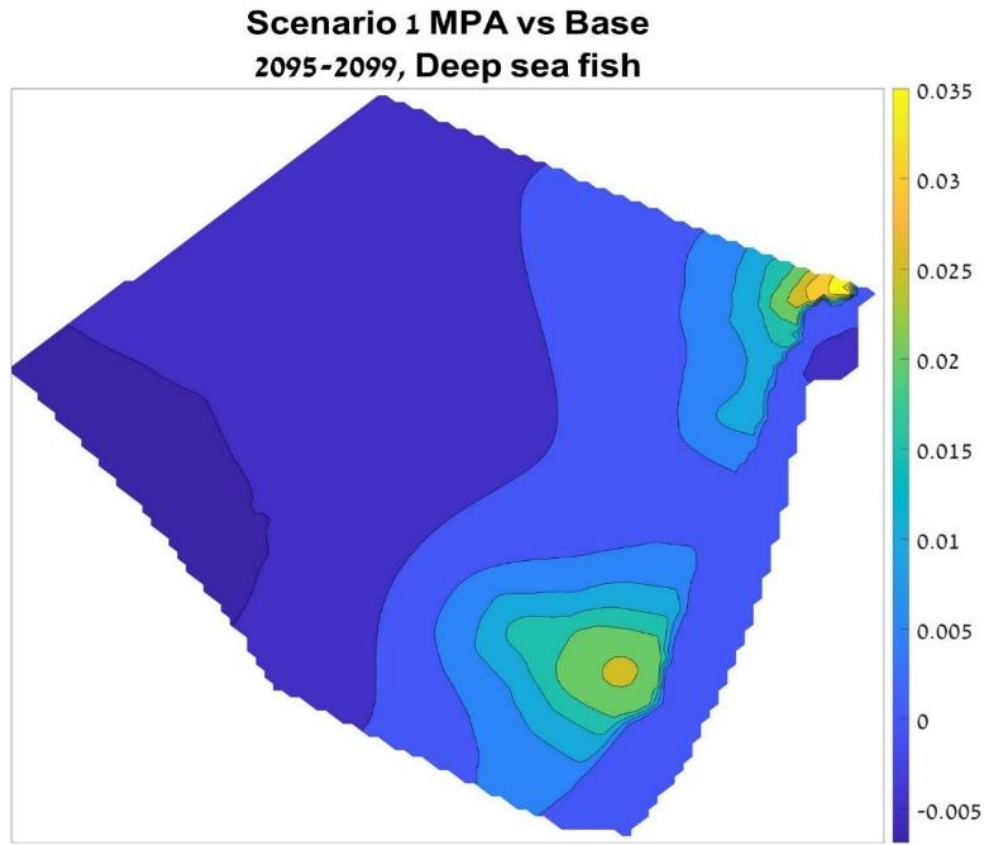
### Management Scenarios (MPAs And MPAs+ Marxan recommendations)

In order to identify and understand the effect of the management measures on the system, a comparison was made between the results at the end of the scenario (2095-2099) with the results of the climate change in which no management actions were carried out (Fig. 15,16, Appendix 5). In this way it was possible to identify the effects of the management measures under the projected climate change.

The results of the management and conservation scenarios under climate change show a clear picture of an increase in biomass in the marine protected areas that were closed to fishing activities. Closing the reserves along the shelf area displayed an increase of up to 7% in the local species biomass in the northern reserve areas and the southern reserve. Regarding deep sea species, the main change was achieved in the northern reserves and the Palmahim reserve.

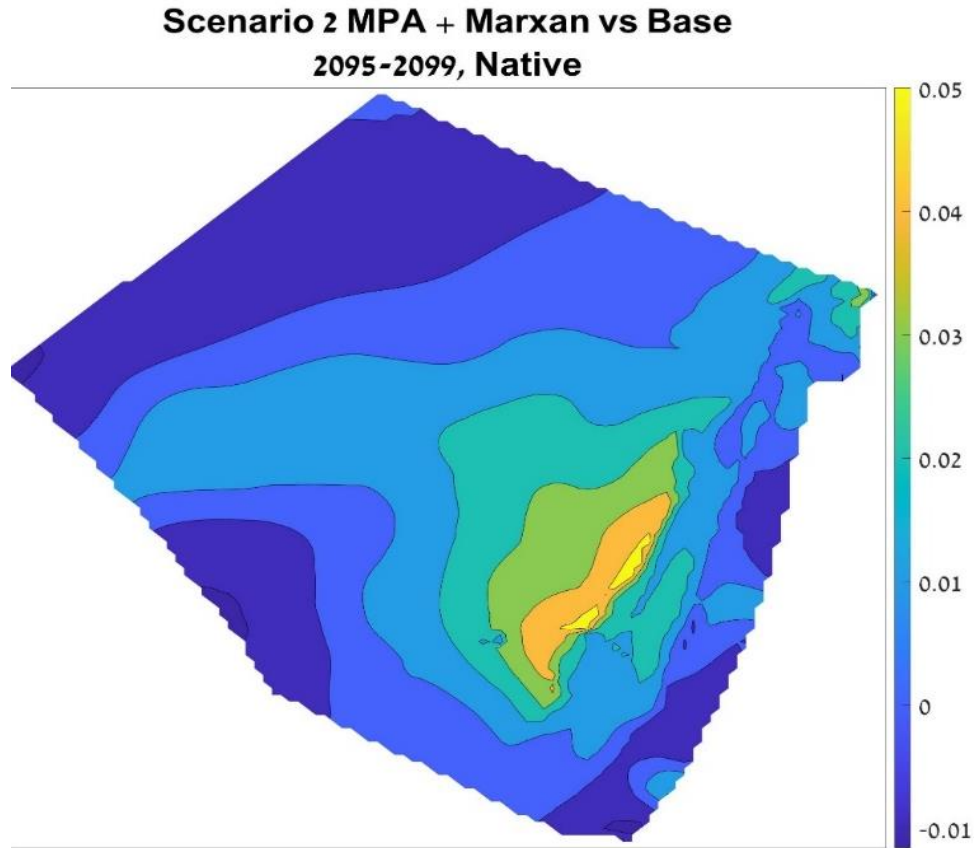


**Figure 15.** Change in the distribution of local species in the scenario of MPAs+ climate change. The map shows the relationship to a situation in which there were no MPAs, but there was climate change.



**Figure 16.** Change in the distribution of deep-sea fishes in the scenario of MPAs+ climate change. The map shows the relationship to a situation in which there were no MPAs, but there was climate change.

We examined the likely impact of the application of the high priority conservation area defined by Marksan when implemented under climate change conditions. A number of changes in biomass and species distributions are obvious (Fig. 17, Appendix 6). Minor positive effects (of 6%) can be seen in deep-sea species compared to the base scenario. However, the main effect can be seen in the biomass of the local species in the region north of the Palmahim disturbance adjacent to the slope. The local species are included in a large number of FGs and encompass a relatively large amount of biomass and therefore the 5% increase is substantial.



**Figure 17.** Change in the distribution of local species in the scenario based on Marxan high priority conservation areas under climate change. The values represent the relative change in relation to climate change scenario without MPAs.

## Discussion and Recommendations

An existing Ecospace ecological spatial model of the Israeli EEZ was modified and updated based on an extensive reanalysis of available data and information through in-depth consultations with topical experts. The modified model allowed us to bridge knowledge gaps that exist in the deep-sea region and simulate the Israeli EEZ and territorial waters ecosystem food web from the Israeli coastline to the margins of the economic waters which is correct for 2022. The creation of the Israeli EEZ Ecospace model allowed us to evaluate the impact of climate change and the high priority conservation regions and MPAs defined by Marxan.

In the construction of the model we separated between functional groups located on the slope and those on the shelf and in the deep-sea. This separation provided a means for examining the effect of the scenarios on the groups located in the deep-sea and, thus, for the first time, and in a unique way, examine the effect of the management and conservation measures on species found in deep-sea region.

Scenario results indicate likely changes in the distribution and biomass of various species as a result of climate change. The projected climate change (under RCP8.5) is expected to result in a shift of local species to deeper waters to seek cooler temperatures and an increase in invasive species biomass in the shallower regions. The implementation of the suggested MPAs results in benefits to the local species resulting in increased biomass with a limited increase in invasive species populations.

Based on the results of the scenarios we tested we provide recommendations divided into two parts:

1) Recommendations related to climate change

2) Recommendations related to the possibilities of preserving and improving the condition of local species

All of the recommendations are related to the planning process which aims to locate and establish protected areas for the variety of species. One of our basic assumptions is that there is a need to preserve and improve the conditions required for the local species. Given a situation where there is protection for them from fishing, their biomass will increase, and in the same area there will be a relative decrease in the biomass of the invasive species. This assumption was confirmed in the results of our simulations. Regions that had a relative increase in local species biomass displayed a decrease in the biomass of the invasive species. Our analysis, however, does not examine the role the invasive species play in the fishing catch and in the ecosystem following their arrival.

From the analysis of the results, two main conclusions can be pointed out:

- The projected climate change will have an impact on the ecosystem and the spatial distribution of the various groups. As a result of an increase in seawater temperatures in the various layers, changes will occur in the entire ecosystem. The changes result from the fact that if a certain species migrates to an alternative habitat due to a search for more favorable conditions. Then, the species that feeds on it also changes its location and thus the reaction continues in the ecosystem. As the results indicated that the first groups to modify their distribution are the groups of local species that will move to colder waters and go deeper towards the slope- it is important to examine, in future planning processes, options to protect species that go deeper. **We recommend focusing on two areas (Fig. 18): the first and smaller one is in the northern part where the slope is steep. The second area is in the southern part which is a shallower area of the deep-sea and thus allows the species to establish themselves there.**
- It is evident that the closure of the protected areas helps preserve the biomass of the local species and suppresses the invasive species - **we recommend trying to increase the amount and areas of the reserves both over the shelf area and in the EEZ. There should be special emphasis on the areas that are close to the slope (e.g. Fig. 16), especially in the southern part of the domain, in the area of the Palmahim MPA.**

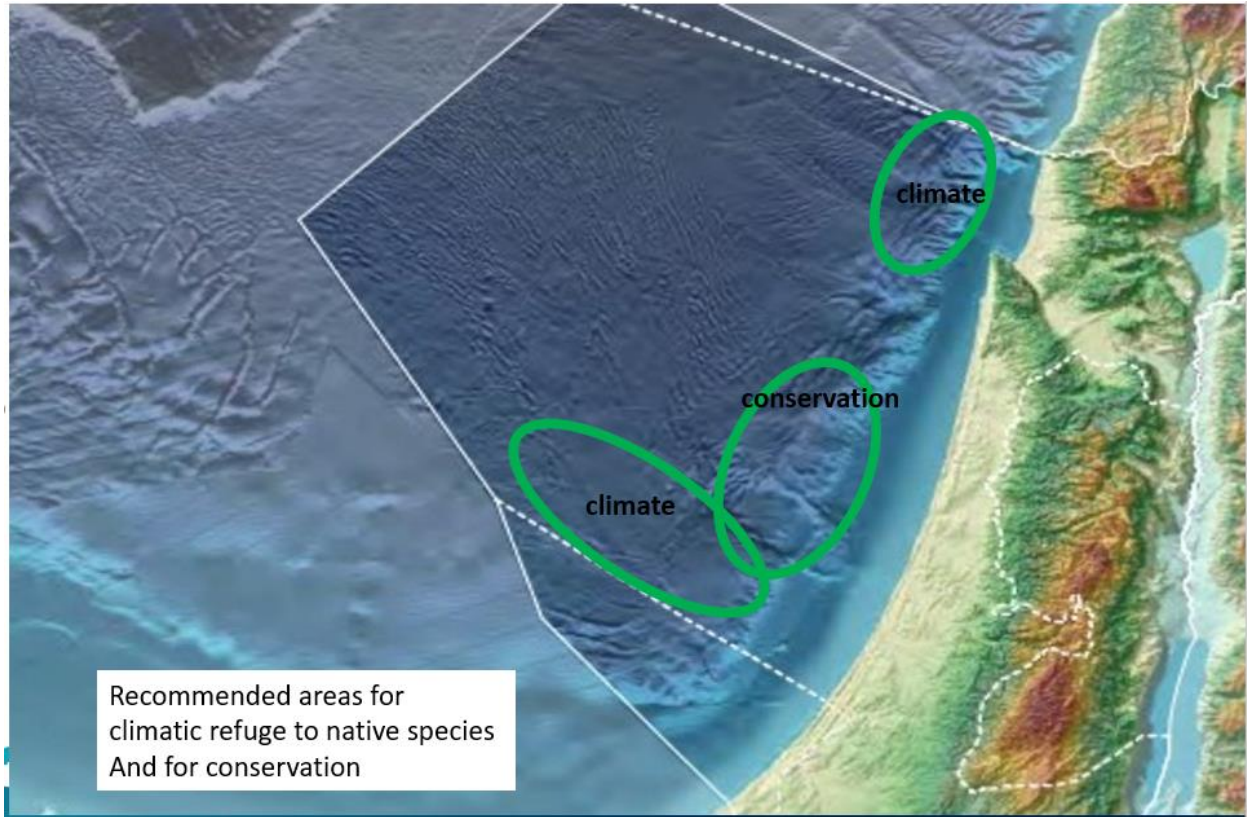


Figure 18 - Map showing the areas recommended for closure based on results of the climate change and conservation scenarios.

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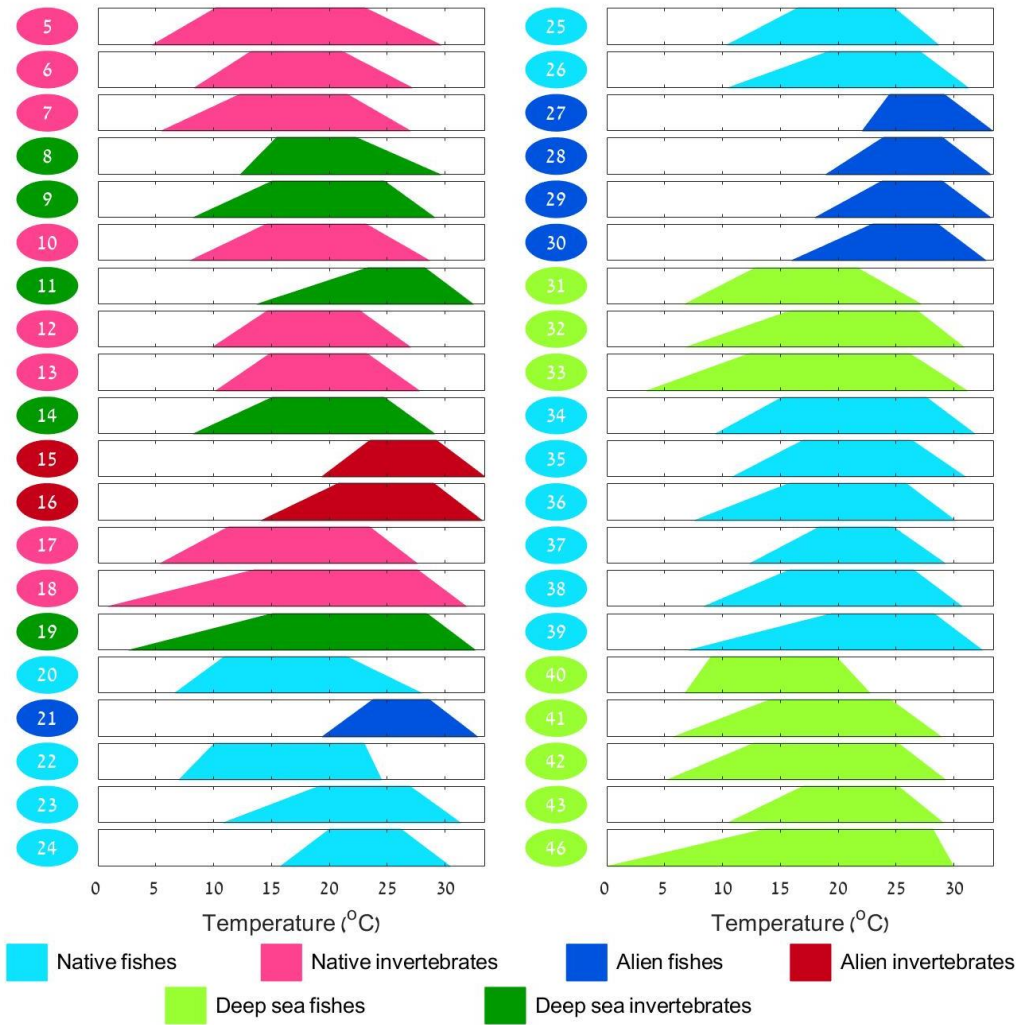
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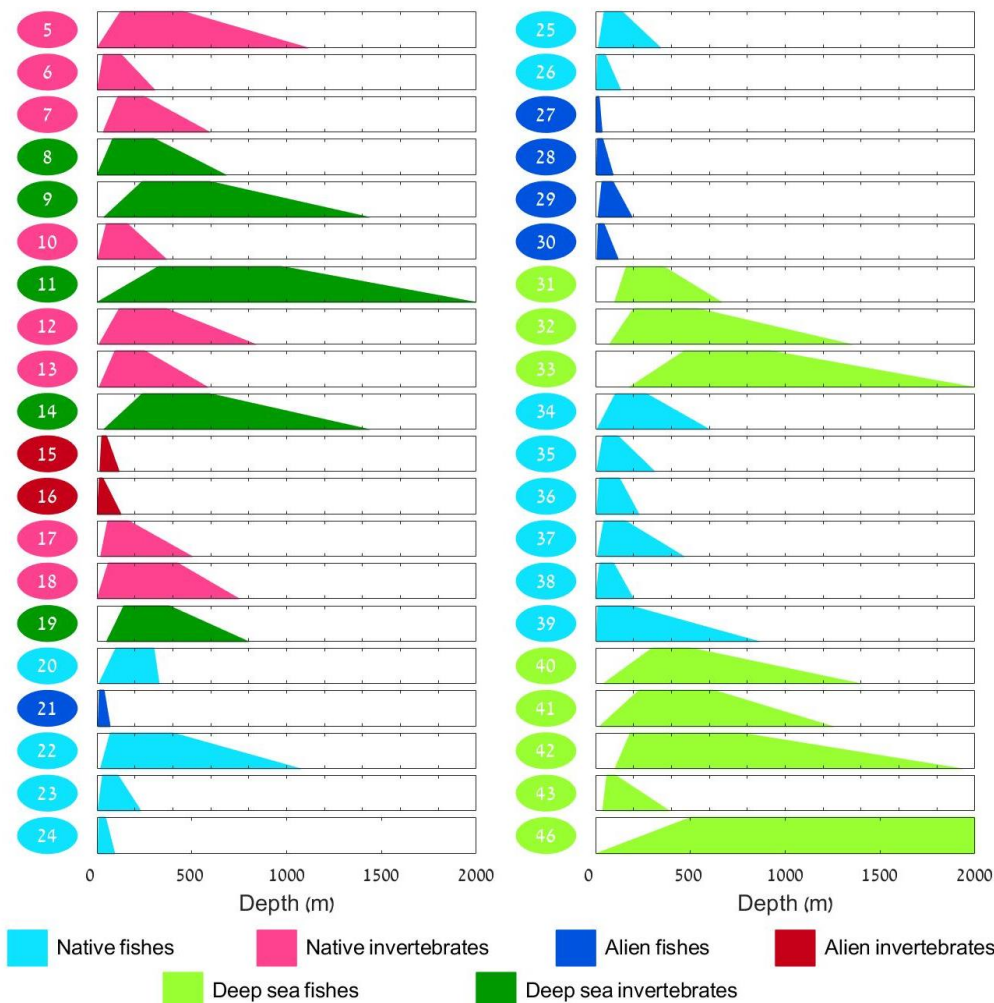
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# Appendix 1 – Spatial distribution functions of the groups in the model

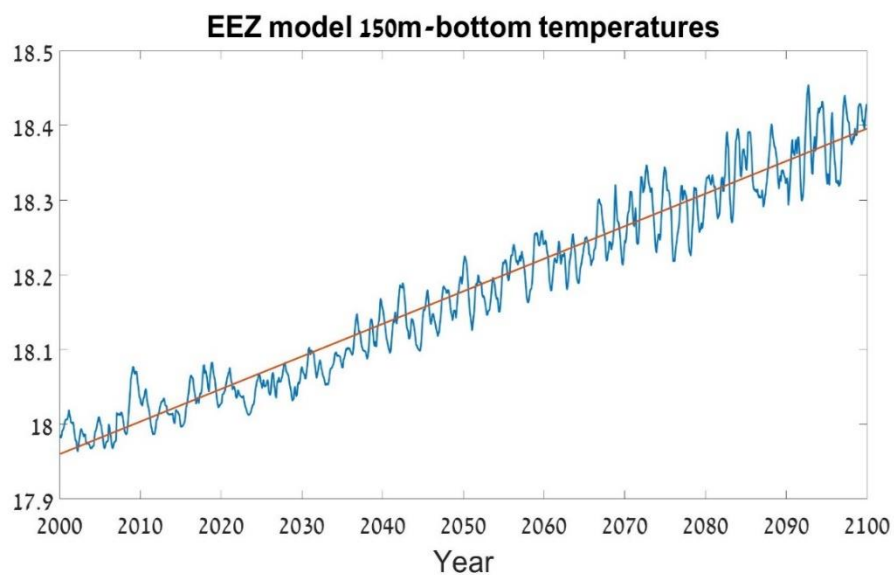
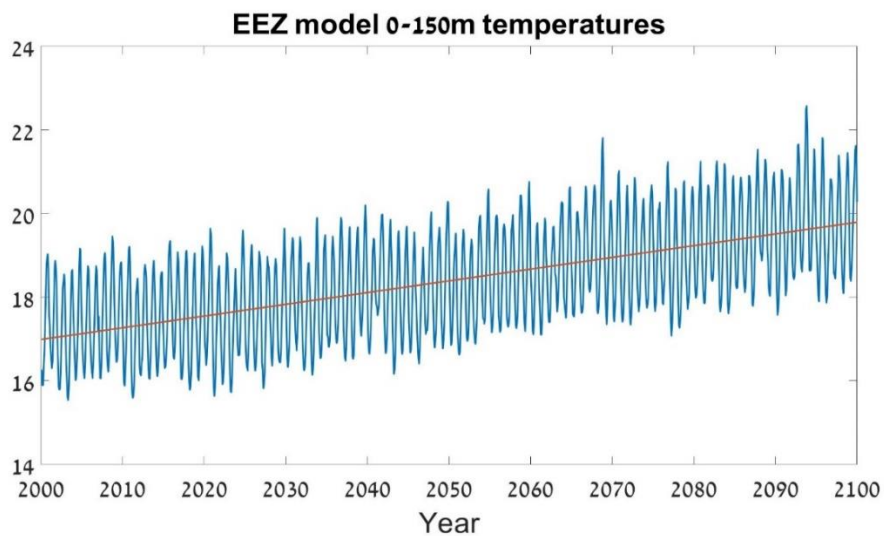


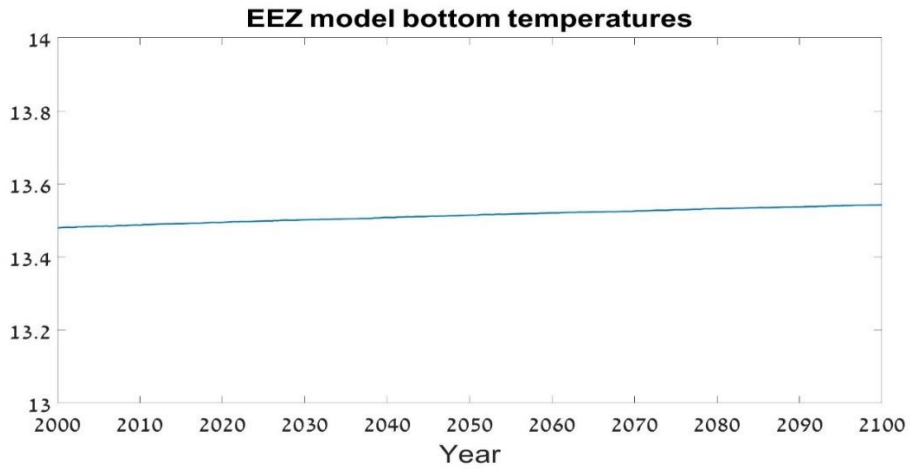


List of the groups in the model:

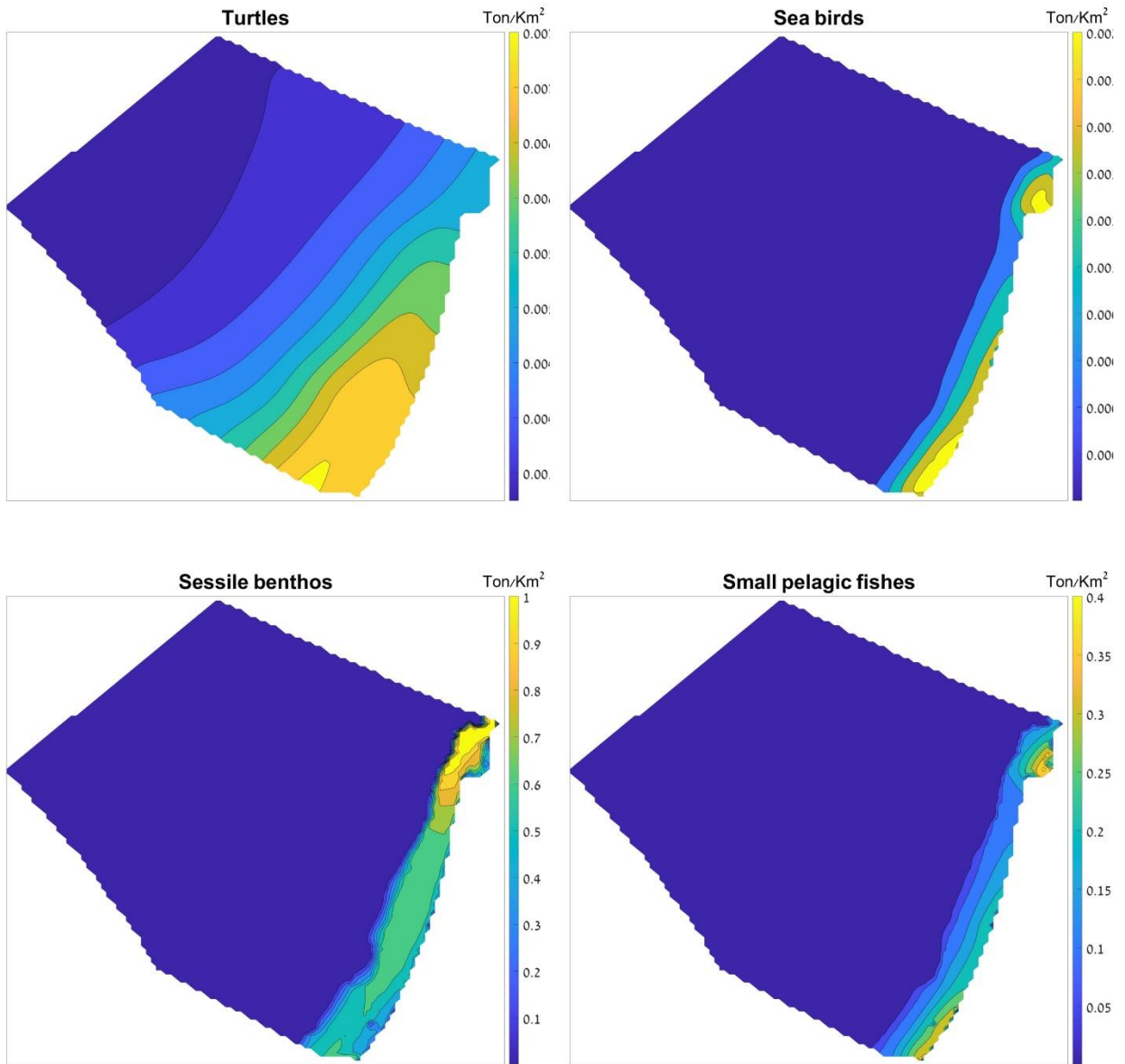
- 1) Phytoplankton
- 2) Benthic primary producers
- 3) Micro and mesozooplankton
- 4) Macrozooplankton
- 5) Gelatinous plankton
- 6) Sessile benthos
- 7) Bivalves
- 8) DS Bivalves
- 9) DS Scapophoda
- 10) Gastropods
- 11) DS Gastropods
- 12) Mobile benthos
- 13) decapods
- 14) DS decapoda
- 15) Allien Shrimps
- 16) Allien Crabs
- 17) Benthic cephalopods
- 18) Benthopelagic cephalopods
- 19) Mesopelagic cephalopods
- 20) Mulletts
- 21) Goatfishes
- 22) Hake
- 23) Flatfishes
- 24) Rocky fishes
- 25) Native demersal fishes (feeding on invertebrates)
- 26) Native Demersal fishes (feeding on fishes)
- 27) Alien Herbivorous
- 28) Old Alien demersal fishes
- 29) Alien demersal fishes (feeding on invertebrates)
- 30) Alien Demersal fishes (feeding on fishes)
- 31) Demersal fishes (upper slope)
- 32) Demersal fishes Mid Slope (400-900)
- 33) Demersal fishes Bathyal planes >1000m
- 34) Demersal sharks (continental shelf)
- 35) Rays and skates
- 36) Small pelagic fishes
- 37) Horse mackerel
- 38) Mackerel
- 39) Large pelagic fishes
- 40) DS-Chimera
- 41) DVM fish
- 42) DS-sharks
- 43) Deep rocky habitat Fishes
- 44) Turtles
- 45) Sea birds
- 46) Dolphins

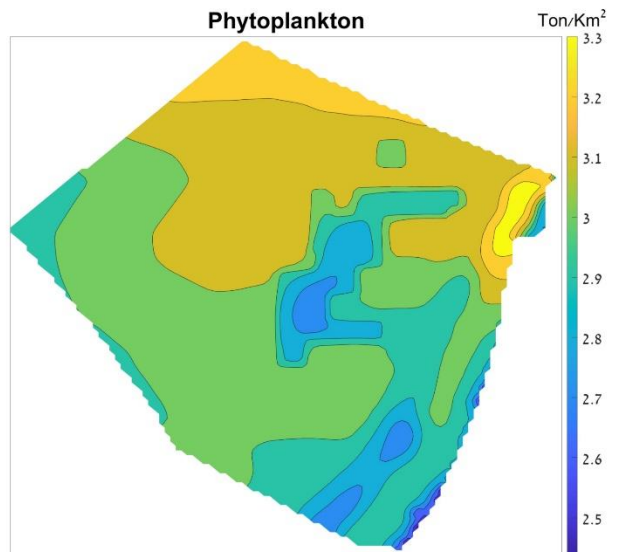
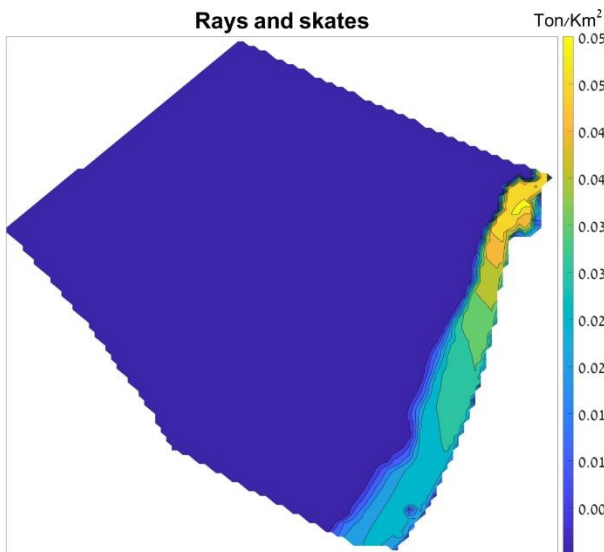
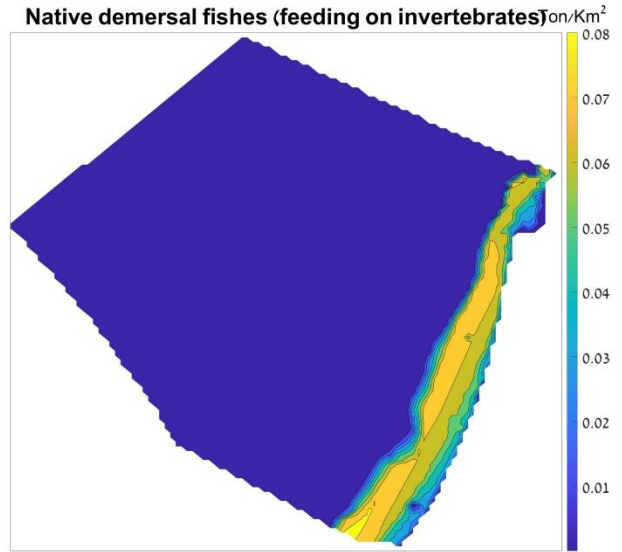
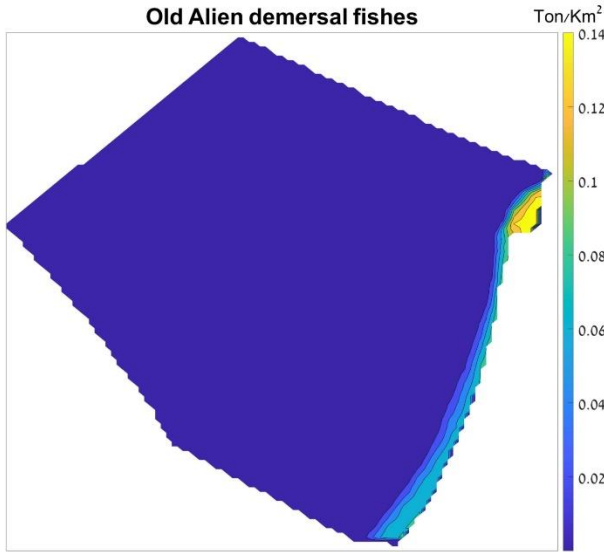
Appendix 2 – Climate Change graphs based on RCP 8.5 scenario (Baklouti et al., 2021)

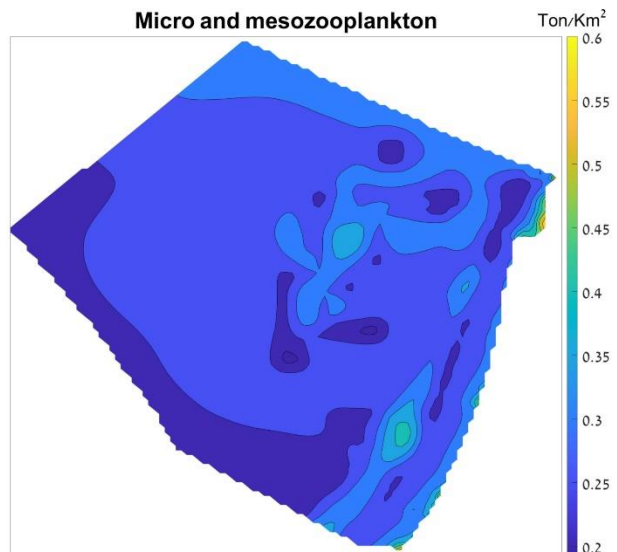
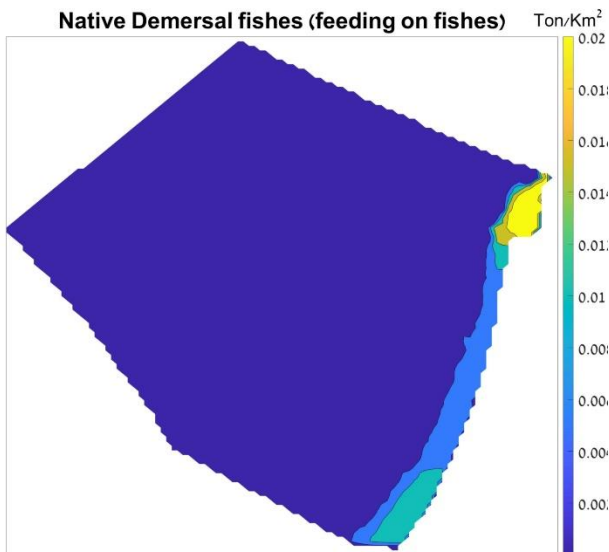
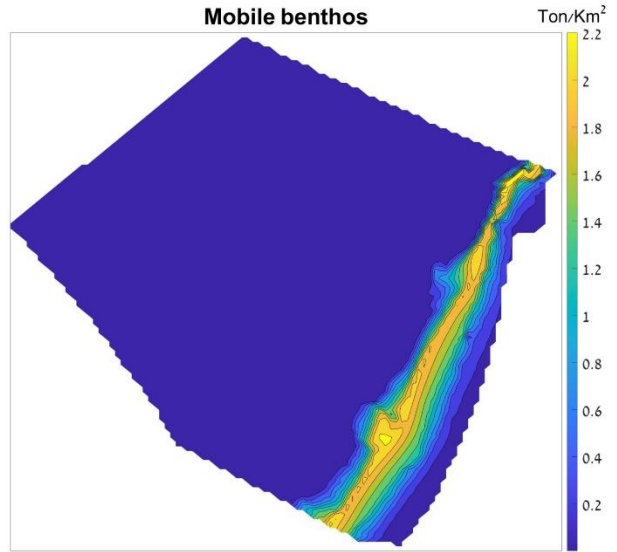
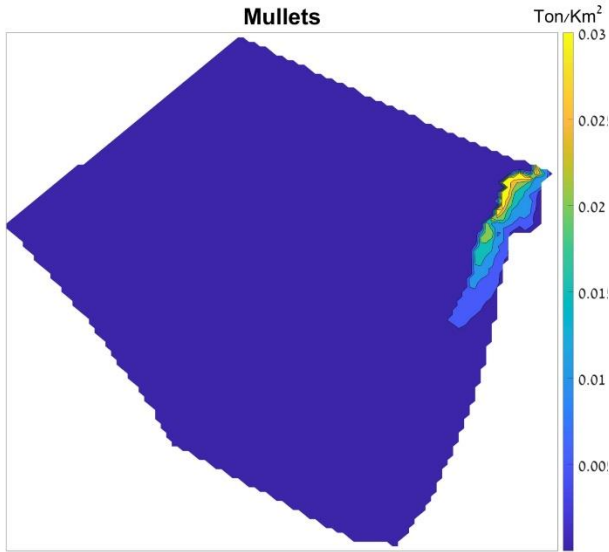


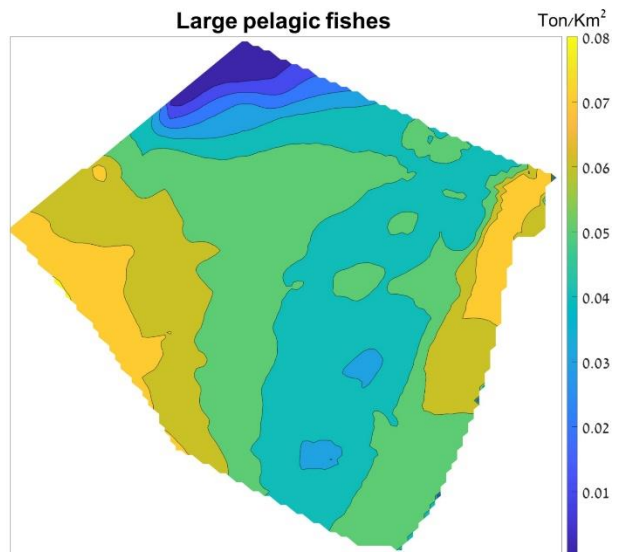
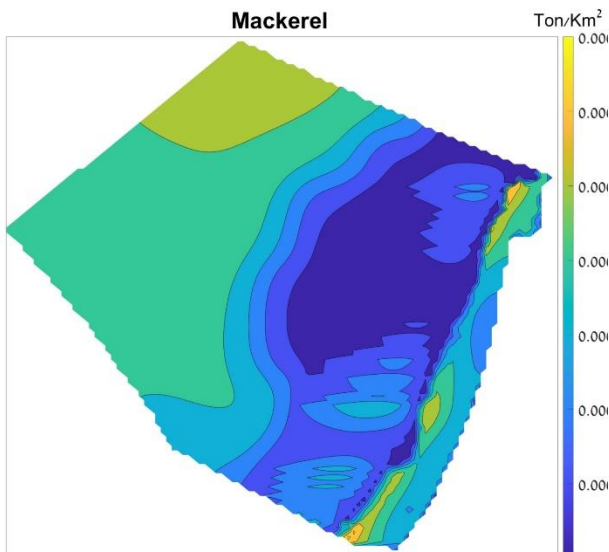
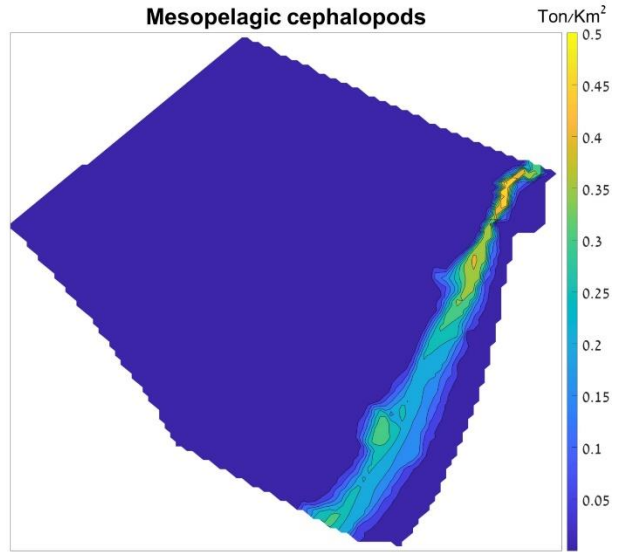
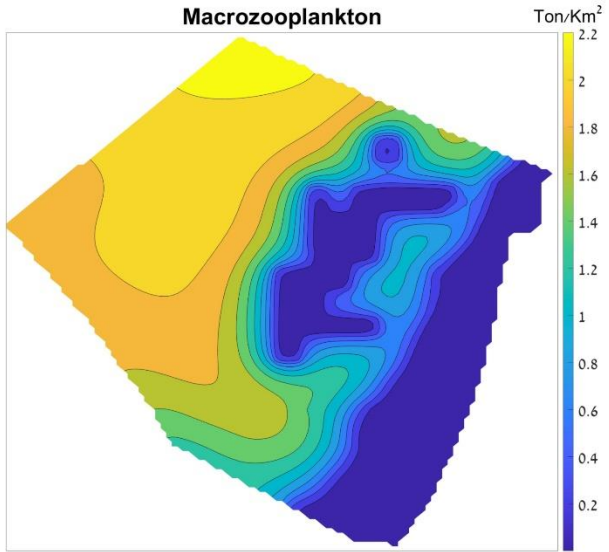


## Appendix 3 – The distribution maps of the groups in 2022

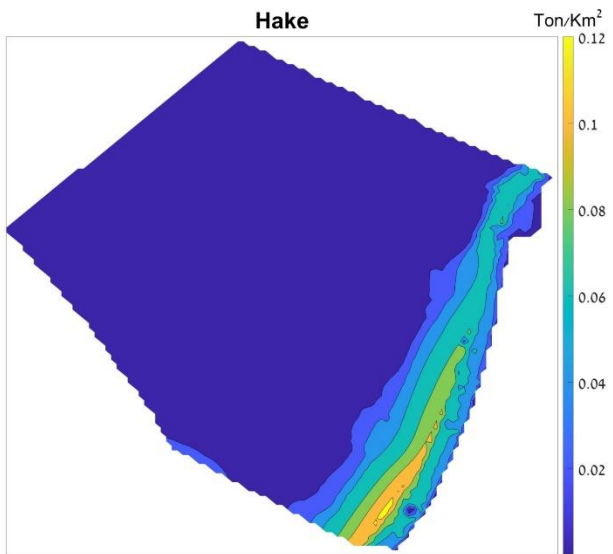
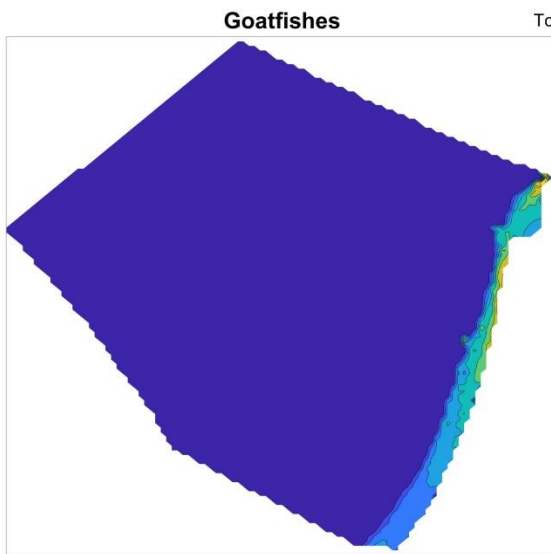
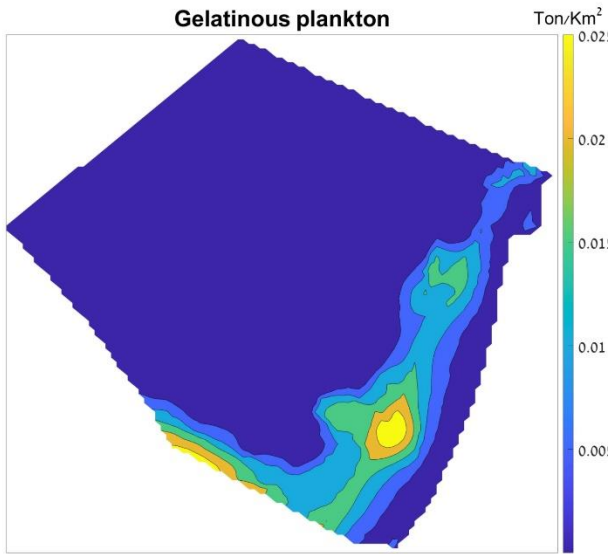
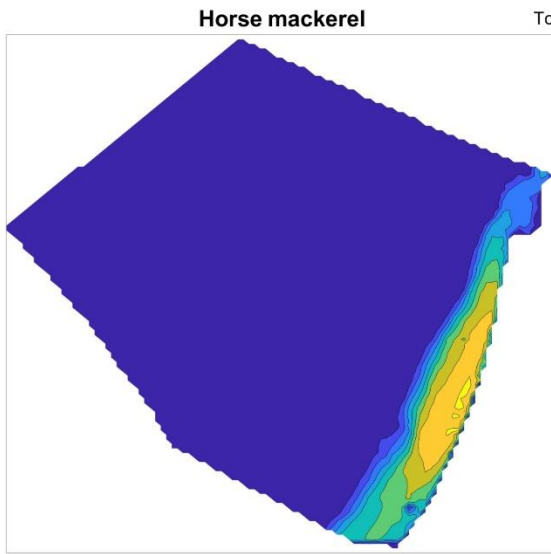


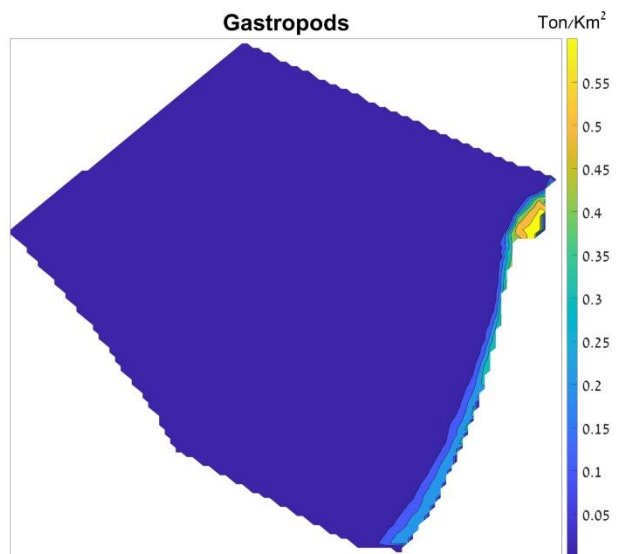
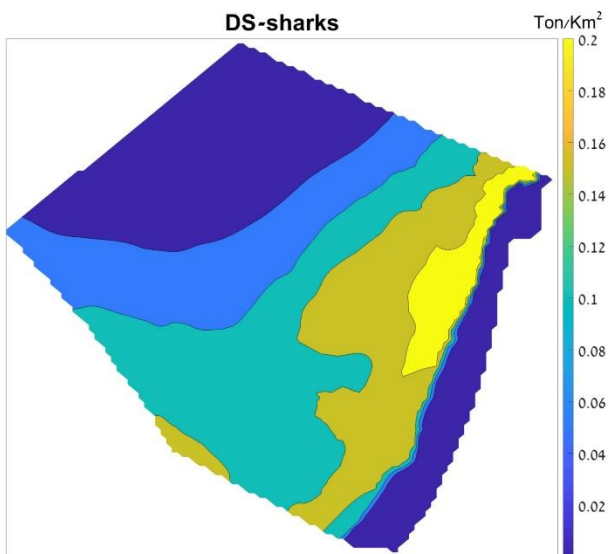
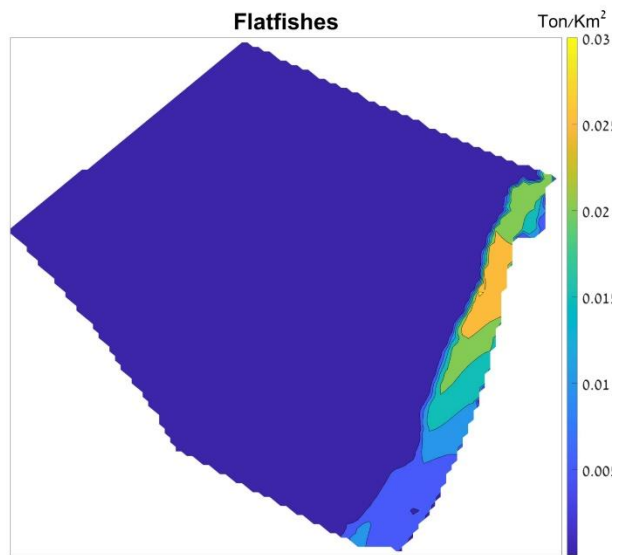
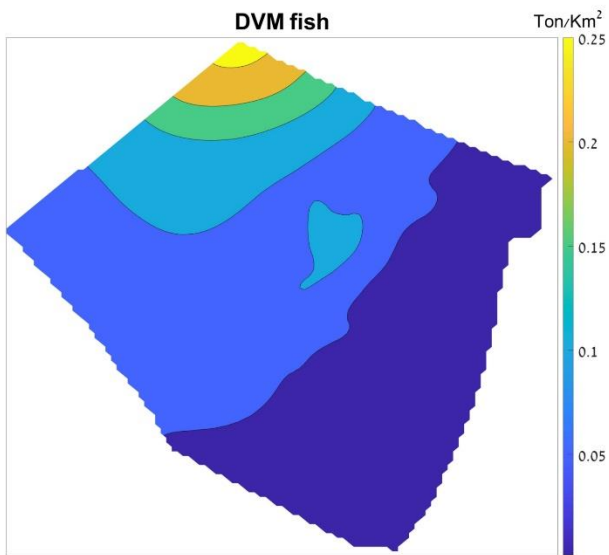


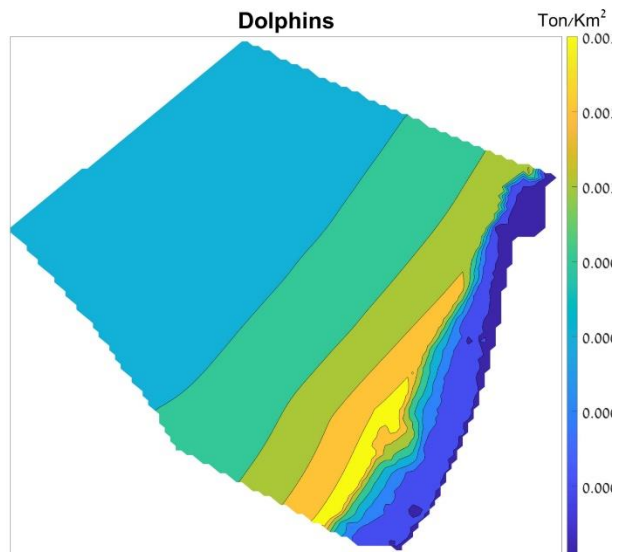
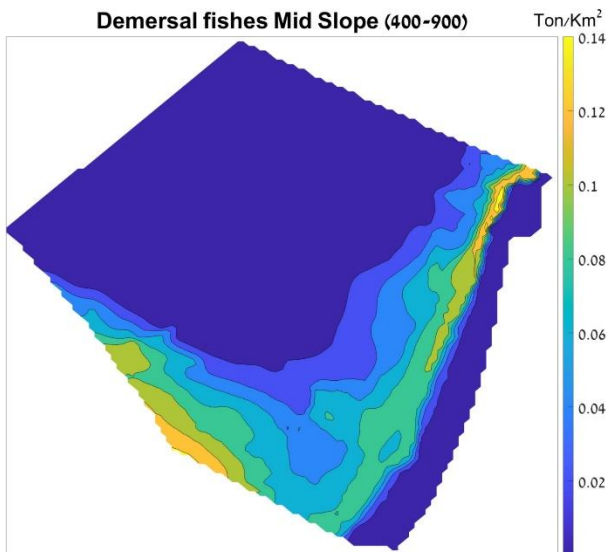
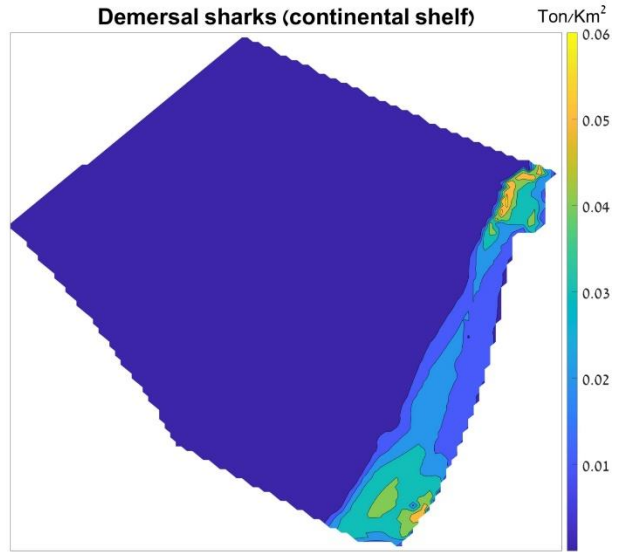
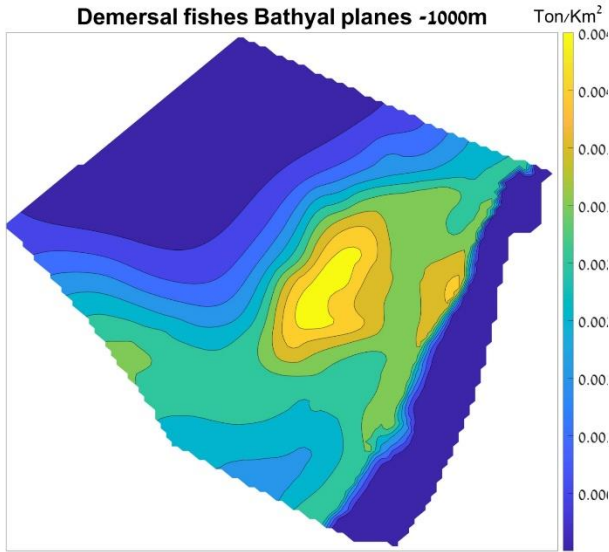


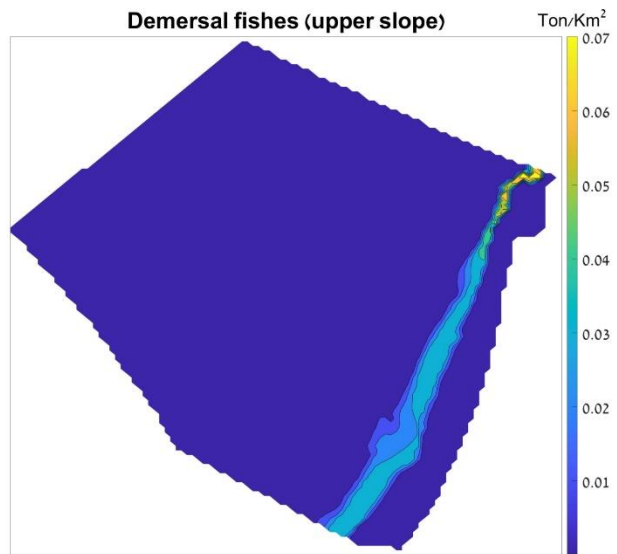
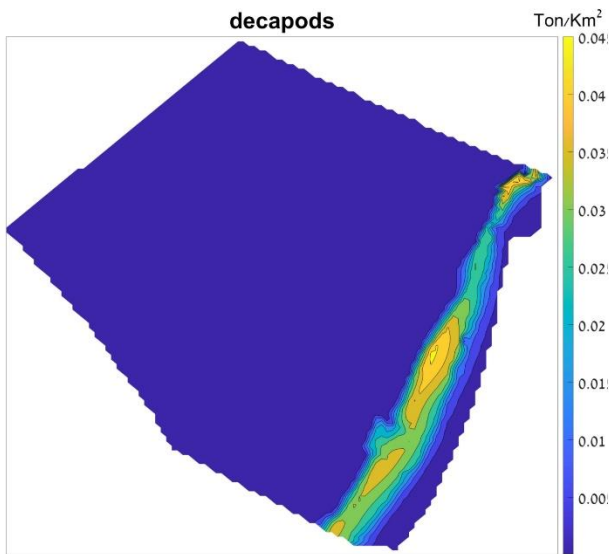
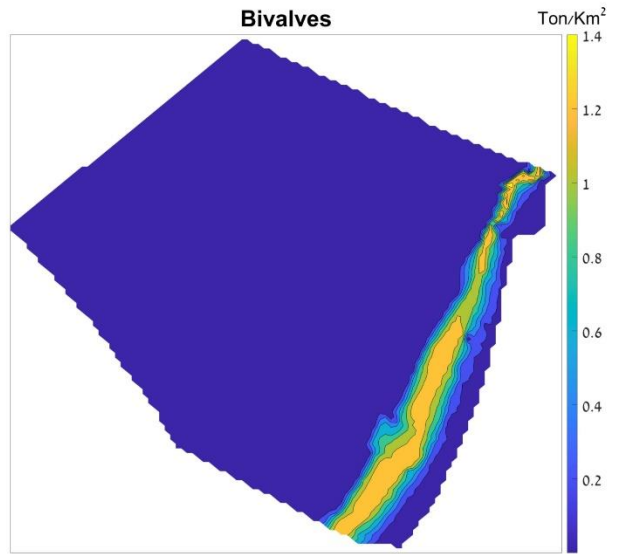
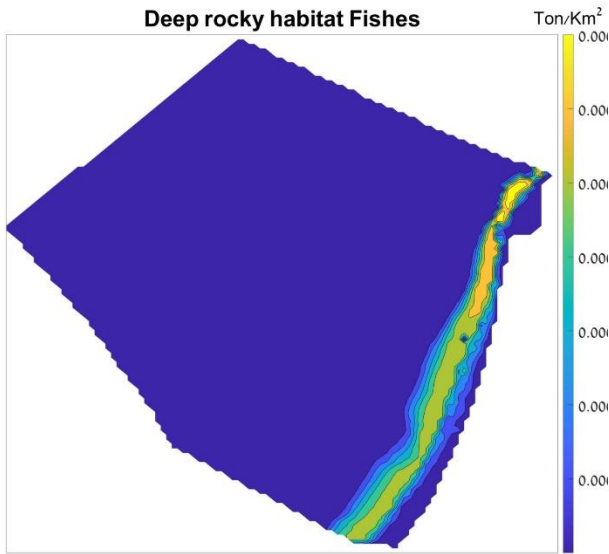


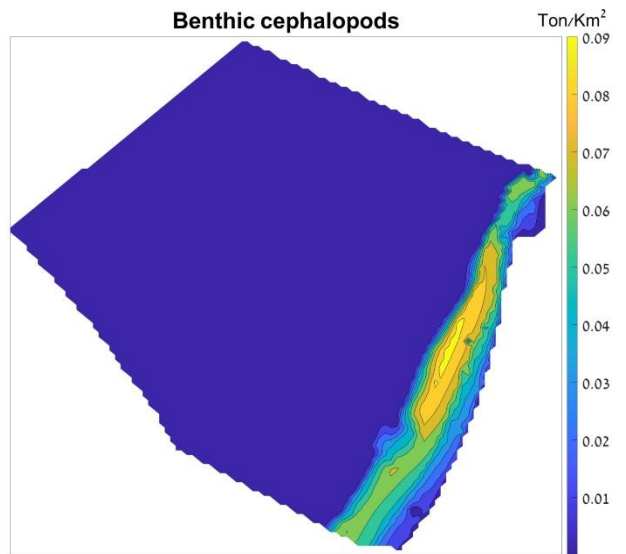
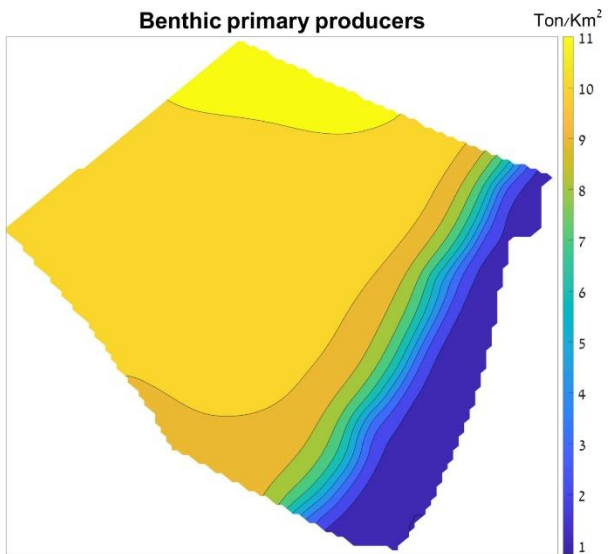
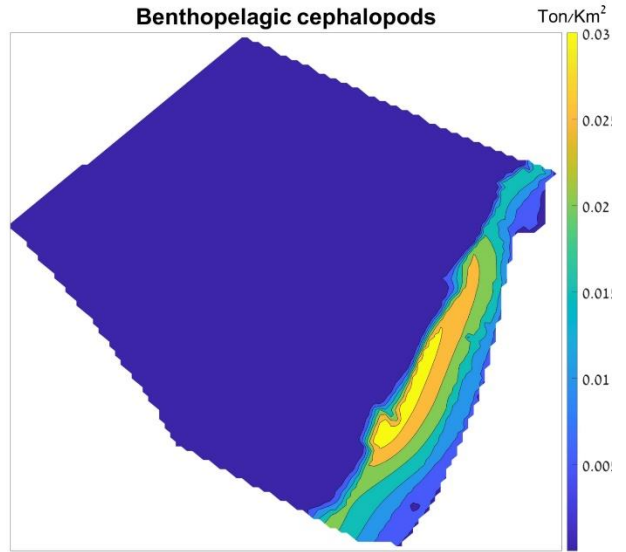
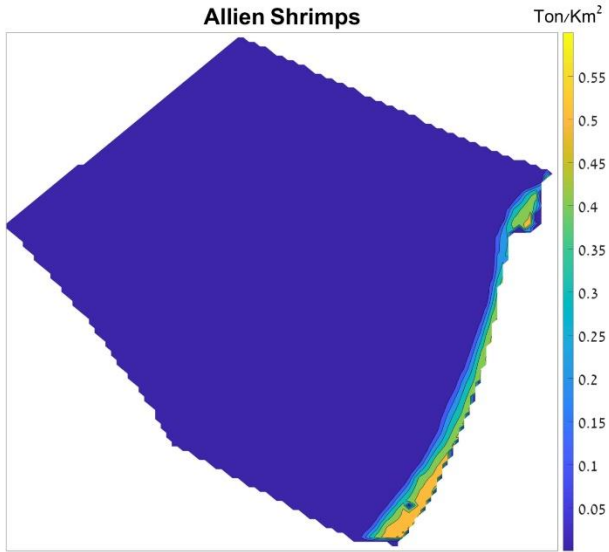


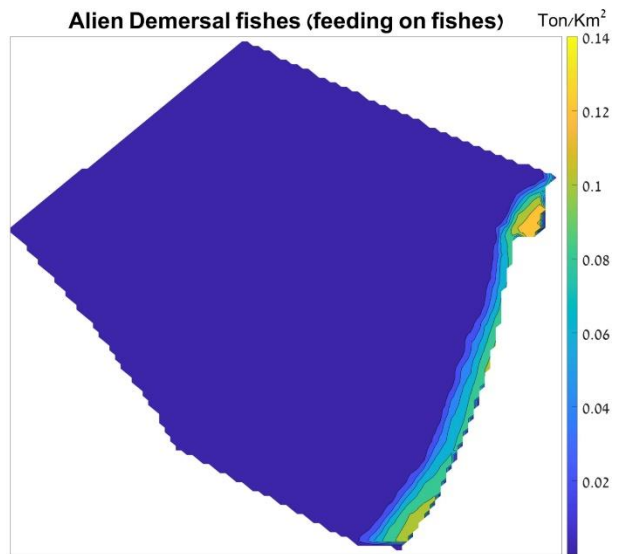
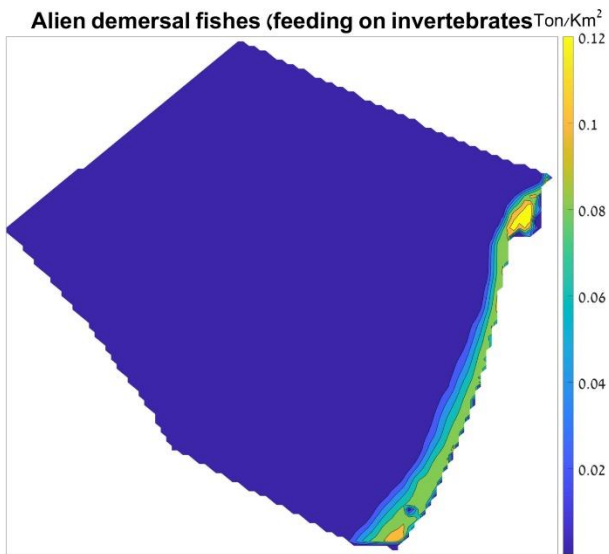
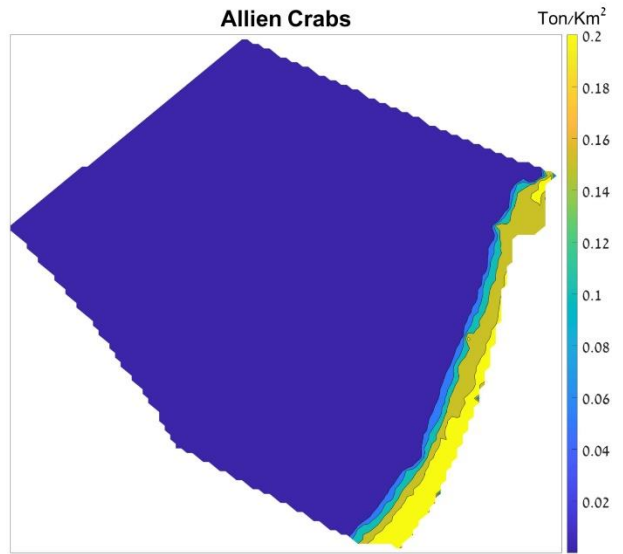
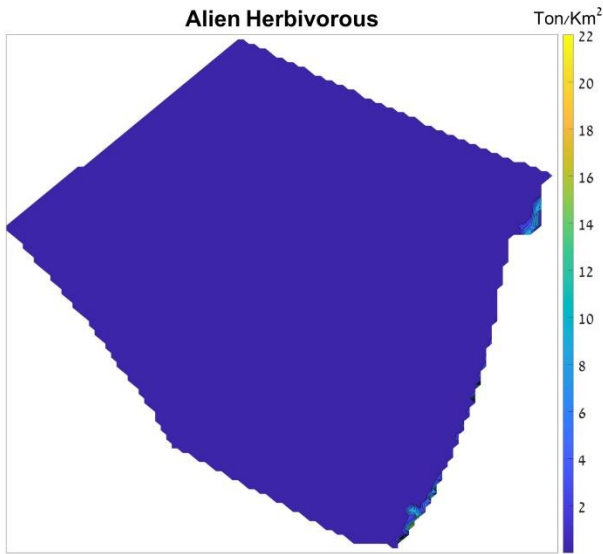


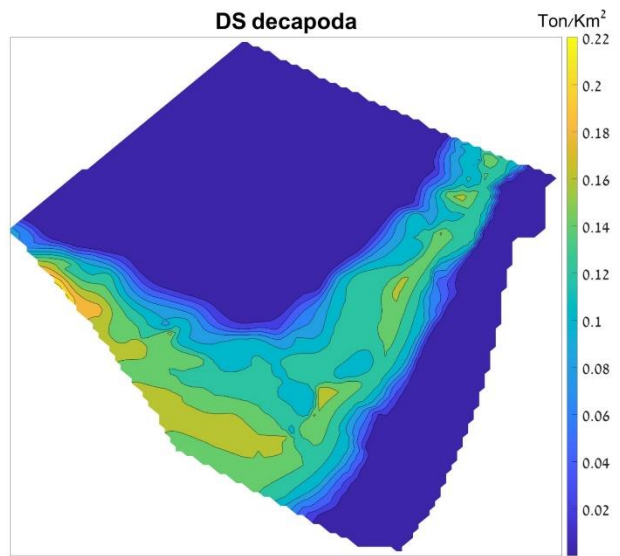
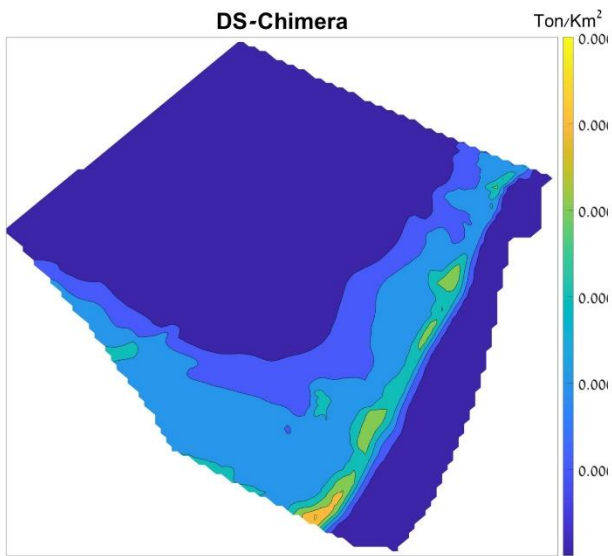
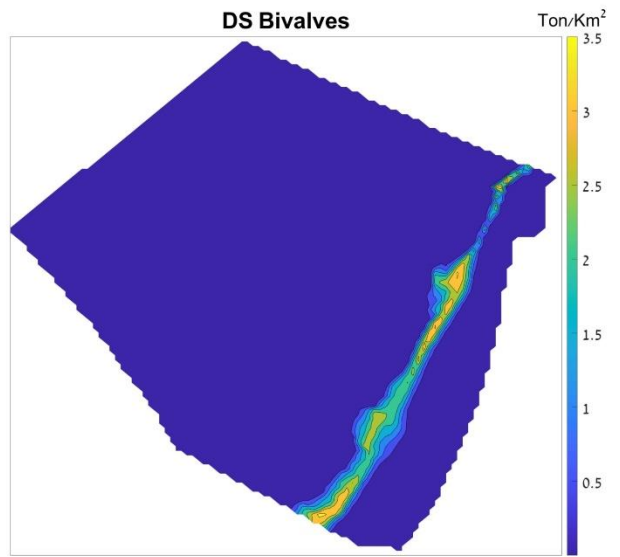






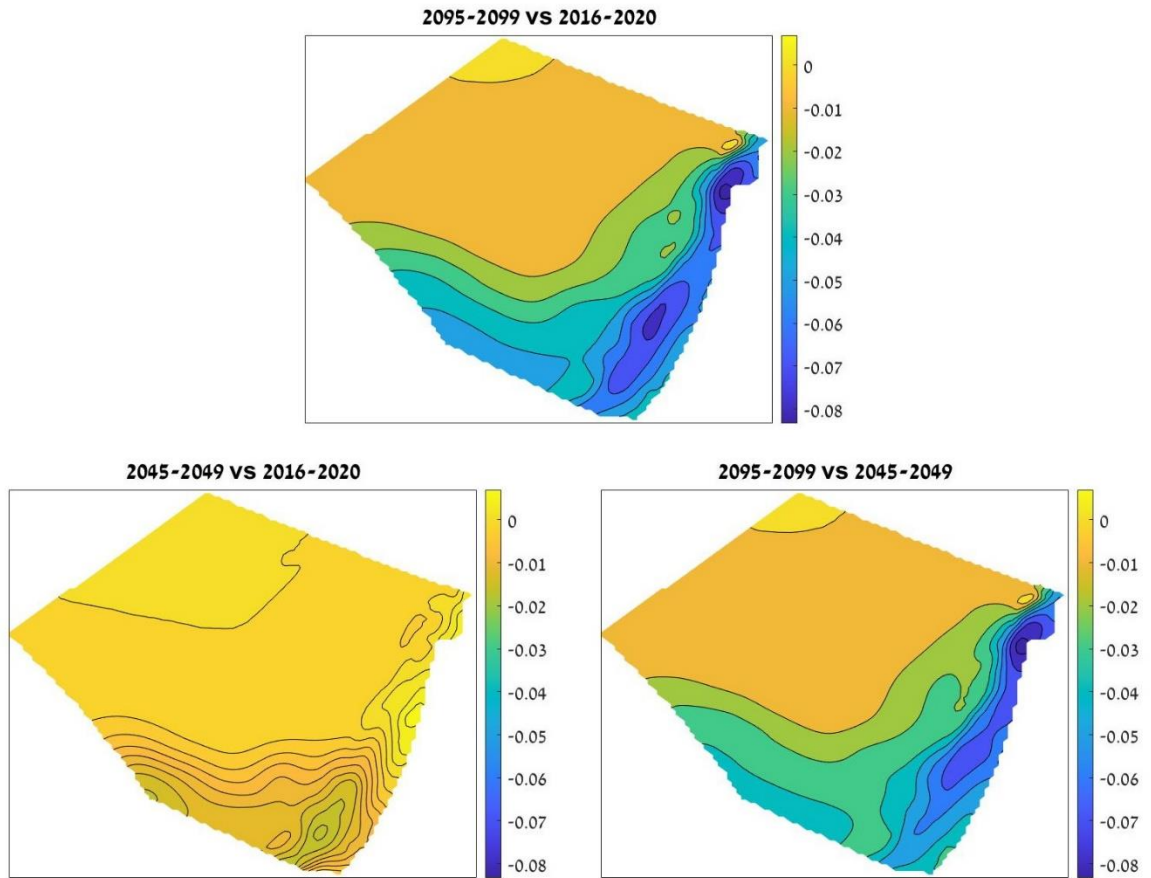






Appendix 4 - Maps of changes in the distribution of the different groups in the space due to climate change

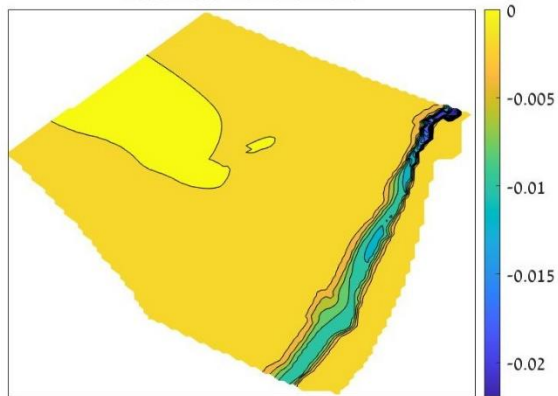
**Base, Zooplankton**



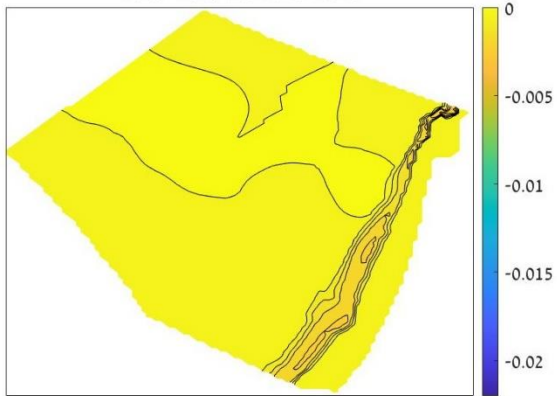


# Base, Slope Fishes

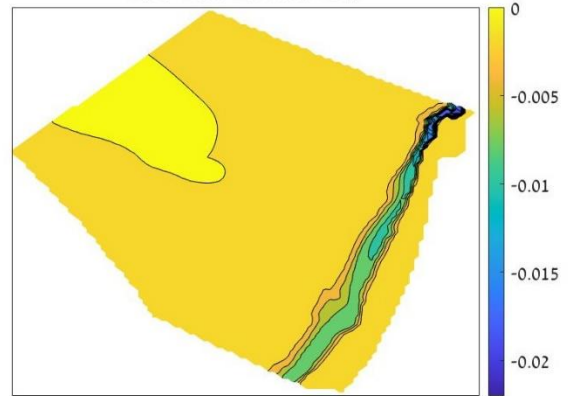
2095-2099 vs 2016-2020



2045-2049 vs 2016-2020

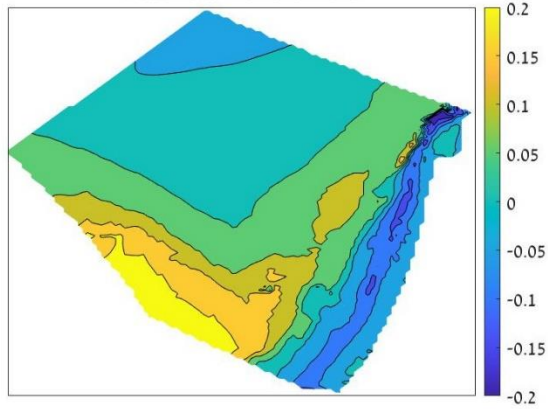


2095-2099 vs 2045-2049

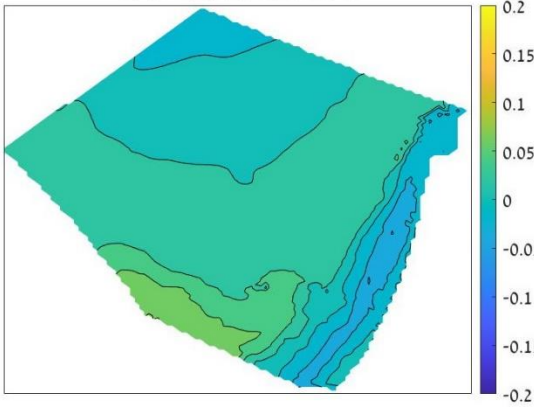


# Base, Native

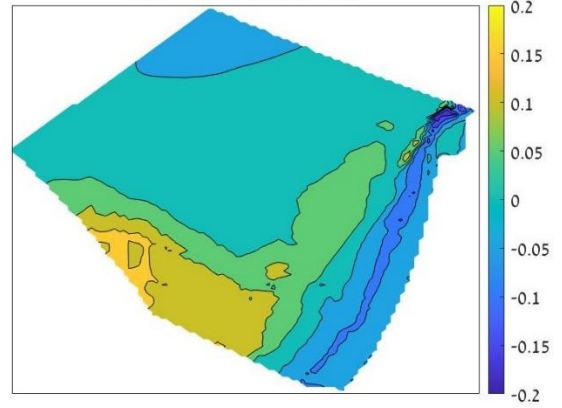
2095-2099 vs 2016-2020



2045-2049 vs 2016-2020

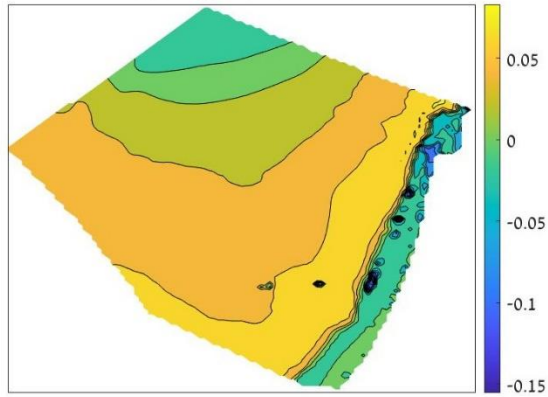


2095-2099 vs 2045-2049

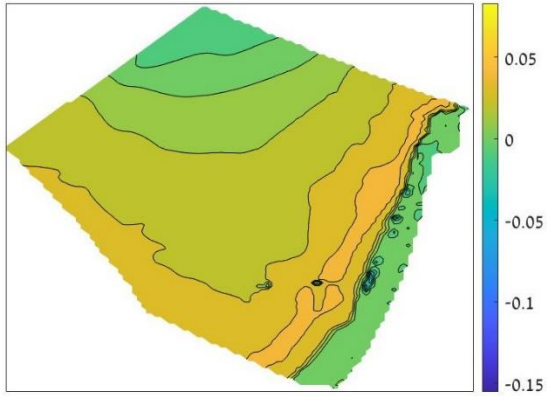


# Base, Native fish

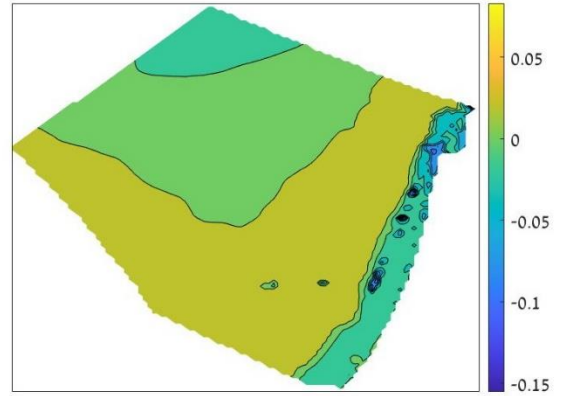
2095-2099 vs 2016-2020



2045-2049 vs 2016-2020

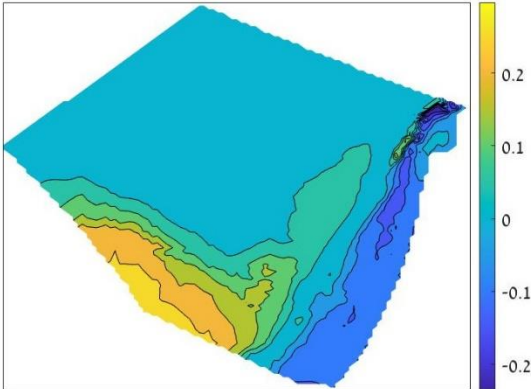


2095-2099 vs 2045-2049

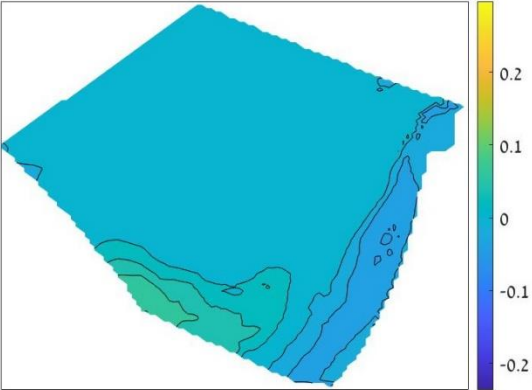


# Base, Invertebrates

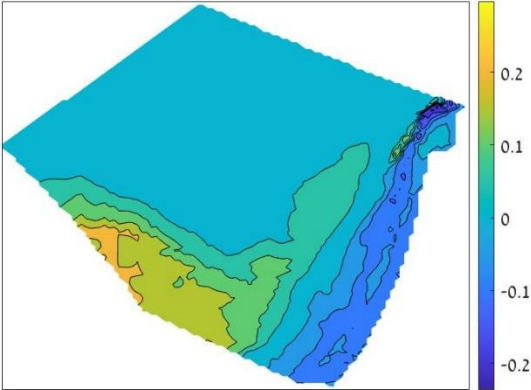
2095-2099 vs 2016-2020



2045-2049 vs 2016-2020

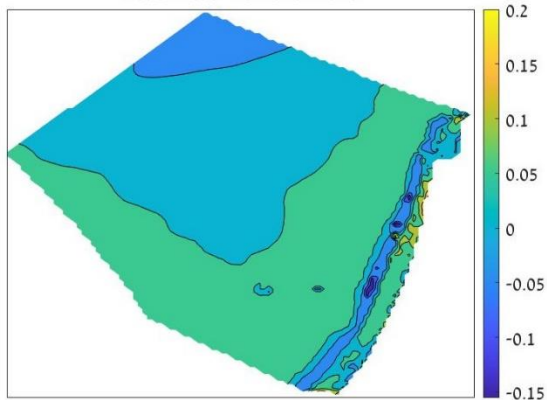


2095-2099 vs 2045-2049

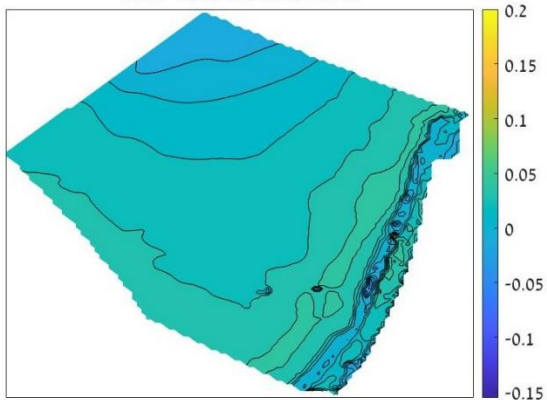


# Base, Fish

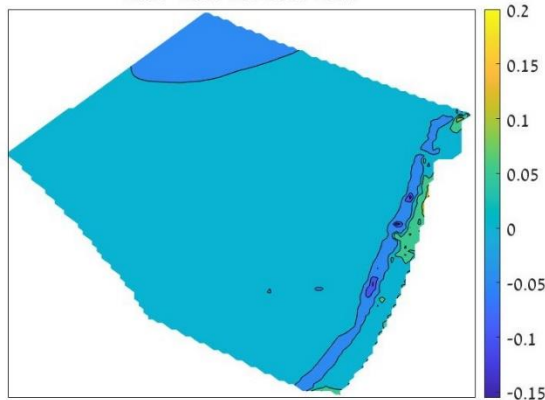
2095-2099 vs 2016-2020



2045-2049 vs 2016-2020

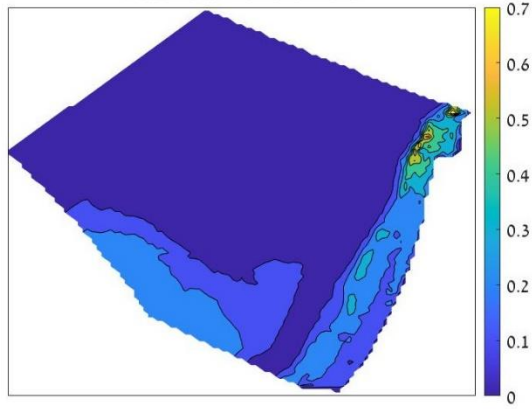


2095-2099 vs 2045-2049

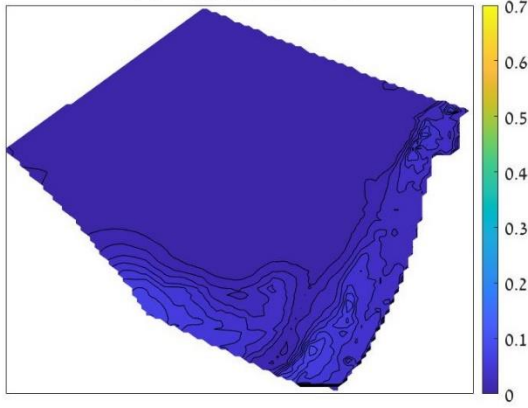


# Base, Deep Sea Invertebrates

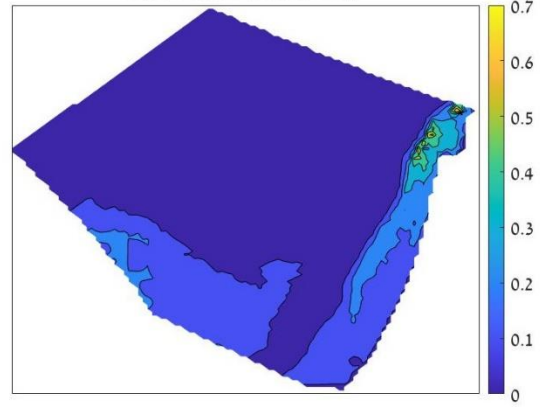
2095-2099 vs 2016-2020



2045-2049 vs 2016-2020

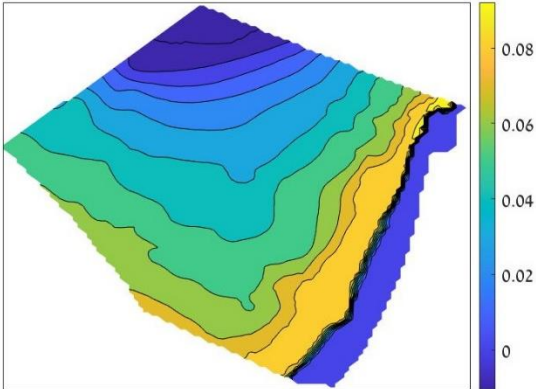


2095-2099 vs 2045-2049

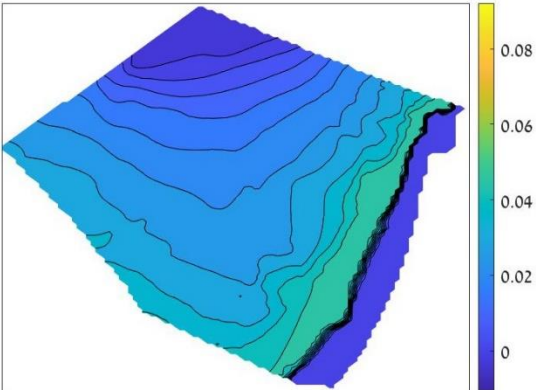


# Base, Deep sea fish

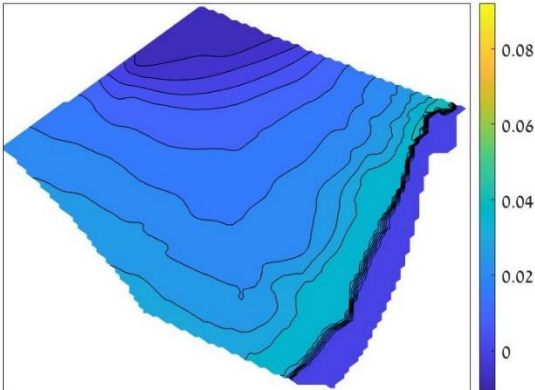
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2045-2049 vs 2016-2020

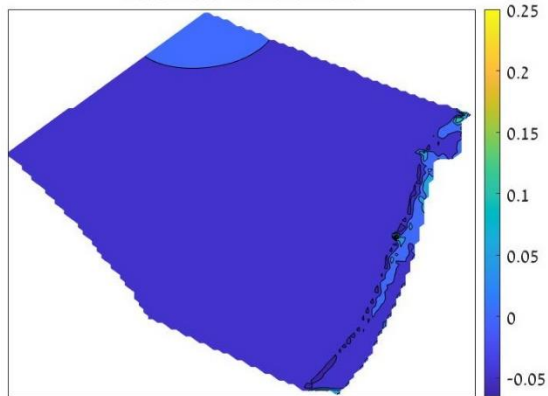


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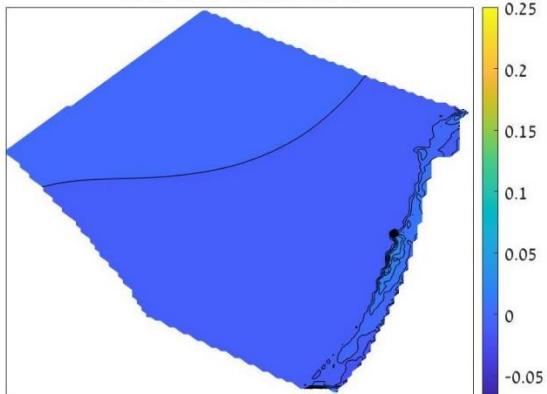


# Base, Alien

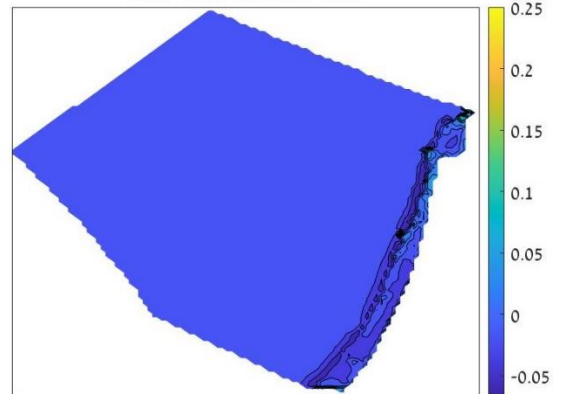
2095-2099 vs 2016-2020



2045-2049 vs 2016-2020



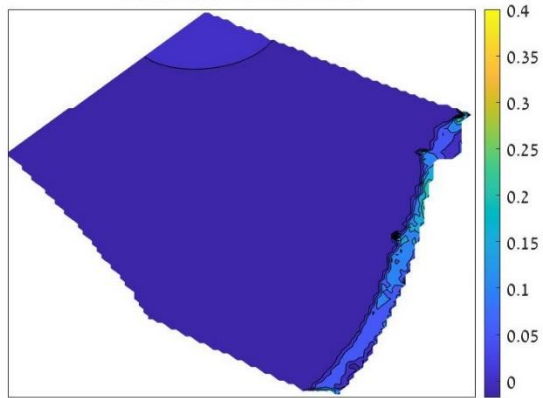
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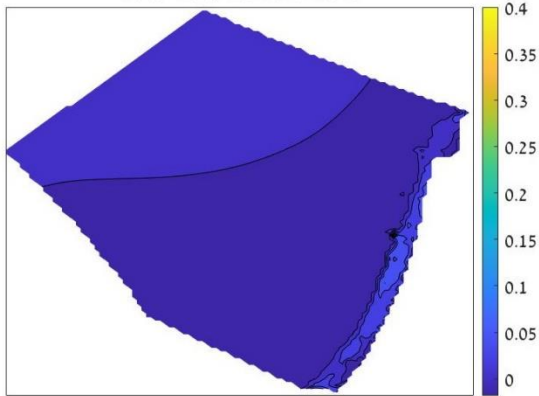


# Base, Alien fish

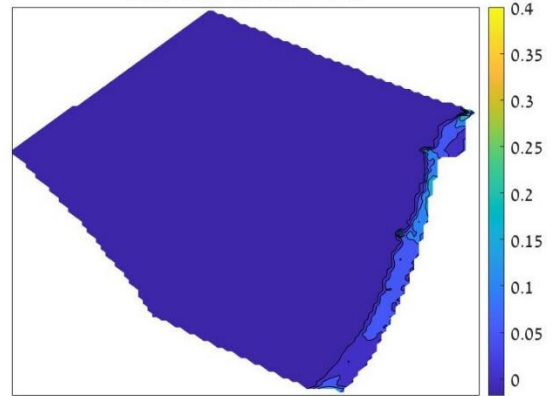
2095-2099 vs 2016-2020



2045-2049 vs 2016-2020

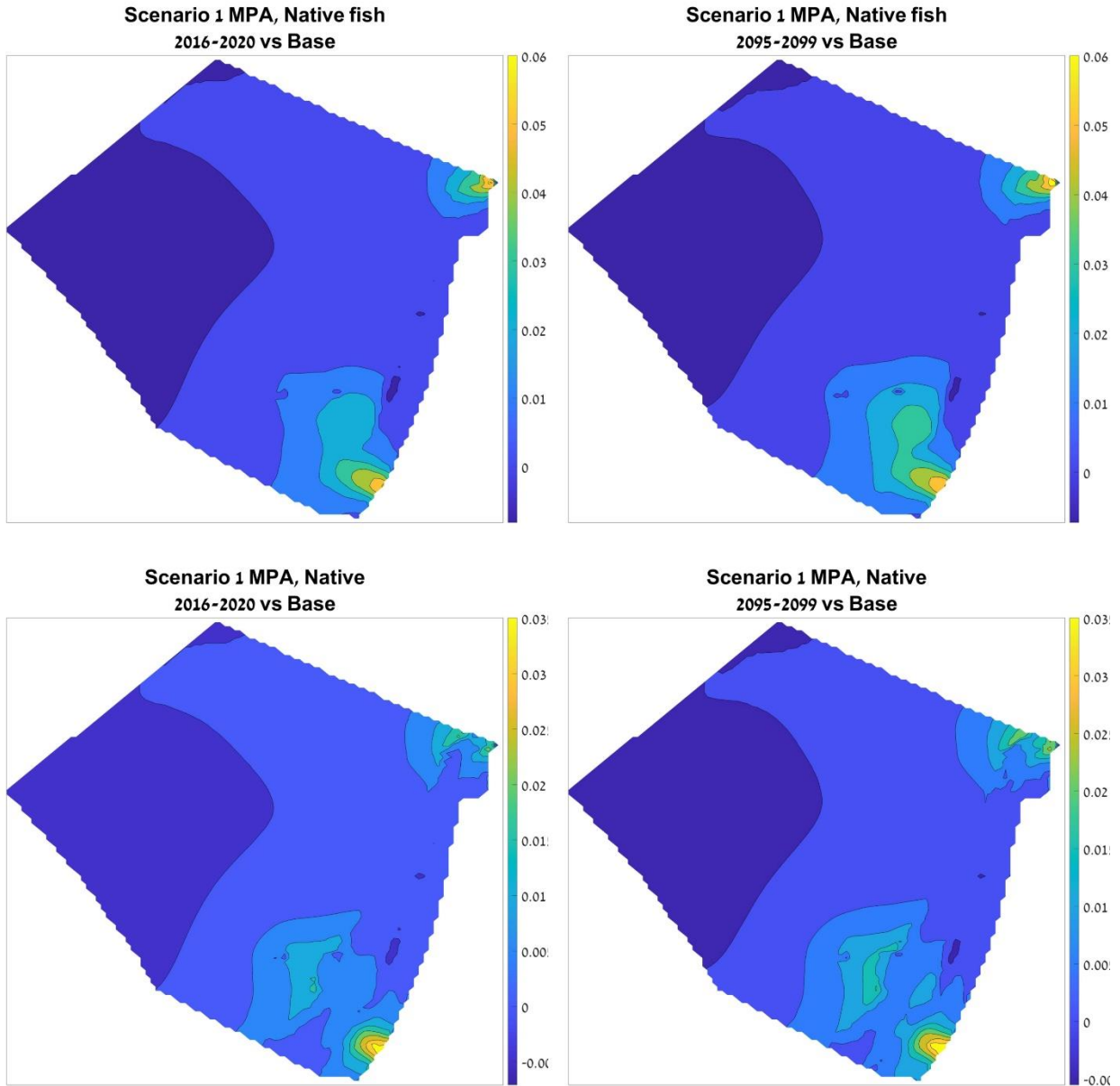


2095-2099 vs 2045-2049

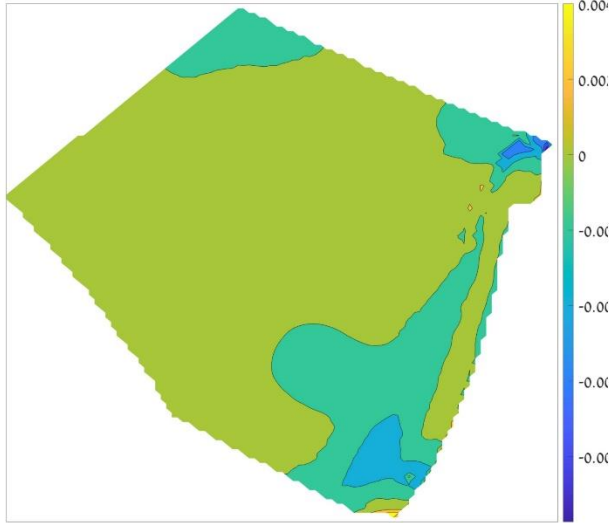




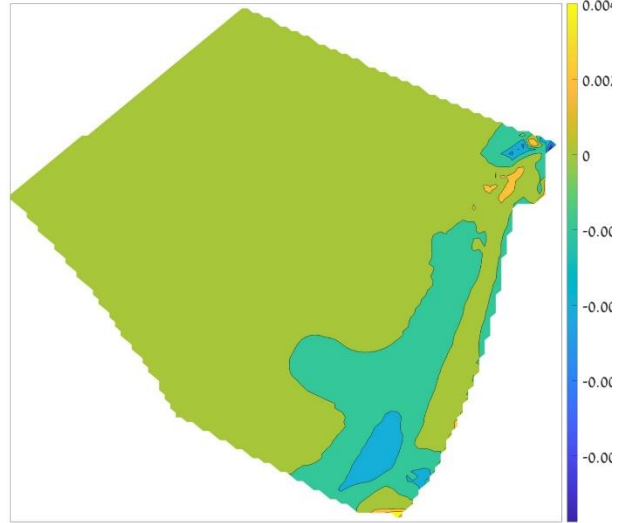
Appendix 5 - Maps of the change in the distribution of the different groups in the scenario where there is a closure of the nature reserves on the continental shelf and given climate change



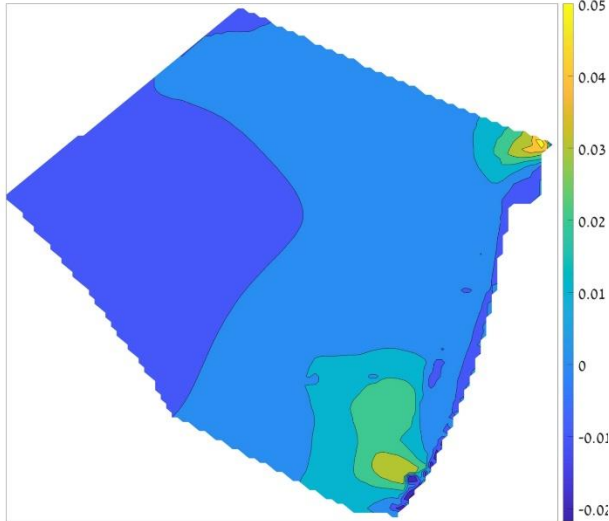
**Scenario 1 MPA, Invertebrates**  
2016-2020 vs Base



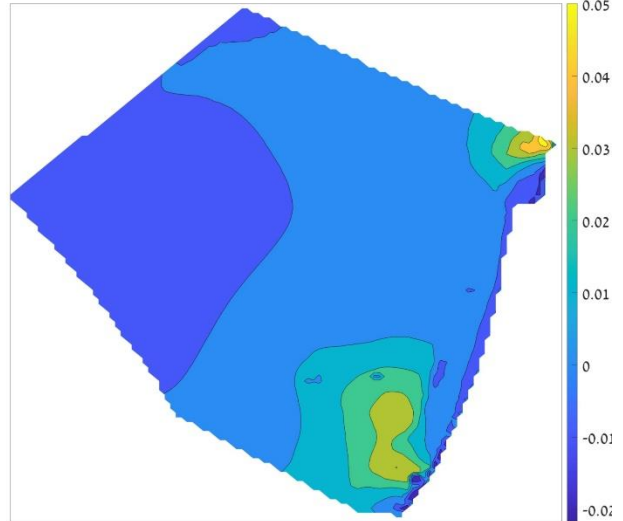
**Scenario 1 MPA, Invertebrates**  
2095-2099 vs Base



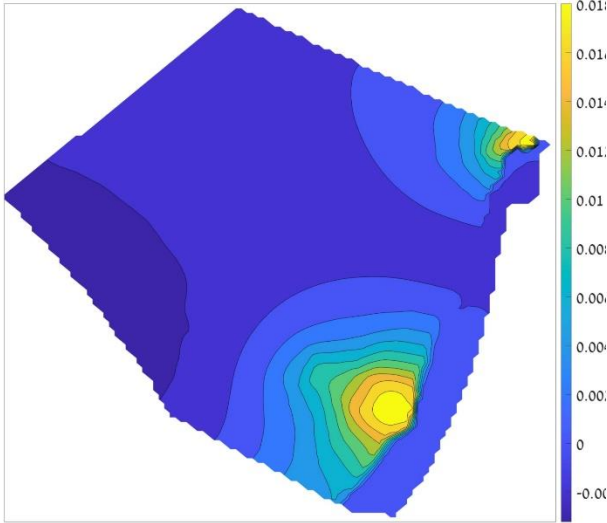
**Scenario 1 MPA, Fish**  
2016-2020 vs Base



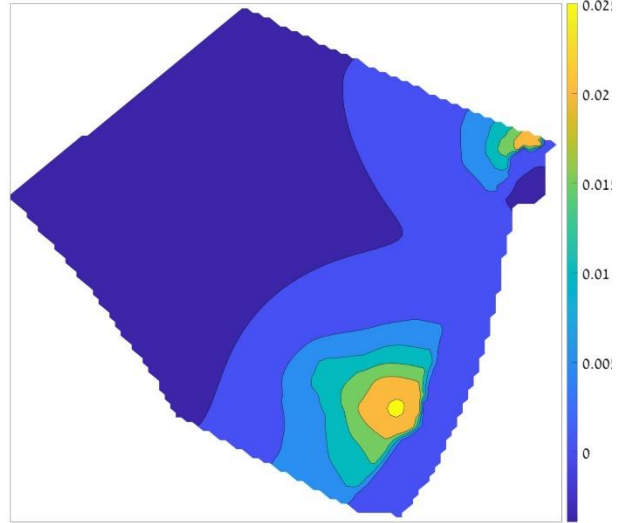
**Scenario 1 MPA, Fish**  
2095-2099 vs Base



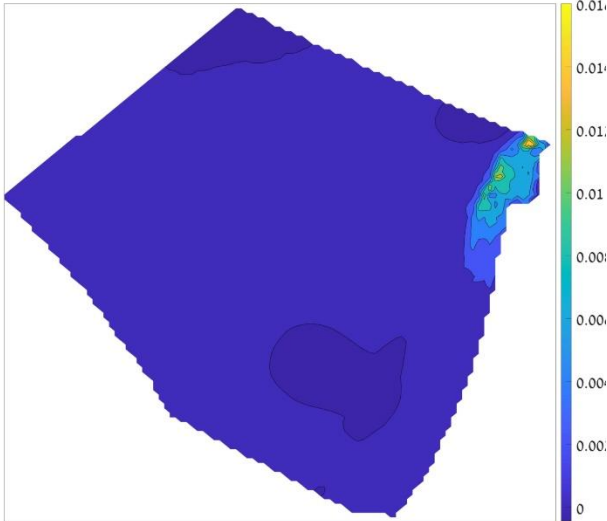
Scenario 1 MPA, Deep sea fish  
2016-2020 vs Base



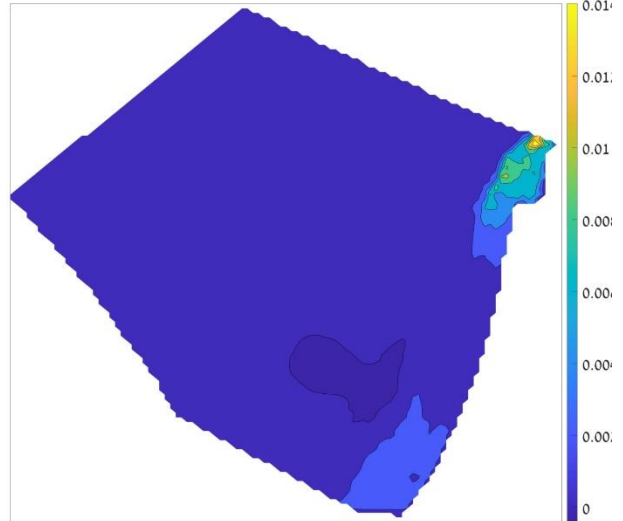
Scenario 1 MPA, Deep sea fish  
2095-2099 vs Base



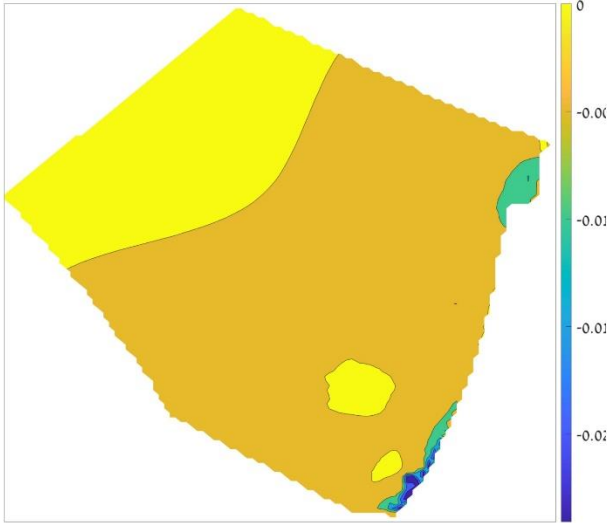
Scenario 1 MPA, Deep Sea Invertebrates  
2016-2020 vs Base



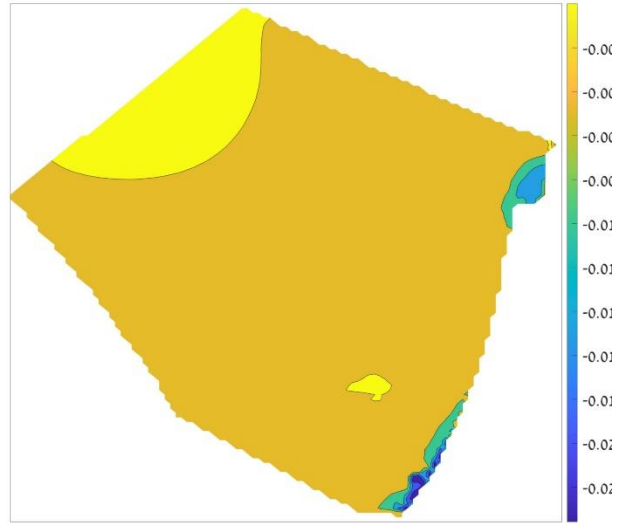
Scenario 1 MPA, Deep Sea Invertebrates  
2095-2099 vs Base



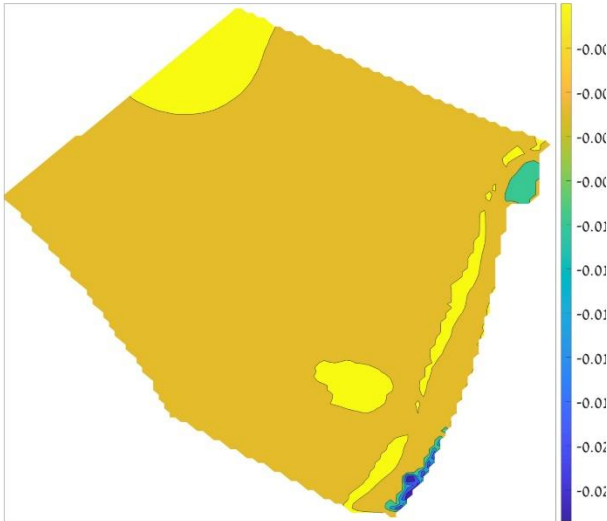
**Scenario 1 MPA, Alien fish  
2016-2020 vs Base**



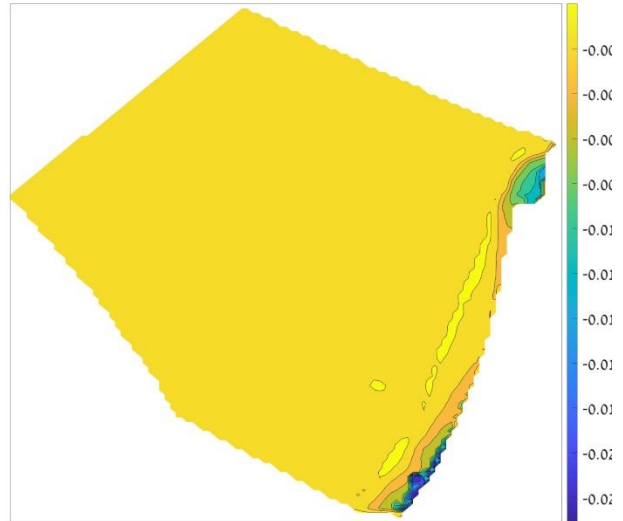
**Scenario 1 MPA, Alien fish  
2095-2099 vs Base**



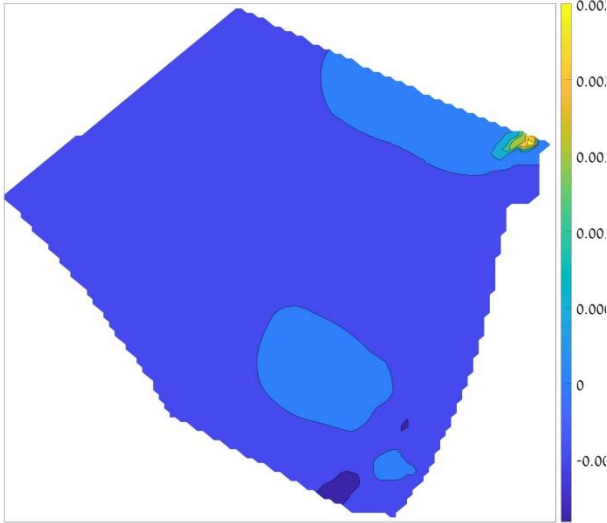
**Scenario 1 MPA, Alien  
2016-2020 vs Base**



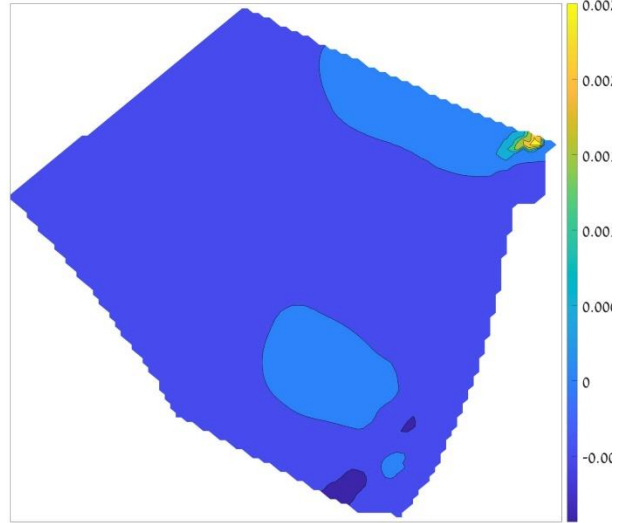
**Scenario 1 MPA, Alien  
2095-2099 vs Base**



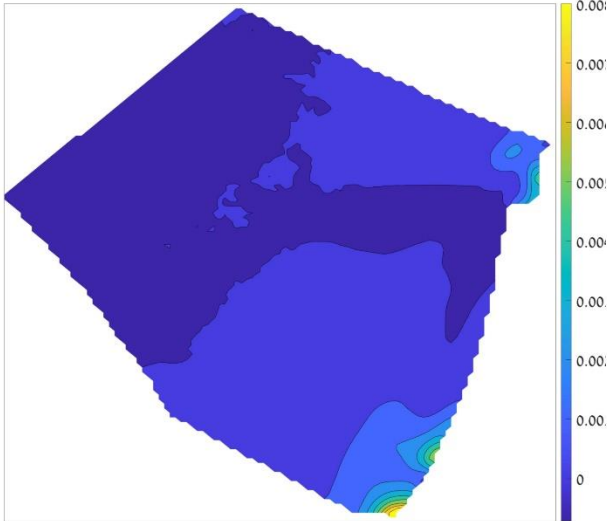
**Scenario 1 MPA, Slope Fishes**  
2016-2020 vs Base



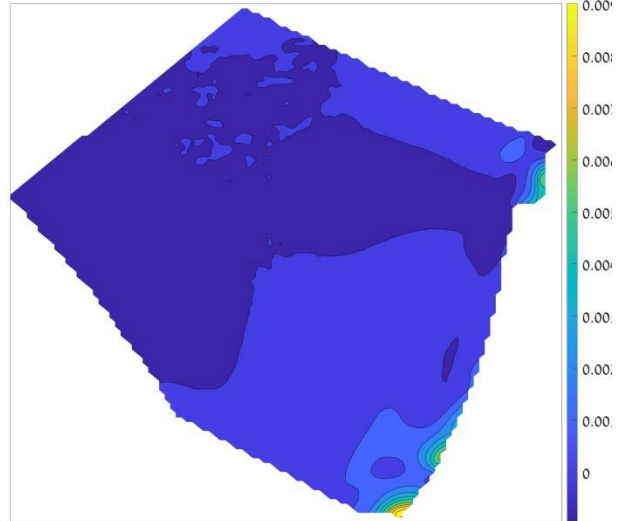
**Scenario 1 MPA, Slope Fishes**  
2095-2099 vs Base



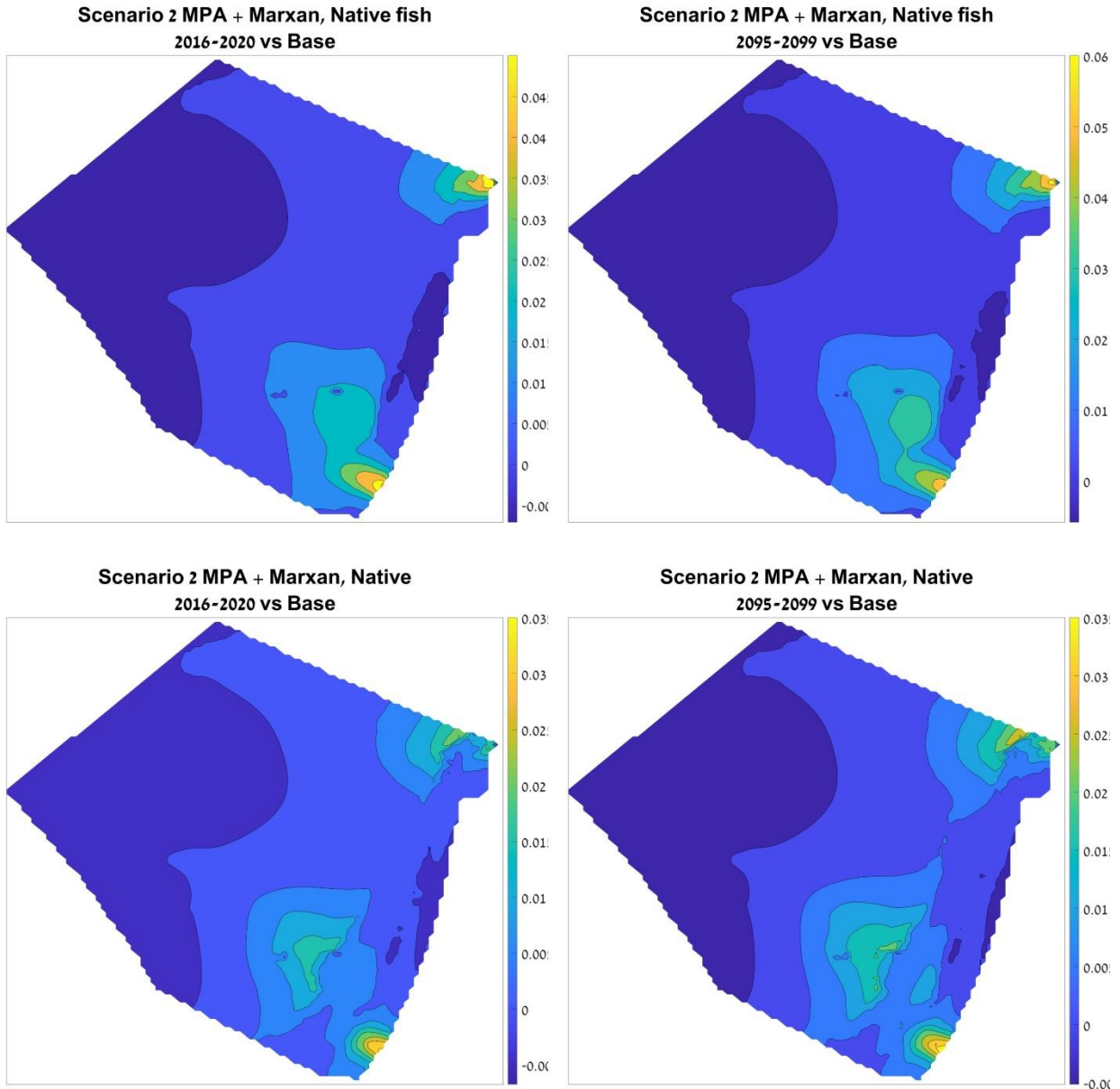
**Scenario 1 MPA, ZooPlankton**  
2016-2020 vs Base



**Scenario 1 MPA, ZooPlankton**  
2095-2099 vs Base

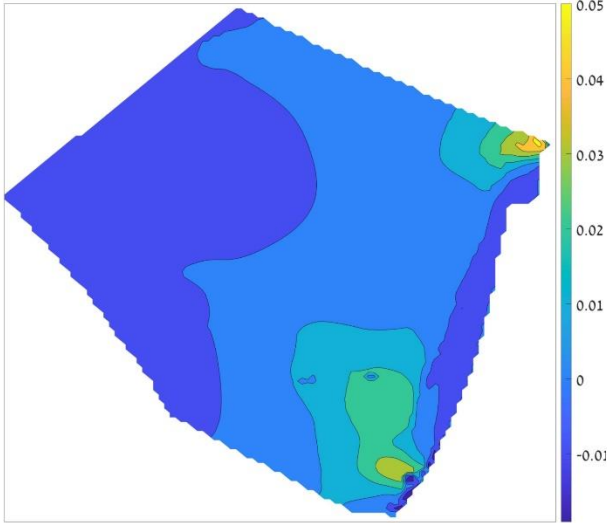


Appendix 6 - Maps of the change in the distribution of the different groups in the scenario in which there is a closure of the nature reserves on the continental shelf and the closure of the areas located in the Marxen software and given climate change

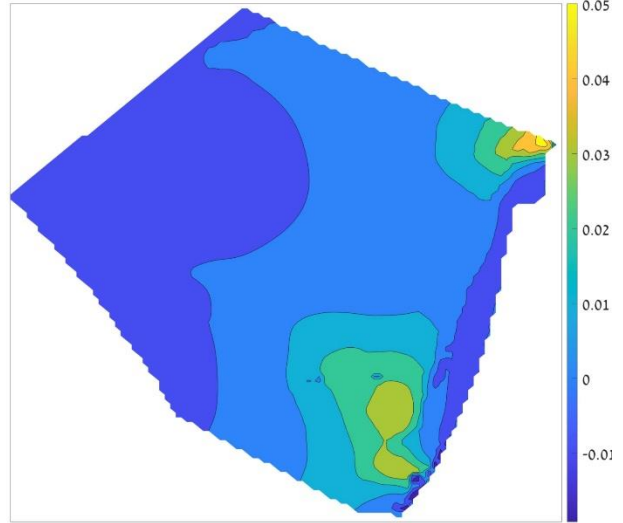




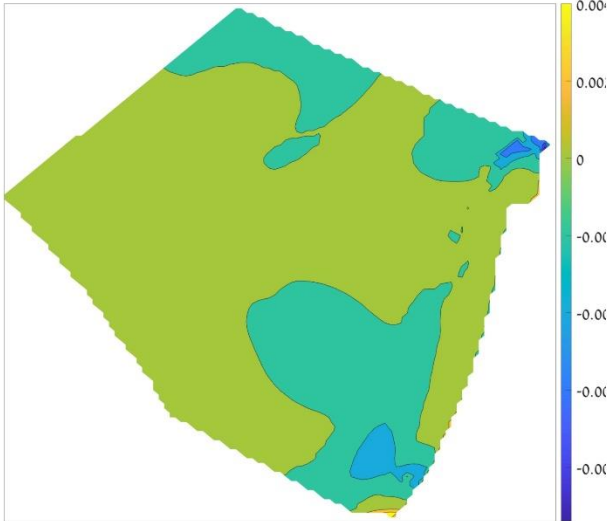
**Scenario 2 MPA + Marxan, Fish**  
2016-2020 vs Base



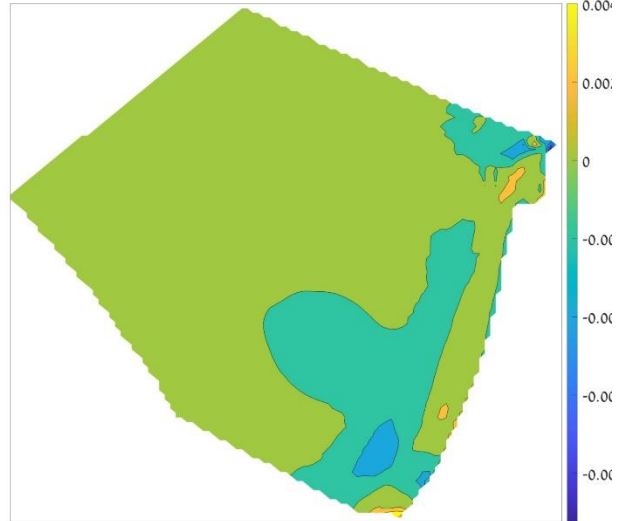
**Scenario 2 MPA + Marxan, Fish**  
2095-2099 vs Base



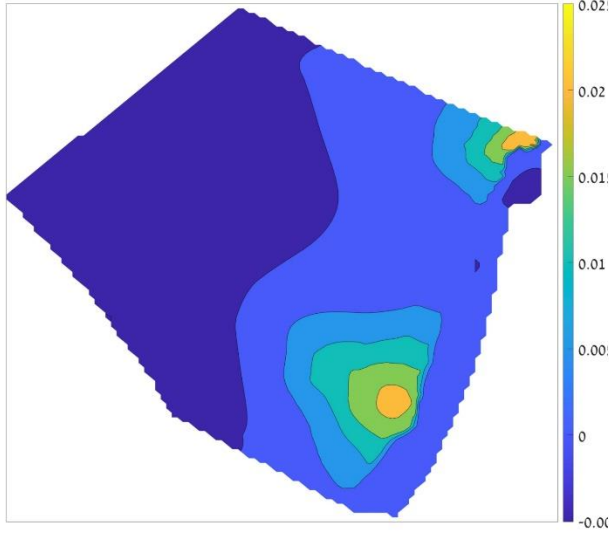
**Scenario 2 MPA + Marxan, Invertebrates**  
2016-2020 vs Base



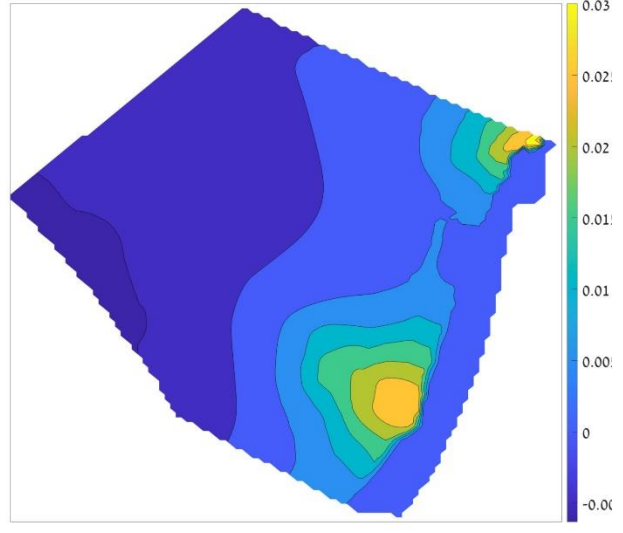
**Scenario 2 MPA + Marxan, Invertebrates**  
2095-2099 vs Base



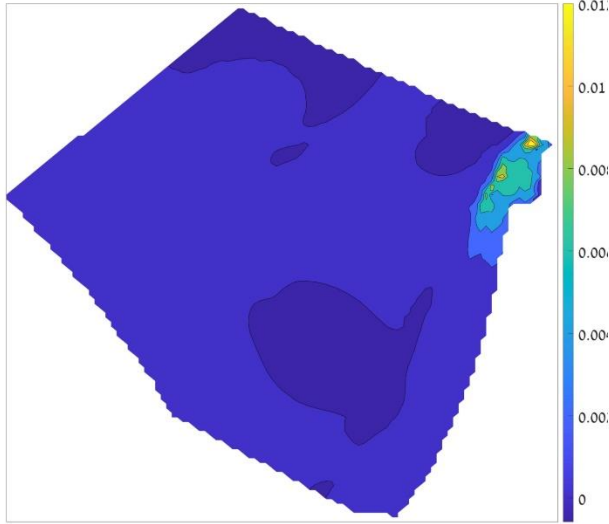
Scenario 2 MPA + Marxan, Deep sea fish  
2016-2020 vs Base



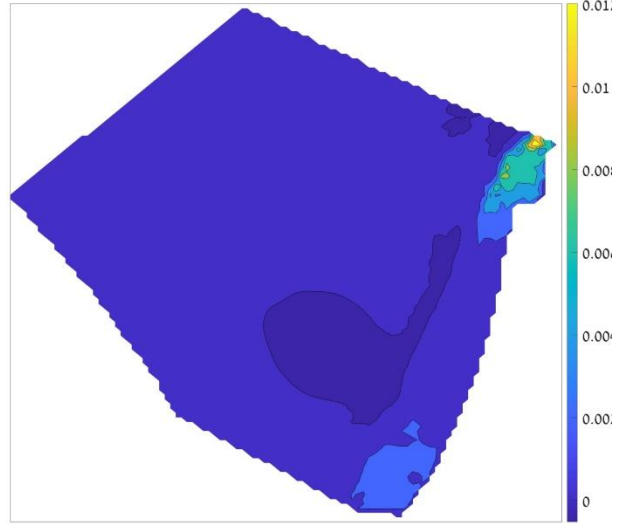
Scenario 2 MPA + Marxan, Deep sea fish  
2095-2099 vs Base



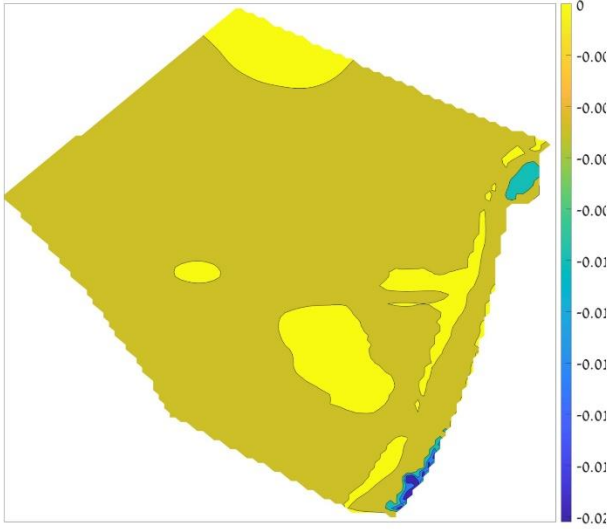
Scenario 2 MPA + Marxan, Deep Sea Invertebrates  
2016-2020 vs Base



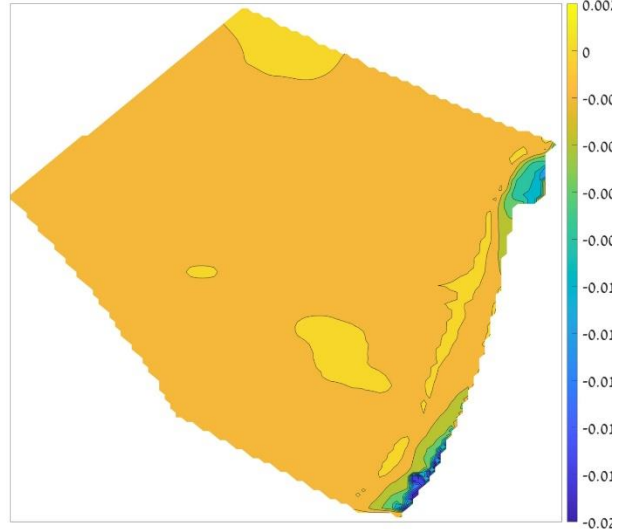
Scenario 2 MPA + Marxan, Deep Sea Invertebrates  
2095-2099 vs Base



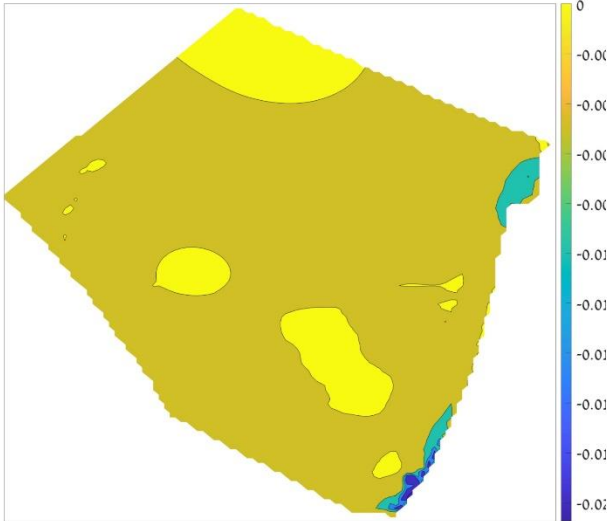
**Scenario 2 MPA + Marxan, Alien**  
2016-2020 vs Base



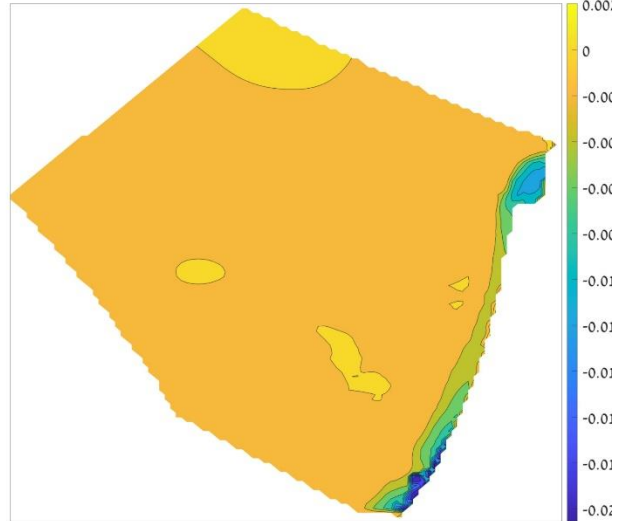
**Scenario 2 MPA + Marxan, Alien**  
2095-2099 vs Base



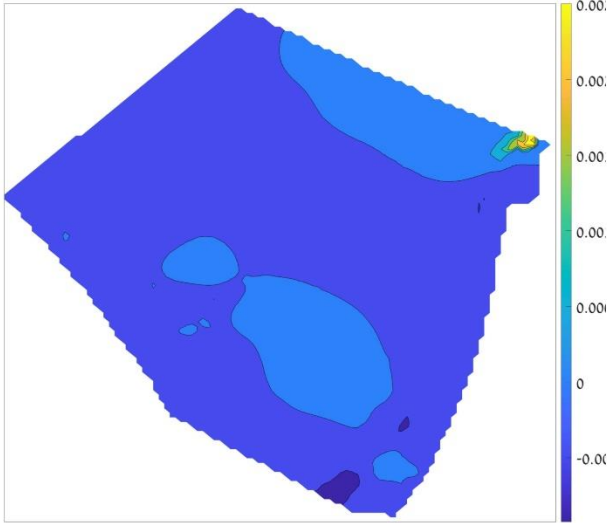
**Scenario 2 MPA + Marxan, Alien fish**  
2016-2020 vs Base



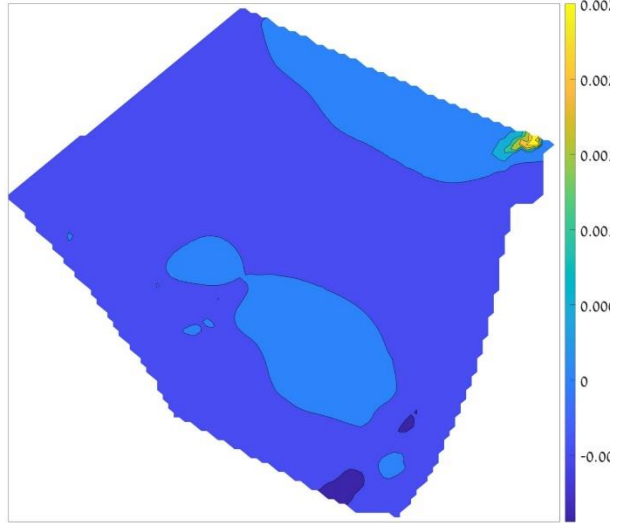
**Scenario 2 MPA + Marxan, Alien fish**  
2095-2099 vs Base



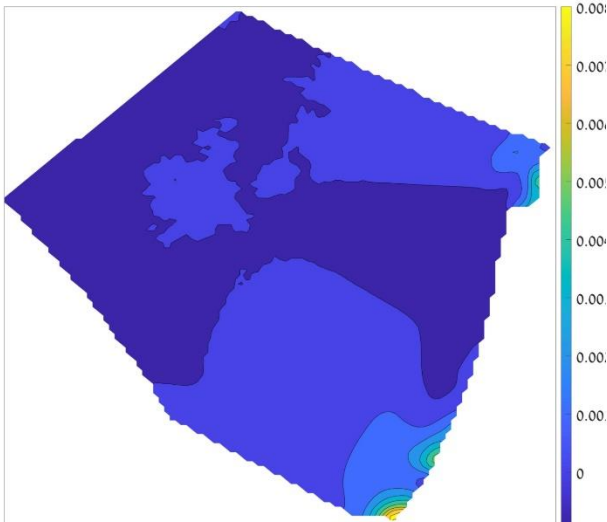
**Scenario 2 MPA + Marxan, Slope Fishes**  
2016-2020 vs Base



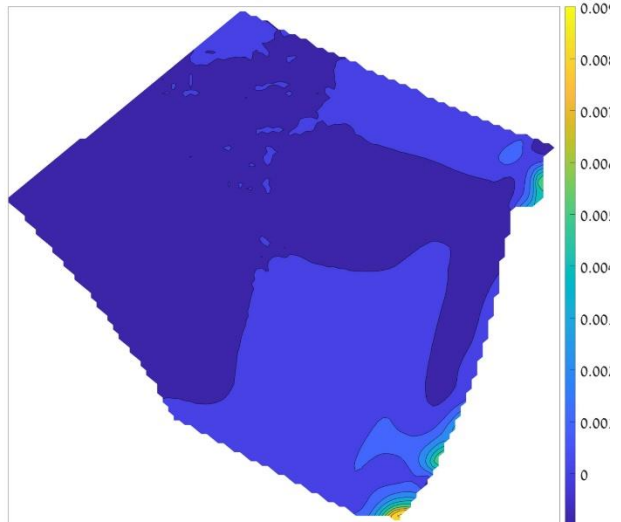
**Scenario 2 MPA + Marxan, Slope Fishes**  
2095-2099 vs Base



**Scenario 2 MPA + Marxan, ZooPlankton**  
2016-2020 vs Base



**Scenario 2 MPA + Marxan, ZooPlankton**  
2095-2099 vs Base



## **Final Report:**

### **Preliminary assessment of connectivity between sensitive benthic habitats in Israel's Exclusive Economic Zone (EEZ) using biophysical models.**

Igal Berenshtein

*University of Haifa, Leon H Charney School of Marine Sciences, Haifa, Israel*

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Lead Principal Investigator: Igal Berenshtein

Award Period (month/year): From 01/2023 To 2/2023

#### **General abstract**

The overall goal of this project was to quantify the connectivity between sensitive benthic habitats in Israel's Exclusive Economic Zone (EEZ) using biophysical models. These habitats include Cold seeps, Coral gardens, and Soft bottom sponge ground. Based on these habitats, five target/ indicator species were chosen to be simulated for larval dispersal: *Lamellibrachia anaximandri* (Annelida; cold seeps), *Rhizaxinella shikmonae* (Porifera; sponge grounds), *Isidella elongate* (Cnidaria; coral gardens), *Swiftia pallida* (Cnidaria; coral gardens), and *Thyasira flexuosa* (Mollusca; cold seeps). I used a previously developed modeling framework which includes high resolution 4-D modeled currents, and biological information about larval traits to run larval dispersal simulation for these species. I quantify the contribution of each habitat site in terms of larval connectivity, based on the number of virtual larvae supplied by, settled in-, and on the level of betweenness centrality (i.e., the degree by which a site serves as a gateway connecting between other sites). The results indicate that for the Cold seeps and Soft bottom sponge ground, proposed Marine Protected Areas largely cover the sites with the high connectivity contribution, whereas for the coral gardens, several highly contributing sites, yet of low probability of presence, are interfacing the proposed "Palmachim Disturbance" MPA. I therefore recommend to slightly expand this proposed MPA to include these sites. Based on this, I highlight the importance of some of these sites, and discuss the implications in terms of natural resource management and spatial conservation planning of the Israeli EEZ. In addition, I emphasize the uncertainties and limitations of my analysis, and provide recommendations for future research.

#### **Introduction**

The Mediterranean marine ecosystem provides critically important ecosystem services from environmental, economic, and social aspects (Liquete *et al.*, 2016). While much of the biomass and biodiversity is located within the coastal and continental shelf regions, the deep sea, which

covers vast areas, consists of unique habitats such as soft-bottom sponge grounds, coral gardens, and cold seeps, and hundreds of species of marine mammals, fish, invertebrates, and reptiles. Yet, this system is under-explored (Reimer *et al.*, 2019) and under high and increasing anthropogenic pressures including fishing (FAO, 2016), pollution (Dong *et al.*, 2022), invasive species (Galil and Zenetos, 2002) and climate change (Albano *et al.*, 2021).

Larval recruitment and connectivity are primary drivers governing marine population and stock dynamics (Hjort, 1914; Houde, 2008), and as such are increasingly being considered in the study and conservation of marine ecosystems, and in particular in the design of MPAs networks (Balbar and Metaxas, 2019). In deep waters (>200 m), larval connectivity had rarely been studied, and yet it is of particular importance due to the remoteness, rarity, sensitivity and isolation of some of the deep-sea habitats and habitants (Kenchington *et al.*, 2019).

## **Aim**

My aim in the current project was to perform a preliminary connectivity analysis for the eastern Mediterranean, focusing on the Israel's EEZ sensitive benthic habitats, and their main indicator species. I employed a bio-physical modeling approach, using the Connectivity Modeling System (Paris *et al.*, 2013), a state-of-the-art Lagrangian individual-based larval dispersal model, which can simulate trajectories of virtual larval fish based on resolved ocean currents, and taxon-specific larval traits (e.g., Cowen *et al.*, 2006; Paris *et al.*, 2007). Specifically, I simulated five focal Indicator species for vulnerable benthic marine ecosystems (IUCN, 2019), and examined their connectivity patterns, computing connectivity-related estimates, such as number of connections, and betweenness centrality. In addition, I performed a preliminary sensitivity analysis, covering realistic ranges of preferred depth in the water-column (or buoyancy) and Pelagic Larval Duration (PLD).

## **Methods**

The methodology is based on a three-pronged approach: (1) Physical oceanography, which includes a nested ocean model simulating four years of data (2017-2020), which was validated with in-situ observations. (2) Biological component, which included a literature review of the target species' larval traits, providing the best available data regarding these species (3) Bio-physical simulations which combines the biological and the physical components producing 3D larval trajectories. These trajectories were then used to analyze the connectivity patterns of the proposed MPAs.

The physical component includes a nested model, with Copernicus Marine Environment Monitoring Service (CMEMS) as the outer model and South Eastern Levantine Israeli Prediction System (SELIPS) as the inner model. The CMEMS currents are based on hydrodynamic model currents output implemented over the Mediterranean Basin with a horizontal grid resolution of  $1/24^\circ$  (~ 4 km) and have 141 vertical levels. The hydrodynamics are supplied by the Nucleus for European Modelling of the Ocean (NEMO; Clementi *et al.*, 2016). The model includes data assimilation schemes of temperature and salinity vertical profiles, as well as those of satellite Sea Level Anomaly observations.

SELIPS is a sub-regional high resolution circulation model operated by Israel Oceanographic and Limnological Research (IOLR) that generates daily forecasts of temperature, salinity, and sea currents in the southeastern region of the Levantine basin. The oceanic general model used to run SELIPS is the Princeton Ocean Model (POM) (Blumberg and Mellor, 1987). The resolution is  $0.01^\circ \times 0.00833^\circ$  (about 1 km) with 27 sigma levels, and the minimal depth is 5 meters. Initial and boundary conditions of temperature, salinity, and water velocity are taken

from ALERMO forecast system (Zafirakou-Koulouris *et al.*, 2012). The validation of SELIPS model was carried out against in-situ measurements of temperature, salinity, and currents direction and velocity from Ashkelon, Hadera, and DEEPLV mooring.

Considering the spatial and temporal scales of SELIPS, the model captures oceanographic meso-scale and sub-mesoscale features such as eddies but does not capture smaller features that occur at shorter distances and durations such as Langmuir cells.

The modeled species included *Lamellibrachia anaximandri* (Annelida; cold seeps), *Rhizaxinella shikmonae* (Porifera; sponge grounds), *Isidella elongate* (Cnidaria; coral gardens), *Swiftia pallida* (Cnidaria; coral gardens), and *Thyasira flexuosa* (Mollusca; cold seeps). The choice of these species is based on their abundance and central ecological role in these sensitive habitats (Shabtay *et al.*, 2022). The abundance of these species was modeled in a 2X2 km grid cells using species distribution model in a previous study (Shabtay *et al.*, 2022). Their traits based on the closest species with available information, mainly Pelagic Larval Duration (PLD), is listed in Table 1. Much of this information is based on the data provided in (Hilário *et al.*, 2015).

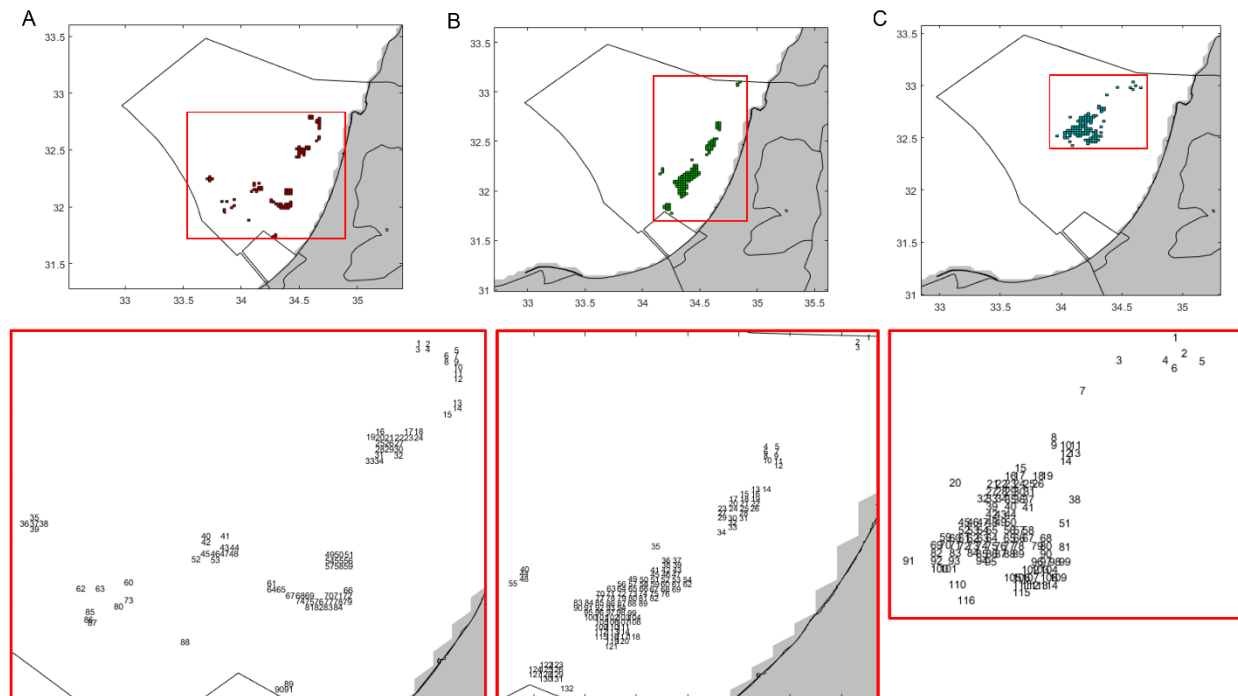


Figure 1. Cold seeps (A), Coral gardens (B), and Sponge Grounds (C) habitats and their polygons. Habitats were modeled in a 2X2 km grid. Polygon numbers are ordered from north to south and are given in the bottom panels.

The validated 4D current fields from the physical component, together with the biological traits are implemented using the CMS. The CMS is a biophysical modeling framework based on a Lagrangian stochastic modeling, developed to study larval dispersal and connectivity. The CMS use outputs from a wide range of hydrodynamic models, including ROMS, and computes the 3D trajectories of virtual larvae through time and space, given a specified set of release locations, and biological and physical traits. The CMS has been extensively used to provide important management insights on invertebrates and fish larval connectivity (e.g., Kough *et al.*, 2013). According to the model, successful settlers are larvae that reach settlement habitat within

their competence window, i.e. larvae that have metamorphosed and are ready for settlement. The use of four years of data (2017-2020) captures the inter-annual variability currents and hence of dispersal trajectories.

To quantify the contribution of the different polygons to connectivity, I computed the three key types of relevant measures: (1) the number of successfully settled larvae supplied by each polygon (i.e., larval source), (2) The number of larvae settled in each polygon (i.e., larval sink), and (3) the betweenness centrality, which measures the proportion of shortest paths between polygons that pass through a given polygon. This represents the degree by which MPAs act as gateways, or stepping stones for dispersal (Andrello *et al.*, 2013). Next, I ranked each of these three estimates, and computed the mean of the ranks as a general measure for connectivity contribution at the polygon's level.

Table 1. Laval traits for the biophysical model. Traits were determined based on the closest taxonomical group for which literature information was available.

Species	Family	Habitat	PLD (d)	Reference
<i>Lamellibrachia anaximandri</i>	Siboglinidae	Cold_Seeps	21 ( <i>Lamellibrachia luymesii</i> ) 45 ( <i>Lamellibrachia satsuma</i> )	(Young <i>et al.</i> , 1996; Miyake <i>et al.</i> , 2006; Southward <i>et al.</i> , 2011)
<i>Thyasira flexuosa</i>	Thyasiridae	Cold_Seeps	1	(De-Bastos, 2016)
<i>Rhizaxinella shikmonae</i>	Suberitidae	Sponge_Grounds	1-4	(Shanks, 2009)
<i>Isidella elongata</i>	Keratoisididae	Coral_Gardens	30.5, 45.5 3, 36.5	(Sun <i>et al.</i> , 2010, 2011; Southward <i>et al.</i> , 2011)
<i>Swiftia pallida</i>	Plexauridae	Coral_Gardens	30.5, 45.5 3, 36.5	(Sun <i>et al.</i> , 2010, 2011; Southward <i>et al.</i> , 2011)

Table 2. Scenarios of CMS biophysical runs for computing general connectivity patterns based on the nested model of CMEMS and SELIP for four years: 2017-2020.

Scenario #	species	Habitat	Depth (m)	PLD (d) Competence period	Number of Virtual larvae released
1	<i>Lamellibrachia anaximandri</i>	Cold_Seeps	5	21-45	11648
2	<i>Lamellibrachia anaximandri</i>	Cold_Seeps	900	21-45	11648
3	<i>Thyasira flexuosa</i>	Cold_Seeps	5	1-2	11648
4	<i>Thyasira flexuosa</i>	Cold_Seeps	900	1-2	11648
5	<i>Rhizaxinella shikmonae</i>	Sponge_Grounds	5	1-4	14848
6	<i>Rhizaxinella shikmonae</i>	Sponge_Grounds	900	1-4	14848
7	<i>Isidella elongate</i> <i>Swiftia pallida</i>	Coral_Gardens	5	1-3	16896
8	<i>Isidella elongate</i> <i>Swiftia pallida</i>	Coral_Gardens	900	1-3	16896
9	<i>Isidella elongate</i> <i>Swiftia pallida</i>	Coral_Gardens	5	22-45	16896



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10	<i>Isidella elongate</i> <i>Swiftia pallida</i>	Coral_Gardens	900	22-45	16896
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## Results

The results indicate generally high level of connectivity between habitat polygons. Longer PLDs and shallower depths result in higher levels of connectivity between remote polygons (Fig. 2). In contrast, at deeper waters, and under shorter PLDs, the dominant feature is self-recruitment, or recruitment to adjacent polygons. For example, in *Thyasira flexuosa* deep sea connectivity patterns, which is nearly completely dominated by self-recruitment. The same conditions for shallow depths (5 m) result in much higher levels of connectivity (Fig. 2C,D, Fig. 2C,D). Similarly, scenarios which involve deep and short PLDs show minimal connections between non-adjacent cells (Fig. 2D, 2F, 2H and 3D, 3F, 3H).

The polygons within each habitat type demonstrated high connectivity due to the relative proximity of the polygons except for the northern-most patch of polygons in the Coral Gardens habitat (e.g., Figs 2J, 3J).

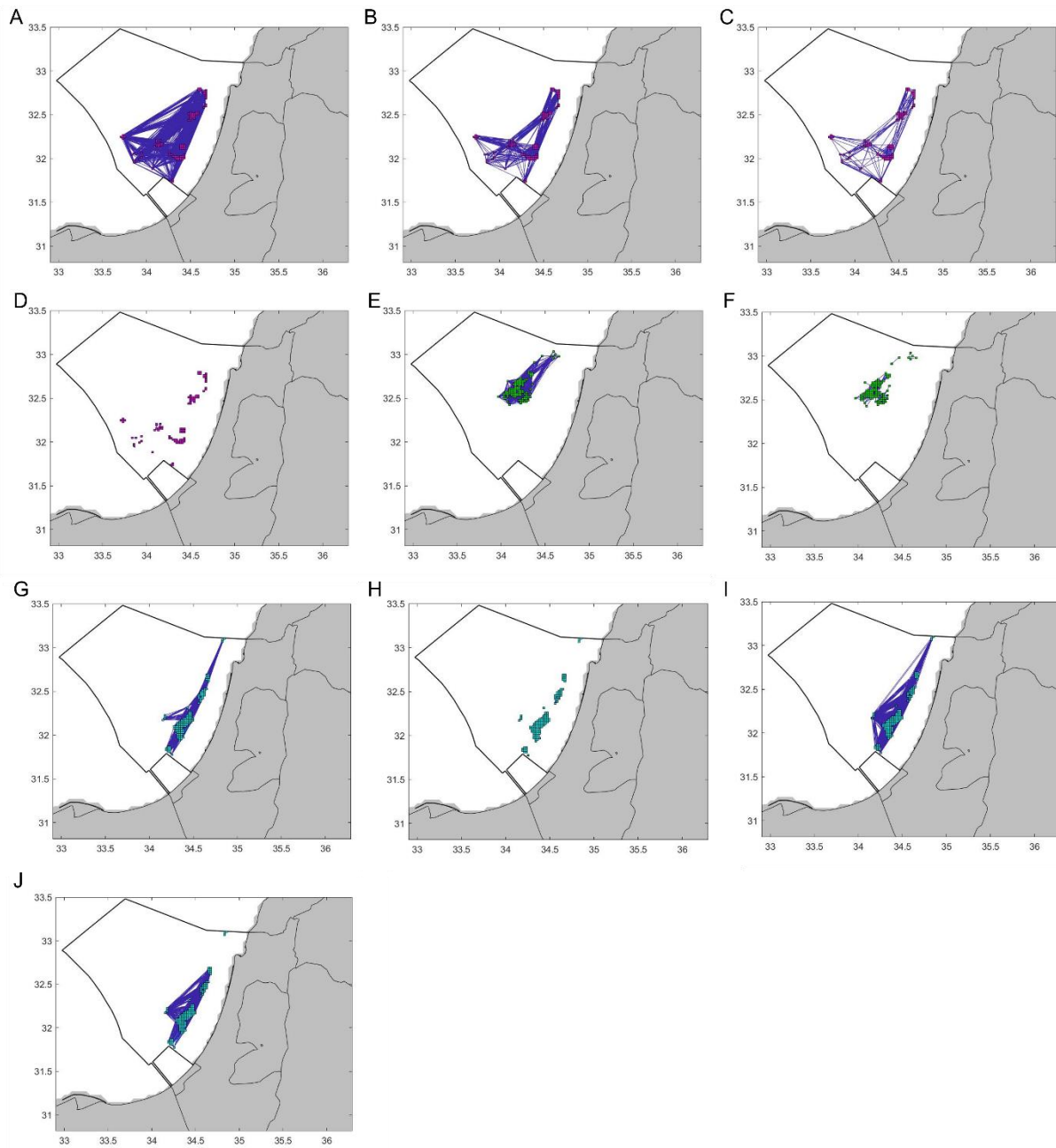


Figure 2. Connectivity maps for the 10 scenarios provided in Table 2, scenarios 1-10 correspond to panels (A)-(J).

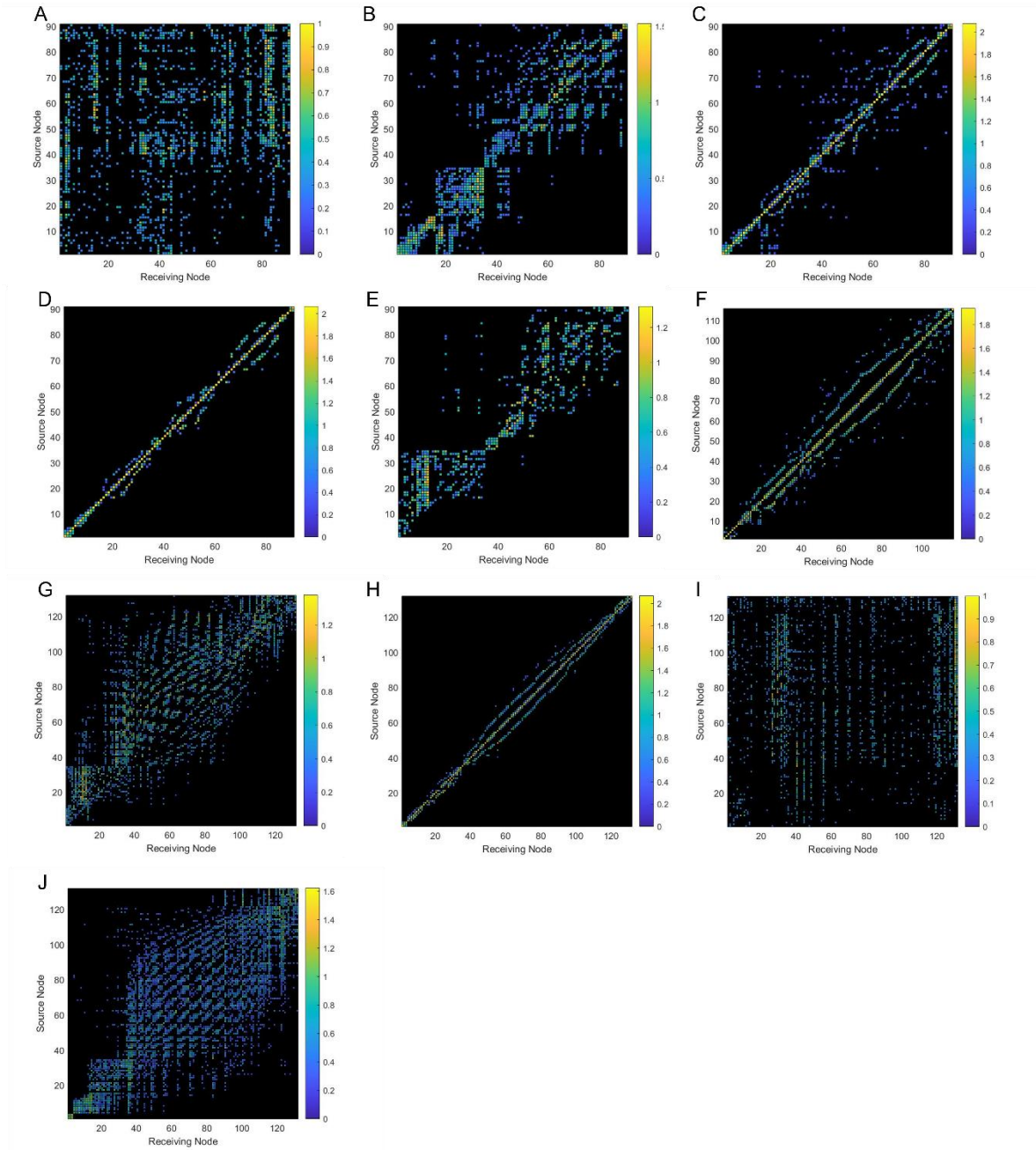


Figure 3. Connectivity matrices for the 10 scenarios provided in Table 2, scenarios 1-10 correspond to panels (A)-(J). Numbers in the left panels' connectivity matrices represent habitat polygons, counted from north to south (see Fig. 1 for more details). Colorbars represent  $\log_{10}$  transformation to larval numbers.

Highly contributing polygons in terms of connectivity for the Cold Seeps habitat are polygons #75-76, which are included in the declared MPA of “Palmachim Disturbance” (Fig. 4). The few polygons that are excluded from the proposed MPAs (#89-91), do not seem to exhibit high contribution for connectivity (Fig. 4). Similarly, highly contributing polygons in terms of connectivity for the Sponge Grounds habitat are polygons #41-42, which are included in the proposed “Sea Heart” MPA (Fig. 5). The few polygons that are excluded from the proposed

MPAs (#3,7), do not seem to exhibit high contribution for connectivity (Fig. 5). Importantly, highly contributing polygons in terms of connectivity for the Coral Gardens habitat are polygons #119,121 which are adjacent to, or at the south border of the “Palmachim Disturbance” declared MPA (Fig. 6). The southernmost patch of polygons that are excluded from the proposed MPAs do not seem to have a high relative contribution to connectivity. In addition, polygons #123-132, which demonstrate moderate contribution to connectivity, are excluded from the proposed MPAs.

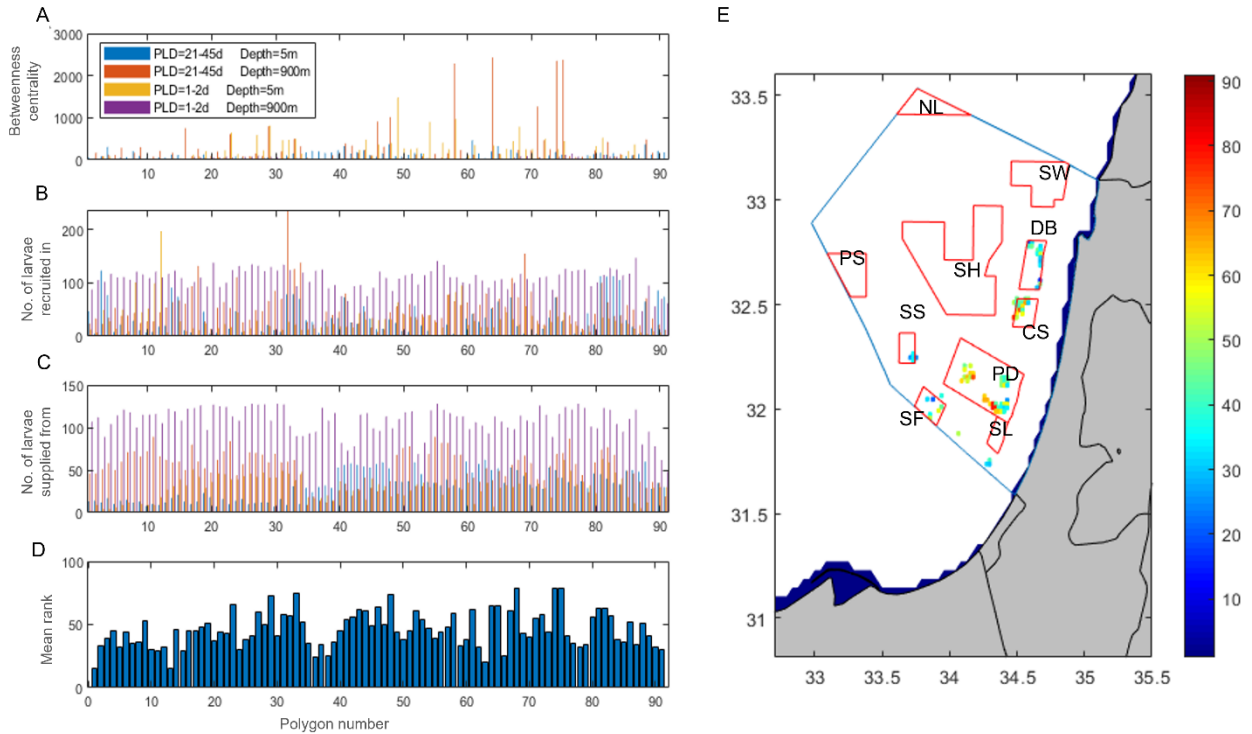


Figure 4. Contribution of the different Cold Seeps habitat polygons to various aspects of connectivity. Colorbar represents the ranked degree of contribution. The proposed MPAs are red polygons in (E): North Levant Canal (NL), Sediment Waves (SW), Dor landslide Base (DB), Central Slope (CS), Sea Heart (SH), Pteropods Skeletons (PS), South Seeps (SS), Palmachim Disturbance (PD), South Landslide (SL).

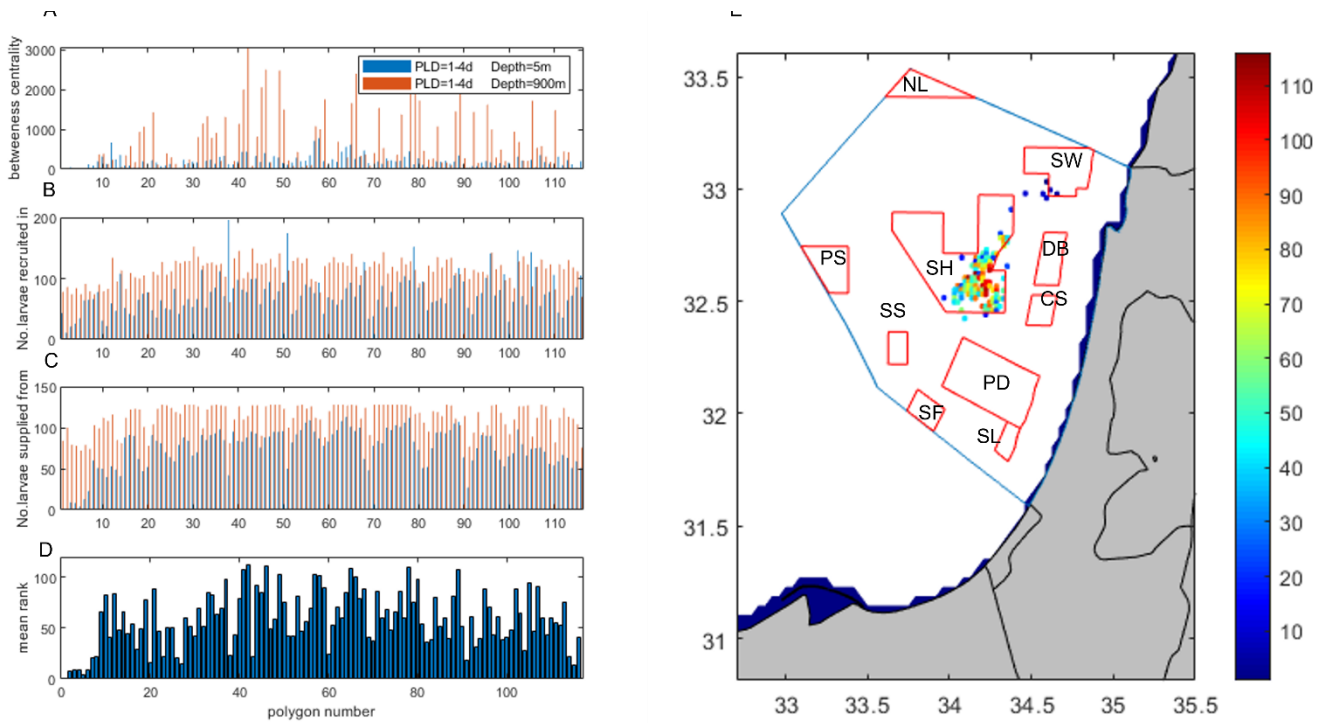


Figure 5. Contribution of the different Sponge Grounds habitat polygons to various aspects of connectivity. Colorbar represents the ranked degree of contribution. The proposed MPAs are represented as red polygons in (E): North Levant Canal (NL), Sediment Waves (SW), Dor landslide Base (DB), Central Slope (CS), Sea Heart (SH), Pteropods Skeletons (PS), South Seeps (SS), Palmachim Disturbance (PD), South Landslide (SL).

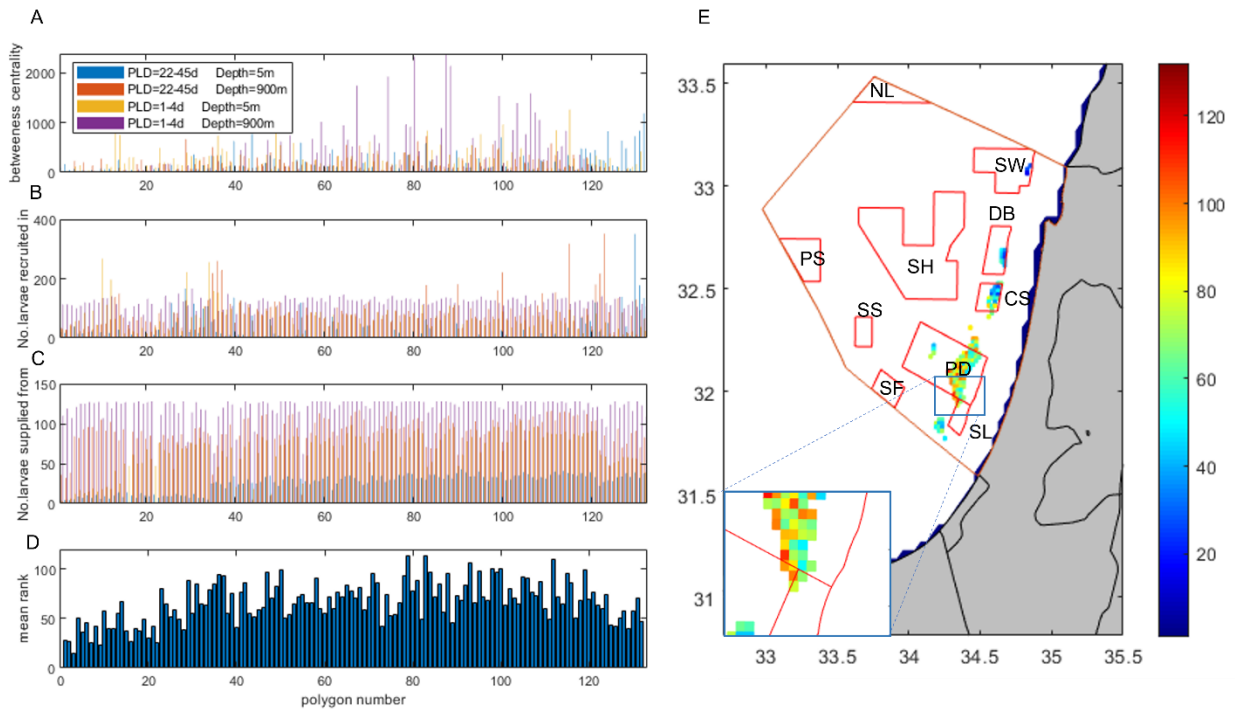


Figure 6. Contribution of the different Coral Gardens habitat polygons to various aspects of connectivity. Colorbar represents the ranked degree of contribution. The proposed MPAs are represented as red polygons in (E): North Levant Canal (NL), Sediment Waves (SW), Dor landslide Base (DB), Central Slope (CS), Sea Heart (SH), Pteropods Skeletons (PS), South Seeps (SS), Palmachim Disturbance (PD), South Landslide (SL).

## Discussion

I presented a preliminary analysis examining the connectivity patterns within three key habitats in the deep-sea benthos of the Israeli EEZ, based on a high-resolution nested ocean model and best available biological information. The general dynamics of connectivity follow expected patterns that have been shown in other systems as well (e.g., Kenchington *et al.*, 2019), such that high PLD and shallow waters support open populations by increasing the dispersal distance of larvae and connecting between sites that are far from each other. In contrast, low PLDs and deep waters support close populations, in which self-recruitment is much more dominant (Figs 2,3). The proposed MPAs seem to capture the polygons with the higher level of connectivity contribution, with the exception of the Coral Gardens that may exclude two highly contributing polygons south of the “Palmachim Disturbance” MPA (Fig. 6). In addition, polygons of coral gardens located south of the “South Landslide” are excluded from the proposed MPAs. These polygons were marked based on species distribution model that predicted their presence there in relatively

low probability. Therefore, these polygons were not highly prioritized for protection. However, including these polygons in MPA should be considered, because they demonstrate moderate contribution to connectivity. This general area (south of the “South Landslide”) seem to include also cold seeps habitat. The evidence for the existence of sensitive deep sea benthic habitats near the Nile delta (Chimienti *et al.*, 2019) may further increase the importance of these polygons for regional connectivity.

It is evident that despite the general northern current in the Israeli Mediterranean, the connectivity matrices are only slightly a-symmetrical, with a milder increase in contribution from south-to-north compared with from north-to-south. This is because of the high frequency and dominance of eddies in this region, which allow a substantial north-to-south movement in addition to the prevailing south-to-north.

The modeling framework used for this report includes multiple sources of uncertainty that are important to mention. First and foremost, there is a global lack of knowledge with respect to the larval vertical dynamics of the focal species and other deep-sea species. This is critical because even slight ontogenetic changes in depth can dramatically influence the dispersal outcome and hence the connectivity patterns. Other biological parameters such as PLDs, are chosen based on the best available information, in some cases for other species, taxonomically close species, in distant locations, such that it may not represent actual local dynamics. Similarly, there is no information about the spawning season of these species, a trait that can substantially influence dispersal outcome. The habitat locations were determined based on Species Distribution Modeling, which also encompasses uncertainties, and may not fully represent the actual locations of these habitats. In addition, the modeled deep-sea current does not necessarily capture the true deep-sea currents, and validation was done only for shallow waters. Previous studies suggested that the dispersal of deep sea corals, for example, is driven by near-bottom cold currents; this too should be considered and preferably tested in the field, characterizing both the current regime, as well as the propagules present in it (IUCN, 2019). Stochastic components such as turbulence encompass additional uncertainty, and the parametrization of iso-trophic Eddie diffusivity in our model (and in most other dispersal models) is over-simplistic, and does not necessarily represent actual circulation dynamics.

## **Conclusions**

First and foremost, the initiative for protecting sensitive and ecologically important deep-sea habitats and their inhabitants is critically important and urgent, given global and local trends in offshore and deep-sea development and anthropogenic threats to our marine ecosystem. It is important to stress the uncertainty in this preliminary analysis, especially with respect to the ontogenetic vertical positioning of the focal larvae. An extensive planktonic sampling using plankton nets and/or e-DNA will substantially improve the accuracy of our estimates and reduce uncertainties.

In addition, genetic connectivity studies of the focal populations will provide complementary information for this analysis, and will shed light on the long-term connectivity patterns in the region. This can also serve as a type of validation of the results provided here. There is limited information about similar habitats outside of the Israeli EEZ because deep-sea sampling campaigns are very rare. However, it is very likely that such habitats exist in the eastern Mediterranean, such that other populations are connected with our focal populations. An effort to discover and survey the locations of such habitats will greatly contribute to the comprehensiveness of the results provided here.

Lastly, my results should be considered in light of local anthropogenic threats, in particular those of the petroleum industry. Oil pollution can be trapped in the water-column in deep waters and persist for extended periods and across large spatial extents (Deepwater Horizon Natural Resource Damage Assessment Trustees *et al.*, 2017). In addition, particulate oil can coalesce with dead plankton and minerals and sink to the bottom, harming sessile marine organisms such as our focal species, and remaining toxic for decades (Deepwater Horizon Natural Resource Damage Assessment Trustees *et al.*, 2017). Naturally, responding to oil spills at such depths is complicated, and mitigation efforts can last for extended periods, sometimes without any ability to actually stop the pollution (Fears, 2018).

In terms of planning, it may be worthwhile to slightly extend the “Palmachim disturbance” MPA to include the southern polygons which exhibit high connectivity contribution.

The effort to conserve and protect our deep-sea marine ecosystem is critically important and aligns with the increasing global understanding of the importance and contribution of our marine environment, and the global trend in the attempt to protect this important environment (Heymans *et al.*, 2020). This is also expressed in the the United Nations (UN) Sustainable Development Goals (SDGs), and the UN recommendation of increasing the coverage of marine protected areas to 30% by 2030.

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