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Food web analysis at the regional and basin scale

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CONTENTS

1. EXECUTIVE SUMMARY

The hindcast with past data and simulation of fisheries and climatic scenarios with coupled Low Trophic Level (LTL) and High Trophic Level (HTL) models are described. The deliverable has been structured around the results obtained by applying the approach described in Libralato and Solidoro (2009) for coupling LTL and HTL model. According to this approach, as explained in an introductory section, Ecopath with Ecosim models are extended to describe LTL processes and then adapted to LTL dynamics, finally the coupled models are then run for calibration (hindcast period 2000-2010) and scenario analysis (2011-2020). Several scenarios are implemented with E2E models regards climatic induced changes and fisheries and results are analysed in terms of a set of health indicators.

Climatic scenarios are implemented by using nutrient river discharge scenarios and data from PERSEUS Deliverable 4.6, i.e., scenarios BAU, BA, MFA, REB, RBE in the LTL module and then running the E2E model. Fisheries scenarios are applied on BAU climate scenario and included 10% increase and decrease of effort by gear (all, demersal trawlers) and of fishing mortality for some key groups (small pelagics and large pelagics).

Results are analysed using a set of 10 indicators measuring ecosystem health (sensu Costanza and Mageau 1999) in terms of vigor, organization and resilience. In order to quantify the effects of fishing, two indicators measuring the effects of fishing were also analysed. Changes in the indicators are evaluated between reference (hindcast 2000-2010) and BAU scenario and changes between future results for BAU (2011-2020) and all other climate and fisheries scenarios.

End to End (E2E) models used were developed for Adriatic Sea, Gulf of Lion, Aegean Sea, West Black Sea, East Black Sea, Black Sea. A section of this deliverable report the detailed work done in each of these areas of investigation, including standardization, coupling, calibration, first indicators, scenario analysis and results in terms of ecosystem indicators.

A final section collate togher all results and analyse them in a coparative way highlighting what has been achieved and the critical points.

SCOPE

The deliverable refers to the specific objectives of 1) developing tools that permits computation of synthetic indices and 2) in particular, tools able to quantify attributes relevant to MSFD. The deliverable by developing, applying and performing scenario analysis for Mediterranean and Black Sea under both fisheries and nutrient discharge changes also by applying indicators on results. Therefore the deliverable contributes to the general objective of i) understand and predict cumulative impacts of natural and anthropogenic pressures (e.g., climate change, fishing, pollution) on marine ecosystems and the sustainability of services they provide, and ii) develop integrated and operational tools for analysing scenarios and suggesting mitigation policies.

FOOD WEB ANALYSIS AT THE REGIONAL AND BASIN SCALE

"Insert here the description of the activities"

The activities included the development and stardandization of integrated tools to provide dynamic assessment of ecosystem health under climatic and fishing scenarios.

Integrated End-to-End models are done by linking hydrodynamic, biogeochemical and food web models for some key seas of the Mediterranean Sea, such as Gulf of Lions, Adriatic Sea and Aegean Sea and for two areas of the Black Sea. The models used are developed with Ecopath with Ecosim software.

Models are calibrated and scenario analyses are performed also using a set of indicators estimated on results from calibrated end-to-end models.

Results are analysed in terms of metrics used as indicators that are considered to characterize the health of the ecosystem: **vigor**, **organization** and **resilience** .

These indicators are used alone or in combination to characterize the "health" of the marine ecosystems. Thus providing a regional and global overview of the state of the Mediterranean Sea and the Black Sea, in the past and in some possible future conditions.

2. End-to-End modeling of the Mediterranean Sea and Black Sea

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2.1 Rationale

The European Marine Strategy Framework Directive (MSFD) (EU, June 2008) requires that by 2020 a good environmental status (GES) will be reached in all of the European seas, by using indicators for 11 qualitative descriptors. Although there is consensus on the need for defining references and GES, the definition of indicators and their comprehensive integration for a complete assessment of marine ecosystem status is not easy.

One of the problems is related to the complexity of natural and anthropogenic impacts and interactions that occur in marine systems, thus there is the need to integrate different processes in tools able to represent processes by confronting past dynamics (hindcast) and estimate future changes under simulated considitions (scenarios) also by using indicators (Cury et al., 2005; Link et al., 2010). End-to-End models are used for integrating hydrodynamic/biogeochemical features of marine systems, i.e. low trophic level processes (LTL in the following), with dynamics of invertebrates, fish and their fisheries, i.e. high trophic level (HTL) (Rose et al., 2010). Ecosystem modelling integrates available information to study direct and indirect trophic interactions among ecosystem compartments, including fishing activities and the environment (Plagányi, É., 2007). It is therefore a useful tool for fisheries management (Christensen and Walters 2004). Moreover, integrated tools provide dynamic assessment of ecosystem health under climatic and fishing scenarios using a set of indicators estimated on results from calibrated end-to-end models.

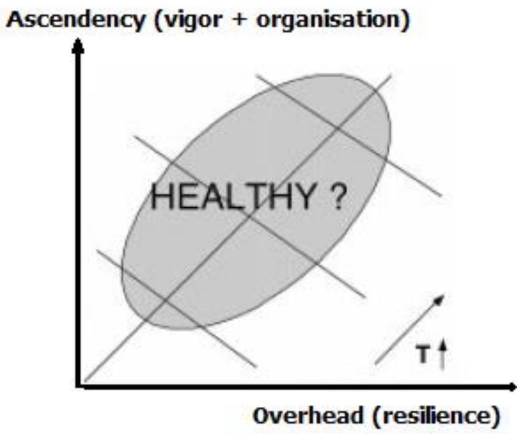

Figure 1. A conceptual diagram of the network analysis-based on quantitative indexes of ecosystem health. The 'healthy' region is indicated by the shaded area, and represents a balance between system vigor, organization, and resilience. Modified from Costanza and Mageau (1999).

Costanza and Mageau (1999) proposed to use some outputs from models to characterize the status of marine ecosystems. In particular, indicators such as **vigor** (i.e. total system throughput and calculated total net primary production), **organization** (i.e. ascendency and capacity) and **resilience** (i.e. overhead) can be used alone or in combination to characterize the "health" of the marine ecosystem (Fig.1).

2.2 Approach adopted

The analysis is made by linking hydrodynamic, biogeochemical and food web models for some key seas of the Mediterranean Sea, such as Gulf of Lions, Adriatic Sea and Aegean Sea and for two areas of the Black Sea. The models used are developed with Ecopath with Ecosim software (Christensen et al., 2005), while the approach for integration is that reported by Libralato and Solidoro (2009).
Model results are used to assess the status of marine ecosystem in terms of ecosystem health components: vigor, organization and resilience (Costanza and Mageau, 1999). Existing Ecopath with Ecosim models were firstly updated and standardized to a common structure (34 and 29 functional groups for the Mediterranean and Black Sea models, respectively). Then these HTL models were coupled to the hydrodynamic-biogeochemical ones following the procedure based on i) extension of HTL model to cover main variables of LTL one, ii) adjustment of extended End-to-End model to represent at best LTL variables (Libralato and Solidoro 2009). For the Mediterranean we used the OPATM-BFM (Lazzari et al., 2012) forced with physical outputs produced by the CMCC-MFS16CM Ocean General Circulation model. The simulation carried out spans the period 2000-2020 with a spin-up phase of 5 years. For the Black Sea a calibrate LTL model was used (Capet et al., 2013).

2.2.1 Ecopath with Ecosim

Ecopath with Ecosim (EwE) software for ecosystem modeling was used in different areas of the Mediterranean Sea to provide quantitative descriptions of the structure of marine food webs and to assess fishing impacts on exploited marine ecosystems.

The broad use of the trophic modelling tool "Ecopath with Ecosim (EwE)" (Christensen and Walters 2004) has contributed to complement previous knowledge of the structure and functioning of marine ecosystems and has enabled the proposal of ecological indicators and reference limits based on model outputs and meta-analysis of models' results (e.g., Christensen, 1995; Libralato et al., 2008; Coll and Libralato, 2013; Heymans et al., 2014; Lynam and Mackinson, 2015).

Ecopath with Ecosim (EwE) is a software package developed for analysing energy flows in marine food webs under the assumption of mass-balance. Some of the Ecological Network Analysis algorithms in NETWRK (Ulanowicz, 1999; Heymans and Baird, 2000) was reprogrammed into Ecopath 2 (Christensen and Pauly, 1992) and have been updated in the Ecopath with Ecosim version 6 (www.ecopath.org). Ecopath with Ecosim (EwE) is a quantitative tool used to analyse aquatic ecosystems. EwE combines software for ecosystem trophic mass balance analysis (Ecopath) with a dynamic modelling capability (Ecosim), and also includes a space-time dynamic routine (Ecospace) which can be used to explore past and future impacts of fishing activities on marine ecosystems (Christensen et al., 2005).

The modelled ecosystem is represented by functional groups (i), which can be composed of single species, groups of species with ecological similarities, or part of a population (i.e., ontogenetic fractions, like juveniles or adults, of a species). Ecopath uses two master equations to describe balance of flows (as nutrients, carbon, mass or energy) in the ecosystem: one equation describes the predator-prey interactions in the modelled food web and the secondone describes the balance at the level of each individual trophic group (Christensen et al., 2005). The first equation estimates the production of each trophic group considered in the model as:

$$P_i = Y_i + B_i \cdot M2_i + E_i + BA_i + P_i \cdot (1 - EE_i)$$ (Eq. 1)

where Pi is the total production of group i, Yi is the total fishery catch rate of i, M2i is the instantaneous predation rate for group i, Ei the net migration rate (emigration - immigration), BAi is the biomass accumulation rate for i, and Pi•(1-EEi) is the 'other mortality' rate for i (Christensen et al., 2005). Equation (1) can be re-written as:

$$B_i \cdot (P/B)_i \cdot EE_i - \sum_{j=1}^{n} B_j \cdot (Q/B)_j \cdot DC_{ji} - Y_i - E_i - BA_i = 0$$ (Eq. 2)

where P/Bi is the production/biomass ratio for i and under most conditions corresponds to the total mortality rate, Z, commonly estimated as part of fishery stock assessment. EEi is the ecotrophic efficiency of group i, describing the proportion of the production that is utilised in the system, Q/Bj is the consumption/biomass ratio of the predator j and DCji is the fraction of prey i in the average diet of predator j (Christensen et al., 2005).

The second equation assure that the balance within each group is respected by setting consumption by group i equals the production by i, plus respiration by i and unassimilated food by i. The units of the model are expressed in terms of nutrient or energy related currencies, and by a unit of surface. Frequently biomass is expressed in t•ww km-2 (ww = wet weight) and production and consumption are expressed in t•ww km-2•yr-1. Nevertheless, although yearly rates are dominating, energy, nutrient and carbon units can also be used. Ecosim is the dynamic expression of the ecosystem over time and is defined by a series of differential equations:

$$\frac{dB_i}{dt} = g_i \sum_j Q_{ji} - \sum_j Q_{ij} + I_i - (M_i + F_i + e_i) B_i \qquad \text{(Eq. 3)}$$

where dBi/dt is the growth rate during time t of group i in terms of its biomass Bi; gi is the net growth efficiency of group i; Mi is the non-predation ‘other’ mortality rate; Fi is the fishing mortality rate; ei is the emigration and Ii is immigration rate (Christensen et al., 2005). The ΣQji expresses the total consumption by group i and is calculated based on the foraging arena concept, where Bi’s are divided into vulnerable an invulnerable components (Walters et al., 1997). ΣQij indicates the predation by all predators of group i (Christensen et al., 2005). The transfer rate (vij) between the vulnerable and invulnerable components sets the top-down or bottom-up control of each interaction (Christensen et al., 2005). For each predator prey interaction the consumption rate Cij is calculated by:

$$C_{ij} = \frac{a_{ij} v_{ij} B_i P_j T_i T_j S_{ij} M_{ij} / D_j}{v_{ij} + v_{ij} T_i M_{ij} + a_{ij} M_{ij} P_j S_{ij} T_j / D_j} \qquad \text{(Eq. 4)}$$

where, aij is the effective search rate for predator i feeding on a prey j, vij is the base vulnerability expressing the rate with which prey move between being vulnerable and not-vulnerable, Bi is prey biomass, Pj is predator abundance, Ti represents prey relative feeding time, Tj predator relative feeding time, Sij user-defined seasonal or long term forcing effects, Mij mediation forcing effects, and Dj represents handing time as a limit to consumption rate (Walters et al., 2000; Christensen et al., 2005).

Ecopath with Ecosim requires three of the following four parameters for each trophic group considered in the model:

- Biomass (B, t•km-2) for the year under consideration;
- Production/Biomass ratio (P/B, year-1);
- Consumption/Biomass ratio (Q/B, year-1);
- Ecotrophic Efficiency (proportion). This parameter indicates the unexplained mortality for each group, it is difficult to estimate and usually is obtained as an output from the model. In addition, Ecopath with Ecosim requires also the specification of the diet composition for each trophic group (i.e. percent contribution in mass of the prey

group to the diet of the predator group), as well as the landings and discards (both are expressed in t•km-2•year-1) for each fishery included in the model and for each the trophic group that is fished . To run the dynamic simulations in Ecosim yearly estimates of biomass, fishing mortality, and catch by species and/or gear are required inputs.

2.2.2 Standardization of model structure

Different structures seem to better grasp ecological features typical of different areas, and allows to keep areas specificity and the optimal complexity based on local experts as the best representation of reality. Nevertheless, although it is always possible to compare models with different structure, previous works (Angelini & Agostinho, 2003) highlighted the influence of HTL model structure, i.e. number and composition of functional groups, on results and in particular on indicators. Actual models have different groups parametrized into multistanza functional groups, and given the peculiarity of this representation was accepted the suggestion to consider model structure without multistanza groups in the HTL-EwE models.

Given that PERSEUS WP4 needs to compare scenarios and models in terms of vigor, organization and resilience, there is a need for standardization of the models structure. In order to define a common structure, an overview of existing structures were considered, including: A) the structure of models for Adriatic, Catalan and Aegean somewhat similar (40 functional groups; e.g. Coll et al. 2006, 2007; Tsagarakis et al., 2010); B) the general structure used by Christensen et al., 2003; C) the simplified structure (16 Functional groups) used by Libralato et al. 2010; D) the least complex among structure for subsystems embedding each and every regional structure; E) the most complex among subregional structures common to all regional systems.

Overall, the structure needs to be ecologically sound for the Mediterranean but also "fishery oriented" and useful to produce results linked with the MSFD. For instance, benthopelagic fish group, usually a poorly defined group, will be included in the standard structure because of its importance for fisheries, especially in the Northern Aegean Sea. Moreover, macrozooplankton group (krill and other invertebrates > 2 mm) from the HTL model that would also be represented in the standardized models. Therefore, it was decided a standardized structure for the extended EwE model (E2E) including 28 living groups and 6 non-living groups as described in the following Table 1.

Aggregation of HTL groups from original models was done by taking their average of rates (P/B and Q/B), using biomass as a weighting factor. Similarly, aggregation of diet was done by considering both the consumption rate and biomass.

Table 1: Standardized food web structure for the Mediterranean Sea E2E models.

#	Group name	Description
1	Phytoplankton	mainly large diatoms
2	Picophytoplankton	
3	Bacteria	eterotrophic bacterioplankton
4	Nano-Microzooplankton	ciliates, fine filter feeders and metazoa
5	Mesozooplankton	carnivorous, mixed filter feeders and herbivorous
6	Macrozooplankton	
7	Gelatinous zooplankton	
8	Anellids	
9	Bivalves and gastropods	
10	Benthic cephalopods	
11	Benthopelagic cephalopods	
12	Small benthic crustaceans	
13	Decapods	
14	Other invertebrates	
15	Sardine	
16	Anchovy	
17	Other small pelagic fish	
18	Medium pelagic fish	
19	Benthopelagic fish	
20	Large pelagic fish	
21	Red mullets	
22	Medium benthodemersal	
23	Hake	
24	Anglerfish	
25	Benthodemersal elasmobranch	
26	Large benthodemersal fish	
27	Seabirds	
28	Dolphins and other +marine mammals	
29	Input P	Input of phosporous
30	PO4	Phospate (inorganic phosporous)
31	DOP	Dissolved Organic Phosporous
32	POP	Particulate Organic Phosporous
33	Discards	
34	Detritus	

2.2.3 E2E modeling approach implemented

The integration of the biogeochemical (low trophic level; LTL) and EwE food web (High Trophic Level, HTL) models followed the procedure described in Libralato and Solidoro (2009). The central idea is that the HTL model will be extended to provide a first, rough, description of also the LTL compartments (extended HTL model) and then an adjustment will be done for the extended HTL model to represent better the LTL dynamics. The limiting nutrient will be used to drive the food web from the bottom: given the current knowledge and models results P (phosporous) was defined for the Mediterranean sea and the NorthWestern Shelf of the Black Sea, whereas N (nitrogen) was instead considered more appropriate for the inner basin of the Black sea (see Black Sea State of the Environment Report 2001-2006/7 page 43). Moreover, since zooplankton groups are usually poorly represented in both LTL and HTL models, it was decided that the two models will be linked at the nutrients level (Libralato and Solidoro, 2009). The effects of the 3D results from the biogeochemical models reparametrized into 0D EwE HTL model will need to be accounted (Solidoro et al., 2010b), through a residual function that will be estimated by the E2E model (EwE extended): this adjusting function will be estimated by comparing E2E and LTL model outputs for nutrient dynamics over time.

In a first step, thus, the HTL models were converted in P and N units. The biomasses, immigration rates, catches and discards of all functional groups in the food web model (HTL functional groups) was converted in phosphorous and nitrogen units, by using conversion factor obtained by assuming an average C:N:P ratio of 88.5:15.7:1 (Sterner and George, 2000; Hjerne and Hansson, 2002) and a general value of 9 gww/gC (Pauly and Christensen, 1995).

Moreover, unassimilated ratio (UN = Q-P-R) for HTL groups was adjusted in order to have zero respiration thus allowing complete conservation of the nutrient (while production and consumption rates were kept untouched). This was accomplished by setting UN=1-P/Q. When aggregating groups, the Q/B values derived from the gross growth efficiency for the model groups that have very wide range of Q/B values (e.g. benthic invertebrates) in order to represent the respiration processes more precisely, i.e. the representation of mass-balance for the model groups on the level of consumption, assimilation and respiratory processes that forms the energy budget of the each group.

The comparison of EE estimates for all functional groups allowed checking the consistency of the food web model in nutrient units with the original one in wet weight units.

For the linking with LTL model, the food web model (EwE) will have some additional boxes (HTL model extension to LTL groups), namely: diatoms [Phytoplankton] and small phytoplankton [Picoplankton]; two groups of zooplankton: ciliates, fine filter feeders and metazoa [microzooplankton], and carnivorous, mixed filter feeders and herbivorous [mesozooplankton]; heterotrophic bacteria [bac], inorganic nutrient [DIN or PO4], dissolved organic matter and particulate organic matter , in terms of phosphorus [DOP] and [POP] or nitrogen [DON] and [PON].

In order to represent these groups in the extended HTL model, all information regarding average concentrations and flows between these additional groups are taken as average values from BGC simulations. Spatially averaged, vertical in integrated values are estimated from outputs regarding the specific part of the LTL model representing the HTL model domains. Other than average concentrations of LTL compartments, diet composition for the zooplankton groups in the extended EwE model are estimated from LTL model run as average yearly proportions. Flows to detritus in the extended EwE model for LTL groups were set to represent average yearly flows in the biogeochemical model, to represent flows of excretion, mortality, bacterial degradation, organic matter decay, alkaline phosphatase, and sinking. These flows are set using average proportions from BGC model runs.

For the PERSEUS case study areas in the Mediterranean Sea: Gulf of Lions, Adriatic Sea, Northern Aegean Sea, results from the BFM model will be used by the participants.

Concerning the Black Sea case study areas; northwestern shelf of the Black Sea and the inner basin and the eastern Black Sea, results from GHERECO, BIMS-ECO, BIOGEN respectively will be used by different partners.

2.3 End-to-End dynamic simulations

2.3.1 End-to-End Model hindcast

Calibration of the dynamic End-to-End model was performed on the 2000-2010 LTL and HTL data, but when local data (fishing effort and biomass estimate) were available before 2000 for HTL groups the longer time series were used to improve model accuracy using climatology estimated for the hindcast (2000-2010) for the LTL groups.

2.3.2 Climatic and fisheries changes for the scenario analysis with End-to-End model

Climate scenarios (2011-2020) were performed using nutrient river discharge scenarios and data from PERSEUS Deliverable 4.6 (i.e., BAU, BA, MFA, REB, RBE, see Table 2). The simulations were performed using nutrient river discharge scenarios and data that are computed from LTL models using forcings derived from D 4.6 as described in Table 2 for the period 2011-2020 (BAU, BA, MFA, REB, RBE). Results of the BAU scenario for the period 2011-2020 were compared to those of the reference period fitted to data (2000-2010: reference period). Results of the models using BA, MFA, REB, RBE data were compared to those of the model using BAU (business as usual) scenario considered as the reference one for the period 2011-2020. In all these scenarios fishing pressure was considered constant between 2010 and 2020.

Fisheries scenarios were applied on BAU climate scenario and included 10% increase and decrease of effort by gear (all, demersal trawlers) and of fishing mortality for some key groups (small pelagics and large pelagics).

Table 2. Synthetic description of Climate and Fisheries scenarios applied to the future conditions (2011-2020): changes described with respect to last year of the hindcast (2010).

Climate scenarios (applied for period 2010-2020)	
BAU	Business as usual: high per capita food consumption; high agricultural productivity as in 2010; no change in efficiency of fertilizers
REB	Regional expanding Block: high per capita food consumption; agricultural productivity as in 2010; rapid increase of N and P in fertilizers
MFA	Market For All: low per capita food consumption; low agricultural productivity; slow increase of N and P in fertilizers in some countries, no change for others
REB	Regional Blue Economy: high per capita food consumption, low meat; medium-high agricultural productivity than in 2010; moderate increase in fertilizers in counties with surplus
BA	Blue Archipelago: low per capita food consumption, low meat; medium agricultural productivity; moderate increase of use of fertilizers
Fisheries scenarios (applied to BAU 2010-2020)	
P10All	Increase by 10% the fishing effort for all the fleets
M10All	Decrease by 10% the fishing effort for all the fleets
P10Btwl	Increase by 10% the fishing effort for the benthic trawls
M10Btwl	Decrease by 10% the fishing effort for the benthic trawls
P10SPF	Increase by 10% the fishing mortality for sardine and anchovy
M10SPF	Decrease by 10% the fishing mortality sardine and anchovy
P10LPF	Increase by 10% the fishing mortality for large pelagic fish species
M10LPF	Decrease by 10% the fishing mortality for large pelagic fish species

2.3.3 Ecosystem health indicators applied

Following Costanza and Mageau (1999) ecosystem health was evaluated by calculating over time a set of indicators used to compare the "health" in terms of vigor, organization and resilience.

Vigor indicators used in the following are the net primary production (NPP), total system Throughput (T), i.e. the total flows in the system (Heymans et al., 2014) and total catch (Catch).

Organization was measured using Kempton's Q (K's Q ; Kempton and Taylor, 1976) that is an index of biodiversity adapted for aggregation of data into functional groups; the fishing in balance index (FiB) used to accout both the trophic level and quantity of cathes (Pauly et al., 2000); Average Mutual Information (AMI) an index derived from network analysis (Ulanowicz 1986); Finn's cycling index (FCI) used to measure the cycling within the food web (Ulanowicz 1986), and the mean path length (mPL) that gives an indication of the complexity of energy pathways (

Resilience was assessed by what is call Entropy – AMI (called H-AMI) and also calculated as (Capacity-Ascencency) / Throughput); the systems Scope for Growth (SfG) was calculated by the difference between Total production and Total primary production.

Moreover, in order to quantify the effects of fishing, a couple of other indicators were also analysed: catch over biomass (C/B) and trophic level of catch (TLc) considered indicators of effects of fishing (Coll and Libralato, 2013; Pauly et al., 1998).

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3. Results at the regional and basin scale

3.1 The Adriatic Sea

Libralato S., Lazzari P.,Solidoro C. (OGS)

3.1.1 The integrated modelling tool: structure and hindcast

The HTL model for the Adriatic Sea is an updated version of the EwE model of the Northern Adriatic Sea (Fig. 2) originally developed by Coll et al. (2007) and updated (Libralato et al., 2010; Akoglu et al., 2015). The original model composed of 40 functional groups (FG) has been updated by i) removing discards and by-catch FGs, ii) splitting phytoplankton and zooplankton in two FGs each to represent small and large taxa; iii) adding bacteria to explicitly represent the microbial loop; iv) adjusting diet of plankton feeders to split the diet into the new plankton FGs. The updated model has 44 FGs and parameters for the plankton groups were updated considering literature information (see Cossarini and Solidoro, 2008 and references therein). The model currency is wet weight. Successively the model has been standardized as described before into a structure of 34 functional groups and has been extended to integrate LTL dynamics.

Figure 2. Domain of the HTL Adriatic model

In the extension of the HTL model to comprise BFM outputs for the Adriatic domain data from 1990 to 2004 were spatially and temporally averaged in order to obtain average yearly fluxes between LTL compartments (mgP m^{-2} $year^{-1}$) and average concentrations (mgP m^{-2}). The diet composition of LTL groups were calculated using average consumption flows. MOreover exchanges between non living compartments representing degradation, excretion, faeces, remineralization, were taken from previous analyses (Akoglu et al., 2015) using results from a BGC model from the Northen Adriatic Sea (Cossarini and Solidoro, 2009). Extended HTL model representing LTL groups for both initial (46 functional groups) and standardized (34 functional groups) models are represented in Figures 20 and 21 respectively.

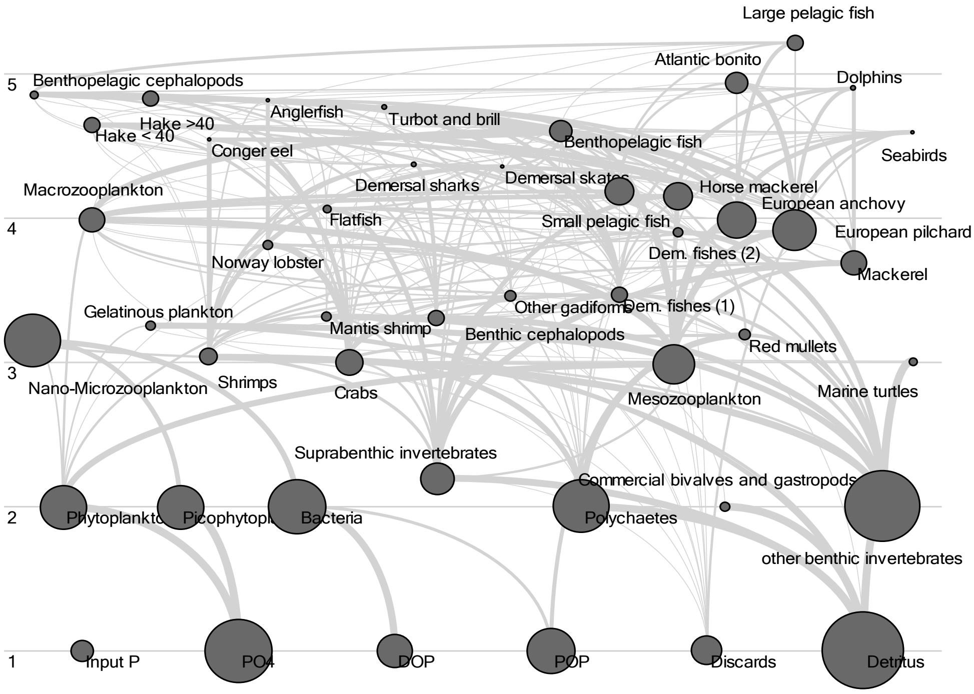

Figure 3. Food web structure of the extended model for the ADR domain (47 FG)

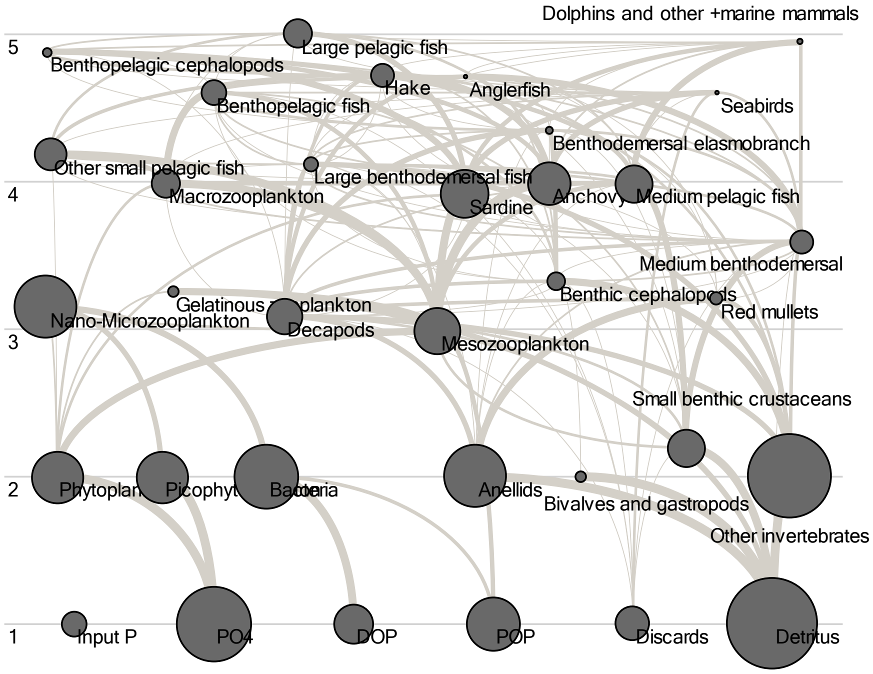

Figure 4. Food web structure of the extended model for the ADR domain standardized (34 FG)

The standardized LTL+HTL model was fit to the time series available: using the outputs from the BFM model for the period 2000-2010 , and using available data for the HTL groups regarding the period 1990-2010. For the LTL groups climatology means (calculated over the period 2000-2010) were used for the period 1990-2000. Result of the fitting is reported in Figure 5.

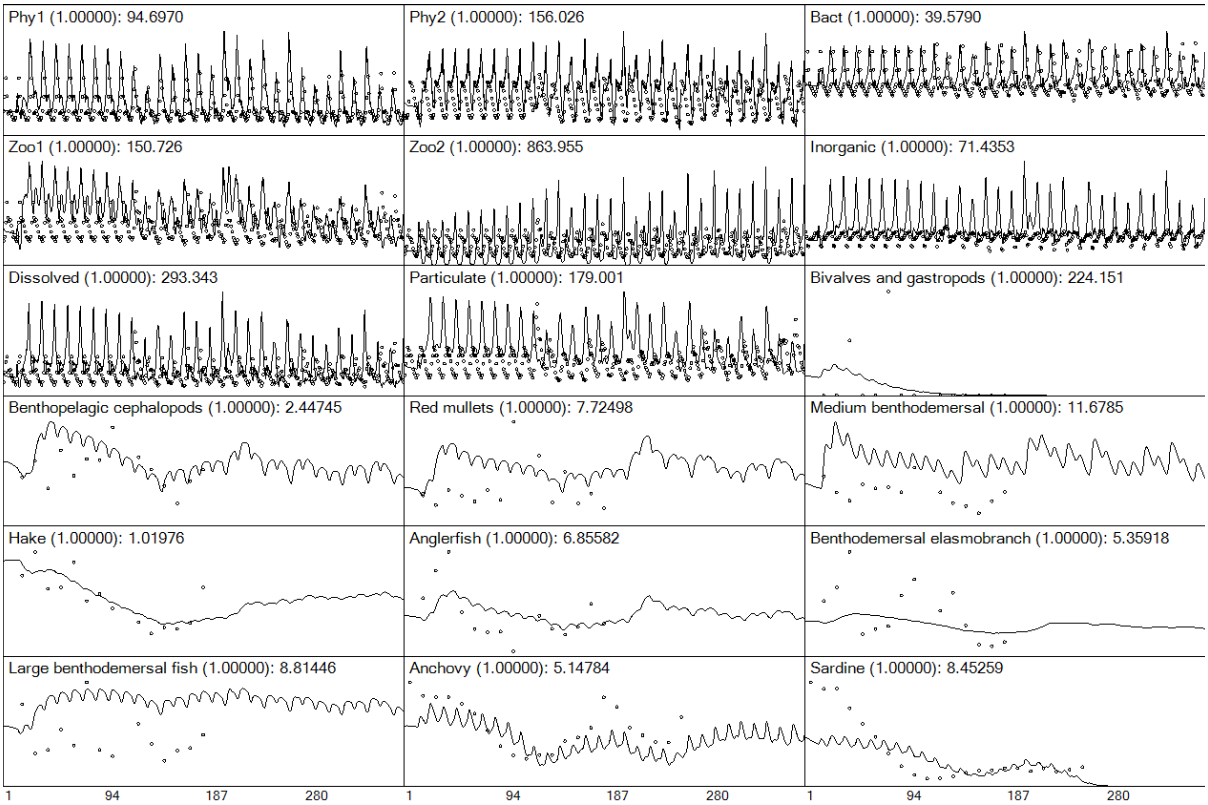

Figure 5. LTL and HTL groups for the Adriatic End-to-End model model fitted to data for the period 2000-2010 for LTL and 1990-2010 for the HTL. Time scale in the x-axis in months.

3.1.2 Summary statistics

A comparison of some global indices from original and standardized Adriatic food webs (Figures 3 and 4) are reported in Table 3. Results permit to highlight that the majority of flux-based indicators are not sensitive to structure of the model.

Table 3. Ecological indicators related to community energetic, structure, flows and information theory for the Adriatic Sea extendend Ecopath models (initial and standardized).

Global indicator	Full extended model 46 FG	Standardized model 34 FG	Units
Sum of all consumption	11238.24	11237.99	mg P/m^2/year
Sum of all exports	7.536942	7.524261	mg P/m^2/year
Sum of all respiratory flows	-0.005499236	-0.005551111	mg P/m^2/year
Sum of all flows into detritus	9735.271	9735.26	mg P/m^2/year
Total system throughput	20981.04	20980.77	mg P/m^2/year
Sum of all production	6604.91	6604.89	mg P/m^2/year
Gross efficiency (catch/net p.p.)	0.17	0.17	
Calculated total net primary production	44.83	44.83	mg P/m^2/year
Total primary production/total respiration			
Net system production	44.84	44.84	
Total primary production/total biomass	0.11	0.11	mg P/m^2
Total biomass/total throughput	0.02	0.02	mg P/m^2/year
Total biomass (excluding detritus)	424.27	424.17	
Total catch	7.67	7.66	
Connectance Index	0.17	0.20	
System Omnivory Index	0.27	0.25	

3.1.3 Scenarios results

Climatic and fisheries scenarios were run accorsing to section 2.3.2. Climate scenarios were performed with OPATB-BFM model for the period 2011-2020, using nutrient river discharge scenarios and data from from PERSEUS Deliverable 4.6 (i.e., BAU, BA, MFA, REB, RBE, see Table 2) and integrated in the End-to-End coupled scheme.

Results from the End-to-End model of the BAU scenario for the period 2011-2020 were compared to those of the reference period fitted to data (2000-2010). Results of the models using BA, MFA, REB, RBE data were compared to those of the model using BAU (business as usual) scenario considered as the reference one for the period 2011-2020. Fisheries scenarios applied to BAU climate (Table 2) included increase and decrease of i) effort by the most important fleets (all, demersal trawlers); ii) of fishing mortality for some key groups (small pelagics and large pelagics).

Results of both climatic and fisheries scenarios for the Adriatic Sea in term of vigor, organization and resilience ("health" ecosystem metrics) as well as in term of indices of exploitation are detailed in Table 4. Future scenario (BAU 2011-2020) shows for all metrics of vigor showed a significant decrease (NPP, T and catch) relative to the reference period (2000-2010). Organization indices all decreased significantly in the future BAU with respect to hindcast reference, except for Finn cycling index that increases significantly. Regarding resilience future climatic conditions (BAU) show an increase in H-AMI and a decrease of SfG. Indicators of fishing impact (C/B and TLc) showed to be also affected by climatic changes by decreasing C/B.

Conversely differences between future climatic scenarios were appreciable only for FCI (decreasing in RBE and MFA) and mPL (decresing in all climate future scenarios but MFA). Overall differences are significant between present and future climate scenarios, while there are small differences in future predictions between climatic scenarios.

Fishing scenarios applied to future BAU (Table 5) show that trawling modifications are inducing the most relevant effects on vigor, organization and resilience. Regarding indicators the most sensitive to fisheries changes seems to be mPL, affected significantly in all scenarios although this can be related to the scattered dynamics of the indicator over time. It is worth mentioning that indirect effects in the End-toEnd system seems to compensate changes at the level of system indicators when applying fisheries changes to all fleets at the same time.

Table 4. Results of LTL and HTL scenarios presented in term of vigor, organization and resilience for the reference and scenarios periods. Details of metrics were indicated previously. Significant differences (> 5%) between BAU scenario and reference period, between others LTL scenarios and BAU reference LTL scenario, as well as between BAU and fishing scenarios, were indicated in bold characters (red for negative values/decrease of metrics and blue for positive values/increase of metrics).

	Vigor			Organization						Resilience		Fisheries impact	
	NPP	T	Catch	K's Q	FiB	AMI	A	FCI	mPL	H-AMI	SfG	C/B	TLc
Ref	2.31	2148.21	1.20	2.95	0.01	2.41	5090.04	34.02	152.95	2.82	718.98	0.00	3.45
BAU	2.13	1850.68	1.01	2.74	0.01	2.32	4287.64	40.85	17.30	3.02	582.09	0.00	3.45
(BAU-Ref)/Ref	**-7.6**	**-13.9**	**-15.7**	**-7.1**	**-23.2**	**-3.7**	**-15.8**	**20.1**	**-88.7**	**7.2**	**-19.0**	**-8.6**	**-0.1**
(BA-BAU)/BAU	0.09	0.76	0.27	-0.02	0.73	0.78	1.39	-1.39	-188.14	-0.74	1.11	-0.30	-0.02
(REB-BAU)/BAU	0.11	0.73	0.24	0.00	0.71	0.67	1.26	0.40	-164.23	-0.64	1.07	-0.31	-0.02
(RBE-BAU)/BAU	0.31	1.34	0.51	-0.07	1.40	0.74	1.90	-5.40	-70.11	-0.79	1.97	-0.55	-0.03
(MFA-BAU)/BAU	0.30	1.21	0.45	-0.05	1.21	0.84	1.85	-5.16	261.71	-0.84	1.79	-0.50	-0.02
(M10All-BAU)/BAU	-0.02	-0.01	-2.78	1.73	-4.60	0.03	0.02	-159.17	-259.48	0.00	-0.02	-2.79	0.08
(M10Btwl-BAU)/BAU	-0.02	26.77	-12.69	1.73	-28.61	2.09	27.54	-32.96	-300.60	-8.91	39.57	-23.09	-2.32
(M10LPF-BAU)/BAU	0.00	0.00	-0.12	-0.02	0.02	0.00	0.00	0.67	66.66	0.00	0.00	-0.12	-0.07
(M10SPF-BAU)/BAU	0.33	0.43	-0.74	0.59	-2.33	0.41	0.77	-12.29	29637.78	-0.45	0.65	-1.02	-0.14
(P10All-BAU)/BAU	0.02	0.01	2.62	-1.61	4.80	0.04	0.04	0.77	-103.13	-0.05	0.01	2.64	-0.10
(P10Btwl-BAU)/BAU	16.49	27.95	-4.42	0.04	-3.40	1.88	28.45	-27.08	-1500.99	-9.09	41.30	-16.11	-3.15
(P10LPF-BAU)/BAU	0.00	0.00	0.11	0.02	-0.02	0.00	0.00	-0.07	-40.95	0.00	0.00	0.12	0.07
(P10SPF-BAU)/BAU	0.00	-0.40	0.56	-0.31	1.87	-0.12	-0.49	0.01	-115.52	0.21	-0.60	0.82	0.12

3.1.3.1 Vigor

The simulations performed with climatic scenarios BA, MFA, REB and RBE changes in the terrestrial inputs show very little differences with BAU scenario. Results (Figure 6) indicate that the order of magnitude of changes induced do not have substantial differences in vigor estimates for the period 2011-2020 calculated with the three different indicators used as NPP, Total system throughput and total fisheries catches

(Figure 6): all results for different scenarios are very close and substantially identical to BAU. When introducing fisheries changes, however, some effects are appreciable (Figure 7), although most scenario results indicate that the order of magnitude of changes induced by the fishing scenarios does not introduce changes in vigor in the Adriatic sea system compared to BAU scenario and constant fishing effort from 2010 to 2020. It is also worth noting that increase of effort doesn't change substantially vigor estimates for all indicators (NPP, T and catches), while decreasing effort has contrasting effects on indices: NPP and T increase, while Catches decreases. Sice results for scenarios with all efforts reduced by 10% (m10All) is similar than results for trawlers, this indicates the prevalence of effects when changing this last fleet only. In fact, appreciable differences are evident especially when reducing fishing effort for trawlers (m10Btwl and m10all) by 10% with evident effects on catches (Figure 7).

Figure 6. Net primary production (NPP), total system throughput (T) and catches as indicators of Vigor reported for hindcast (2000-2010) and climatic scenario (2011-2020) for the Adriatic Sea system.

Figure 7 Indicators of Vigor reported for hindcast (2000-2010) and fisheries scenarios applied to BAU climate (2011-2020) for the Adriatic Sea system.

3.1.3.2 Organization

Similar dynamics over time were obtained for all organization indices in the different climatic scenarios. Results (Figure 8) indicates minimal differences in future estimates (2011-2020) under BAU and other climatic scenarios for K'sQ, FiB, AMI and Ascendency (always below 5% change with BAU). Results for FCI and mPL however indicates some problems in the use of the indicators that revealed changes even before 2010. These indicators show very similar changes over time under all different climatic scenarios, but have presence of spikes that might result in apparent differences in mean value, but whose significance need to be considered opportunely.

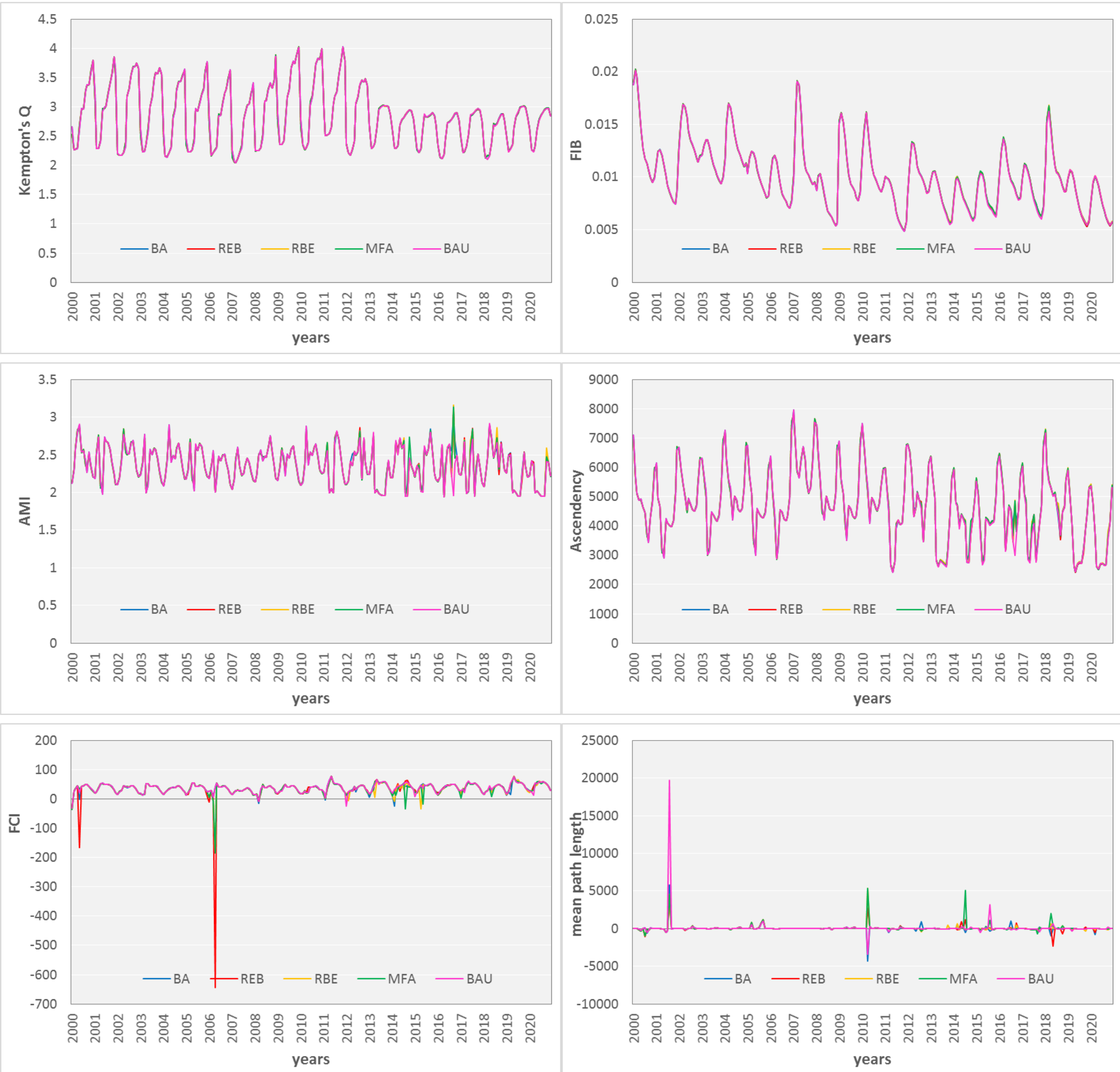

Figure 8. Organisation estimated metrics for the climatic change scenarios (see also Table 2) applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

Organization indices estimated revealed appreciable differences between fisheries scenarios and BAU for all indicators used (Figure 9). Even in the case of Organization indices, the Adriatic system showed to be sensitive with respect to the increase in the trawling activity especially and therefore on increase applied to all fleets (including trawling). In fact, future scenario (2011-2020) show increased values of Kempton's Q, scendency and AMI when applying +10% increase of trawling effort. Effect of FiB was reversed, showing a decrease when increasing the tttraaawling effort by 10%. All other fleets and fisheries changes (small pelagic mortality, large pelagic mortality) and especially all scnarios with release of fisheries pressure by 10% showed minimal effects on the Organization indicators. FCI and mPL showed to be very difficult to assess.

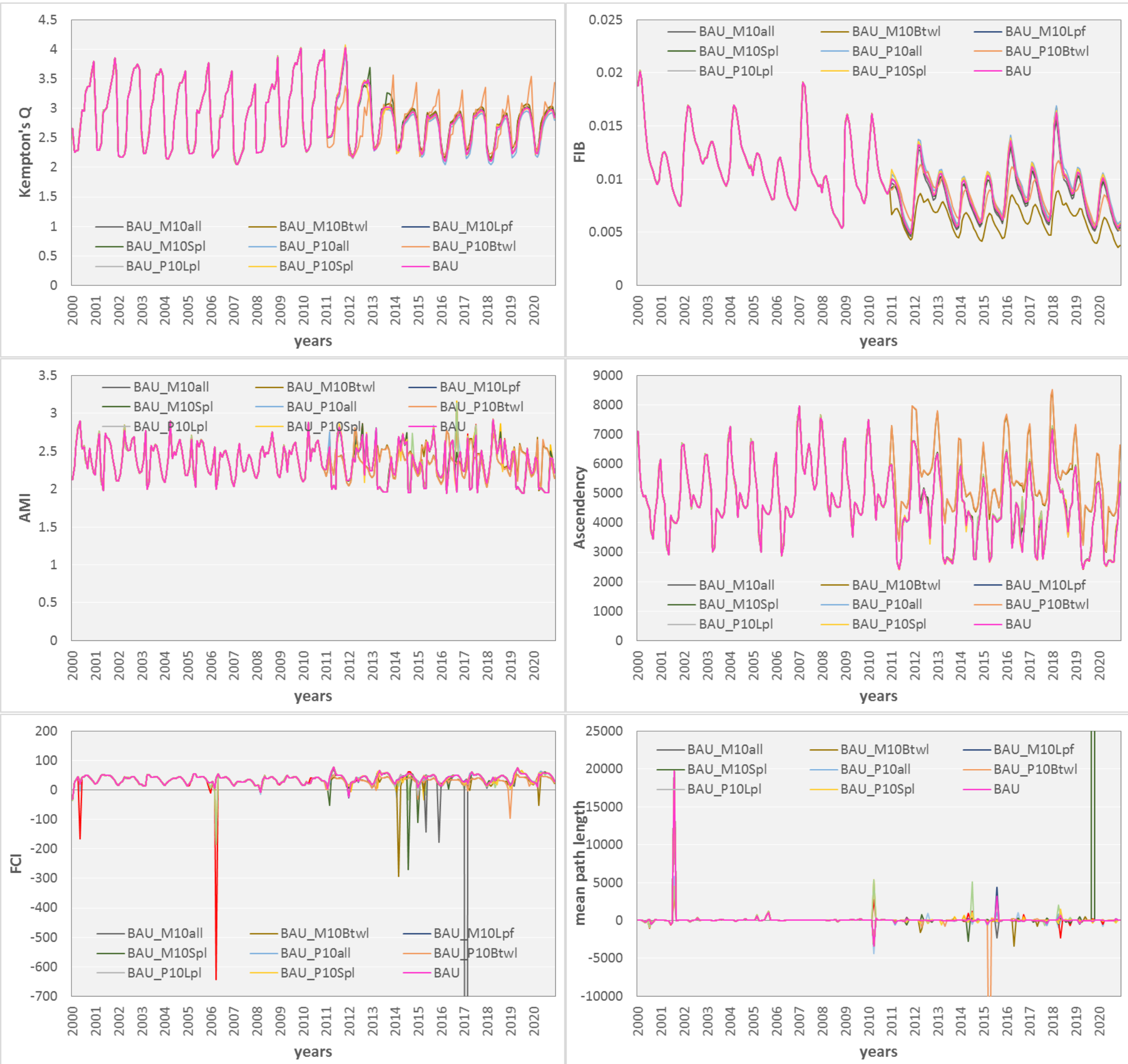

Figure 9. Organisation estimated metrics for the scenarios wih fisheries changes (see also Table 2) applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the fisheries scenarios in the coupled model used the same BAU climatic scenario.

3.1.3.3 Resilience

Resilience indicators for climatic and fisheries scenarios are reported in figures 10 and 11, respectively. The simulation with the End-to-End model fot the Adriatic Sea carried out with BA, MFA, REB and RBE terrestrial inputs resulted in minimal differences between them and BAU on the resilience of the system. The simulations carried out with fishing scenarios applied to BAU climate indicates effects especially of the application of changes in the trawling effort: reduction of effort by 10% for trawlers in the 2011-2020 scenario resulted in reduction of Entropy - Average Mutual Information and increase in the Scope for Growth (Figure 10).

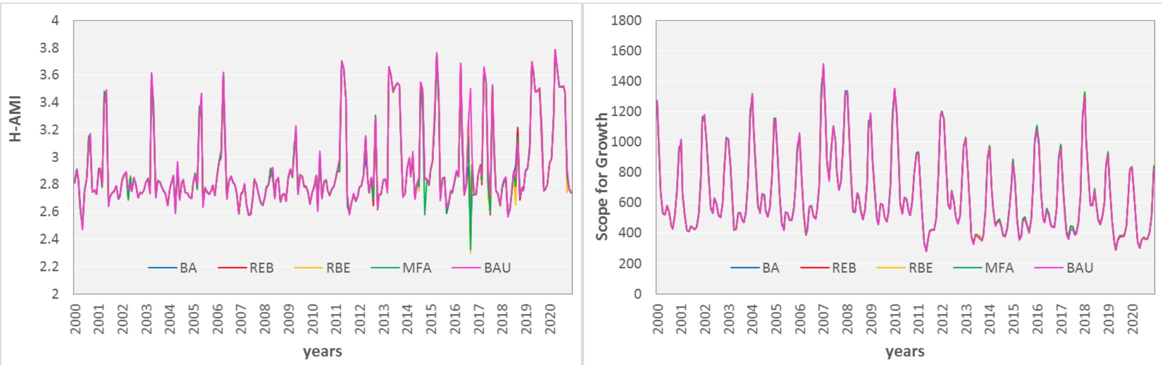

Figure 10 Resilience metrics estimated under the 5 climatic scenarios (see also Table 2) showing minimal differences between scenarios and BAU for the Adriatic Sea.

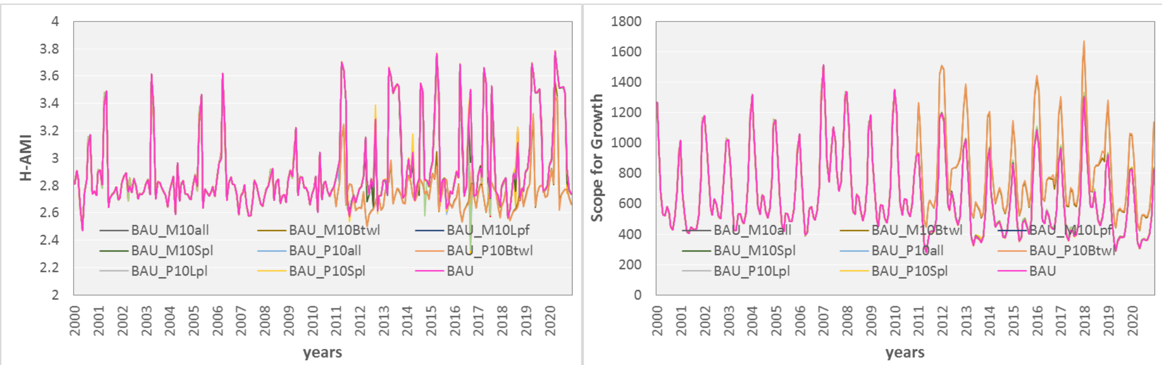

Figure 11 Resilience metrics estimated under the fisheries scenarios (see also Table 2) applied over the period 2011-2020.

3.1.3.4 Indices of exploitation

Also in the case of mean trophic level of the catches and catch/biomass ratio, the climatic scenarios do not show significant differences in the future dynamics (2011-2020) between BAU and the other scenarios (Figure 12). Conversely fishing changes applied to BAU were resulting in scenarios with notable differences. The most relevant changes are obtained when changing trawling activity. It is worth noting that both increasing and decreasing trawling has negative effect on the C/B ratio suggesting the presence of important fedbacks and trophic interactions (through discard and scavenging) in the Adriatic Sea mediated by trawling.

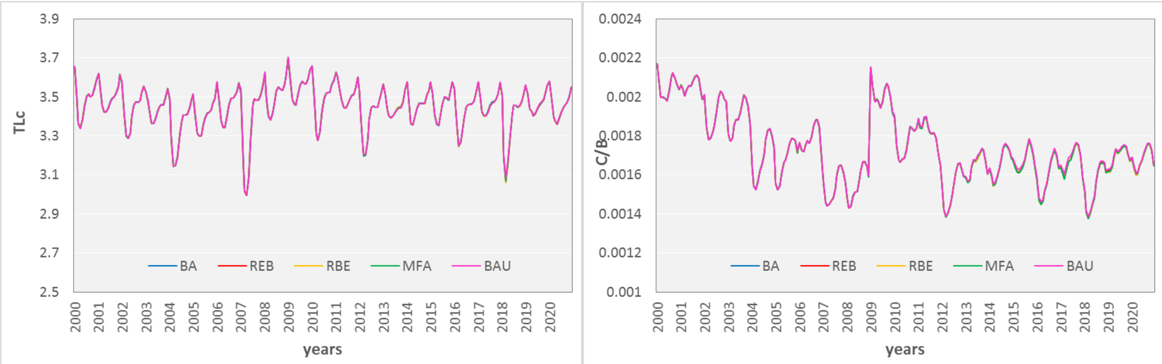

Figure 12. Trophic level of the catches and Catch/Biomass ratio estimated for the Adriatic sea under climatic scenarios.

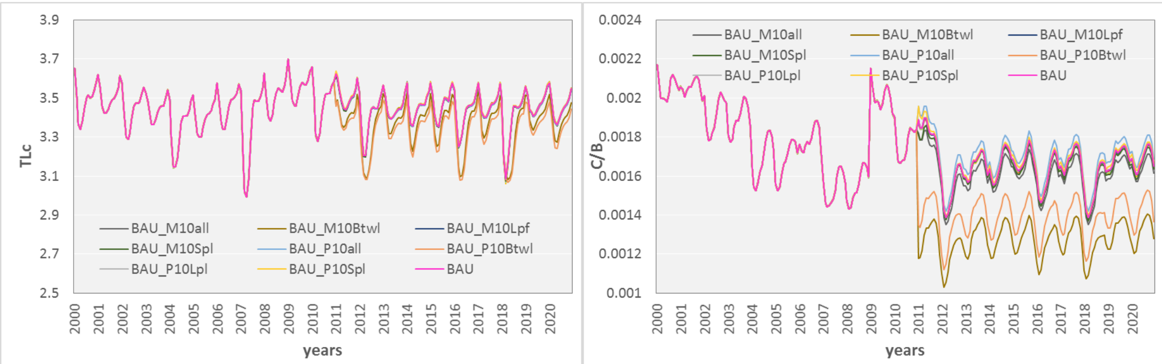

Figure 13 Trophic level of the catches and Catch/Biomass ratio estimated for the Adriatic sea under fishing scenarios.

3.1.4 Discussions

The Adriatic Sea system has been studied by coupling effects of LTL model scenarios (BFM) and HTL dynamics under climate and fisheries changes.

Results indicate that there are small differences between climate scenarios for the 2011-2020 (predictions), suggesting that the time frame of 10 years is quite short for evaluating consistent effects of different policies. Appreciable diffrences, instead, are emerging when comparing past reference (2000-2010) and future (2011-2020) under the same BAU scenario. These changes consists in the reduction of vigor and organization components of the ecosystem health. In fact NPP, T, Catches (Vigor indicators) and K's Q, FiB, AMI, A, mPL (organization indicators) showed negative changes between past reference (2000-2010) and future (2011-2020). Only the Finn cycling index (FCI), one of the organization indices, is shiwing an increase between past and future, but a detailed analysis of the dynamics show the difficulties in using this indicator for robust evaluations due to erratic and spiking dynamics. Indicators of resilience showed significant but opposite direction H-AMI increased and SfG decreased, highlighting the problems of theoretical direction of change with respect to the health.

Differences between climatic scenarios were never significant except for mPL whose changes are significant for all climatic scenarios, and FCI showing significant changesfor RBE e MFA scenarios. The erratic changes and peaks in these two indices, however, suggest caution in making overall conclusions on the basis of these two indicators. Overall the conclusion is that the differences in all metrics for health, i.e., vigor, resilience and organization are not significant between climatic scenarios.

Effects of fisheries changes strongly depend on the fleet perturbed. Basically changes in small pelagic and large top predators mortality result in non significant modification of indices. Effects of changes in trawling are much more pervasive than climatic changes in general and other fisheries resulting in significant increase for NPP, T (increase of vigor), increase of ascendency (organization). Among resilience indicators SfG increased while H-AMI decreased under changes of trawling, thus further supporting the conclusion that these two indicators are tightly negatively linked.

Fisheries scenarios further support the findings that FCI and mPL are indicators too erratic, thus significance of changes based on the mean values are quite influenced by spikes thus poorly useful.

Fishing indicators showed significant changes when applying changes in the trawling activity, but not much affected by other fisheries changes.

3.1.5 References

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3.2 Gulf of Lions' continental shelf

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3.2.1 The integrated modelling tool: structure and hindcast

In the case of the Gulf of Lions the model standardization and update consisted in creating the **GoL shelf** model that comprised the continental shelf only of the Gulf of Lions (11000 km^2, from 20 to 200 m) (Fig. 14). The **end-to-end GoL** model was built by incorporating and forcing the HTL EwE **GoL shelf** model with outputs from the LTL coupled OPATB-BFM model for the Gulf of Lion shelf area.

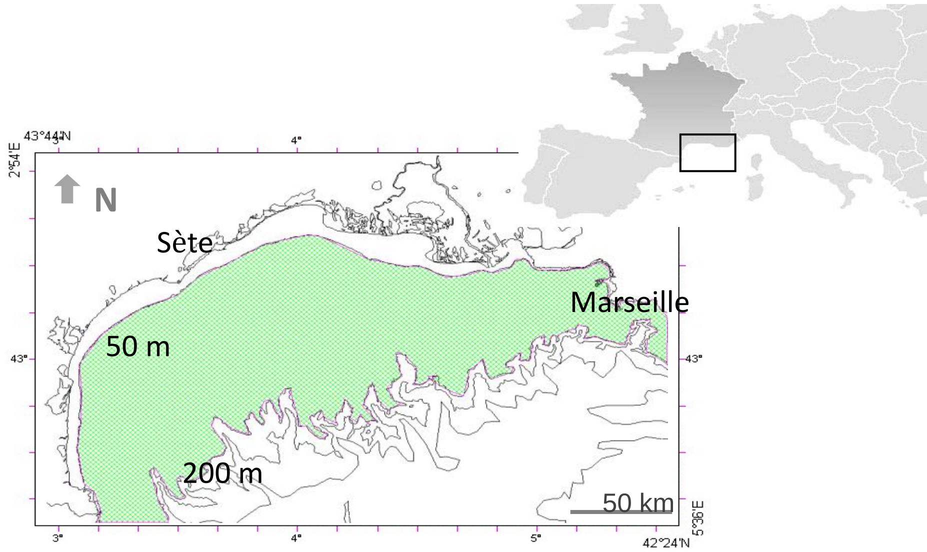

Figure 14. Study area situated on the continental shelf of the Gulf of Lions (north-western Mediterranean Sea).

The OPATB-BFM LTL model has a horizontal resolution 12 km, vertical resolution from 3 m at surface to 300 in deeper layers. The LTL model is forced with the offline approach and uses the physical outputs (U, V, W, Kv, T, S) produced by the CMCC-MFS16CM Ocean General Circulation model. The simulation carried out spans the period 2000-2020 with a spin-up phase of 5 years. Temperature increase is congruent with the RCP 8.5 CO_2 mixing ratio scenario. The sea surface temperature increase, comparing the 2001-2010 decade with the 2011-2020 one, is in the range [0 .08] Degrees Celsius. The structure of the new model coupled was indicated in the Fig 15.

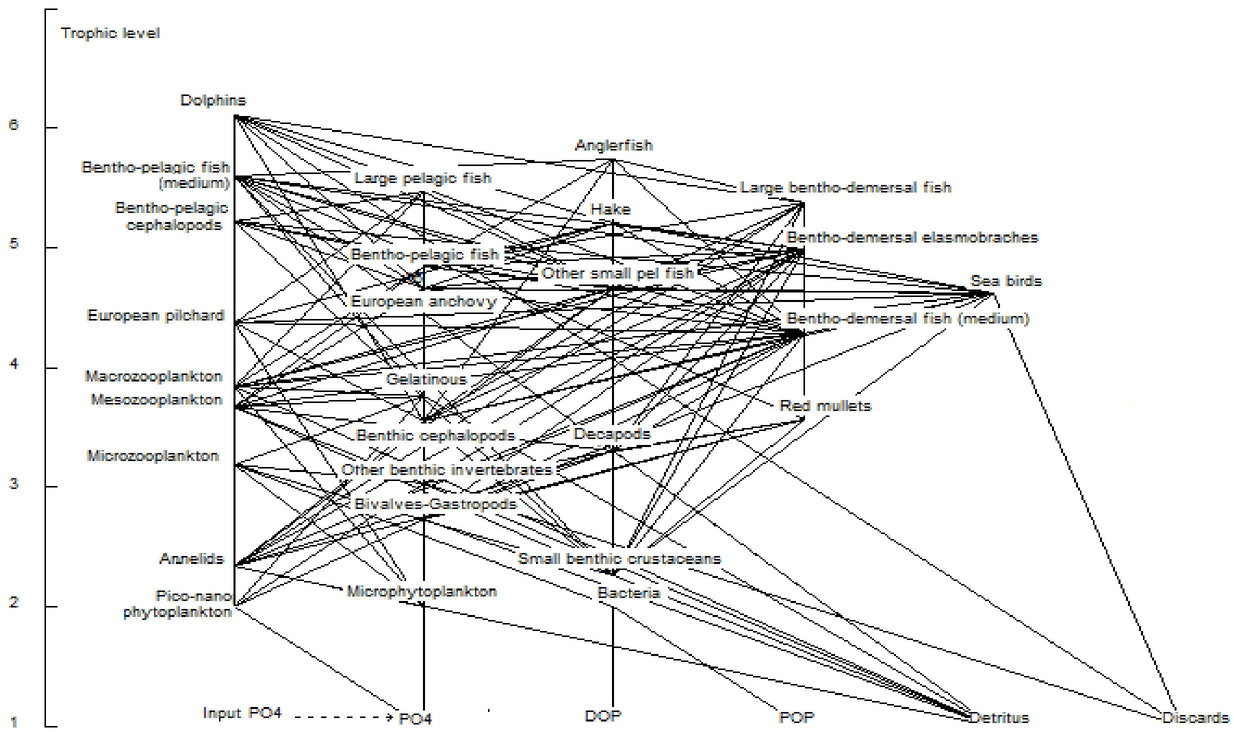

Figure 15. Structure of the foodweb in the end-to-end **Ecopath GoL shelf** model. The links between the different compartments show the trophic flows.

Coupling between LTL and HTL model was made following the procedure of Libralato and Solidoro (2009). Coupling the GoL shelf with outputs of the biogeochemical model required rearrangement of some parameters like: detritus fate for HTL, P/B for Input PO4 and diet for mesozooplankton. Calculated forcing function for some groups coming from the BFM (bacteria, pico and microphytoplankton) were build in Ecosim and applied relative to their respectives “prey” (PO4, POP, DOP). Corrections of trophic level outputs were made (as in the initial version of the model PO4, DOP and POP had the trophic leve 1). A new calibration of the coupled LTL-HTL GoL shelf model was necessary. The coupled model was then fitted to LTL and HTL data for the period 2000-2010 (Fig. 16). This period was considered as the reference one to be compared with the scenarios period 2011-2020.

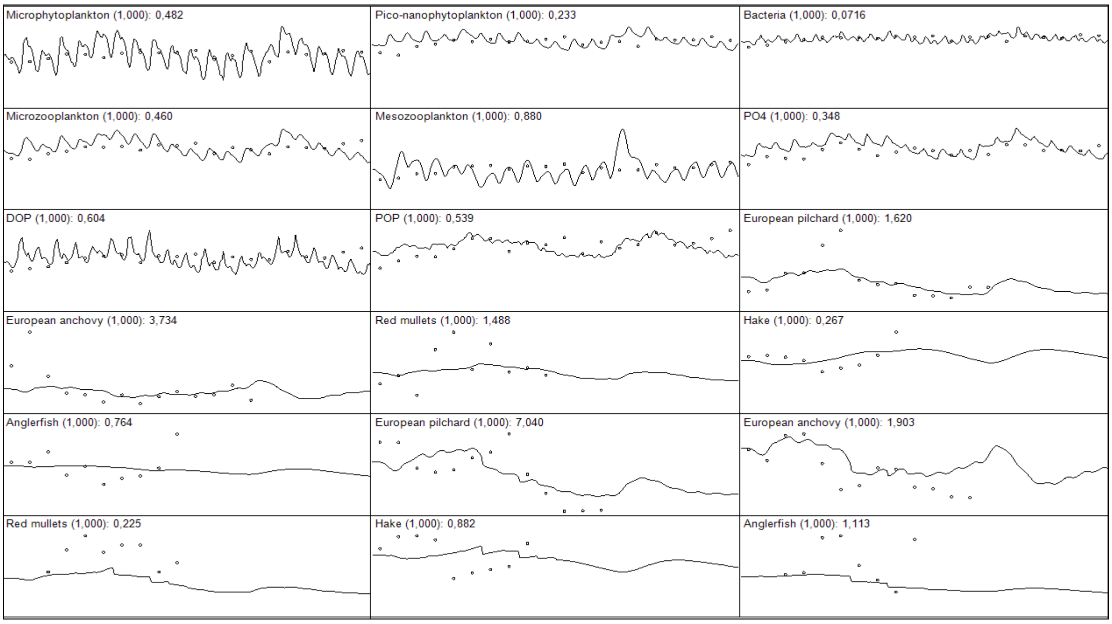

Figure 16. LTL and HTL groups fitted to data for the period 2000-2010.

3.2.2 Summary statistics

Results from the end-to-end coupled model of the Gulf of Lions simulations in terms of aggregated summary statistics and network flows are shown in Table 5. Coupling methodology and the new calibration induced some changes in these results compared to the initial model (18th month report of Perseus).

Table 5. Ecological indicators of the Ecopath GoL shelf coupled model

Global indices	value	unit
Sum of all consumption	1286.4	mg P/m^2/year
Sum of all exports	0.6	mg P/m^2/year
Sum of all respiratory flows	0	mg P/m^2/year
Sum of all flows into detritus	980.3	mg P/m^2/year
Total system throughput	2267.2	mg P/m^2/year
Sum of all production	737.5	mg P/m^2/year
Mean trophic level of the catch	3.9	
Gross efficiency (catch/net p.p.)	0.0	
Calculated total net primary production	24.5	mg P/m^2/year
Net system production	24.6	mg P/m^2/year
Total primary production/total biomass	0,1	
Total biomass/total throughput	0,2	
Total biomass (excluding detritus)	450.5	mg P/m^2
Total catches	0,6	mg P/m^2/year
Connectance Index	0.2	
System Omnivory Index	0.3	

3.2.3 Scenarios results

Results of both LTL and HTL scenarios in term of vigor, organization and resilience ("health" ecosystem metrics) as well as in term of indices of exploitation were detailed in Table 6. In BAU scenario (2011-2020) relative to the reference period (2000-2010) some metrics of vigor (total catch), organization (fishing in balance and Finn cycling index) and exploitation (trophic level of catch) were significantly decreasing.

Table 6. Results of LTL and HTL scenarios presented in term of vigor, organization and resilience for the reference and scenarios periods. Details of metrics were indicated in Table 2. Significant differences (> 5%) between BAU scenario and reference period, between others LTL scenarios and BAU reference LTL scenario, as well as between BAU and fishing scenarios, were indicated in bold characters (red for negative values/decrease of metrics and green for positive values/increase of metrics).

Gulf of Lions	**Vigor**			**Organisation**						**Resilience**		**Exploitation**	
"health" metrics	NPP	T	Catch	K's Q	FiB	AMI	A	FCI	mPL	H-AMI	SfG	C/B	TLc
Reference period (Ref.P)													
2000-2010 (fitted to data)	1,02	2620,06	0,54	1,05	0,00	2,21	5795,52	-150,11	10,27	3,18	765,88	0,00	3,60
Agriculture and climate scenarios (2011-2020)													
BAU reference scenario (constant fishing effort)	1,06	2688,98	0,58	1,04	0,00	2,21	5952,10	-287,50	9,91	3,18	794,75	0,00	4,04
(Ref.P - BAU)*100/Ref.P	-4,2	-2,6	**-6,7**	0,9	**-91,7**	-0,1	-2,7	**-91,5**	3,6	0,1	-3,8	-1,9	**-12,2**
(BAU-BA)*100/BAU	0,22	0,10	0,04	-0,02	-0,93	0,01	0,10	**-337,01**	-0,18	-0,01	0,14	-0,06	-0,07
(BAU-MFA)*100/BAU	0,12	-0,52	-0,47	-0,04	0,58	0,01	-0,52	**-65,75**	0,47	0,08	-0,77	0,13	-0,10
(BAU-REB)*100/BAU	0,23	0,00	-0,01	-0,01	-0,28	0,01	0,01	**-201,92**	-0,01	0,01	-0,01	-0,02	-0,06
(BAU-RBE)*100/BAU	0,35	0,24	0,24	0,00	-1,16	0,01	0,26	**-52,76**	-0,30	-0,01	0,35	-0,08	-0,05
Fisheries scenarios (2011-2020)													
(BAU-p10All)*100/BAU	0,02	0,11	**-5,17**	0,90	**31,18**	-0,02	0,10	**-322,33**	-0,17	-0,01	0,14	**-5,25**	0,83
(BAU-m10All)*100/BAU	-0,02	-0,13	**5,39**	-0,99	**-24,15**	0,02	-0,11	**73,81**	0,21	0,02	-0,17	**5,47**	-0,88
(BAU-p10Btwl)*100/BAU	0,02	0,11	**-5,17**	0,90	**31,18**	-0,02	0,10	**-322,33**	-0,17	-0,01	0,14	**-5,25**	0,83
(BAU-m10Btwl)*100/BAU	-0,02	-0,13	3,94	0,46	**-14,81**	0,01	-0,12	**-383,47**	0,23	0,02	-0,16	4,00	-0,72
(BAU-p10SPF)*100/BAU	0,00	0,02	-4,36	-0,06	**26,25**	0,01	0,03	**-65,83**	0,00	-0,01	0,04	-4,41	0,46
(BAU-m10SPF)*100/BAU	0,00	-0,02	4,38	0,06	**-22,41**	-0,01	-0,03	**-30,62**	0,00	0,01	-0,03	4,43	-0,51
(BAU-p10LPF)*100/BAU	0,00	0,00	-0,01	0,00	-0,21	0,00	0,00	**-47,31**	0,01	0,00	0,00	-0,01	-0,01
(BAU-m10LPF)*100/BAU	0,00	0,00	0,03	0,00	0,21	0,00	0,00	**-83,55**	-0,01	0,00	0,00	0,03	0,01

3.2.3.1 Vigor

The simulation carried out with BA, MFA, REB and RBE terrestrial inputs indicates that the order of magnitude of changes induced by these LTL scenarios does not introduce changes in vigor in the Gulf of Lions compared to BAU scenario for the period 2011-2020 (Figure 17). The simulation carried out with HTL fishing scenarios indicates that the order of magnitude of changes induced by the fishing scenarios does not introduce changes in vigor in the Gulf of Lions compared to BAU scenario and constant fishing effort from 2010 to 2020 for most of them. However, when increasing by 10% fishing effort for all fishing gears (p10All) or for benthic trawls (p10Btwl) catch significantly decreased, while when decreasing by 10% fishing effort for all fishing gears (m10All) catch significantly increased (Figure 18, Table 5).

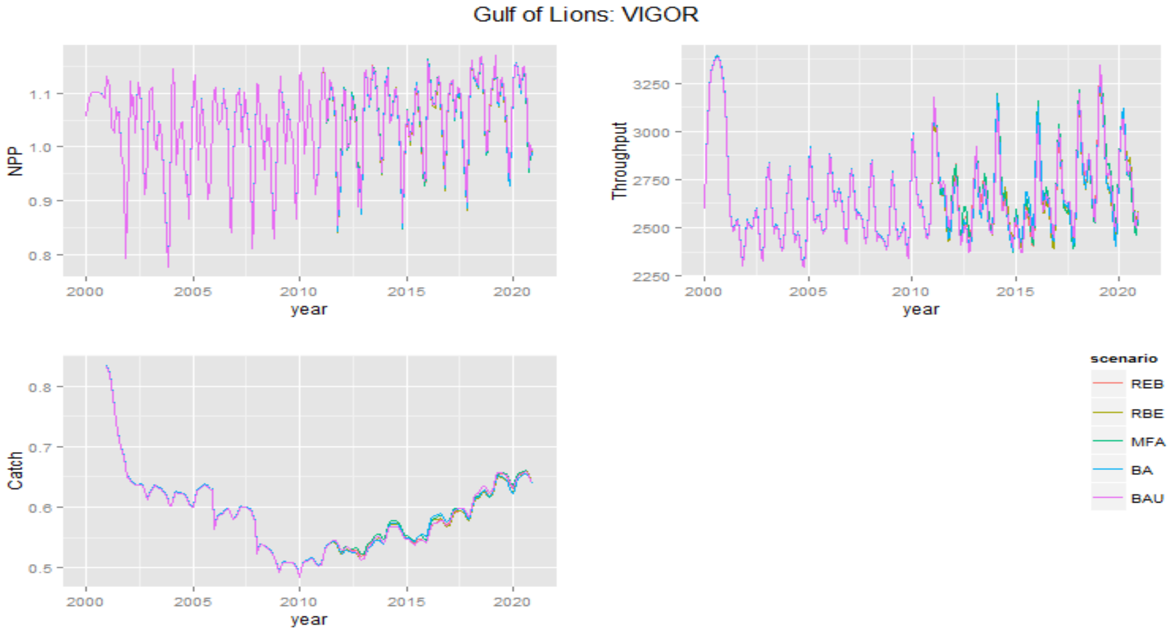

Figure 17. Vigor estimated metrics for the LTL scenarios (see also Table 2) applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

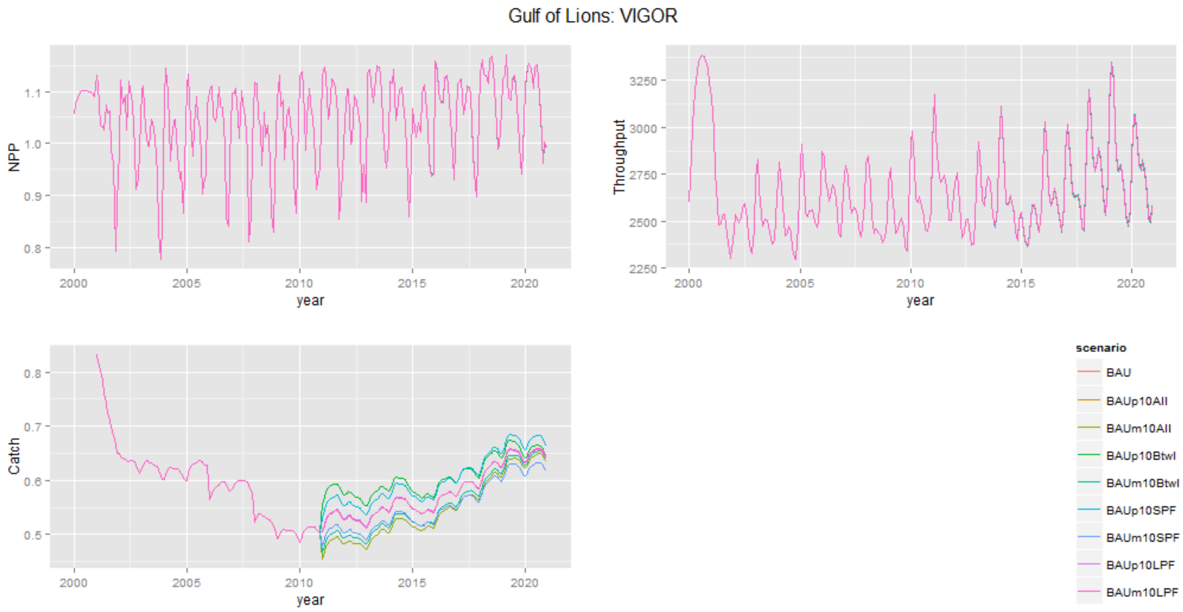

Figure 18. Vigor estimated metrics for the HTL scenarios (see also Table 2) applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the HTL scenarios in the coupled model used the same BAU scenario LTL data.

3.2.3.2 Organization

The simulation carried out with BA, MFA, REB and RBE terrestrial inputs indicates that the order of magnitude of changes induced by the these LTL scenarios does not introduce significant changes for most of the estimated metrics of organisation in the Gulf of Lions compared to BAU scenario. In LTL scenarios there was less than 5% change in Kempton's Q, Fishing in Balance, Average Mutual Information, Ascendency, mean Path length metrics (Figure 19, Table 6). However there were rather high significant changes in FCI (Finn's Cycling Index) between scenarios with the highest decrease by 337% in BA compared to BAU and the lowest decrease by 53% in RBE compared to BAU (Figure 19, Table 6).

The simulation carried out with BAU terrestrial inputs and fishing scenarios indicates that the order of magnitude of changes induced by the fishing scenarios does not introduce changes for most of the metrics in organization in the Gulf of Lions compared to BAU scenario and constant fishing effort from 2010 to 2020. In HTL scenarios there was less than 5% change in Kempton's Q, Average Mutual Information, Ascendency and mean Path Length metrics (Figure 20). However there was a significant change in Fishing in Balance and Finn's Cycling Index which increased or decreased in the different fishing scenarios compared to the reference BAU one with constant fishing effort from 2010 to 2020 (Fig. 20, Table 6).

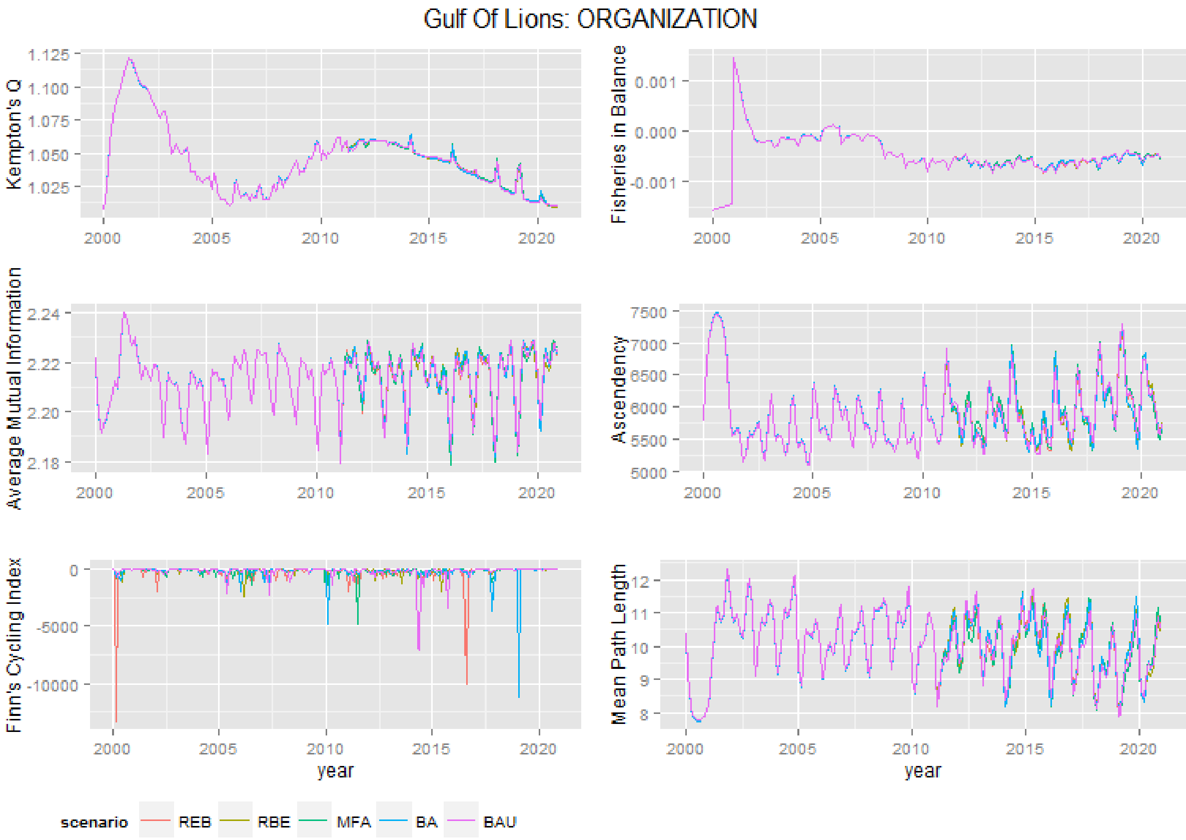

Figure 19. Organisation estimated metrics for the LTL scenarios (see also Table 2) applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

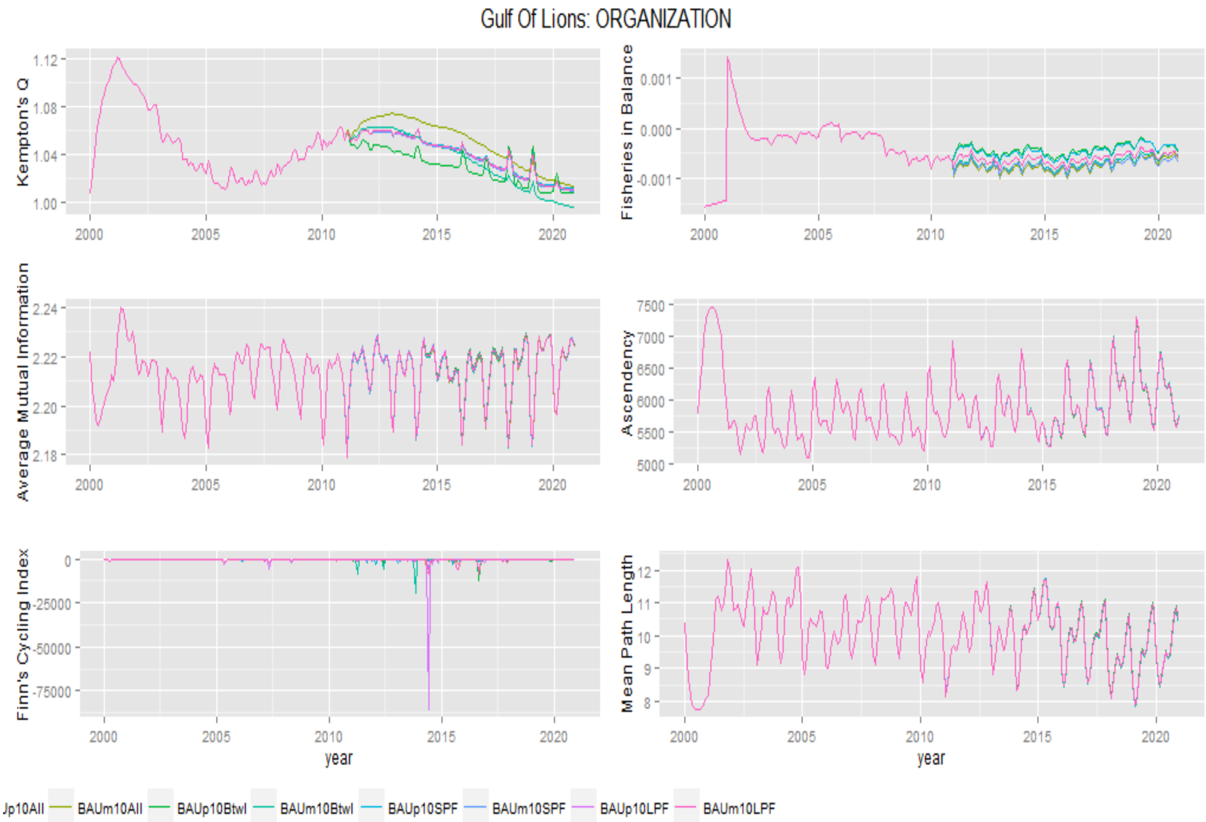

Figure 20. Organisation estimated metrics for the HTL scenarios (see also Table 2) applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the HTL scenarios in the coupled model used the same BAU scenario LTL data.

3.2.3.3 Resilience

The simulation carried out with BA, MFA, REB and RBE terrestrial inputs indicates that the order of magnitude of changes induced by the LTL scenarios does not introduce changes in resilience in the Gulf of Lions compared to BAU scenario. The simulation carried out with BAU terrestrial inputs and HTL fishing scenarios indicates that the order of magnitude of changes induced by the fishing scenarios does not introduce changes either in resilience in the Gulf of Lions compared to BAU scenario and constant fishing effort from 2010 to 2020. In both LTL and HTL scenarios there was less than 5% change in Entropy - Average Mutual Information and Scope for Growth metrics (Figures 21 and 22).

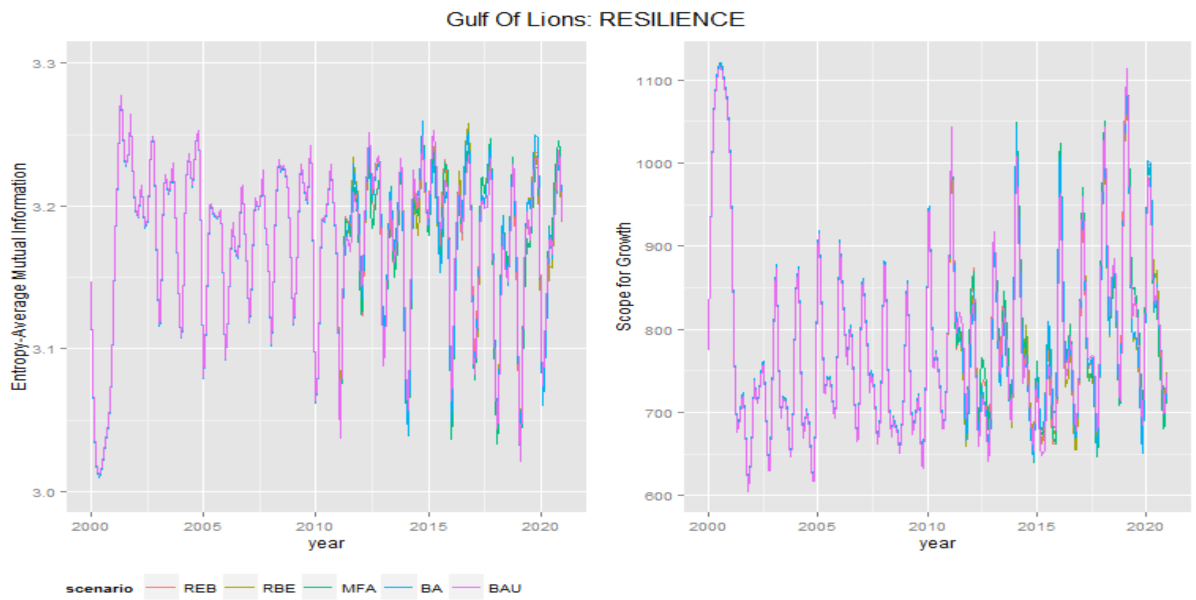

Figure 21. Resilience estimated metrics for the LTL scenarios (see also Table 2) applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

Figure 22. Resilience estimated metrics for the HTL scenarios (see also Table 2) applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the HTL scenarios in the coupled model used the same BAU scenario LTL data.

3.2.3.4 Indices of exploitation

The simulation carried out with BA, MFA, REB and RBE terrestrial inputs indicates that the order of magnitude of changes induced by the LTL scenarios does not introduce changes on indices of exploited systems in the Gulf of Lions compared to BAU scenario (Figure 23).

The simulation carried out with HTL fishing scenarios indicates that the order of magnitude of changes induced by the fishing scenarios does not introduce changes in indices of exploitation in the Gulf of Lions compared to BAU scenario and constant fishing effort from 2010 to 2020 for most of them. However, when increasing by 10% fishing effort for all fishing gears (p10All) or for benthic trawls (p10Btwl) catch/biomass index significantly decreased, while when decreasing by 10% fishing effort for all fishing gears (m10All) catch/biomass index significantly increased (Figure 24, Table 5).

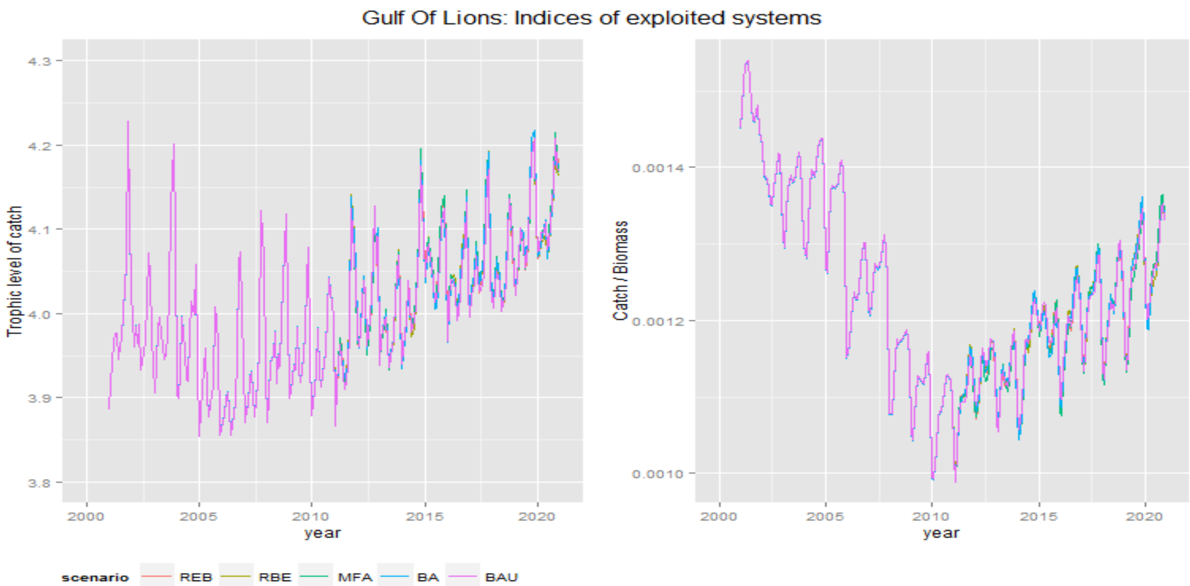

Figure 23. Indices of exploited systems estimated for the LTL scenarios (see also Table 2) applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

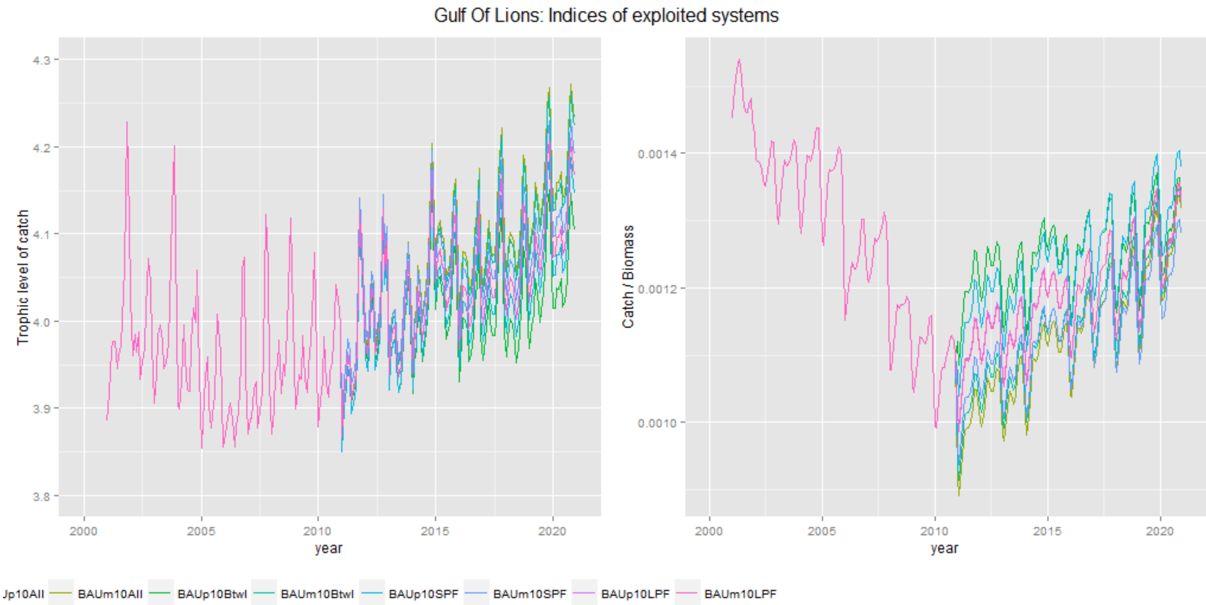

Figure 24. Indices of exploited systems estimated for the HTL scenarios (see also Table 2) applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the HTL scenarios in the coupled model used the same BAU scenario LTL data.

3.2.4 Discussions

In LTL scenarios (2011-2020) relative to the reference period (2000-2010) some metrics of vigor (total catch), organization (fishing in balance and Finn cycling index) and exploitation (trophic level of catch) were significantly decreasing indicating that these agriculture inputs may significantly decrease some metrics of health of marine foodwebs. However the exploitation metrics (trophic level of catch) are to be related generally more to the fishing effort hypotheses (constant at the level of 2009-2010) than to agriculture inputs. We also have to mention a decrease by 9% of fishing effort (number of boats) in the time series 2000-2009 that impacted the foodweb and catches over this period by also after.

More significant effects in term of metrics of health of marine foodwebs appear when testing HTL (fisheries) scenarios, particularly related to catch or catch/biomass (vigor, exploitation indices), but also to the organization (fishing in balance and Finn cycling index). According to scenarios sometimes effect were positive sometimes negative. The highest effects were related to changes in fishing effort for all fishing gears or for benthic trawls.

The tested scenarios were coherent with previous change in fishing effort for the fitted period. Higher change in primary production and fisheries effort should be tested in order to detect the limit of resilience of the system and the time necessary to recover.

Boats power should be included also in the estimation of the fishing effort. For the simulations presented in this report only the number of boats by fleets was available and used. Moreover some changes appeared in the fishermen behavior related to a high increase in biomass of a non commercial small pelagic fish species (sprat, captured since 2008 in the same time with sardine and anchovy). Their activity strongly decreased in the last years and this was not reproduced by the model and may also have induced changes in the foodweb. Increase of invasive non commercial or commercial species may also change fishermen behavior and foodwebs interactions and can be predicted only in scenarios.

Ecopath and Ecosim models were constructed using Ifremer landing and biomasse databases from this area. Scientific field campaigns, new methods of biomass estimation for some species, laboratory studies of organisms' diets (Le Bourg et al., 2015) and integration of local data into foodweb model are essential in order to improve them and to be able to provide information for the management of these ecosystems (Banaru et al., 2013).

The results of the present work contribute to characterize the descriptors D4 marine food webs and D3 exploited species of the **MSFD** in the Gulf of Lions (Northwestern Mediterranean Sea) and to estimate and compare the "health" of Mediterranean foodwebs. However, in spite of a good pedigree of the model (0.67), and high quantities of data available for the Gulf of Lions, the results of the scenarios tested with this ecosystem coupled model should be taken with caution considering the limits of the models and the data.

Complementary methods of modeling (spatial, individual-based models) and continue efforts to improve field ecological knowledge of this area are recommended to be done in order to bring a better comprehension of the system.

The results of this report concerning the Gulf of Lions will be compared to the other Mediterranean foodwebs from the Adriatic and Aegean seas.

3.2.5 References

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3.3 North Aegean Sea continental shelf

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3.3.1 The integrated modelling tool: structure and hindcast

In the current work we used an end-to-end model built for the North Aegean Sea (NAS) ecosystem to simulate a series of environmental (related to climate effects and river runoffs) and fisheries related scenarios. The outputs of these simulations were analyzed by exploring trends of ecosystem metrics related to the three ecosystem attributes, vigor, organization and resilience.

The end-to-end NAS model area is defined by the 20 m and 300 m isobaths (Figure 25) covering 8374 km^2 in total. This is mainly the area where trawlers, purse seiners and the biggest fraction of artisanal fleets operate.

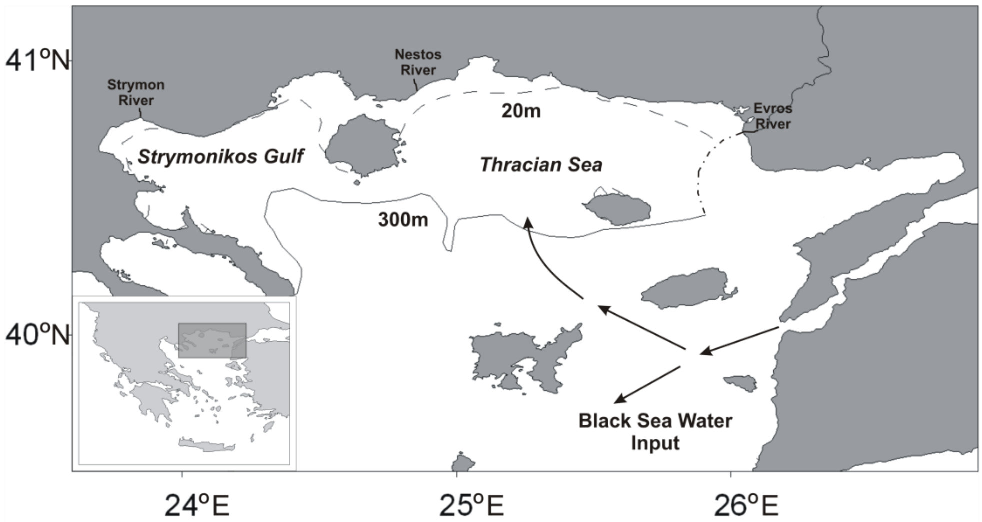

Figure 25. North Aegean Sea (Strymonikos Gulf and Thracian Sea). Isobaths of 20m and 300m which define the model area are shown, as well as the most important rivers of the area. Arrows indicate the direction of Black Sea Water Input.

Outputs of the OPATB-BFM LTL (Lazzari *et al*. 2012) were used as input for the biomasses and diet matrix of the LTL groups as well as to drive the LTL components of the model. The LTL groups included five plankton groups (Phytoplankton, Picophytoplankton, Bacteria, Nano-microzooplankton, Mesozooplankton) which derived from aggregation of the OPATB-BFM, as well as four nutrient related groups (Input PO4, PO4, DOP, POP). Flows and biomasses of the model are expressed in phosphorus, P, which is considered the limiting nutrient in the Mediterranean.

The HTL model is based on the previously developed Ecopath model in the area for the period 2003-2006 (Tsagarakis *et al.*, 2010). This model was adjusted to input data from the early 1990s (mainly 1991-1993), averaging data from separate years. The 1990s model followed a standardized structure which was agreed for all the Mediterranean areas (Gulf of Lions, Adriatic, NAS) and which is described in detail in PERSEUS D4.4. In brief, the HTL fraction of the model was represented by 23 living FGs and two detritus groups (detritus and discards). Input data for the 1990s model included bottom trawl surveys (Bertrand *et al.*, 2002; Labropoulou and Papaconstantinou, 2004), fisheries (El.Stat., 2011) and discards (Anon, 2008) data and other sources of information described in detail in Tsagarakis *et al.* (2010). For each species, production and consumption values were retrieved from the literature (Froese and Pauly, 2014) or estimated based on empirical equations (Pauly, 1980; Pauly *et al.*, 1990), while for multispecies functional groups (FG) these values were weighted with the relative biomass of each species in the FG. Input for diet composition was also based on a literature review. Finally, compared to the 2000s model, several small modifications were also made based on updated literature. Five fishing fleets were considered in the model: (1) bottom trawls, (2) purse seines, (3) static artisanal nets (gill and trammel nets), (4) longlines and troll baits (targeting European hake and large pelagic fish) and (5) pots targeting cephalopod species (octopuses and cuttlefish). Bottom trawls and purse seines constitute the industrial fishery while the rest belong to the artisanal fishery in the area. Species-specific and fleet-specific discards to marketable ratios were estimated using data collected by observers on board commercial boats in the area (Anon., 2008) and applied to estimate the amount of discards generated on an annual basis.

The structure of the food web of the coupled model is shown in Figure 26. For the coupling between LTL and HTL components of the model we followed the methodology described in Libralato and Solidoro (2009). The coupling of the HTL and LTL components required modifications of the values of some parameters such as detritus fate for HTL, P/B for Input PO4 and slight modifications on the diets. Calculated forcing function for some groups coming from the BFM (bacteria, pico- and phytoplankton) were build in Ecosim and applied relative to their respectives "prey" (PO4, POP, DOP). An environmental anomaly forcing function was estimated based on LTL groups biomass time series and was then applied to force input PO4. P/B, Q/B and catches were divided by 12 in order to run it in shorter time step (1/12 of month). Corrections of trophic level outputs were made (as in the initial version of the model PO4, DOP and POP had the trophic level 1). The coupled model was then fitted to LTL and HTL data for the period 1993-2010 (Figure 27 and Figure 28). For the period 1993-2000, no input from the OPATM-BFM was available thus forcing was based on time series constructed based on climatology using data from the 2000-2010 period. The 2000-2010 period was considered as the reference one to be compared with the different scenarios for the period 2011-2020.

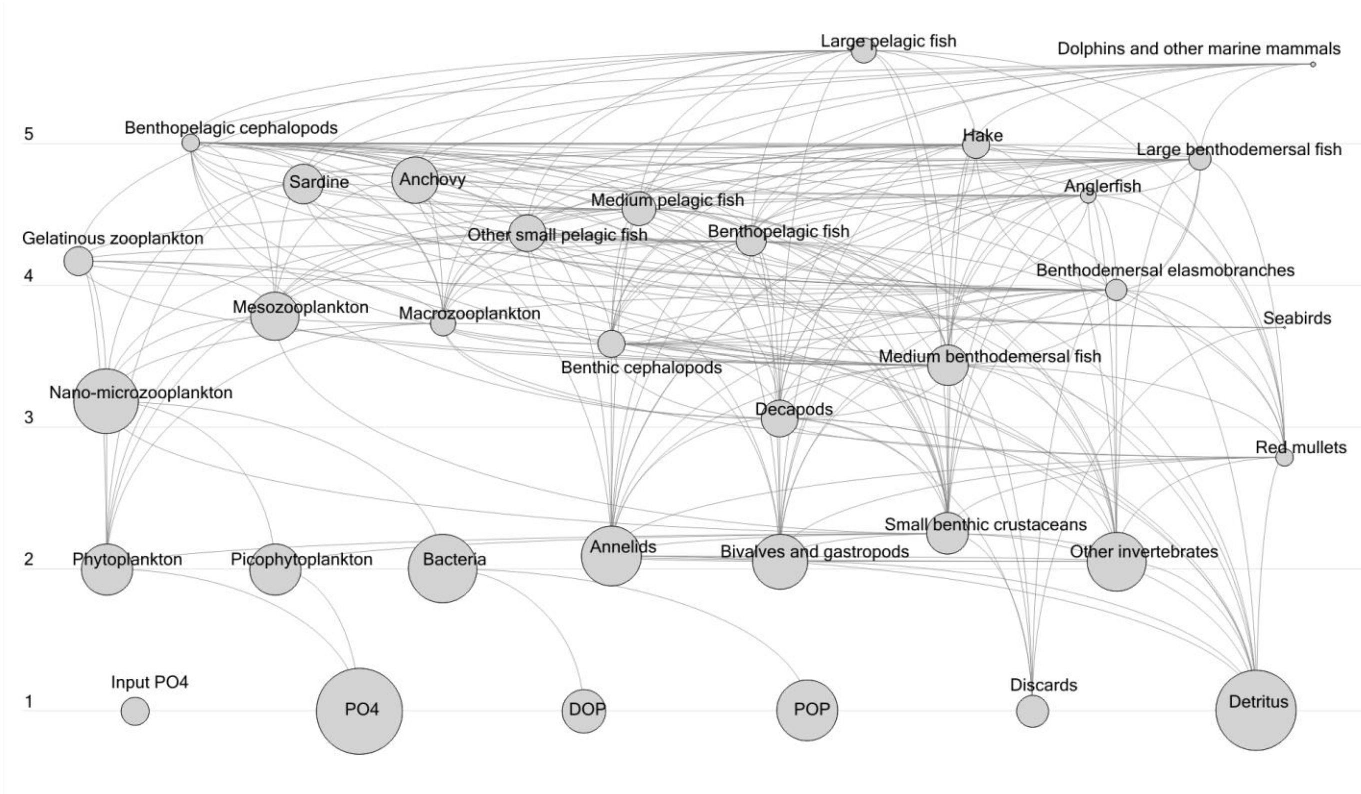

Figure 26. Structure of the foodweb of the end-to-end NAS model. The links between the different compartments show the trophic flows.

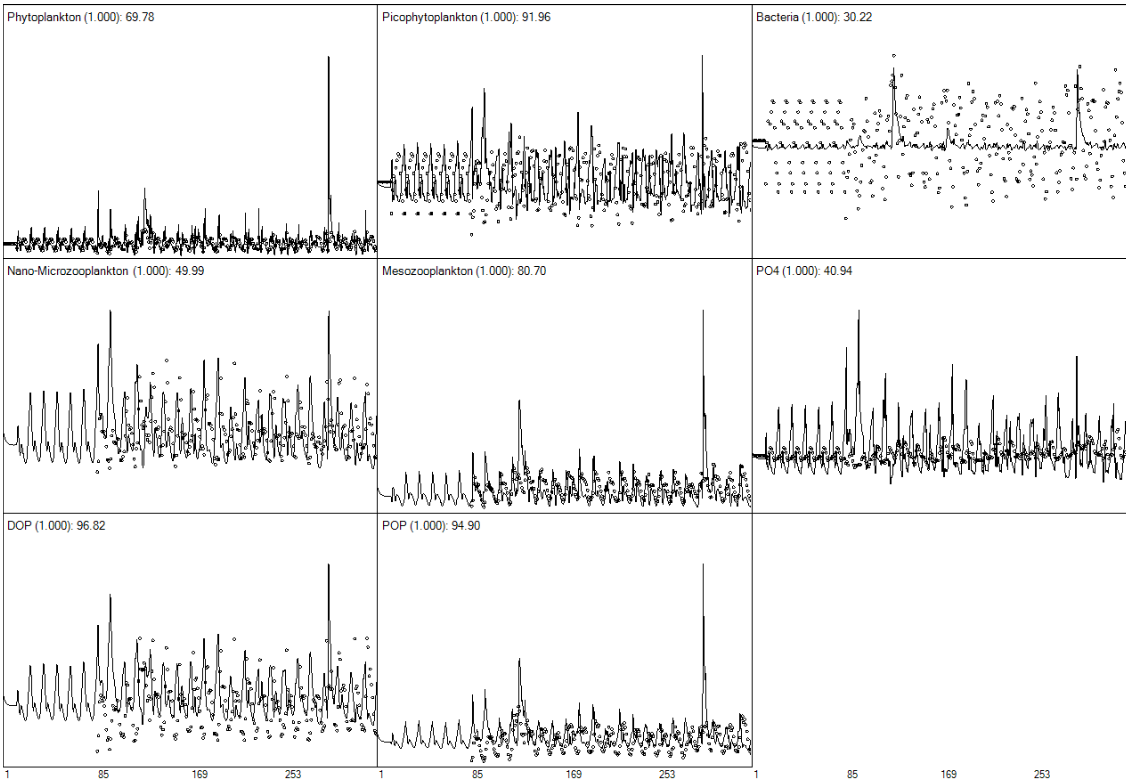

Figure 27. Fitting of LTL groups to data for the period 1993-2010.

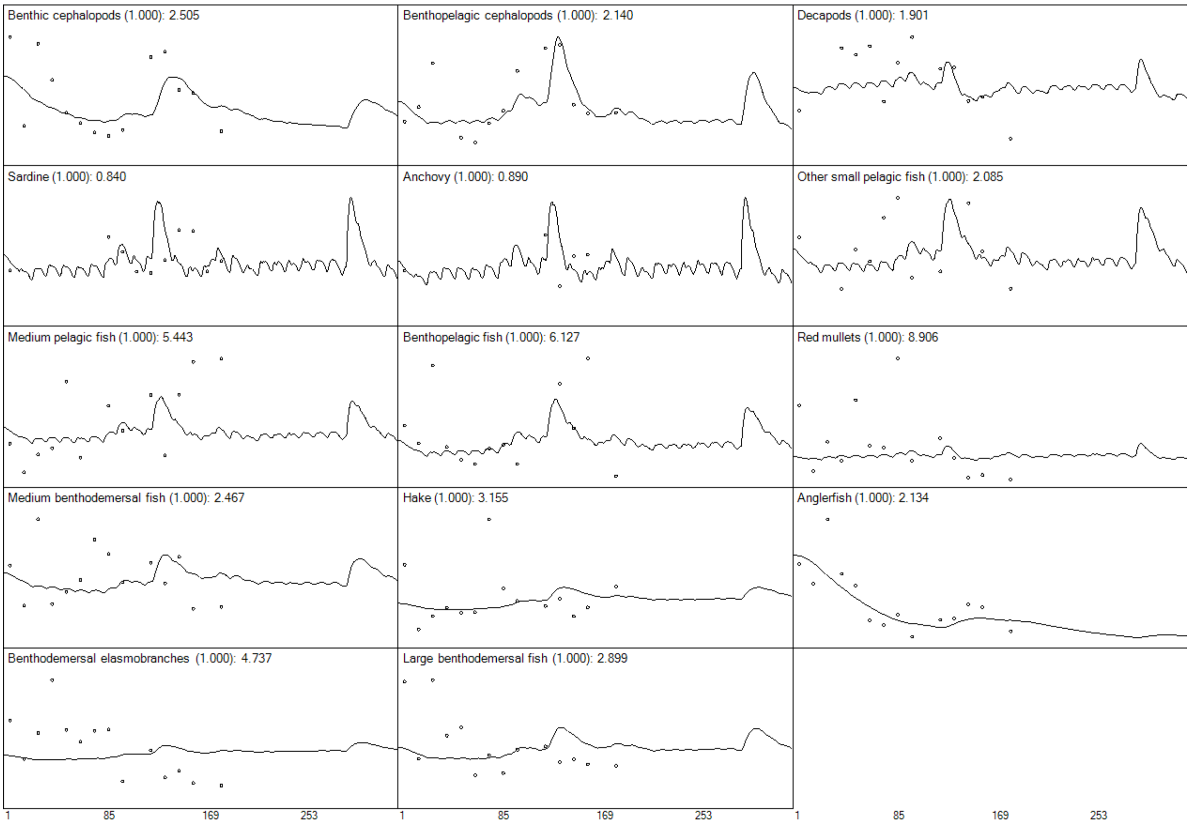

Figure 28. Fitting of LTL groups to data for the period 1993-2010.

3.3.2 Summary statistics

Results from the end-to-end coupled model of the NAS in terms of aggregated summary statistics and network flows are shown in Table 6. Coupling methodology and the new calibration induced some changes in these results compared to the initial model (18th month report of PERSEUS). These are mainly attributed to the fact that in the last version of the model P/B, Q/B and catches were divided by 12 in order to run it in shorter time step (1/12 of month).

Table 6. Ecological indicators of the Ecopath NAS coupled model

Global indices	value	unit
Sum of all consumption	759.33	mg P/m^2/year
Sum of all exports	0.70	mg P/m^2/year
Sum of all respiratory flows	0.00	mg P/m^2/year
Sum of all flows into detritus	605.97	mg P/m^2/year
Total system throughput	1365.99	mg P/m^2/year
Sum of all production	441.36	mg P/m^2/year
Mean trophic level of the catch	3.82	
Gross efficiency (catch/net p.p.)	1.20	
Calculated total net primary production	0.59	mg P/m^2/year
Net system production	0.59	mg P/m^2/year
Total primary production/total biomass	0.004	
Total biomass/total throughput	0.12	
Total biomass (excluding detritus)	158.82	mg P/m^2
Total catches	0.70	mg P/m^2/year
Connectance Index	0.32	
System Omnivory Index	0.26	

3.3.3 Scenarios results

Results of both LTL (agriculture and climate) and HTL (fisheries) scenarios in term of vigor, organization and resilience (“health” ecosystem metrics) as well as in term of indices of exploitation were detailed in Table 7. In the reference period (2000-2010) catch (metric of vigor) and Scope for Growth (metric of resilience) were higher compared to BAU scenario (2011-2020) while some metrics of organization (Fishing in Balance and Finn cycling index) were lower by more than 5%. In BAU scenario all indices of vigor as well as Scope for Growth (resilience) was higher by 5-12% compared to three (MFA, REB, RBE) out of five LTL scenarios. Indices of organization showed mixed results for these 3 scenarios with Kempton's Q, Ascendency and Finn's Cycling Index being higher in BAU and Fishing in Balance and mean Path Length lower (Table 7). As concerns fisheries scenarios only few indicators changed more than 5%. Only FiB was constantly higher in BAU compared to the scenarios that fishing effort or fishing mortality was increased and was lower when decreased (Table 7).

As also seen in Table 7 apparent changes in time series were mostly observed for 3 (MFA, REB, RBE) out of five LTL scenarios compared to BAU and trends among them were similar. BA scenario also differentiated compared to BAU but mean values across the entire simulated period (2011-2020) were closer to the BAU scenario.

Table 7. Indices related to vigor, organization and resilience for the LTL and HTL scenarios of the North Aegean Sea. Absolute values are presented for the reference and scenarios periods, while relative changes are reported for the remaining scenarios. Significant differences (> 5%) between reference (BAU and reference period) and all other, between other scenarios are indicated in bold and in shaded cells (red for negative values/decrease of metrics and green for positive values/increase of metrics).

North Aegean Sea		**Vigor**				**Organisation**				**Resilience**		**Exploitation**	
"health" metrics	NPP	T	Catch	K's Q	FiB	AMI	A	FCI	mPL	H-AMI	SfG	C/B	TLc
Reference period (Ref.P)													
2000-2010 (fitted to data)	1.38	1616.60	0.67	6.78	0.00	1.98	3190.16	36.78	7.86	2.65	461.37	0.00	3.84
Agriculture and climate scenarios (2011-2020)													
BAU reference scenario (constant fishing effort)	1.34	1542.40	0.63	6.46	0.00	1.98	3042.62	44.90	8.24	2.66	429.40	0.00	3.83
(Ref.P - BAU)*100/Ref.P	2.6	4.6	**5.5**	4.8	**-329.7**	0.0	4.6	**-22.1**	-4.8	0.0	**6.9**	-0.5	0.2
(BAU-BA)*100/BAU	-0.1	0.1	-1.9	**-5.0**	**-13.4**	-0.2	-0.3	-5.1	2.1	-0.4	0.1	2.2	-0.1
(BAU-MFA)*100/BAU	**5.1**	**7.2**	**11.9**	**5.8**	**-153.2**	0.1	**7.2**	**12.9**	**-5.5**	0.6	**11.5**	0.8	0.5
(BAU-REB)*100/BAU	**5.1**	**7.1**	**11.7**	**5.8**	**-151.7**	0.1	**7.0**	**6.7**	**-5.2**	0.6	**11.3**	0.8	0.5
(BAU-RBE)*100/BAU	**5.1**	**7.0**	**11.6**	**5.6**	**-150.9**	0.1	**7.0**	**14.1**	**-5.1**	0.6	**11.2**	0.8	0.5
Fisheries scenarios (2011-2020)													
(BAU-p10All)*100/BAU	0.0	0.0	**-6.9**	-0.3	**106.2**	0.0	0.0	**8.8**	0.1	0.0	0.1	**-7.2**	0.2
(BAU-m10All)*100/BAU	0.0	0.0	**7.2**	0.8	**-94.3**	0.0	-0.1	-4.4	-0.1	0.0	-0.1	**7.5**	-0.2
(BAU-p10Btwl)*100/BAU	0.0	0.0	-1.7	0.2	**20.8**	0.0	0.0	-1.4	0.0	0.0	0.0	-1.8	0.1
(BAU-m10Btwl)*100/BAU	0.0	0.0	1.7	-0.2	**-20.4**	0.0	0.0	-3.8	0.0	0.0	0.0	1.8	-0.1
(BAU-p10SPF)*100/BAU	0.0	0.0	-2.8	0.4	**60.6**	0.0	0.1	-4.6	0.1	0.0	0.0	-3.0	0.0
(BAU-m10SPF)*100/BAU	0.0	0.0	3.0	-0.4	**-54.8**	0.0	0.0	-4.8	-0.1	0.0	0.0	3.1	0.0
(BAU-p10LPF)*100/BAU	0.0	0.0	0.0	-0.6	0.7	0.0	0.0	-4.9	0.0	0.0	0.0	-0.1	0.0
(BAU-m10LPF)*100/BAU	0.0	0.0	0.1	0.7	-0.8	0.0	0.0	-1.8	0.0	0.0	0.0	0.1	0.0

3.3.3.1 Vigor

Regarding indicators related to vigor, these changes were higher in the catch than in NPP and Throughput for LTL scenarios (Figure 29). Fisheries scenarios did not affect NPP and Throughput but catch was increased when fishing effort or mortality was increased (Figure 30).

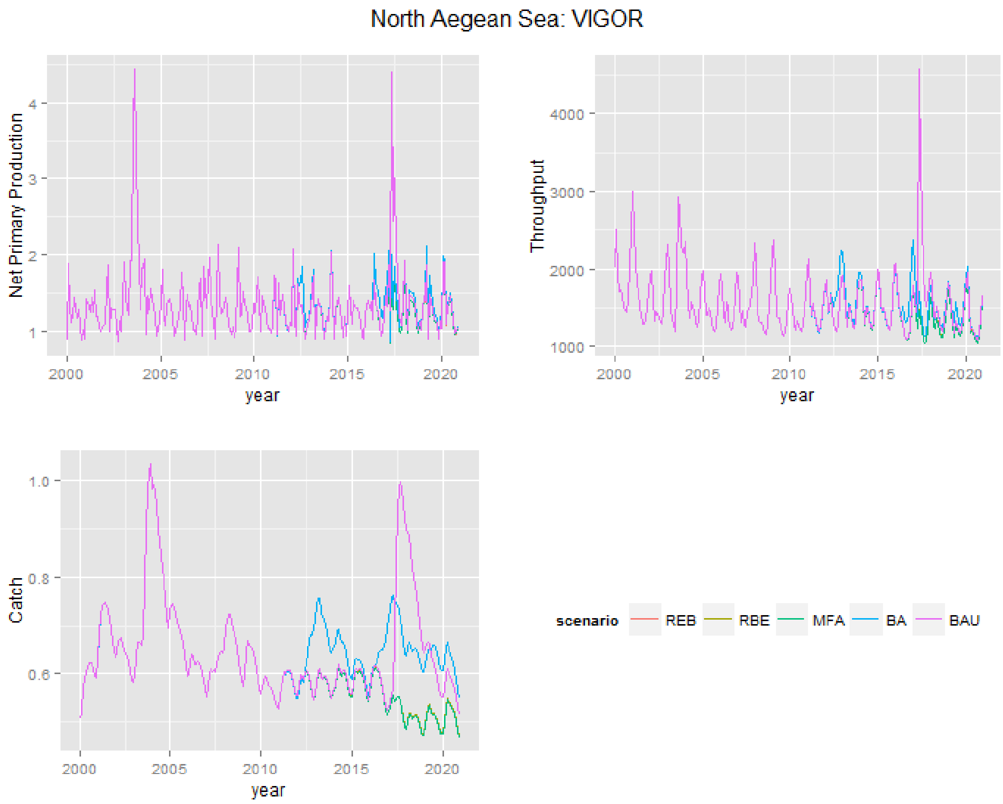

Figure 29. Vigor estimated metrics for the LTL scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

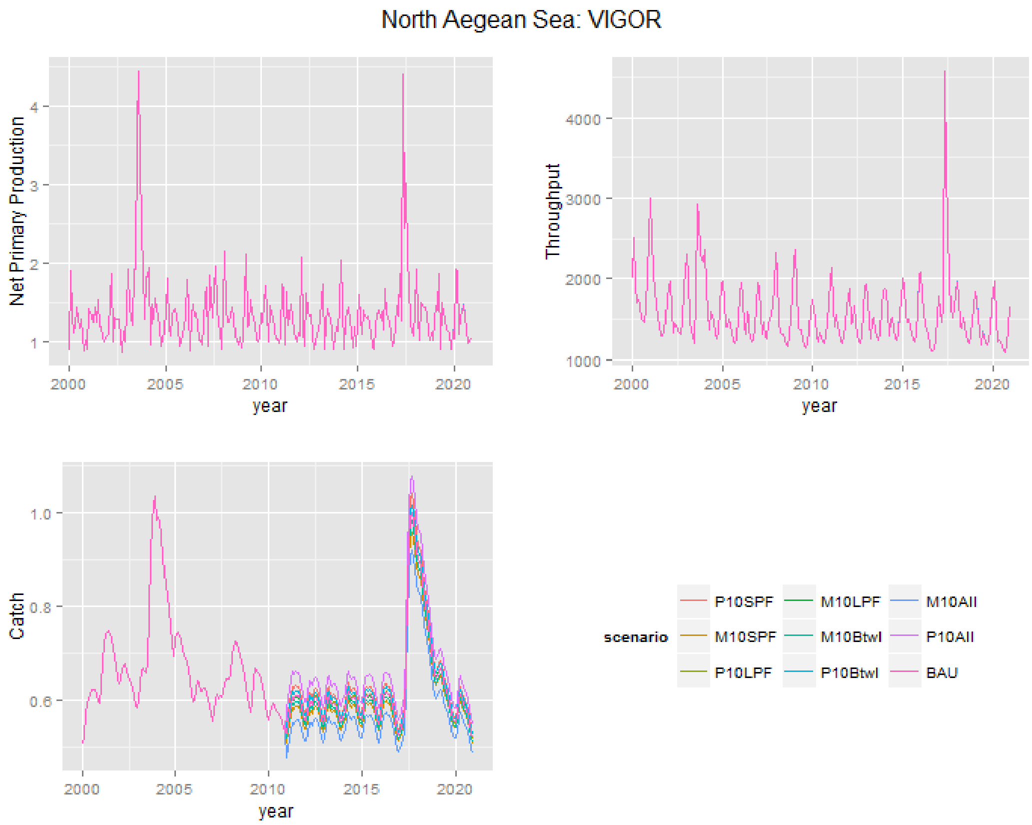

Figure 30. Vigor estimated metrics for the HTL (fisheries) scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the HTL scenarios in the coupled model used the same BAU scenario LTL data.

3.3.3.2 Organization

Time series of indices related to organization were very similar for MFA, REB, RBE which deviated from BAU especially after 2017. BA differentiated from BAU earlier, after 2012 but values were closer to BAU. These changes were more apparent for Kempton's Q, FiB, FCI and Ascendency (Figure 31). Fisheries related scenarios changed mainly for Kempton's Q, FiB and FCI (Figure 32).

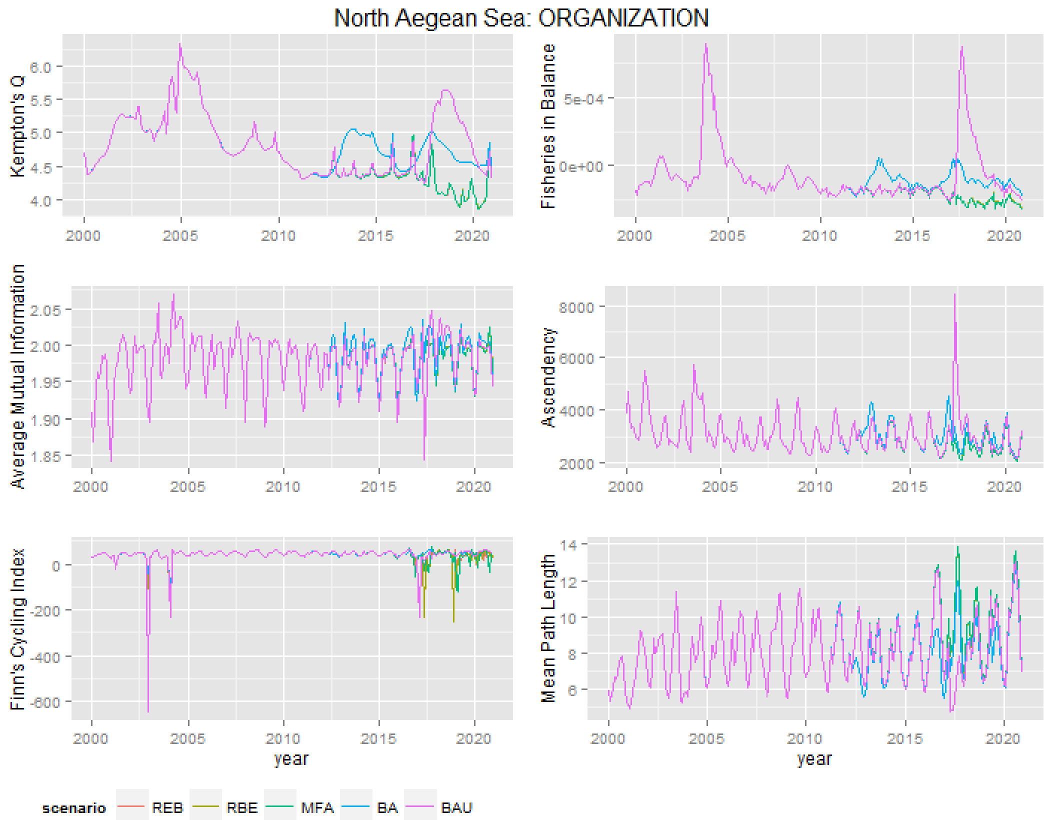

Figure 31. Organisation estimated metrics for the LTL LTL scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

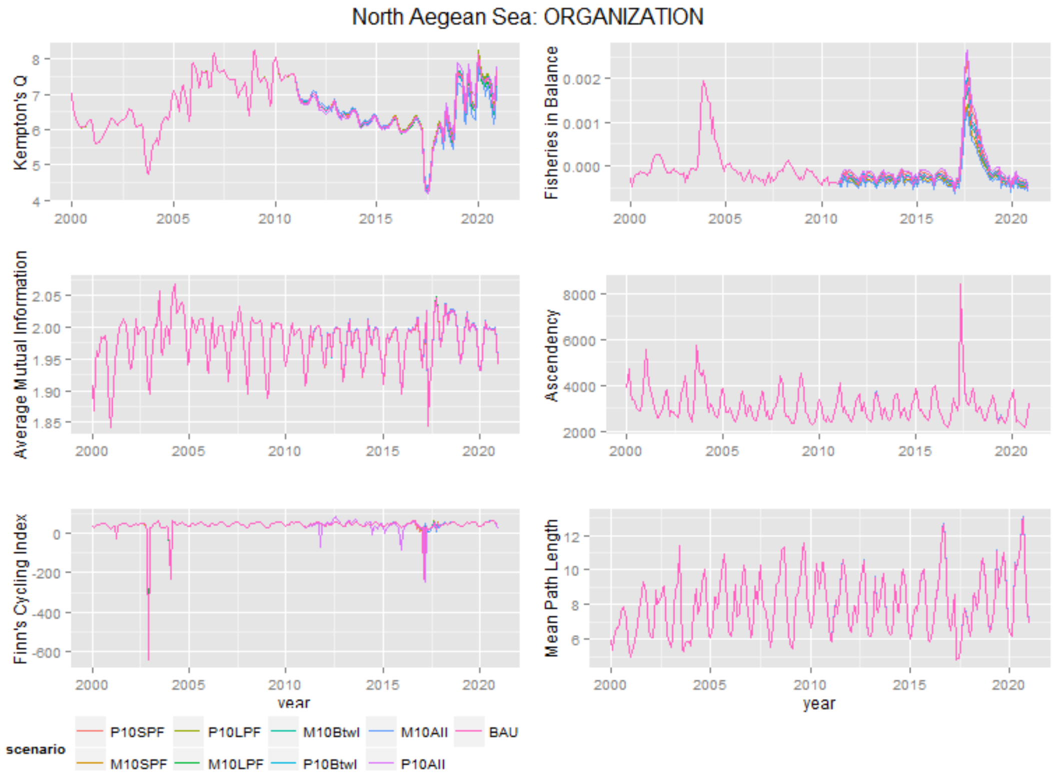

Figure 32. Organisation estimated metrics for the HTL (fisheries) scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the HTL scenarios in the coupled model used the same BAU scenario LTL data.

3.3.3.3 Resilience

In time series of indicators related to resilience the situation was similar to the two other ecosystem attributes. LTL scenarios MFA, REB and RBE differentiated from BAU again after 2017 (Figure 33) at lower values overall. On the other hand these indicators were not sensitive in fisheries scenarios (Figure 34).

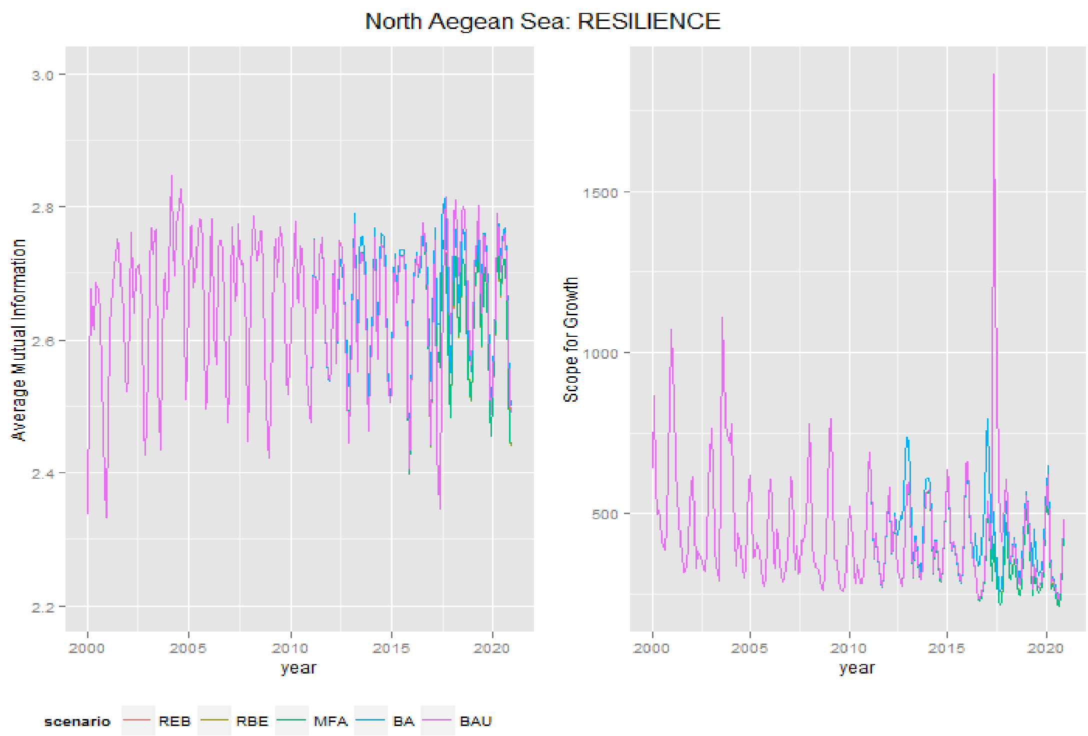

Figure 33. Resilience estimated metrics for the LTL LTL scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

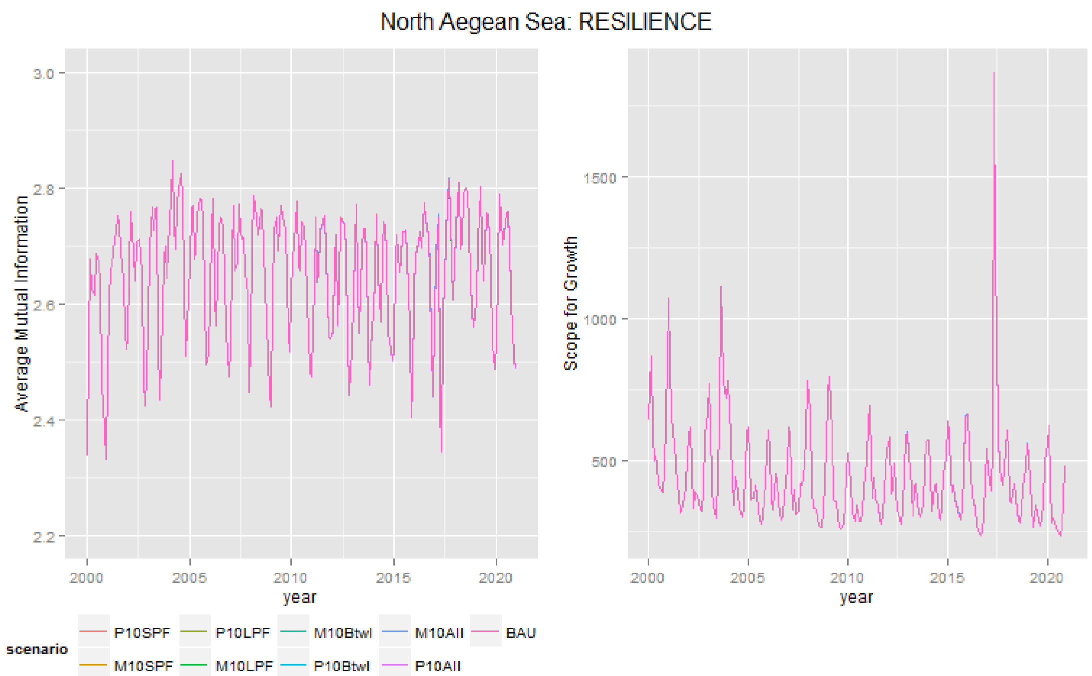

Figure 34. Resilience estimated metrics for the HTL (fisheries) scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the HTL scenarios in the coupled model used the same BAU scenario LTL data.

3.3.3.4 Indices of exploitation

Catch over Biomass ratio as well as mean Trophic Level of the Catch deviated a lot from BAU in LTL scenarios (Figure 35), however mean values were similar for the simulated period. In fisheries related scenarios, Catch over Biomass ratio was higher when fishing effort and mortality was increasing while mTL didn't show apparent changes (Figure 36).

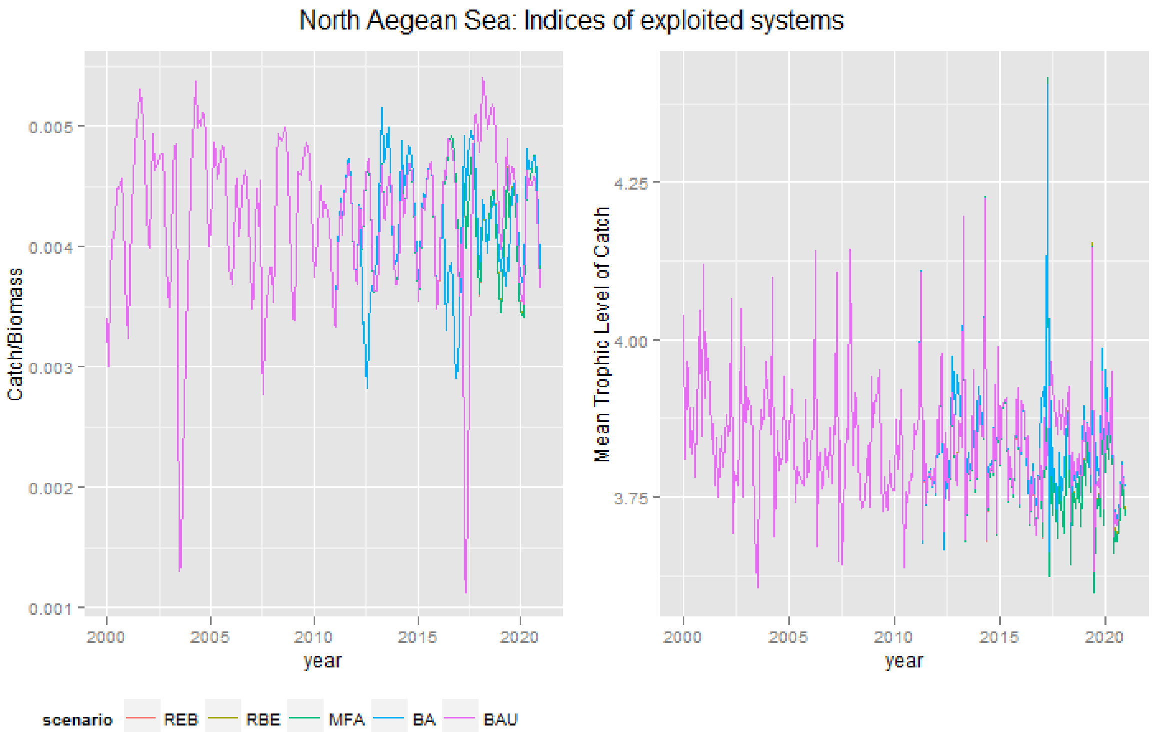

Figure 35. Indices of exploited systems estimated for the LTL scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

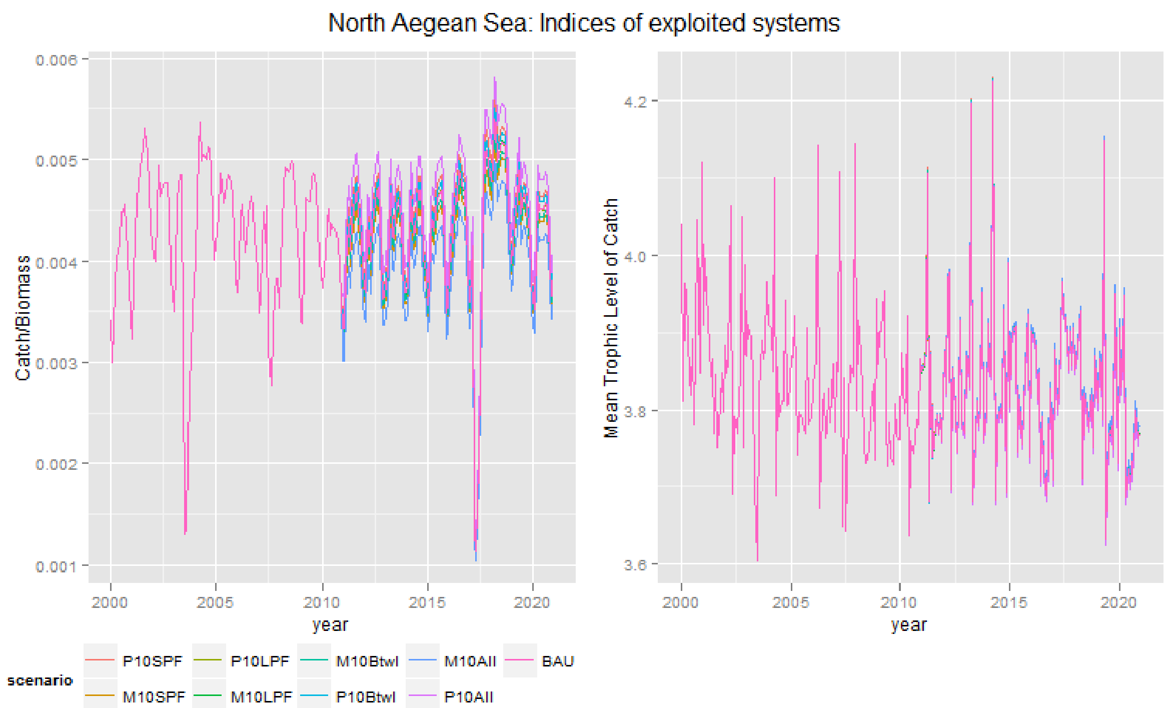

Figure 36. Indices of exploited systems estimated for the HTL (fisheries) scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the HTL scenarios in the coupled model used the same BAU scenario LTL data.

3.3.4 Discussions

Among the scenarios examined, three of the climate ones (MFA, RBE, REB) showed the larger changes compared to BAU. The simulated changes in the nutrient inputs had a negative effect on the system Vigor as seen by the reduction in the Throughput, Net Primary Production and Catch. Similar effect was found for Resilience (specifically Scope for Growth) while the effect of Organisation related metrics was mixed with some descending (Kempton's Q, Ascendancy, Finn Cycling Index) and other ascending (Fishing in Balance, mean Path Length). In general the level of change compared to BAU was substantial for these three scenarios, however among them the changes were almost irrelevant.

The time series of the different metrics under the fisheries related scenarios followed similar patterns with BAU but positively or negatively shifted, depending on the change in fishing effort/mortality. The catch increased as a direct effect of increasing fishing effort/mortality (and vice versa), however the effect on FiB index was opposite implying that there was an impact on fisheries sustainability. The most apparent effects were when changing the fishing effort of all gears (+/- 10%) followed by the scenarios that fishing mortality of small pelagic fish (SPF) was altered. The latter was probably due to the fact that SPF dominate mid-trophic levels and may affect both higher and lower trophic levels, which is known as wasp-waist control (Cury *et al.*, 2000) and impacts several ecosystem components, as reflected in the values of the metrics. However, in general the examined metrics showed lower changes under the fisheries scenarios compared to the climate driven ones. It should be further explored whether this is related to the fact that flows among LTL groups dominate the system and the model's (and metrics) response is more sensitive to nutrient changes than to modifications on the fisheries.

Not all metrics showed sensitivity to the examined scenarios. For example AMI, H-AMI and TLc showed very little sensitivity in contrast to e.g., FiB and Catch. In addition, even the sensitive metrics showed contrasting trends in some cases. This highlights the need to use several metrics for the assessment of ecosystem status, as already proposed by several authors (e.g., Christensen, 1995; Coll *et al.*, 2016). Still, in general it can be said that the climate scenarios under study do not contribute to MSFD goals of achieving good environmental status in the NAS, at least not for the two descriptors that are most relevant to this analysis, D4 food webs and D3 exploited species. The reduction of fishing effort/mortality is a positive management scenario towards this direction but a larger reduction is probably needed for substantial improvement.

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3.4 West Black Sea

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3.4.1 The integrated modelling tool: structure and hindcast

In the current work we used an end-to-end model built for the West Black Sea (WBS) ecosystem to simulate a series of environmental (related to climate effects and river runoffs) and fisheries related scenarios. The outputs of these simulations were analyzed by exploring trends of ecosystem metrics related to the three ecosystem attributes, vigor, organization and resilience.

The GHER model implemented in the Black Sea northwestern shelf (BS-NWS) includes hydrodamics (Capet et al, 2012), pelagic biogeochemistry (Grégoire et al., 2008; Capet A., 2014) and benthic biogeochemistry (Capet et al, 2015). It has a horizontal resolution of 15 km, and used a double-sigma vertical coordinate systems (terrain-following, 20 layer from 0-120 m + 11 layers below). Although the focus is on the BS-NWS, this implementation considers the entire BS basin in order to avoid boundary conditions problems at the shelf break. Forcings for the HTL models were derived using projections of river runoff and nutrient load (D.4.6) and atmospheric conditions (D.4.2). A base simulation covered the years 1980-2010. From 2010 to 2020, five different sets of riverine load scenarios were used to elongates the simulation initialized from the base simulation.

Given the short projection time considered, the riverine forcing data provided for different socio-economical scenario showed only very small differences. As could be expected, the differences between LTL simulations obtained using these different forcing sets are similarly very smalls.

The GHER LTL simulation used for end-to-end WBS model shown in this report were performed using nutrient river discharge scenarios and data (BAU, BA, MFA, REB, RBE) that are computed as described in **Error! Reference source not found.** for the period 2011-2020.

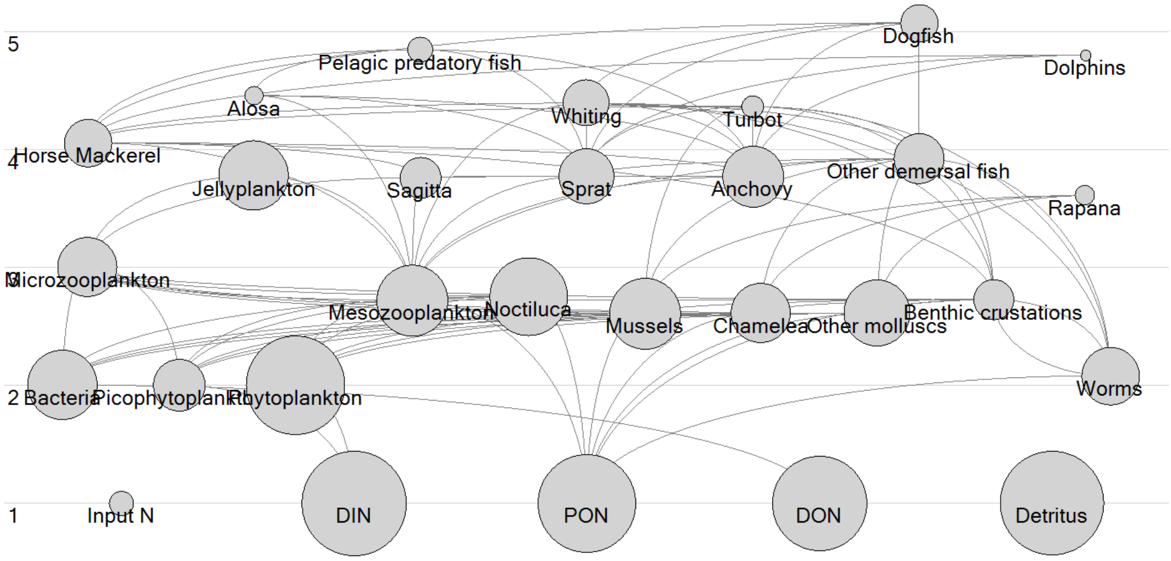

Figure.37 Food web diagrams of the regional WBS model

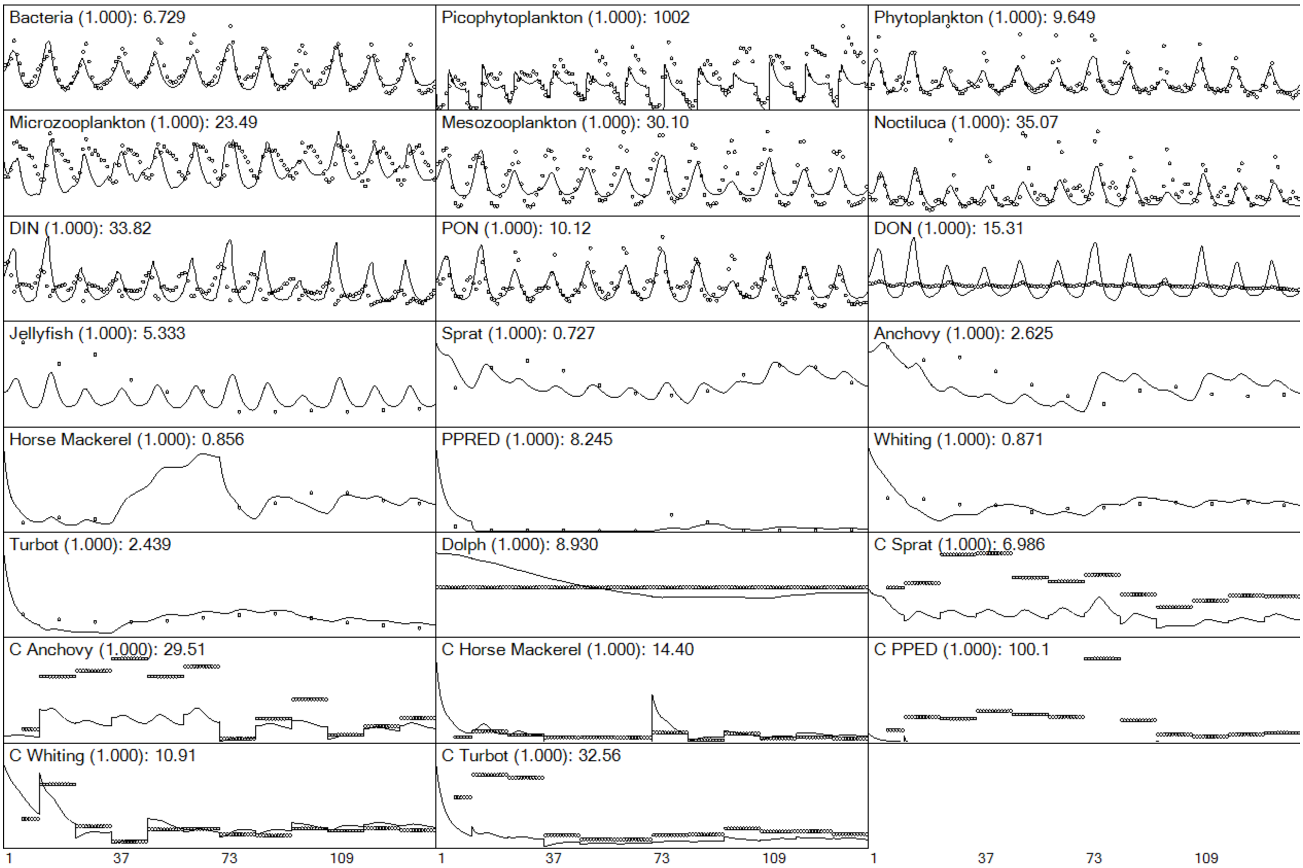

Figure 38. Time dynamic model estimates (lines) of the main trophic groups in the WBS model 2000-2010, fitted to empirical data (dots)

3.4.2 Scenarios results

Results of the BAU scenario for the period 2011-2020 were compared to those of the reference period fitted to data (2000-2010). Results of the models using BA, MFA, REB, RBE data were compared to those of the model using BAU (business as usual) scenario considered as the reference one for the period 2011-2020. In all these LTL scenarios fishing pressure was considered constant between 2010 and 2020.

Results are presented in Table 8. and Figures 4-11. LTL scenarios present almost no significant differences to the reference (BAU) scenario. LTL changes in the end-to-end model are mainly driven by the input of the LTL model. The fisheries scenarios have more pronounced (significant) effects that can be interpreted in the light of the important fishing pressures in the WBS. Further results will be presented in terms of Vigor, Organisation, Resilience and Exploitation.

Table 8. Indices related to vigor, organization, resilience and exploitation for the LTL and HTL scenarios of the West Black Sea. Absolute values are presented for the reference and scenarios periods, while relative changes are reported for the remaining scenarios. Statistically significant differences (p>0.05) between reference (BAU and reference period) between other scenarios are indicated in bold and in shaded cells (red for negative values/decrease of metrics and green for positive values/increase of metrics).

Gulf of Lions	**Vigor**			**Organisation**						**Resilience**		**Exploitation**	
"health" metrics	NPP	T	Catch	K's Q	FiB	AMI	A	FCI	mPL	H-AMI	SfG	C/B	TLc
Reference period (Ref.P)													
2000-2010 (fitted to data)	0.994	118489.97	0.99	3.08	0.02	2.22	54489.43	32.42	6.39	2.64	6348.90	0.00035	3.89
BAU reference scenario	0.995	116357.05	0.95	2.89	0.00	2.22	53335.54	27.36	6.45	2.65	6127.89	0.00034	3.87
(BAU-Ref.P)*100/Ref.P	0.13	-1.80	-3.49	-6.21	-104.04	0.10	-2.12	-15.60	0.90	0.33	-3.48	-3.15	-0.50
(BA-BAU)*100/BAU	0.01	-0.25	-0.05	-0.08	3.34	0.02	-0.27	-0.87	0.12	0.02	-0.47	0.02	0.00
(MFA-BAU)*100/BAU	0.01	-0.22	-0.08	-0.04	4.13	0.01	-0.24	-1.63	0.12	0.02	-0.41	0.07	0.00
(REB-BAU)*100/BAU	0.00	-0.13	-0.06	0.04	3.27	-0.01	-0.14	-1.98	0.11	0.01	-0.23	0.18	0.01
(RBE-BAU)*100/BAU	0.02	-0.31	-0.08	-0.14	4.74	0.03	-0.34	0.00	0.14	0.02	-0.57	-0.06	0.00
Fisheries scenarios													
(P10All-BAU)*100/BAU	0.00	0.00	8.15	-16.11	-420.13	0.00	0.00	24.94	-0.01	0.00	0.00	8.16	-0.27
(M10all-BAU)*100/BAU	0.00	0.00	-8.10	-10.89	357.76	0.00	0.00	26.01	0.02	0.00	0.00	-8.10	0.33
(P10dem-BAU)*100/BAU	0.00	0.00	1.22	-13.86	-14.33	0.00	0.00	8.17	0.00	0.00	0.00	1.23	-0.01
(M10dem-BAU)*100/BAU	0.00	0.00	-0.73	-13.46	1.09	0.00	0.00	-6.92	0.01	0.00	0.00	-0.74	0.03
(P10SPF-BAU)*100/BAU	0.00	0.00	7.51	-13.84	-412.87	0.00	0.00	-8.02	-0.01	0.00	0.00	7.50	-0.20
(M10SPF-BAU)*100/BAU	0.00	0.00	-7.13	-13.49	344.44	0.01	0.00	24.68	0.02	0.00	0.00	-7.13	0.25

3.4.2.1 Vigor

LTL scenarios have no pronounced effect on Vigor in the WBS (Table 8, Fig. 39)

Fisheries scenarios have pronounced effect on the Catch in the WBS (Table 8, Fig. 40) and this effect is nearly proportional (by 7-8%) to the increase/decrease of the fishing pressure over the total fishing effort and the effort applied to the small pelagic stocks which have a dominant shere of the total catch.

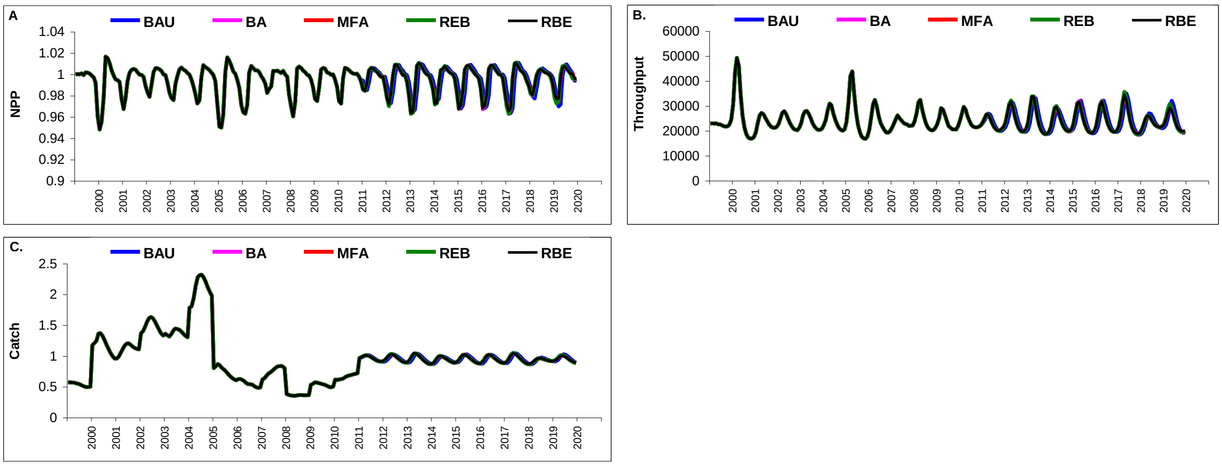

Figure 39. Vigor estimated metrics for the LTL scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

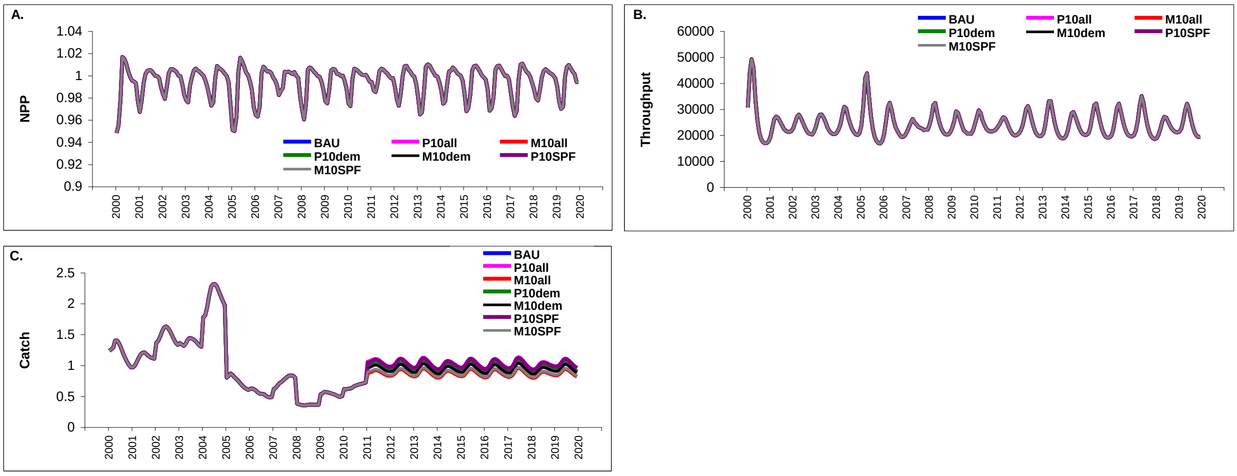

Figure 40. Vigor estimated metrics for the HTL (fisheries) scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the HTL scenarios in the coupled model used the same BAU scenario LTL data.

3.4.2.2 Organization

Projection of the BAU scenario (2011-2020) significantly declined in terms of Kempton's Q, FiB and FCI (Table 8) related to the reference period (2000-2010). Other scenarios did not show significant differences to the BAU reference scenario.

The Fishing in Balance (FiB) indicator declined when total/small pelagics fishing effort was increased, and respectively increased when effort was reduced by 10% (Table 8, Fig. 42). Kempton's Q showed decrease in all fisheries scenario but most significantly when total effort was increased. Finn's Cycling Index (FCI) significantly increase when total fishing effort was increased and decrease, and when fishing mortality of small pelagic stocks was decreased.

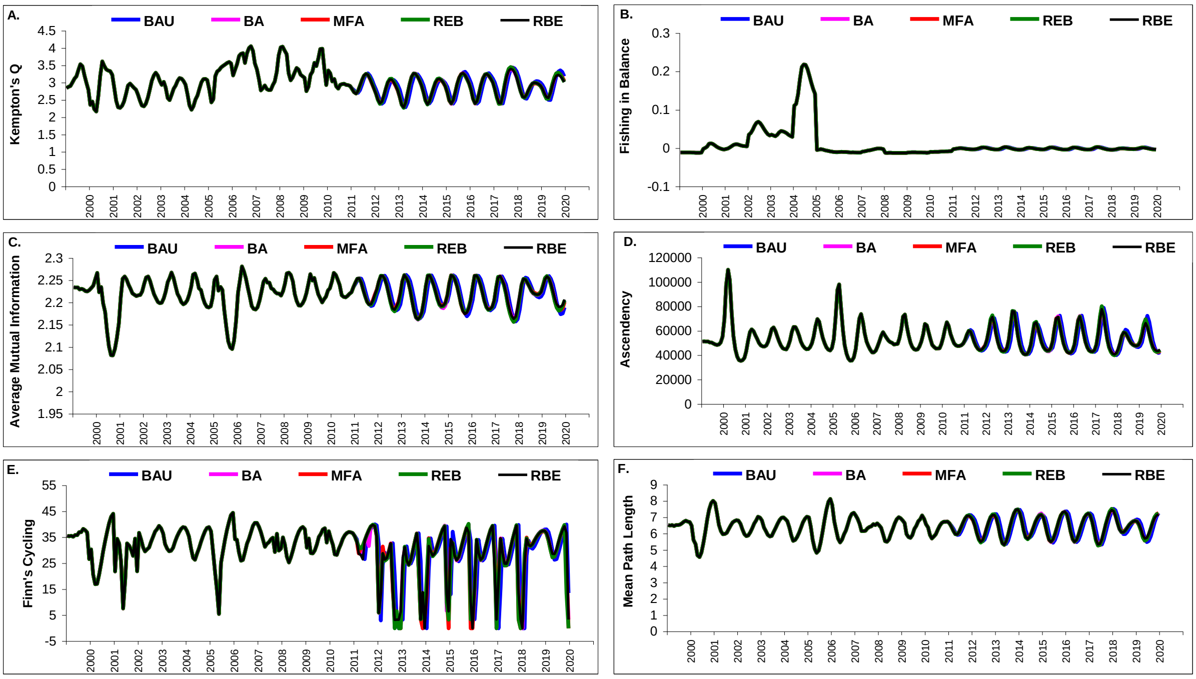

Figure 41. Organisation estimated metrics for the LTL LTL scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

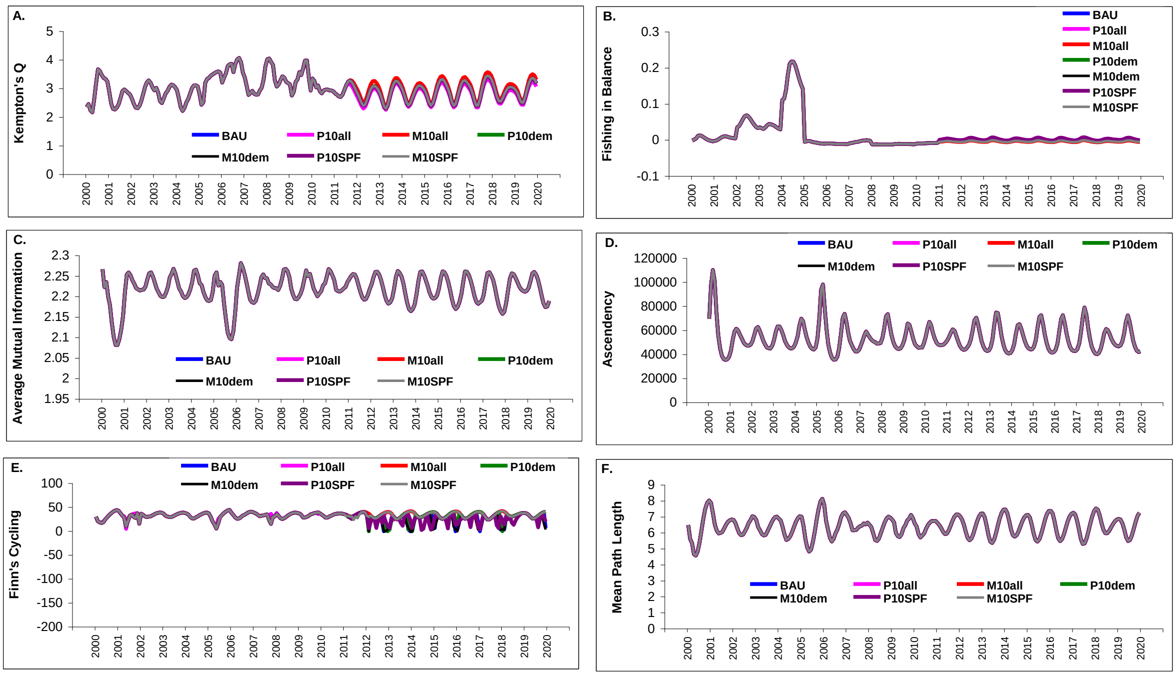

Figure 42. Organisation estimated metrics for the HTL (fisheries) scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the HTL scenarios in the coupled model used the same BAU scenario LTL data.

3.4.2.3 Resilience

No significant changes were registered in terms of resilience indicators in the WBS model (Table 8., Figs. 43, 44).

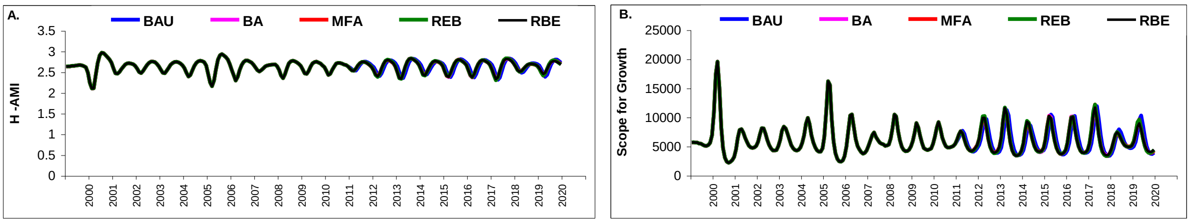

Figure 43. Resilience estimated metrics for the LTL LTL scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

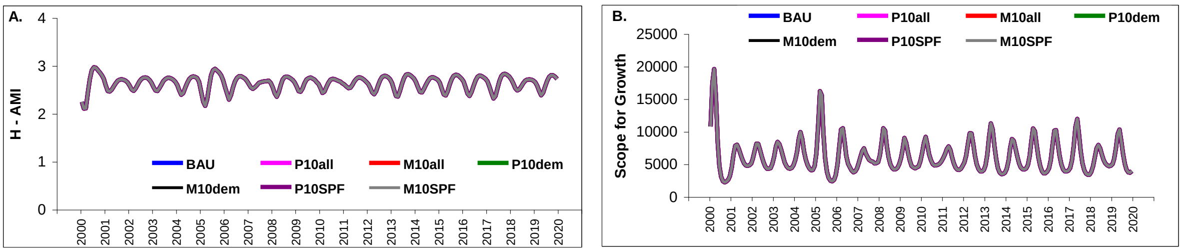

Figure 44. Resilience estimated metrics for the HTL (fisheries) scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the HTL scenarios in the coupled model used the same BAU scenario LTL data.

3.4.2.4 Indices of exploitation

Some decrease in Trophic Level of the Catch (TLc) the projected of the BAU scenario (2011-2020) compared to the reference period (2000-2010) is to be noted (Table 8, Figure 45)

In fisheries scenarios, again pronounced changes are evident when varying total fishing effort and effort applied to small pelagic stocks: respectively Catch over Biomass ratio is up/down when effort increases/decrease, and conversely Trophic Level of the Catch decreases/increases when effort is up/down (Table 4., Fig. 46).

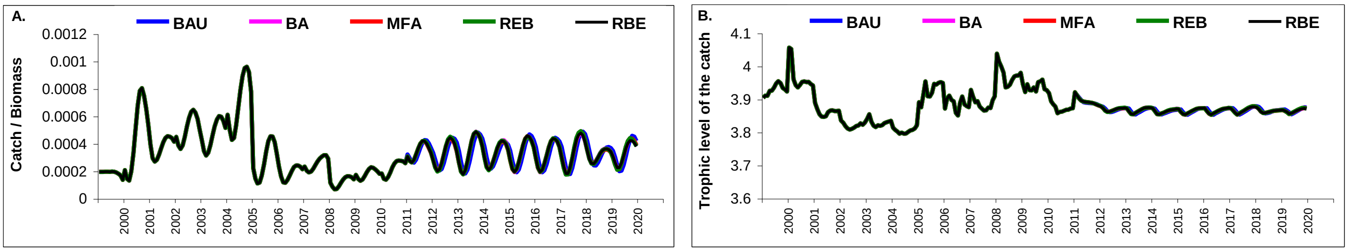

Figure 45. Indices of exploited systems estimated for the LTL scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

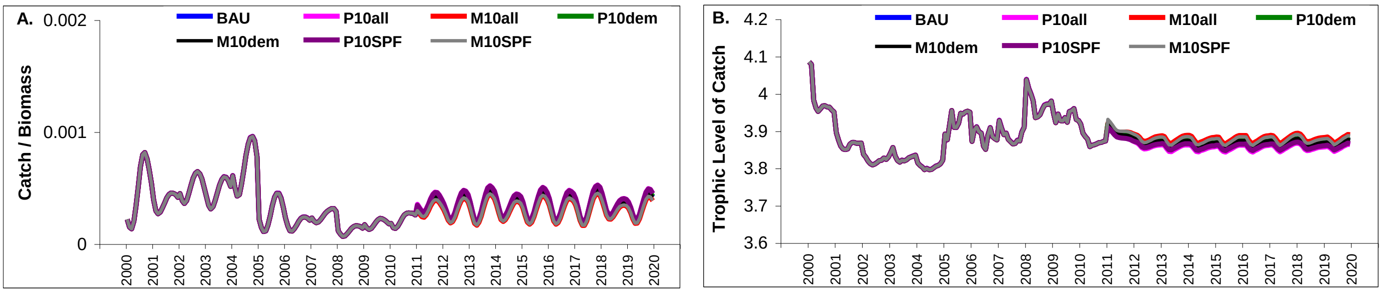

Figure 46 Indices of exploited systems estimated for the HTL (fisheries) scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the HTL scenarios in the coupled model used the same BAU scenario LTL data.

3.4.3 Discussions

Some indicators of organisation: Kemtonn's Q, Fishing in Balance and Finn's Cycling Index showed decreasing trend of projected reference (BAU) scenario in 2011-2020. The Trophic level of the catch has also shown a significant albeit small decrease during the projection period. The other LTL scenarios (BA, MFA, REB, RBE) did not differ significantly from the reference (BAU) scenario

The fisheries scenarios have significant effects in the WBS model proportional to the changes of the fishing effort. Reducing total fishing effort as well as fishing of small pelagic fishes (which are dominant part of the total catch) had positive effects on the indicators of organisation such Fishing in Balance and Finn's Cycling Index and on the Trophic level of the catch, and the increase of the fishing effort has an opposite effect. However it should be noted that those effects are rather small, and indicators such as total Throughput, Ascendency, Information and Scope for Growth are insensitive to such small variation in fishing pressure.

Compared to the similar end-to-end model of the East Black Sea (EBS) presented later in the report, these effect are to be expected, as fish biomass and catches have more important share in the trophic network of the WBS.

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3.5 East Black Sea

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3.5.1 The integrated modelling tool: structure and hindcast

The hydrodynamical model is based on the three-dimensional GFDL MOM (Staneva et al, 2010). Solid boundaries are non-slip and insulating for temperature and salinity. Convection is parameterized by convective adjustment that is often used to remove static instabilities. The model has 24 vertical levels; mixing and diffusion in the horizontal are parameterized with biharmonic operators. The vertical diffusion in the model is parameterized as stability dependent.

The structure of the biogeochemical model BIOGEN (Lancelot et al., 2002, Staneva et al, 2005,2010)-state variables and processes linking them- is schematically illustrated in Fig. 49. The model describes the cycling of carbon, nitrogen, phosphorus and silicon through aggregated chemical and biological compartments of the planktonic and benthic systems. Each biological component represents a set of different organisms grouped together according to their trophic level and functional ecological behaviour. BIOGEN thus includes 34 state variables assembled in five models. The results of coupling between different physical models (mixed layer model, box-like model and 3-D basin-wide general circulation model) and ecosystem model (Lancelot et al., 2002) demonstrate that simulated phytoplankton evolution compares well with the SeaWiFS satellite data. The impact of natural and anthropogenic matter from the land to the coastal environment and identifying limitations on the nutrient capacity of the coastal waters by studying extreme events for the Black Sea have been studied (Tsiaras et al. 2008, Staneva at al., 2010).

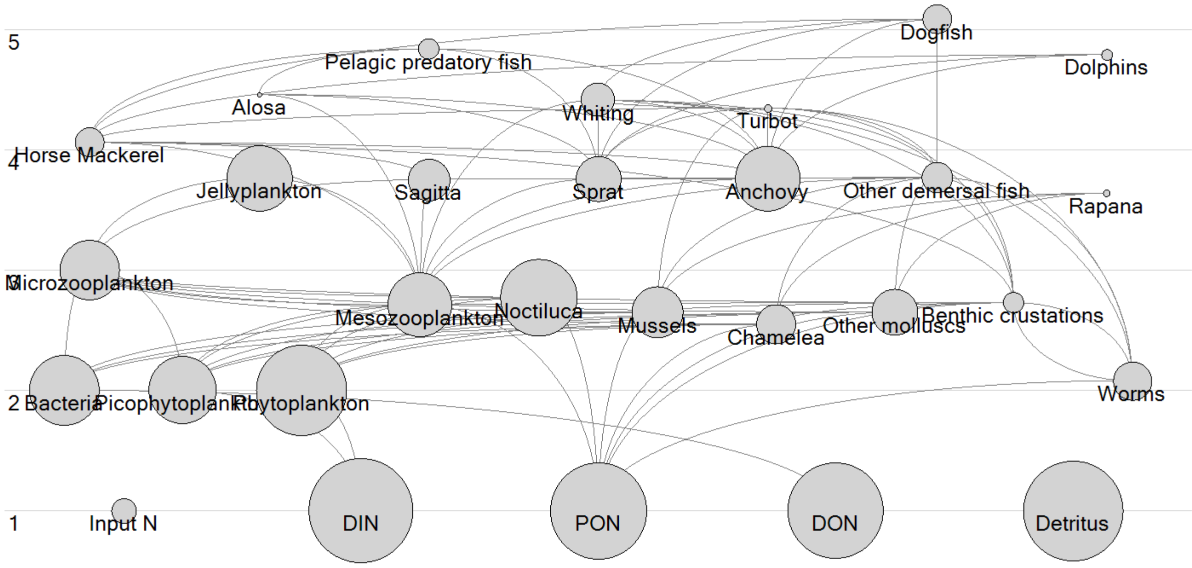

Figure 47. Food web diagrams of the regional EBS model

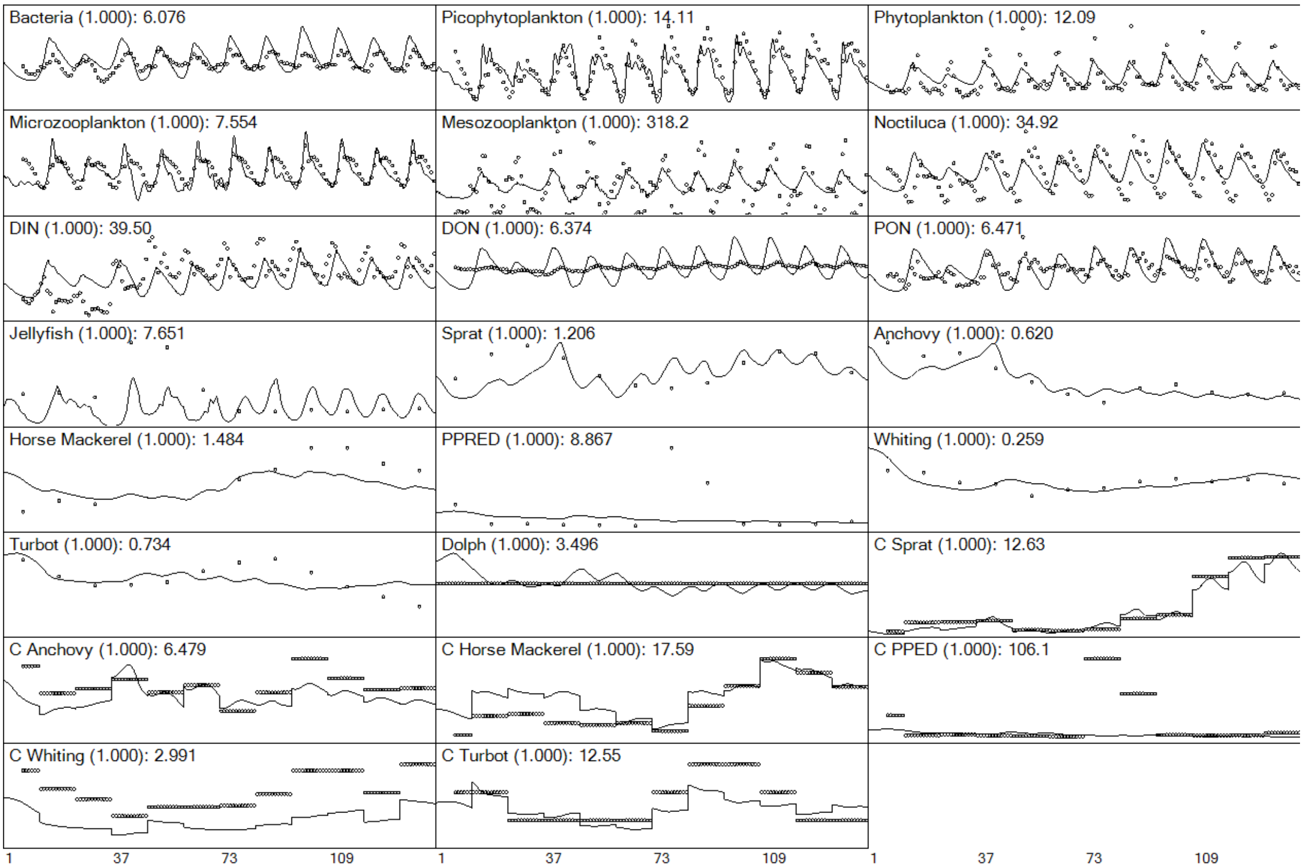

Figure 48. Time dynamic model estimates (lines) of the main trophic groups in the EBS model 2000-2010, fitted to empirical data (dots)

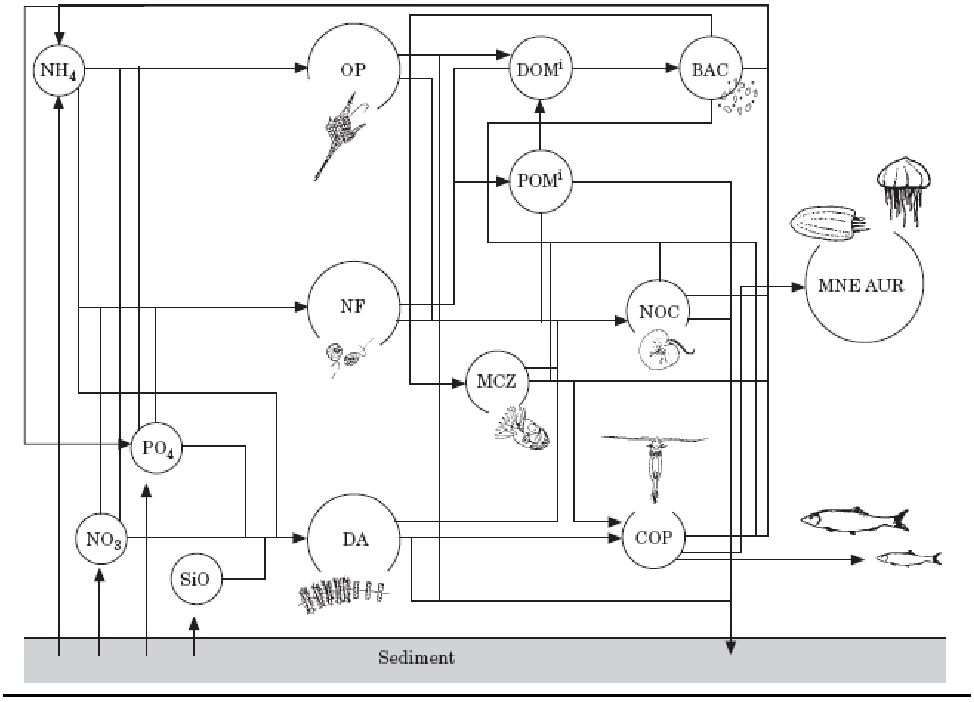

Figure 49 Diagrammatic representation of the structure of the BIOGEN model.

The atmospheric forcing that we used is the one provided within the PERSEUS project and described in details in D4.3. The river-run off data as well as the nutrient loads for the different scenario are taken from deliverable 4.6 data sets.

For the spin-up phase the coupled model is first run for 10 years with "climatological forcing" prepared as an average of the forcing from 1980 to 2010 . Then the control run (CTRL) has been performed for the period of 1983 to 2010. Five different scenario are done for the period from 2010 to 2020. Nutrient river discharge scenarios and data (BAU, BA, MFA, REB, RBE) that are computed as described in Table 2 for the period 2011-2020 are used as a river forcing for those scenario, respectively. The results are then compared with the CTRL run. The differences between the scenarios lays in the non-linear response of the ecosystem to the changes of the nutrient loads.

3.5.2 Scenarios results

Results are presented in Table 9. and Figures 50-57. LTL scenarios present significant differences to the reference (BAU) scenario. LTL changes in the end-to-end model are mainly driven by the input of the LTL model. The BAU scenario in the projection period (2011-2020) resulted in significant decrease in terms of biomass and flow (Throughput, Catch, Ascendency, AMI) but an increase in some structural indices such as (Fishing in Balance, mean path length and trophic level of the catch. The RBE scenario shows pronouncedly different trajectory than the other LTL scenarios (Table 9, Figures 50, 52, 54, 56). The fisheries scenarios have less significant effects that can be interpreted in the light that only one fishery (for anchovy) has a pronounced fishing pressure in the EBS. Further results will be presented in terms of Vigor, Organisation, Resilience and Exploitation.

Table 9. Indices related to vigor, organization, resilience and exploitation for the LTL and HTL scenarios of the East Black Sea. Absolute values are presented for the reference and scenarios periods, while relative changes are reported for the remaining scenarios. Statistically significant differences (p>0.05) between reference (BAU and reference period) between other scenarios are indicated in bold and in shaded cells (red for negative values/decrease of metrics and green for positive values/increase of metrics).

EBS	**Vigor**			**Organisation**						**Resilience**		**Exploitation**	
"health" metrics	NPP	T	Catch	K's Q	FiB	AMI	A	FCI	mPL	H-AMI	SfG	C/B	TLc
Reference period (Ref.P)													
2000-2010 (fitted to data)	0.991	78660.30	1.53	1.72	-0.03	2.18	37870.71	32.63	5.73	2.36	4100.64	0.00115	3.83
BAU	0.995	73047.48	0.98	1.62	-0.13	2.18	34889.48	33.67	6.00	2.39	3579.30	0.00084	3.88
(BAU-Ref.P)*100/Ref.P	0.43	-7.14	-36.09	-6.25	278.49	-0.13	-7.87	3.17	4.64	1.23	-12.71	-27.11	1.07
(BA-BAU)*100/BAU	-0.15	6.43	1.90	1.42	-2.08	0.28	6.90	-3.80	-4.34	-0.55	11.19	-8.63	-0.36
(MFA-BAU)*100/BAU	-0.18	4.20	1.34	0.91	-1.42	0.18	4.53	-1.61	-2.93	-0.41	7.43	-5.76	-0.25
(REB-BAU)*100/BAU	-0.12	2.69	0.93	0.62	-0.95	0.12	2.90	0.67	-1.92	-0.26	4.75	-3.67	-0.17
(RBE-BAU)*100/BAU	-0.13	-13.84	-5.34	10.15	6.86	-1.13	-14.50	18.53	12.62	0.23	-22.71	25.38	1.10
Fisheries scenarios													
(P10All-BAU)*100/BAU	0.00	-0.20	-0.38	-0.69	2.15	-0.02	-0.22	-0.87	0.12	0.01	-0.33	-0.11	0.34
(M10all-BAU)*100/BAU	0.00	0.25	0.63	0.88	-2.69	0.02	0.27	4.17	-0.15	-0.02	0.41	0.25	-0.35
(P10dem-BAU)*100/BAU	0.00	0.00	0.66	0.11	-0.05	0.00	0.00	-12.69	0.00	0.00	0.00	0.66	0.00
(M10dem-BAU)*100/BAU	0.00	0.00	-0.67	-0.06	0.05	0.00	0.00	3.27	0.00	0.00	0.00	-0.67	0.00
(P10SPF-BAU)*100/BAU	0.00	-0.19	-0.94	-0.93	1.90	-0.02	-0.21	-1.23	0.12	0.01	-0.31	-0.69	0.33
(M10SPF-BAU)*100/BAU	0.00	0.24	1.02	1.07	-2.24	0.02	0.26	1.02	-0.14	-0.01	0.39	0.67	-0.31

3.5.2.1 Vigor

The BAU scenario in the projection period (2011-2020) resulted in significant decrease in terms of biomass and flow (Throughput, Catch). These further decrease in the RBE scenario (Table 9, Fig. 50). By the end of the projection period (after 2015) the Catch equal those of the other scenarios but Throughput is still lower (Fig. 50).

Fisheries scenarios have no pronounced effect on Vigor in the EBS (Table 9, Fig. 51)

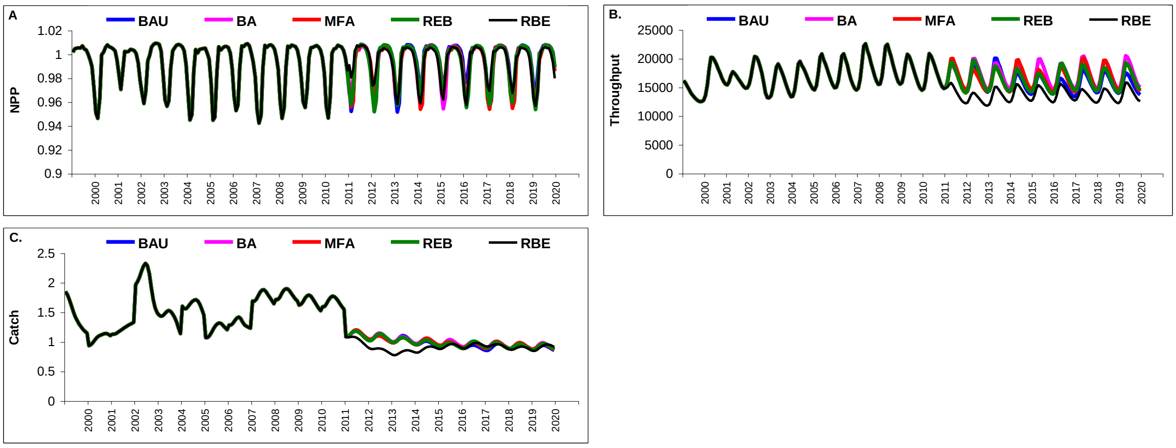

Figure 50. Vigor estimated metrics for the LTL scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

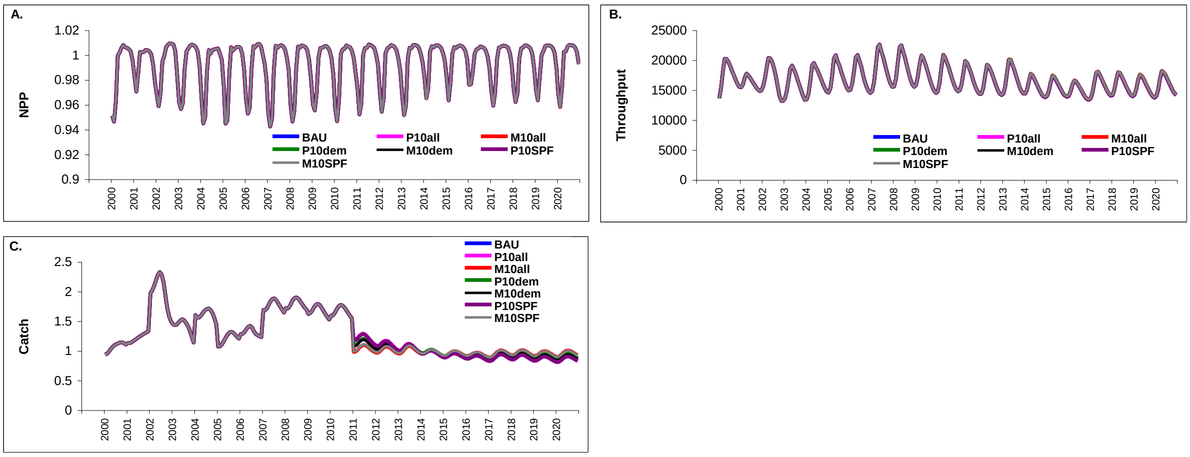

Figure 51. Vigor estimated metrics for the HTL (fisheries) scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the HTL scenarios in the coupled model used the same BAU scenario LTL data.

3.5.2.2 Organization

The BAU scenario in the projection period (2011-2020) showed significant changes compared to the reference period in terms of indicators of organisation (2000-2010, Table 9, Fig. 5). The BA and RBE scenarios also differed significantly from the BAU reference scenario according to all indicators in Table 9 (Fig. 52). The MFA and REB scenarios showed significant differences from the BAU reference scenario in terms of Average Mutual Information (AMI), Ascendency (A), and Mean Path length (mPL, Table 9, Fig. 52). Significant decrease of the Fishing in Balance (FiB) indicator are noted in the cases of decreases of the fishing effort on all fisheries and small pelagic stocks. Finn's Cycling Index (FCI) changed significantly when total effort was reduced and when fishing effort of demersal gears was increased/reduced (Table 9).

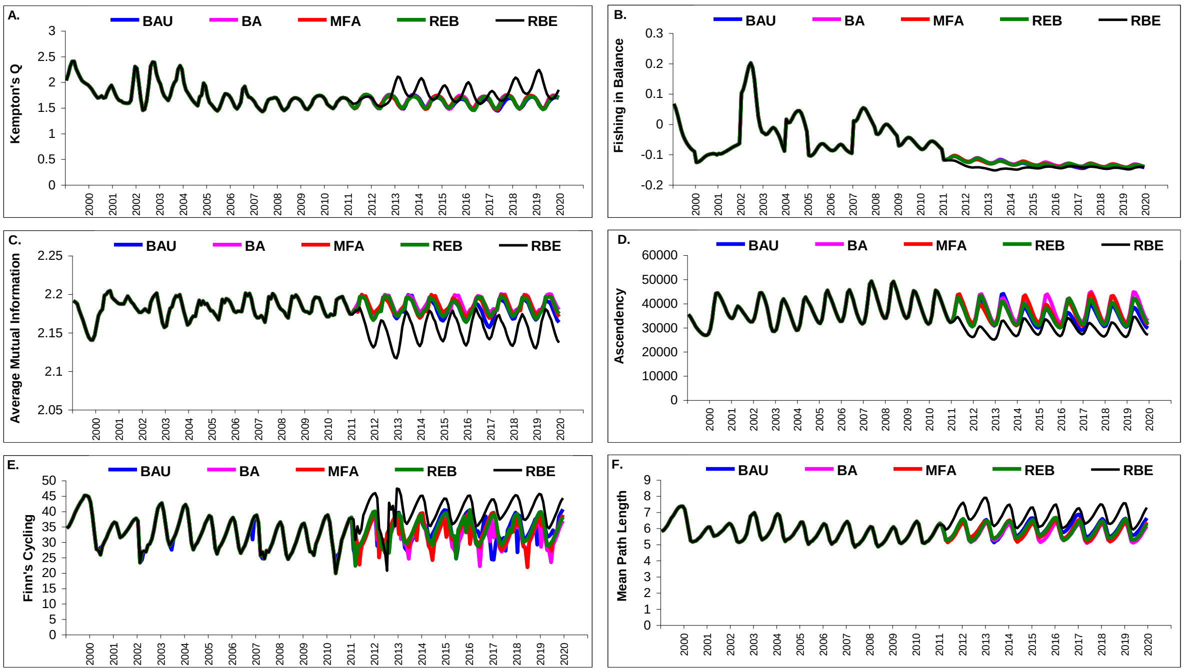

Figure 52. Organisation estimated metrics for the LTL LTL scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

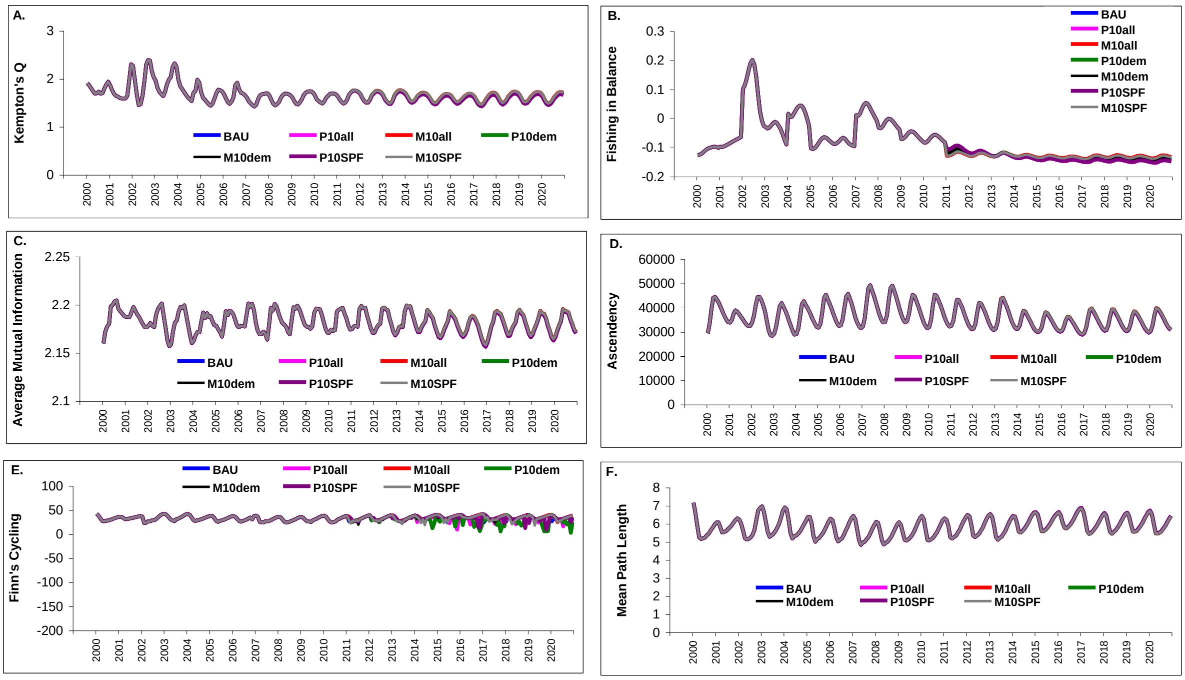

Figure 53. Organisation estimated metrics for the HTL (fisheries) scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the HTL scenarios in the coupled model used the same BAU scenario LTL data.

3.5.2.3 Resilience

The Scope for Growth (SfG) metric indicated significant decrease in resilience of the EBS system over the projection period (2011-2020) and in the case of the RBE scenario (Table 9., Fig. 54). Entropy - Average Mutual Information index (H-AMI) apparently increased over the projection period (2011-2020). BA, MFA, REB scenario show significantly higher SfG compared to the BAU reference scenario (Table 9.).

Resilience indicators were not sensitive in fisheries scenarios (Figure 55).

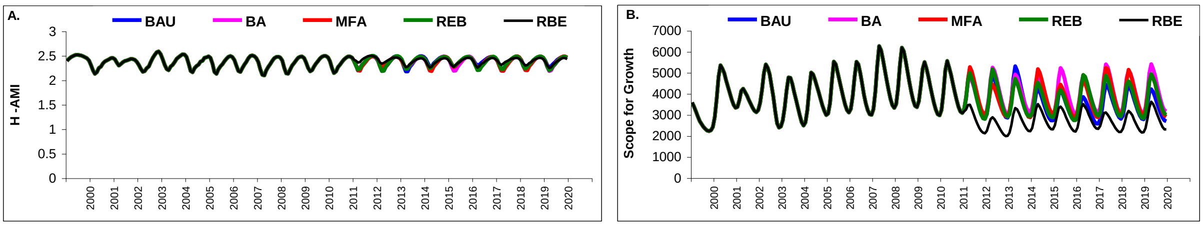

Figure 54. Resilience estimated metrics for the LTL LTL scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

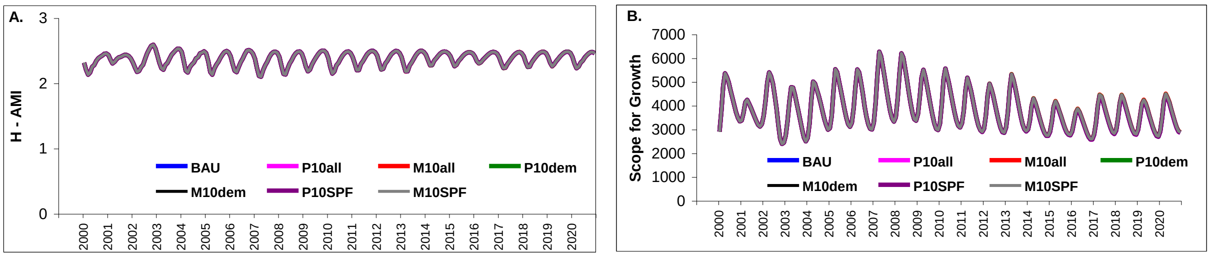

Figure 55. Resilience estimated metrics for the HTL (fisheries) scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the HTL scenarios in the coupled model used the same BAU scenario LTL data.

3.5.2.4 Indices of exploitation

Significant change in indices of exploitation in LTL scenarios are not easy to interpret. First, Catch over Biomass ratio significantly decreased and Trophic Level of the Catch (TLc) increased in the projected period of the BAU scenario (2011-2020) compared to the reference period (2000-2010, Table 9., Fig. 56). Both indices of exploitation significantly increased in the RBE scenario compared to the reference BAU, decreased in all other scenarios (Table 9., Fig. 57).

In fisheries scenarios, there were marked increases/decreases in the Trophic Level of the Catch (TLc) in the cases of respective increased/decreased fishing effort over all fisheries and the small pelagic stock. This effect can be interpreted by the fact that fisheries catches in the EBS are strongly dominated by the anchovy fishery, and the mean TLc would be expected to decrease with the removal of anchovy, which as a planktivore has a relatively low trophic level between fishes.

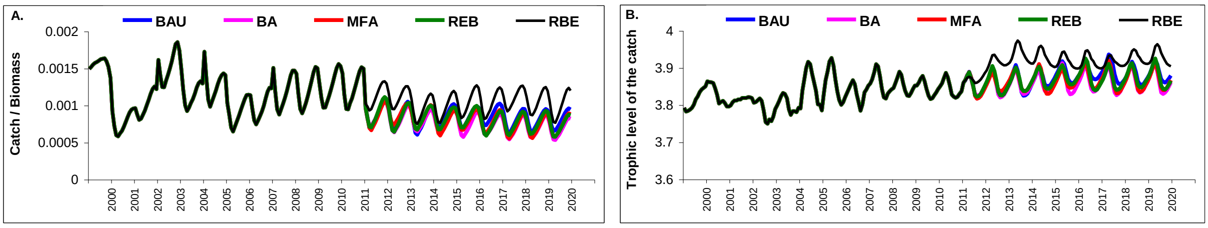

Figure 56. Indices of exploited systems estimated for the LTL scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data.

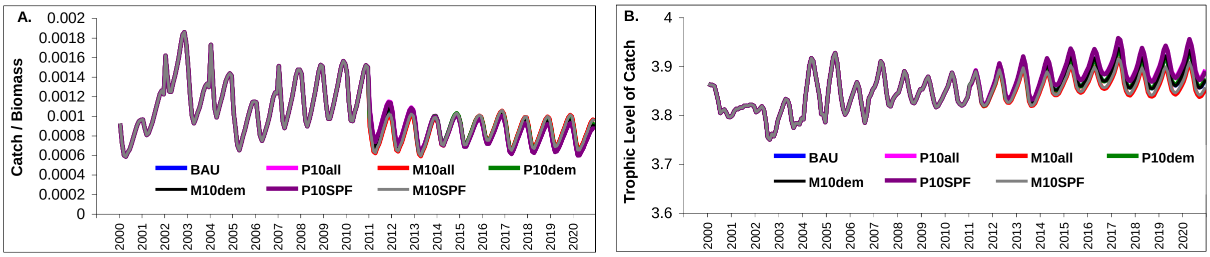

Figure 57. Indices of exploited systems estimated for the HTL (fisheries) scenarios applied for the period 2011-2020. The 2000-2010 period corresponds to the coupled model fitted to data. All the HTL scenarios in the coupled model used the same BAU scenario LTL data.

3.5.3 Discussions

LTL changes in the end-to-end model seem to be mainly driven by the output of the LTL model. All scenarios except the RBE scenario yield decreasing trends in primary production. These can explain the significant decreases in biomass and thus indicators based on ecosystem size and growth such as Throughput, Catch, Ascendency, Scope for Growth and Catch/Biomass over the projection period 2010-2020. Some scenarios (BA, MFA, REB) show less decrease in flow based indices than the reference BAU scenario. Relative increases in the mean Trophic level of the catch can be interpreted as a result of decrease of the biomass of anchovy which is the dominant fish species sitting relatively low in the trophic pyramid (as a planktivore). Generally speaking, LTL projection do not show improvements in terms of vigor, organisation and resilience as represented by the system indicators explored in this study.

The fisheries scenarios have less significant effects on the EBS model. Small changes in the Fishing in Balance index seem counterintuitive. Some increase in the Finn's Cycling Index are resulting from the reductions in total fishing effort and effort applied to demersal stocks. Changes appearing in the mean Trophic level of the catch seem to be driven by the relative amount of anchovy in the catches.

The EBS system seems to be not sensitive to effects of the fishing pressure. This might be due to the fact that the fishing pressure in the EBS is less significant compared to the fishing pressure in the West Black Sea (WBS). Also most of the fishing effort in the

EBS is directed to the anchovy stock, whilst other stocks (e.g. sprat, whiting) contribute little to the fisheries catches (unlike in the WBS system).

3.5.4 References

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3.6 Black Sea Ecosystem (POM/BIMS-ECO/EwE)

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(METU)

3.6.1 The integrated modelling tool: structure and hindcast

For more than a decade, end-to-end (E2E) models have increased the understanding of ecosystems at a broader scale including the feedbacks and interactions between coupled physical, chemical and biological systems (Fulton, 2010; Shin et al., 2010; Rose et al., 2010; Travers et al., 2007). These models were considered as integrated ecosystem models that included ecosystem components from primary producers up to top predatory organisms and their interactions with the abiotic environment (Fulton, 2010). With such models, not only were the impacts of anthropogenic activities such as fishing and pollution examined, but long-term effects of climate variability and its consequences on the ecosystem scale could have also been investigated.

The Black Sea ecosystem is of great interest for its six riparian countries two of which are EU member states. Therefore, investigation of possible future changes in this ecosystem and impacts of them on the goods and services it provides, i.e. commercial fish and shellfish, is crucial. In this research, utilising an E2E modelling tool, the near-future changes that could be observed in the Black Sea ecosystem under the influence of variable fisheries exploitation conditions were investigated.

The Black Sea EwE model used in this research is based on Akoglu et al. (2014). The EwE model of the Black Sea was built to represent the general food web structure of the inner Black Sea basin, avoiding the extremely variable conditions of the Northwestern Shelf (NWS). The model covered an area of 150 000 km2 where fisheries operated intensively (Oguz et al., 2008) in the vicinity of the exclusive economic zones (EEZs) of the six riparian countries. The geographical representation of the model did not include depths greater than 150 m in the open Black Sea where anoxia prevails.

The coupled E2E model was set-up according to Libralato and Solidoro (2009) with Ecopath with Ecosim (EwE) utilising BIMS-ECO biogeochemical model simulation of the Black Sea between 2000-2010. The lower-trophic-level compartments of the EwE Black Sea model were adjusted and re-parameterised according to the long-time averaged outputs from the hindcast (2000-2010) simulation of the BIMS-ECO model run. The final coupled model scheme is shown in Figure 58.

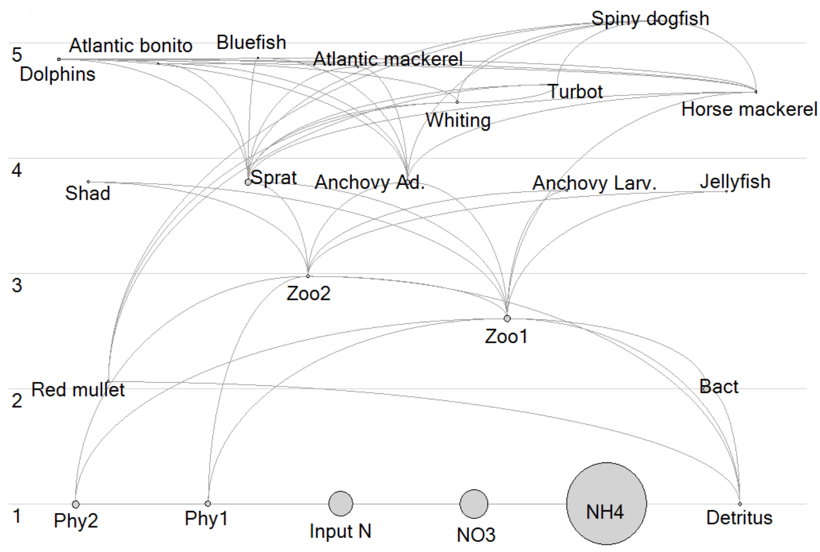

Figure 58. The structure of the BIMS-ECO - EwE coupled model of the Black Sea ecosystem.

The skill of the coupled model is shown in Figure 59 comparatively against statistical data (for catches), biogeochemical model simulated data (biomasses of the LTL and concentrations of the non-living groups) and other conventional model derived biomass estimates (Virtual Population Analysis (VPA) estimates for fish groups).

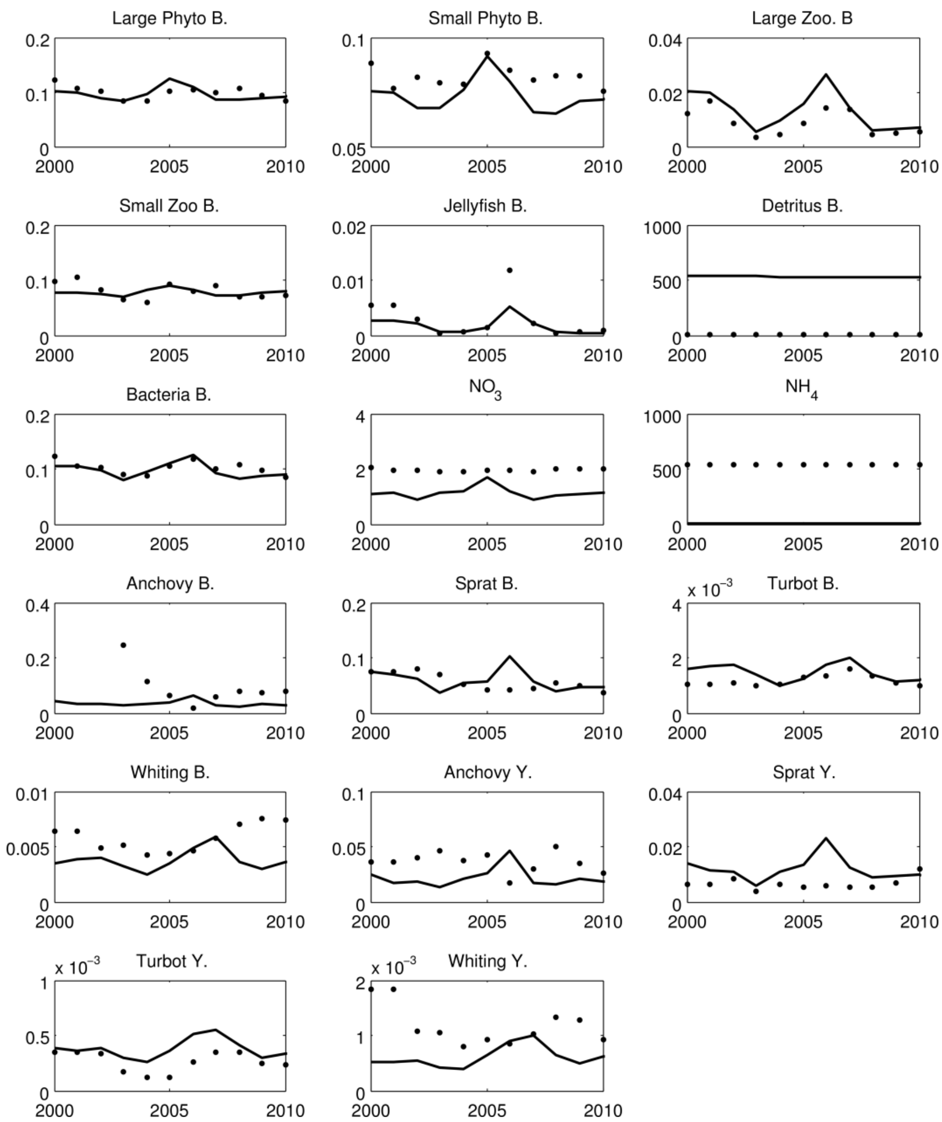

Figure 59. Hindcast validation of the coupled E2E model. For LTL groups (phytoplankton, zooplankton, jellyfish, bacteria, detritus, NH_4 and NO_3), dots represent model (standalone biogeochemical model BIMS-ECO) simulated data. For fish groups, dots represent VPA (virtual population analysis) estimated biomass values (abbreviated as "B.") and catch statistics (abbreviated as "Y."). All black lines denote E2E model simulated biomasses, concentrations or yields in gN m^{-2} y^{-1} where appropriate.

3.6.2 Scenarios results

For comparison between scenarios, a set of metrics and indicators was derived utilising flows and biomasses of the coupled model simulations between the years 2010 and 2020 (**Error! Reference source not found.**). The time series results of these metrics and indicators were compared against the time series of metrics and indicators obtained in the BAU (business as usual, PERSEUS DoW) scenario using Kruskal-Wallis non-parametric one-way ANOVA (analysis of variance) test. Further, relative changes in the indicators and metrics in different scenarios compared to the BAU scenario were calculated utilising the formula

$$RelativeChange = \frac{(IndicatorValue_{Scenario} - IndicatorValue_{BAU})}{Indicatorvalue_{BAU}}$$

3.6.3 Vigor, Organization, Resilience

The comparative summary of the indicators and metrics of the fisheries scenarios against BAU scenario is given in Table 10. Statistically significant (Kruskal-Wallis test @ p = 0.1) differences calculated in indicators and metrics compared to the BAU scenario are marked in red. The comparisons of the primary production (PP) metric between scenarios were calculated as nil because the primary production in the coupled model set-up was forced and identical in all scenarios. As can be inferred from the table, only a handful of indicators and metrics which are directly related to the fisheries (catch ;Figure 60), catch/biomass (Figure 63) and FiB (Figure 61) were found to be statistically different for certain scenarios. Many of the indicators and metrics were found to be similar between scenarios. Indicators especially related to the flows and the energetic capacity of the ecosystem did not differ significantly between scenarios because the LTL structure and its related flows were identical and based on BAU scenario in all fishing scenarios. As can be inferred, changes in the exports from the system (different levels of fisheries exploitation) did not suffice to contrast these indicators and metrics between the fisheries scenarios.

Table 10. Relative change in indicators between different fisheries scenarios. Red cells indicate statistically significant changes at p = 0.1 according to the Kruskal-Wallis test.

Fractional Change	PP	T	Catch	Q	FiB	AMI	A	FCI	mPL	H-AMI	SfG	C/B	mTLc
P10All	0	-0.00003	0.18186	-0.03642	0.15884	-0.00003	-0.00006	-0.00026	-0.00001	0.00001	-0.00036	0.18279	0.00133
M10All	0	0.00000	-0.00109	0.00018	-0.00104	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00109	-0.00001
P10Btwl	0	-0.00001	0.00817	-0.00922	0.13540	0.00000	-0.00001	-0.00008	-0.00001	0.00006	-0.00012	0.00957	-0.00119
M10Btwl	0	0.00000	-0.00006	0.00002	-0.00092	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00006	0.00001
P10SPF	0	-0.00002	0.17198	0.00205	0.02375	-0.00003	-0.00004	-0.00017	-0.00001	-0.00004	-0.00021	0.17114	0.00223
M10SPF	0	0.00000	-0.00168	0.00013	-0.00019	0.00000	0.00000	0.00000	0.00000	0.00000	0.00001	-0.00175	-0.00002
P10LPF	0	0.00000	0.00065	-0.02776	-0.00029	0.00000	-0.00001	0.00000	0.00000	0.00001	-0.00004	0.00070	0.00008
M10LPF	0	0.00000	0.00000	0.00036	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00001	0.00000

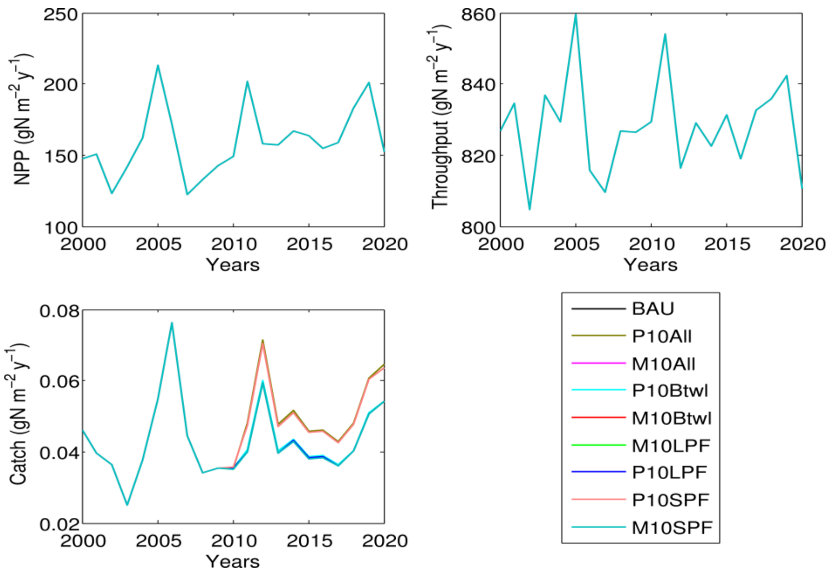

Figure 60. Indicators and metrics related to the ecosystem's vigor.

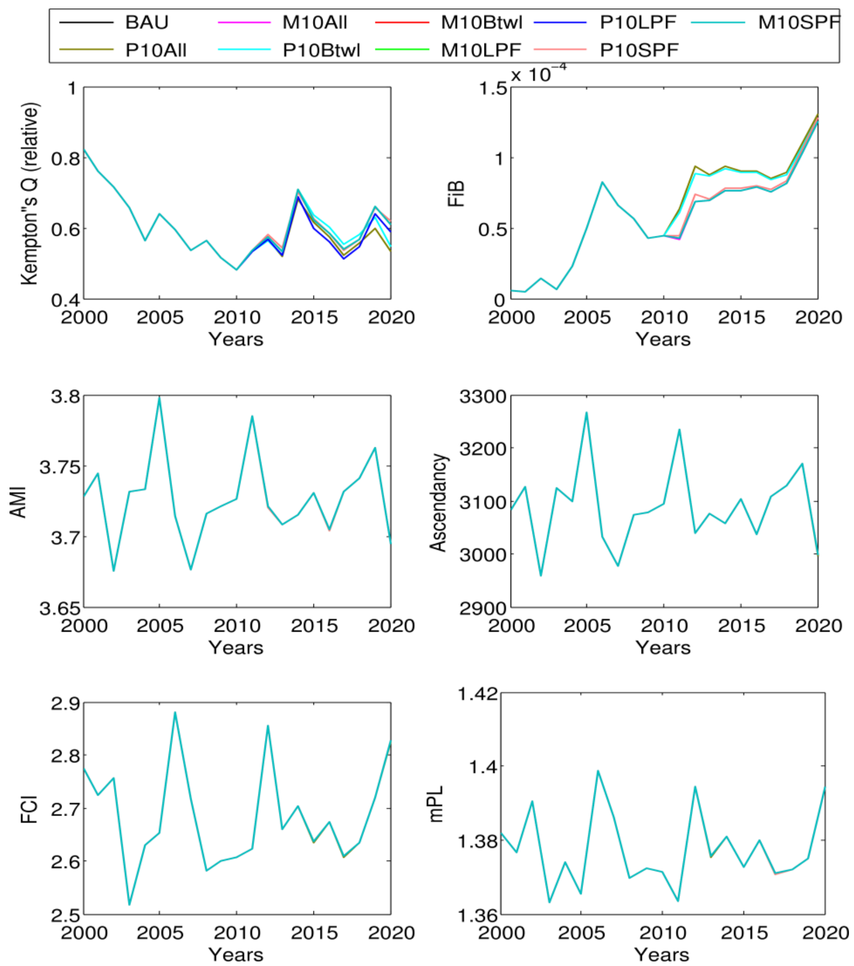

Figure 61. Indicators and metrics related to the ecosystem's organisation.

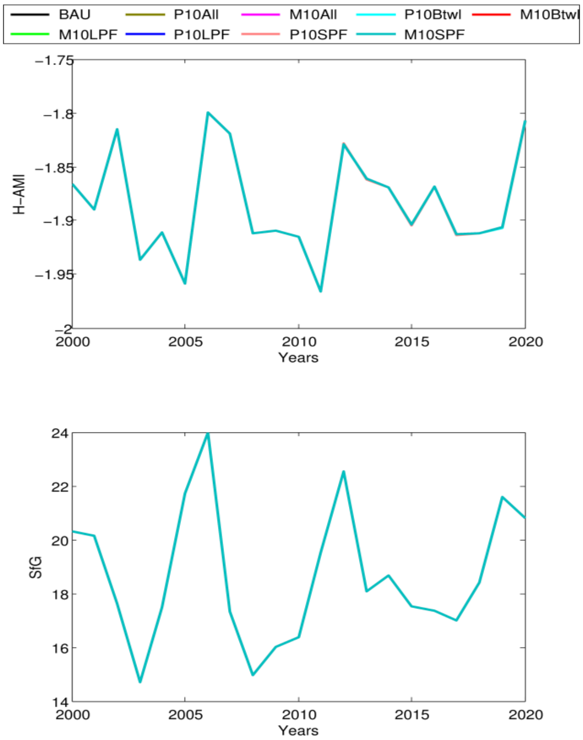

Figure 62. Indicators and metrics related to the ecosystem's resilience.

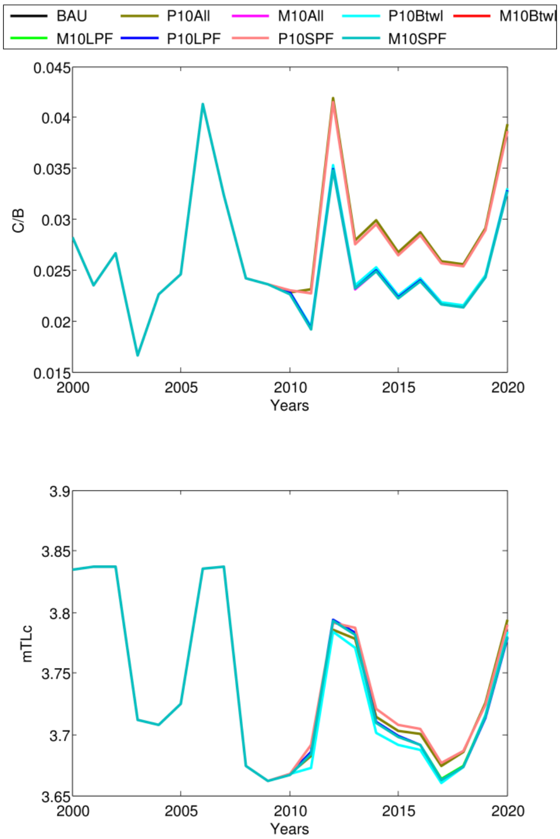

Figure 63 Other commonly used indicators and metrics.

3.6.4 Discussions

Significant changes were observed for three catch-related indicators in scenarios where fishing pressure/effort was increased 10% for all fish species (P10All) and small pelagic fish (P10SPF) (Table 10). Acknowledging that the Black Sea fisheries dwell on small pelagic fish stocks, any increase in the fishing pressure/effort of the fleet(s) targeting small pelagic fish (i.e. purse seiners, which is one of the two fleets defined in the model) introduced significant changes in catch-related metrics; i.e. catch (Figure 60), and hence, catch/biomass (Figure 63), and indicator FiB (Figure 61). However, it is worth noting that FiB was found to be significantly different only in P10All scenario but not in P10SPF scenario contrary to the previous two metrics. This could be the result of the fact that small pelagic fish has already been exploited to its limits in the Black Sea ecosystem and a 10% increase did not suffice to create a significant change in the catches of its stocks. Contrastingly, FiB was found to be significantly different in P10Btwl, where effort of bottom trawlers was increased by 10%. This suggested that in the Black Sea, fisheries targeting benthic fish still bear a potential for development that could lead to increased catches. The increases of fishing effort/pressure in other scenarios did not introduce any fluctuations in yield so as to be reflected with a significant change in the FiB indicator. Considering large pelagic fish, scenarios (P10LPF and M10LPF) did not differ compared to the BAU scenario. This could be justified with the fact that fisheries on large pelagic fish in the Black Sea is marginal since the onset of 1970s due to the overexploitation of their stocks during 1960s, and since then, a very high exploitation level is applied on these stocks leaving no possibility for recovery of their stocks let alone significant changes in their catches (Akoglu et al., 2014).

From a holistic (ecosystem-based) point of view, all these scenarios did not introduce a change in the Black Sea ecosystem's resilience but only in its vigor (through catch) and organisation (through FiB). However, with the only changes reflected in exploitation-related indicators and metrics, it is not possible to evaluate and infer the status of its ecosystem's health. To do so, these analyses should also be complemented with LTL scenarios of RBE, REB, BA and MFA.

3.6.5 References

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4. Food web analysis of ecosystem health at the regional and basin scale

Solidoro C.[1],Libralato S.[1], Akoglu E. [2], Arkın S. [2], Banaru D.[3] , Capet A.[4,1], Daskalov G.[5], Fach Salihoğlu B. [2], Frangoulis C. [7], Giannoulaki M. [7], Gregoire M.[4] , Kandilarov R.[6] , P. Lazzari [1] , Machias A. [7], Salihoglu B.[2] , Somarakis S. [7] , Staneva J. [6] , Tsagarakis K.[7]

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Results from the End-to-End models of the BAU scenario for the period 2011-2020 were compared to those of the reference period fitted to data (Reference, 2000-2010), while all other climatic and fisheries scenarios were compared with BAU 2011-2020 (see also Table 2). Synthesis of results are reported in Table 11 below.

4.1 Scenarios of climatic changes under Business as Usual conditions (2000-2010 vs 2011-2020)

A common result in all systems is that ecosystem health indicators are significantly different between past (hindcast; 2000-2010) and future (2011-2020) under Business as usual nutrient forcing (see BAU-Ref/Ref rows; Table 11). This reflect the fact that current trends of climatic conditions are accounted and result effective in the different areas. However, direction if change is not uniform.

All three indicators for Vigor (NPP, T, Catches) are decreasing in Adriatic, Aegean Sea, in East Black Sea T and catches are decreasing while in West Black Sea, between vigor indicators only catches is decreasing. All three Vigor indicators are instead increasing in the Gulf of Lion, the only regional area for which there is this tendency. In spite of the particular case of Gulf of Lion, all other results reveal a general tendency for decreasing Vigor in the system.

Similarly between reference (2000-2010) and future BAU, Organization indices generally decreased for Adriatic and West Black sea; for both East Black Sea and Aegean Kempton's and Ascendency decrease, while FiB, FCI and mPL increased. For Gulf of Lions, confirming the opposite direction of change, most of significant changes for organization indicators was in terms of increase.

A look at resilience indicators show mainly Scope for Growth having significant changes between reference (2000-2010) and future BAU. SfG decreases significantly in all systems except for Gulf of Lions where a significant increase is expected. H-AMI is expected to increase significantly only in Adriatic.

Overall, climatic conditions seems to bring the system to decrease Vigor and Resilience for all systems, except Gulf of Lions. The set of indicators for Organization were not giving enough consensus for delineating a common solid pattern.

Table 11. Summary of results in terms of indicators of ecosystem health (columns) for climatic and fisheries scenarios applied to Mediterranean and Black Sea systems (rows). In bold are reported the average values for REF and BAU scenario; other values are percent change. Positive (blue) and negative (red) relevant changes are highlighted (light color = changes >2%; darker color = changes >5%) (next page)

		Vigor			Organisation						Resilience		Exploitation	
		NPP	T	Catch	K's Q	FiB	AMI	A	FCI	mPL	H-AMI	SfG	C/B	TLc
Gulf of Lion	***Ref (2000-2010)***	***1.02***	***2620.06***	***0.54***	***1.05***	***-3.E-04***	***2.21***	***5795.52***	***-150.11***	***10.27***	***3.18***	***765.88***	***1.E-03***	***3.60***
	BAU (2010-2020)	***1.06***	***2688.98***	***0.58***	***1.04***	***-6.E-04***	***2.21***	***5952.10***	***-287.50***	***9.91***	***3.18***	***794.75***	***1.E-03***	***4.04***
	(BAU-Ref)/Ref	**4.2**	**2.6**	**6.7**	**-0.9**	**91.7**	**0.1**	**2.7**	**91.5**	**-3.6**	**-0.1**	**3.8**	**1.9**	**12.2**
	climatic scenarios													
	(BA-BAU)/BAU	-0.22	-0.10	-0.04	0.02	0.93	-0.01	-0.10	337.01	0.18	0.01	-0.14	0.06	0.07
	(MFA-BAU)/BAU	-0.12	0.52	0.47	0.04	-0.58	-0.01	0.52	65.75	-0.47	-0.08	0.77	-0.13	0.10
	(REB-BAU)/BAU	-0.23	0.00	0.01	0.01	0.28	-0.01	-0.01	201.92	0.01	-0.01	0.01	0.02	0.06
	(RBE-BAU)/BAU	-0.35	-0.24	-0.24	0.00	1.16	-0.01	-0.26	52.76	0.30	0.01	-0.35	0.08	0.05
	fisheries scenarios													
	(P10All-BAU)/BAU	-0.02	-0.11	5.17	-0.90	-31.18	0.02	-0.10	322.33	0.17	0.01	-0.14	5.25	-0.83
	(M10All-BAU)/BAU	0.02	0.13	-5.39	0.99	24.15	-0.02	0.11	-73.81	-0.21	-0.02	0.17	-5.47	0.88
	(P10Btwl-BAU)/BAU	-0.02	-0.11	5.17	-0.90	-31.18	0.02	-0.10	322.33	0.17	0.01	-0.14	5.25	-0.83
	(M10Btwl-BAU)/BAU	0.02	0.13	-3.94	-0.46	14.81	-0.01	0.12	383.47	-0.23	-0.02	0.16	-4.00	0.72
	(P10SPF-BAU)/BAU	0.00	-0.02	4.36	0.06	-26.25	-0.01	-0.03	65.83	0.00	0.01	-0.04	4.41	-0.46
	(M10SPF-BAU)/BAU	0.00	0.02	-4.38	-0.06	22.41	0.01	0.03	30.62	0.00	-0.01	0.03	-4.43	0.51
	(P10LPF-BAU)/BAU	0.00	0.00	0.01	0.00	0.21	0.00	0.00	47.31	-0.01	0.00	0.00	0.01	0.01
	(M10LPF-BAU)/BAU	0.00	0.00	-0.03	0.00	-0.21	0.00	0.00	83.55	0.01	0.00	0.00	-0.03	-0.01
Adriatic Sea	***Ref (2000-2010)***	***2.31***	***2148.21***	***1.20***	***2.95***	***1.E-02***	***2.41***	***5090.04***	***34.02***	***152.95***	***2.82***	***718.98***	***2.E-03***	***3.45***
	BAU (2010-2020)	***2.13***	***1850.68***	***1.01***	***2.74***	***9.E-03***	***2.32***	***4287.64***	***40.85***	***17.30***	***3.02***	***582.09***	***2.E-03***	***3.45***
	(BAU-Ref)/Ref	**-7.6**	**-13.9**	**-15.7**	**-7.1**	**-23.2**	**-3.7**	**-15.8**	**20.1**	**-88.7**	**7.2**	**-19.0**	**-8.6**	**-0.1**
	climatic scenarios													
	(BA-BAU)/BAU	0.09	0.76	0.27	-0.02	0.73	0.78	1.39	-1.39	-188.14	-0.74	1.11	-0.30	-0.02
	(MFA-BAU)/BAU	0.30	1.21	0.45	-0.05	1.21	0.84	1.85	-5.16	261.71	-0.84	1.79	-0.50	-0.02
	(REB-BAU)/BAU	0.11	0.73	0.24	0.00	0.71	0.67	1.26	0.40	-164.23	-0.64	1.07	-0.31	-0.02
	(RBE-BAU)/BAU	0.31	1.34	0.51	-0.07	1.40	0.74	1.90	-5.40	-70.11	-0.79	1.97	-0.55	-0.03
	fisheries scenarios													
	(P10All-BAU)/BAU	0.02	0.01	2.62	-1.61	4.80	0.04	0.04	0.77	-103.13	-0.05	0.01	2.64	-0.10
	(M10All-BAU)/BAU	-0.02	-0.01	-2.78	1.73	-4.60	0.03	0.02	-159.17	-259.48	0.00	-0.02	-2.79	0.08
	(P10Btwl-BAU)/BAU	16.49	27.95	4.42	0.04	3.40	1.88	28.45	-27.08	-1500.99	-9.09	41.30	-16.11	-3.15
	(M10Btwl-BAU)/BAU	-0.02	26.77	-12.69	1.73	-28.61	2.09	27.54	-32.96	-300.60	-8.91	39.57	-23.09	-2.32
	(P10SPF-BAU)/BAU	0.00	-0.40	0.56	-0.31	1.87	-0.12	-0.49	0.01	-115.52	0.21	-0.60	0.82	0.12
	(M10SPF-BAU)/BAU	0.33	0.43	-0.74	0.59	-2.33	0.41	0.77	-12.29	29637.78	-0.45	0.65	-1.02	-0.14
	(P10LPF-BAU)/BAU	0.00	0.00	0.11	0.02	-0.02	0.00	0.00	-0.07	-40.95	0.00	0.00	0.12	0.07
	(M10LPF-BAU)/BAU	0.00	0.00	-0.12	-0.02	0.02	0.00	0.00	0.67	66.66	0.00	0.00	-0.12	-0.07
Northern Aegean Sea	***Ref (2000-2010)***	***1.38***	***1616.60***	***0.67***	***6.78***	***-3.E-05***	***1.98***	***3190.16***	***36.78***	***7.86***	***2.65***	***461.37***	***4.E-03***	***3.84***
	BAU (2010-2020)	***1.34***	***1542.40***	***0.63***	***6.46***	***-1.E-04***	***1.98***	***3042.62***	***44.90***	***8.24***	***2.66***	***429.40***	***4.E-03***	***3.83***
	(BAU-Ref)/Ref	**-2.6**	**-4.6**	**-5.5**	**-4.8**	**329.7**	**0.0**	**-4.6**	**22.1**	**4.8**	**0.0**	**-6.9**	**0.5**	**-0.2**
	climatic scenarios													
	(BA-BAU)/BAU	0.13	-0.07	1.88	4.96	13.36	0.22	0.27	5.07	-2.09	0.40	-0.05	-2.17	0.11
	(MFA-BAU)/BAU	-5.09	-7.23	-11.85	-5.83	153.22	-0.08	-7.17	-12.94	5.48	-0.58	-11.50	-0.79	-0.48
	(REB-BAU)/BAU	-5.09	-7.10	-11.73	-5.77	151.72	-0.08	-7.05	-6.75	5.24	-0.58	-11.30	-0.79	-0.46
	(RBE-BAU)/BAU	-5.10	-7.03	-11.64	-5.64	150.86	-0.08	-6.97	-14.08	5.11	-0.58	-11.17	-0.79	-0.45
	fisheries scenarios													
	(P10All-BAU)/BAU	-0.02	-0.03	6.88	0.28	-106.24	-0.01	-0.04	-8.75	-0.12	-0.03	-0.07	7.18	-0.16
	(M10All-BAU)/BAU	0.02	0.03	-7.22	-0.83	94.32	0.04	0.07	4.43	0.13	0.01	0.07	-7.51	0.17
	(P10Btwl-BAU)/BAU	0.00	0.00	1.69	-0.18	-20.80	-0.01	-0.01	1.40	-0.03	0.00	-0.01	1.76	-0.07
	(M10Btwl-BAU)/BAU	0.00	0.00	-1.72	0.16	20.35	0.01	0.01	3.82	0.03	0.00	0.01	-1.78	0.07
	(P10SPF-BAU)/BAU	-0.01	-0.02	2.80	-0.36	-60.61	-0.03	-0.05	4.61	-0.08	0.00	-0.04	2.99	0.00
	(M10SPF-BAU)/BAU	0.02	0.02	-2.95	0.37	54.82	0.03	0.04	4.80	0.09	0.01	0.05	-3.14	0.00
	(P10LPF-BAU)/BAU	0.00	0.00	0.04	0.62	-0.67	0.00	0.00	4.87	-0.03	0.00	0.00	0.07	0.00
	(M10LPF-BAU)/BAU	0.00	0.00	-0.07	-0.72	0.85	0.00	-0.01	1.78	0.03	0.00	0.00	-0.11	-0.01
West Black Sea	***Ref (2000-2010)***	***0.99***	***1E+05***	***0.99***	***3.08***	***2.E-02***	***2.22***	***5E+04***	***32.42***	***6.39***	***2.64***	***6E+03***	***4.E-04***	***3.89***
	BAU (2010-2020)	***1.00***	***1E+05***	***0.95***	***2.89***	***0.E+00***	***2.22***	***5E+04***	***27.36***	***6.45***	***2.65***	***6E+03***	***3.E-04***	***3.87***
	(BAU-Ref)/Ref	**0.1**	**-1.8**	**-3.5**	**-6.2**	**-104.0**	**0.1**	**-2.1**	**-15.6**	**0.9**	**0.3**	**-3.5**	**-3.2**	**-0.5**
	climatic scenarios													
	(BA-BAU)/BAU	0.01	-0.25	-0.05	-0.08	3.34	0.02	-0.27	-0.87	0.12	0.02	-0.47	0.02	0.00
	(MFA-BAU)/BAU	0.01	-0.22	-0.08	-0.04	4.13	0.01	-0.24	-1.63	0.12	0.02	-0.41	0.07	0.00
	(REB-BAU)/BAU	0.00	-0.13	-0.06	0.04	3.27	-0.01	-0.14	-1.98	0.11	0.01	-0.23	0.18	0.01
	(RBE-BAU)/BAU	0.02	-0.31	-0.08	-0.14	4.74	0.03	-0.34	0.00	0.14	0.02	-0.57	-0.06	0.00
	fisheries scenarios													
	(P10All-BAU)*100/BAU	0.00	0.00	8.15	-16.11	-420.13	0.00	0.00	24.94	-0.01	0.00	0.00	8.16	-0.27
	(M10all-BAU)*100/BAU	0.00	0.00	-8.10	-10.89	357.76	0.00	0.00	26.01	0.02	0.00	0.00	-8.10	0.33
	(P10dem-BAU)*100/BAU	0.00	0.00	1.22	-13.86	-14.33	0.00	0.00	8.17	0.00	0.00	0.00	1.23	-0.01
	(M10dem-BAU)*100/BAU	0.00	0.00	-0.73	-13.46	1.09	0.00	0.00	-6.92	0.01	0.00	0.00	-0.74	0.03
	(P10SPF-BAU)*100/BAU	0.00	0.00	7.51	-13.84	-412.87	0.00	0.00	-8.02	-0.01	0.00	0.00	7.50	-0.20
	(M10SPF-BAU)*100/BAU	0.00	0.00	-7.13	-13.49	344.44	0.01	0.00	24.68	0.02	0.00	0.00	-7.13	0.25
East Black Sea	***Ref (2000-2010)***	***0.99***	***8E+04***	***1.53***	***1.72***	***-3.E-02***	***2.18***	***4E+04***	***32.63***	***5.73***	***2.36***	***4E+03***	***1.E-03***	***3.83***
	BAU (2010-2020)	***1.00***	***7E+04***	***0.98***	***1.62***	***-1.E-01***	***2.18***	***3E+04***	***33.67***	***6.00***	***2.39***	***4E+03***	***8.E-04***	***3.88***
	(BAU-Ref)/Ref	**0.4**	**-7.1**	**-36.1**	**-6.3**	**278.5**	**-0.1**	**-7.9**	**3.2**	**4.6**	**1.2**	**-12.7**	**-27.1**	**1.1**
	climatic scenarios													
	(BA-BAU)*100/BAU	-0.15	6.43	1.90	1.42	-2.08	0.28	6.90	-3.80	-4.34	-0.55	11.19	-8.63	-0.36
	(MFA-BAU)*100/BAU	-0.18	4.20	1.34	0.91	-1.42	0.18	4.53	-1.61	-2.93	-0.41	7.43	-5.76	-0.25
	(REB-BAU)*100/BAU	-0.12	2.69	0.93	0.62	-0.95	0.12	2.90	0.67	-1.92	-0.26	4.75	-3.67	-0.17
	(RBE-BAU)*100/BAU	-0.13	-13.84	-5.34	10.15	6.86	-1.13	-14.50	18.53	12.62	0.23	-22.71	25.38	1.10
	fisheries scenarios													
	(P10All-BAU)*100/BAU	0.00	-0.20	-0.38	-0.69	2.15	-0.02	-0.22	-0.87	0.12	0.01	-0.33	-0.11	0.34
	(M10all-BAU)*100/BAU	0.00	0.25	0.63	0.88	-2.69	0.02	0.27	4.17	-0.15	-0.02	0.41	0.25	-0.35
	(P10dem-BAU)*100/BAU	0.00	0.00	0.66	0.11	-0.05	0.00	0.00	-12.69	0.00	0.00	0.00	0.66	0.00
	(M10dem-BAU)*100/BAU	0.00	0.00	-0.67	-0.06	0.05	0.00	0.00	3.27	0.00	0.00	0.00	-0.67	0.00
	(P10SPF-BAU)*100/BAU	0.00	-0.19	-0.94	-0.93	1.90	-0.02	-0.21	-1.23	0.12	0.01	-0.31	-0.69	0.33
	(M10SPF-BAU)*100/BAU	0.00	0.24	1.02	1.07	-2.24	0.02	0.26	1.02	-0.14	-0.01	0.39	0.67	-0.31
Black Sea	fisheries scenarios													
	P10All	0.00	0.00	0.18	-0.04	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00
	M10All	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	P10Btwl	0.00	0.00	0.01	-0.01	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
	M10Btwl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	P10SPF	0.00	0.00	0.17	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00
	M10SPF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	P10LPF	0.00	0.00	0.00	-0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	M10LPF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

4.2 Comparison of different scenarios of climatic changes (2011-2020)

Climate scenarios (2011-2020) performed using nutrient river discharge scenarios and data from PERSEUS Deliverable 4.6 (i.e., BA, MFA, REB, RBE) applied to LTL models coupled with HTL resulted in modest changes with respect to BAU for the same period (Table 11; rows reporting changes (BA-BAU)/BAU; (MFA-BAU)/BAU; (REB-BAU)/BAU; (RBE-BAU)/BAU).

Vigor indicators didn't show any significant change for Gulf of Lions, Adriatic and West Black Sea. For the Aegean Sea all vigor indicators decreased significantly under MFA, REB, RBE scenarios, but not under BA. For East Black Sea T increased significantly with respect to BAU in all climatic scenarios, while a significant decrease is obtained for REB.

Results for Organization indices reveal quite a different effects and a common pattern per area, indicator and scenario is difficult to highlight, although the indicator that changed significantly under climatic scenarios with respect to BAU is especially FCI. The Finn Cycling Index changes on one side revels the high sensitivity to forcing changes, but a more detailed analysis (trajectories) reveal also very herratic changes with spikes over time that are imposing caution in the use of this indicator. The same seems to occour also for mPL that showed significant differences among scenarios in Adriatic system (Table 11). Thus considering a part these two indicators of organization, it results that climatic scenarios result in significant changes for organization indicators especially in Aegean Sea and in East Black Sea. FiB increase in all climatic scenarios with respect to BAU in Aegean, while differences for Kempton's Q and Ascendency are negative for MFA, REB and RBE climate scenarios. Climate scenarios BA, MFA, REB, RBE resulted in increasing FiB with respect to BAU in West Black Sea.

Resilience indicators showed differences between climatic scenarios only for Aegean (negative effects on SfG for all scenarios) and East Black Sea (positive change in all scenarions except RBE). In general therefore, climatic scenarios don't differ in terms of resilience from BAU.

It is worth noting that climatic scenarios have effects on fisheries related indicators only in East Black Sea (Table 11).

4.3 Effects of changes in fisheries pressure on BAU (2011-2020)

Fisheries scenarios have important effects on ecosystem indicators in all systems. The vigor indicator "catches" is of course sensitive to these scenarios in all systems, but for Adriatic Sea the changes in trawling effort is also resulting in influencing system throughput (T), suggesting an increase of Vigor. Similarly, among Organization indices the Fisheries in Balance (Fib) was directly affected by changes in fishing pressure (Table 11) but also FCI was increasing in Gulf of Lions, FCI and mPL was generally decreasing in Adriatic, but also AMI and Ascendency was increasing in Adriatic under change of trawlers effort; kempton's index was decreasing in all fihseries scenario for West Black Sea. It is therefore difficult to grasp a coherent direction of change in organization under stress induced by fisheries.

Regarding resilience indicators, no significant changes were detected, and the only modification in resilience under fisheries changes resulted in Adriatic for trawlers that decrease H-AMI and increase SfG.

Fisheries related indicators resulted in changes as expected, indicating in almost all systems that trawlers are the fisheries inducing most of the impact.

4.4 Conclusions

Results for the Mediterranean and the Black Sea show that changes from Reference to BAU were in general greater than changes between climatic future scenarios.

Synthesis of all results reported for all basins and areas reveals (Table 11) show important context dependence responses of ecosystem health indicators to simulated scenarios. In fact although some changes related to fisheries effects are similar, especially effects of climatic changes on indicators are quite different from system to system (Table 11).

The efforts implemented for standardizing the food webs to avoid comparative problems (Christensen, 1995; Angelini and Agostinho, 2005; Ulanowicz, 1986; Coll and Libralato 2013; Heymans et al., 2014) into a common structure and for using the same approach for developing End-to-End scenario, support the idea that model structure and modelling conceptualization is adequately uniform among case studies and suggest the conclusion that local conditions are determinant for results obtained. Precisely, local conditions in terms of fishing pressure and nutrient discharge at initial status are relevant for local assessments of ecosystem health. Therefore initial conditions in which the models were developed are crucial also for effects combined of climate and fisheries

The flexibility of the Ecopath with Ecosim tool (Christensen and Walters, 2004; Christensen et al., 2005; Walters et al. 1997) demonstrated the possibility for implementing end-to-end approaches (Libralato and Solidoro, 2009) based also on existing model (Coll et al., 2007; Libralato et al., 2010; Banaru et al. 2013; Tsagarakis et al., 2010; Akoglu et al., 2014). Moreover the approach adopted for coupling these HTL models with low trophic level models , i.e. idrodynamic biogeochemical models (Lazzari et al., 2012; Capet el al., 2005; Oguz et al., 2008) resulted to be sensitive enough to both climate and fisheries changes.

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