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BLACK SEA 4 FISH

# Multispecies modelling of Black Sea resources using mass-balance models (Ecopath with Ecosim, EwE)

BS4F Presentation series


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IBER – BAS


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- Species in aquatic ecosystems do not exist in isolation, but are connected via complex trophodynamic relationships. These different types of interactions affect their population dynamics. The conventional methods for fish stock assessment are based on a single species modeling, which assess the fishing impact on the population of individual target species. The single species models are informative for the current state of a given species, but also make short-term predictions for the state of its stock. In recent years, concern is being directed to the effect of fishing on the wider ecosystem. The different fishing technologies make the fishery multispecies. The real composition of the catches cannot be controlled or predicted. Therefore, fisheries management very often affects not only the target species but also the not-target ones.

- The multispecies models could improve our understanding about some population parameters as natural mortality as well as to explain the different ecological linkages amongst the species (target and non-target) into the ecosystem. The multispecies models may provide more realistic information  than the single-species ones - they are plausible, improve the understanding of the dynamics of fish stocks and are important tool then providing long - term management advices.

# Ecopath with Ecosim - EwE

The Ecopath system is built for the estimation of the biomass of the various elements (species or groups of species) of an aquatic ecosystem.

- Ecopath: Provides a quantitative representation of the studied ecosystem (a snapshot), in terms of trophic flows and biomasses for a defined time period. The ecosystem is represented by functional groups (species, groups of species). The key principle of Ecopath is mass balance: for each group represented in the model, the energy removed from that group, for example by predation or fishing, must be balanced by the energy consumed, i.e. consumption.

$$(1) \quad Pi = Yi + Bi.M2i + Ei + BAi + Pi\,.(1 - EEi),$$

$$(2) B\,.\,(P/B)_i = \sum B_j\,.(Q/B)_j\,.DC_{ij} + Y_i + E_i + BA_j + B_i.(P/B)_i\,.(1 - EE_i),$$

- The energy balance within each group is ensured when:

Consumption = production + respiration + unassimilated food

Ecosim - simulates the Ecopath network behaviour over time (time-dynamic model) and must be based on an existing Ecopath model. Ecosim is used to assess the effects of the environment conditions and fisheries on the ecosystems, as well as to develop sustainable fisheries management strategies.

$$dB_i/dt = g_i \sum Q_{ji} - \sum Q_{ij} + I_i - (MO_i + F_i + E_i).\ B_i,$$

Vulnerabilities – (foraging arena' concept), where Bi's are divided into vulnerable and invulnerable components, and it is the transfer rate (vij) between these two components that determines if control is top-down, bottom-up, or of an intermediate type.

# Input data

- B (t. $km^{-2}$ )
- P/B ($year^{-1}$)
- Q/B ($year^{-1}$)
- EE (the proportion of the production that is exported out of the ecosystem - i.e. by fishing activity, or consumed by predators within it)
- Diet matrix (food spectrum)
- Landings

## EwE model - Black Sea, 1990-2010

- 32 functional groups, describing the trophic net/structure of the Black Sea: marine mammals (1 groups); fish (9 groups); benthic crustaceans (6 groups); primary producers (6 groups); pelagic invertebrates (9 groups); detritus (1 group)

## Balancing Ecopath model

The model is considered balanced when the results show consistent values for the following:

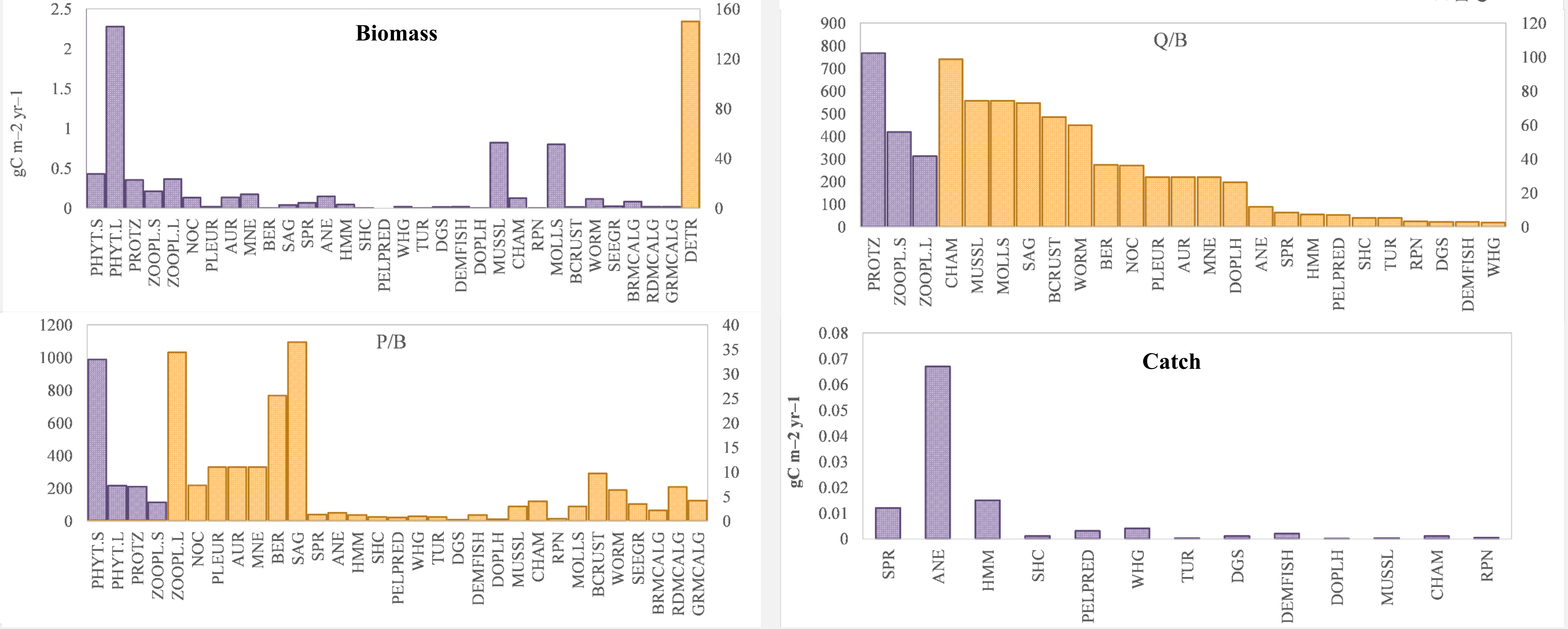
- **Estimates of EE<1;**
- P/Q - 0.1 and 0.35;
- R/B - high values for small organisms and top predators

## Tuning Ecosim model to real data

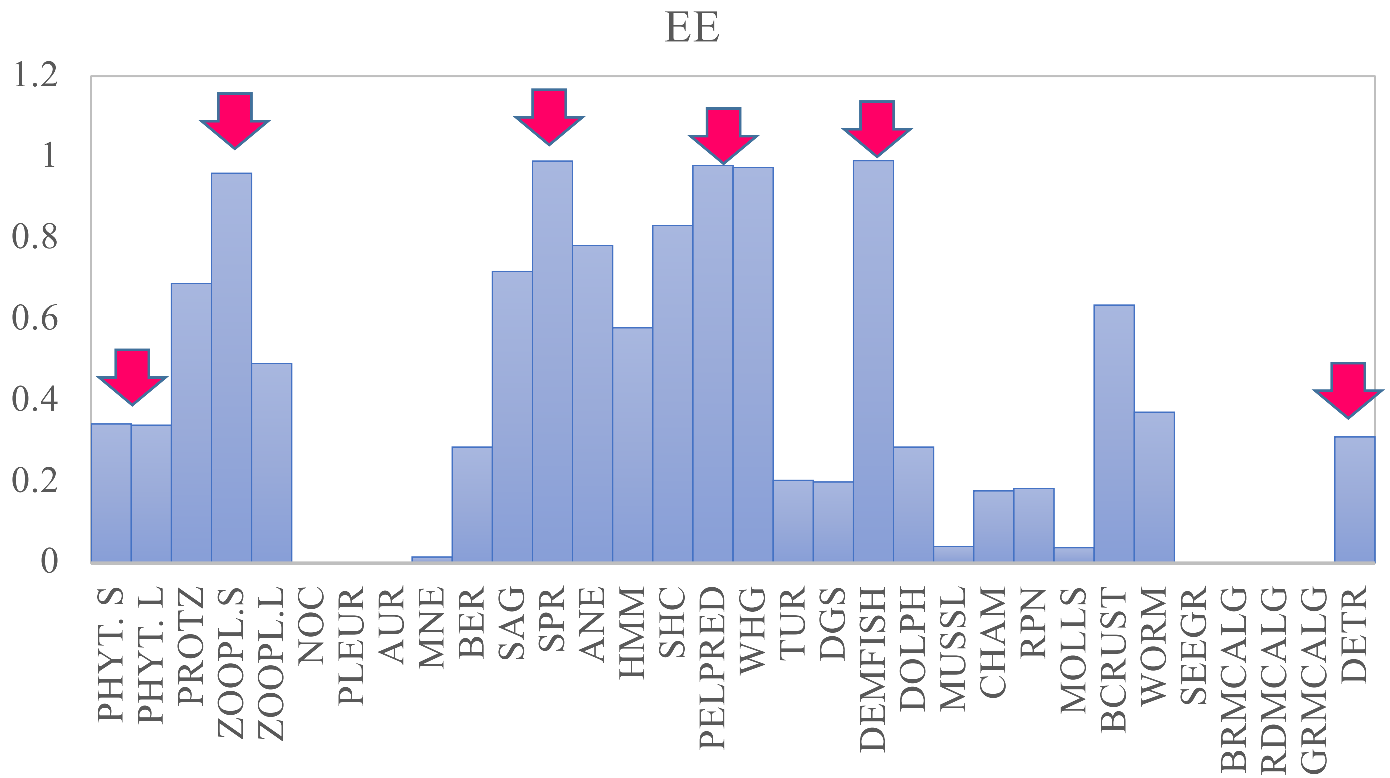
- Ecosim can incorporate time series data (biomass, landings, fishing mortality)
- The model enables the estimation of a statistical measure of goodness-of-fit to these data, comparing predicted model results to available (observed) trajectories. This goodness-of-fit measure is a weighted sum of squared deviations (SS) of log biomasses and catches from log predicted biomasses and catches.
- Vulnerabilities - how sensitive the time series predictions ‘supported’ by data are to the vulnerabilities
- Forcing functions - represent physical or other environmental parameters, which influence the trophic interactions. These forcing functions, can be used to modify the Q/B ratio of the consumer groups, or to force primary production directly (by changing P/B).

# Ecosim scenarios as a tool  for experimental study of the Black Sea ecosystem

- Scenario 0 (Basic) – without forcing function (keeping F unchanged)
- Scenario  1 (-50 F% SMPEL) – decreasing F with 50% of small pelagics – SPR, ANE, HMM
- Scenario 2 (+50 F% SMPEL) – increasing F with 50% of small pelagics – SPR, ANE, HMM
- Scenario 3 (-50 F% PELPRED) - decreasing F with 50% of  pelagic predators (BON, BLU)
- Scenario 4 (+50 F% PELPRED) - increasing F with 50% of pelagic predators (BON, BLU)
- Scenario 5 (-50 F% DEMFISH) - decreasing F with 50% of demersal fish (WHG, DGS, TUR)
- Scenario 6 (+50 F% DEMFISH) - increasing F with 50% of demersal fish (WHG, DGS, TUR)




- Graphic representation of the input data of EwE for the Black Sea, 1990-2010. The biomasses and landings are presented as gC $m^{-2}$ $yr^{-1}$. Due to high differences in the values of the parameters, part of the functional groups are presented on the second axis (orange color).




# Ecotrophic efficiency

- **Abbreviations: PHYT. S** – phytoplankton small; **PHYT. L** – phytoplankton large; **PROTZ** - protozoa; **ZOOPL. S** – zooplankton small; **ZOOPL. L** – zooplankton large; **NOC** - N. scintillans; **PLEUR** - P. pileus; **AUR** - A. aurita; **MNE** – M. leidyi; **BER** – B. ovata; **SAG** – P. setosa; **SPR** - sprat; **ANE** - anchovy; **HMM** – horse mackerel; **SHC** - shad; **PELPRED** – pelagic predators; **WHG** - whiting; **TUR** - turbot; **DGS** – piked dogfish; **DEMFISH** – other demersal fish **DOLPH** - dolphins; **MUSSL** – black mussel; **CHAM** - C. gallina; **RPN** – rapa whelk; **MOLLS** – other mollusians; **BCRUST** – benthic crustaceans; **WORM** – worms; **SEEGR** - seagrasses; **BRMCALG** – brown macroalgae; **RDMCALG** - red macroalgae; **GRMCALG** – green macroalgae; **DETR** – detritus.

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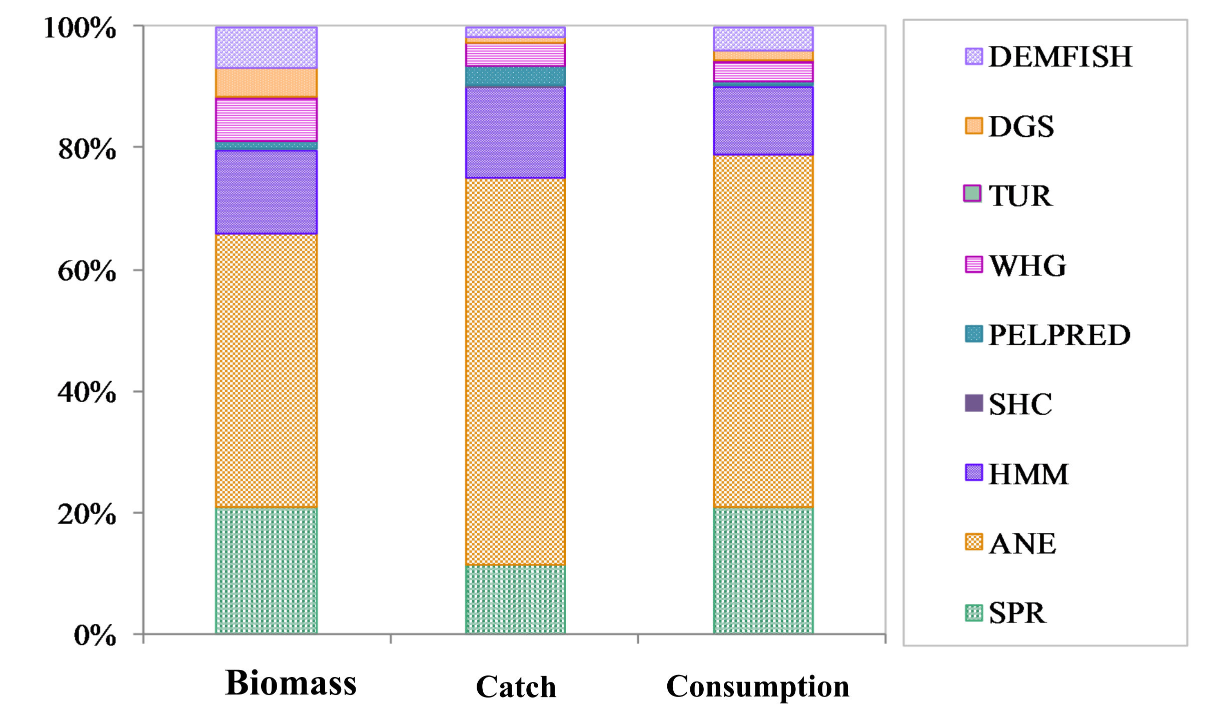
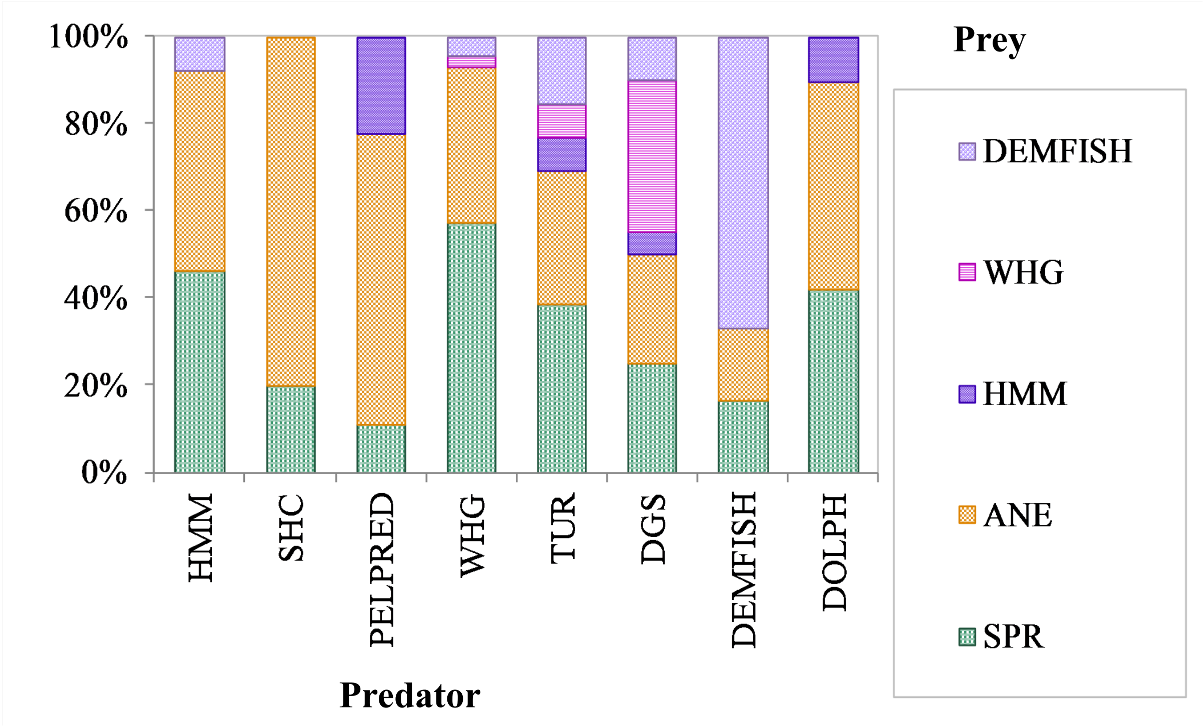
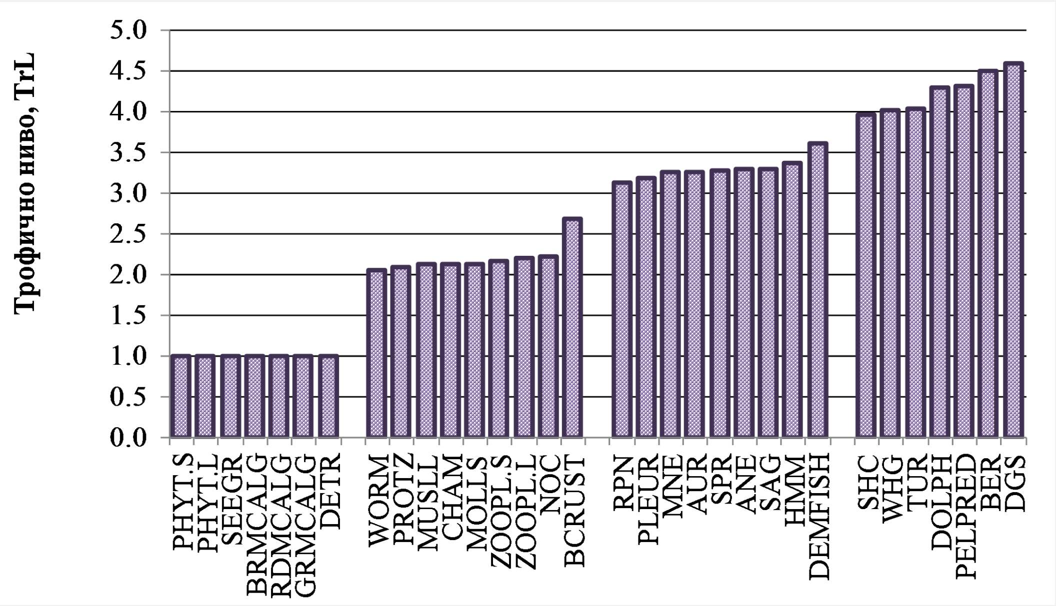
# Analysis of the Black Sea Ecosystem using Ecopath modeling, 1990 - 2010

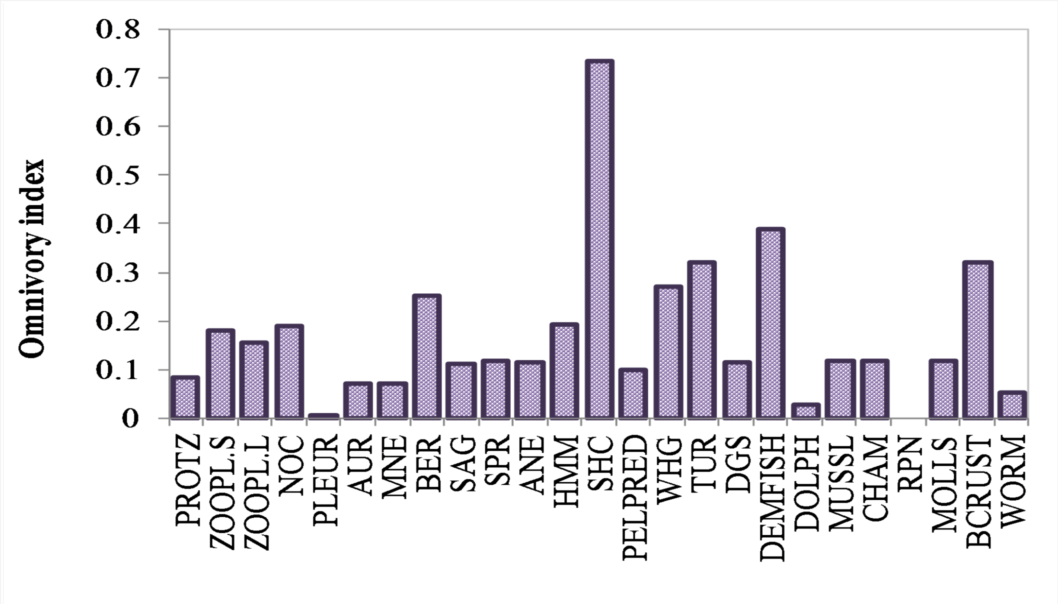


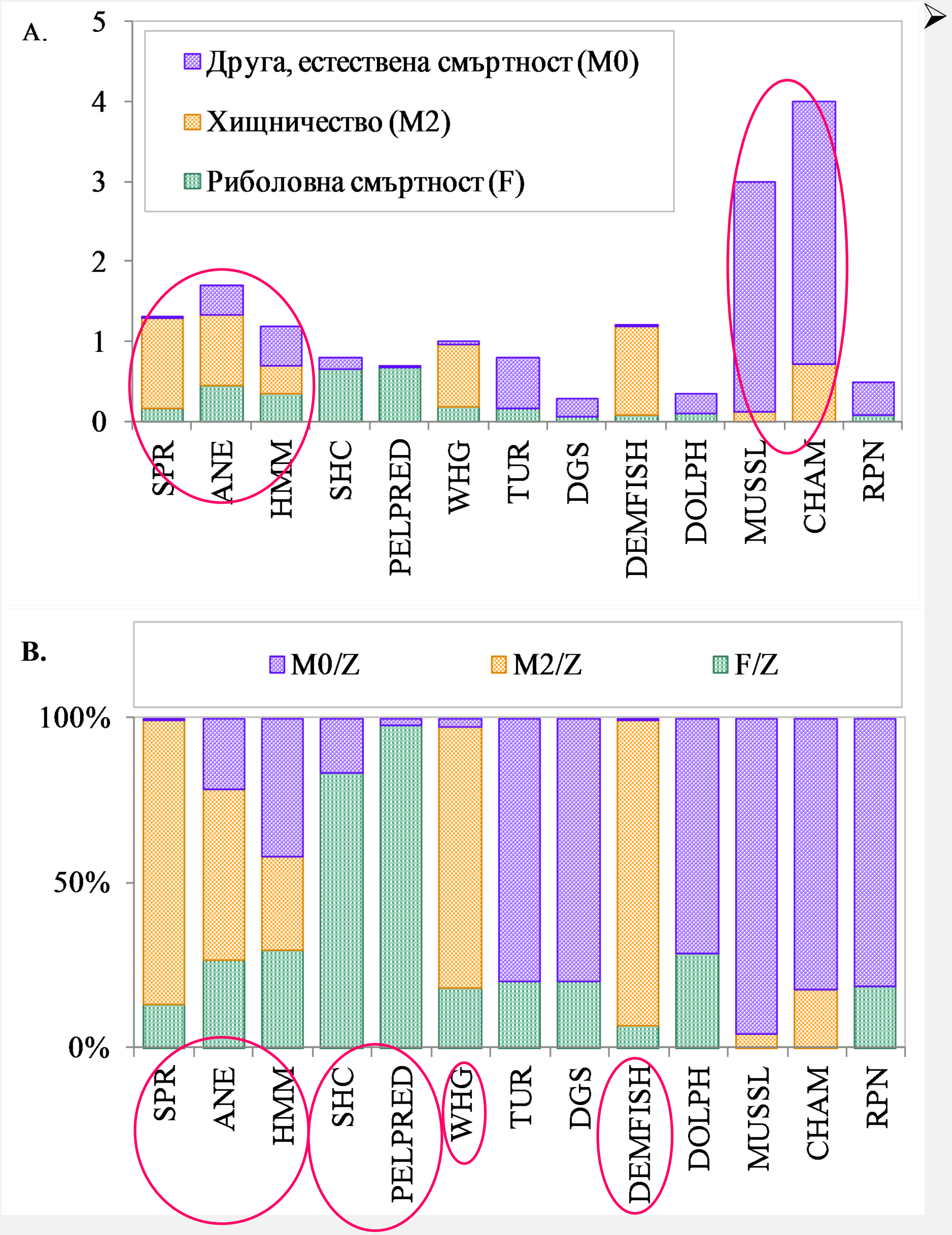




- Partitioning (%) of the biomass, catch and total consumed biomass from all of the predatory fish in the Black Sea, EwE, 1990-2010.
- Fish consumption by other predatory fish in the Black Sea, EwE, 1990-2010.

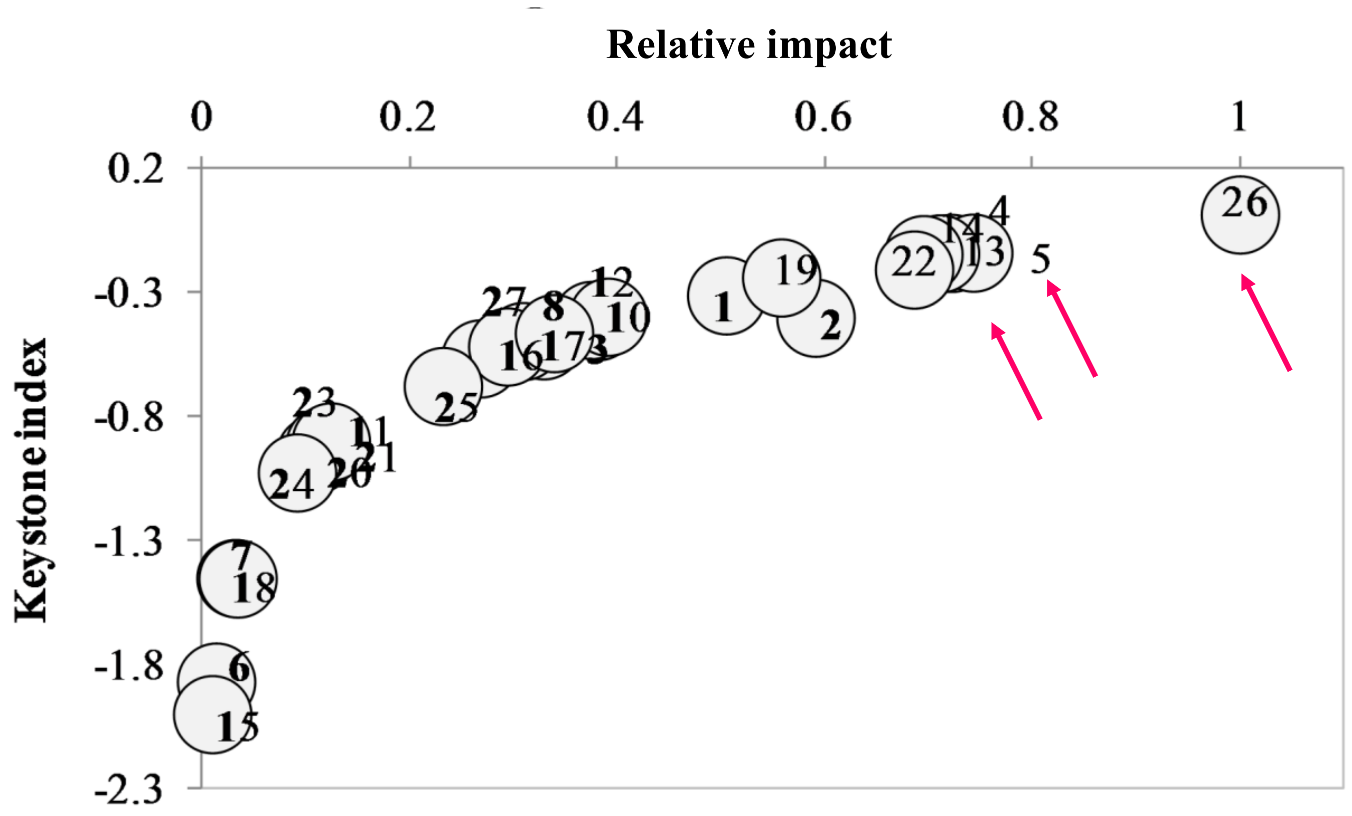
- # Trophodynamic indicators



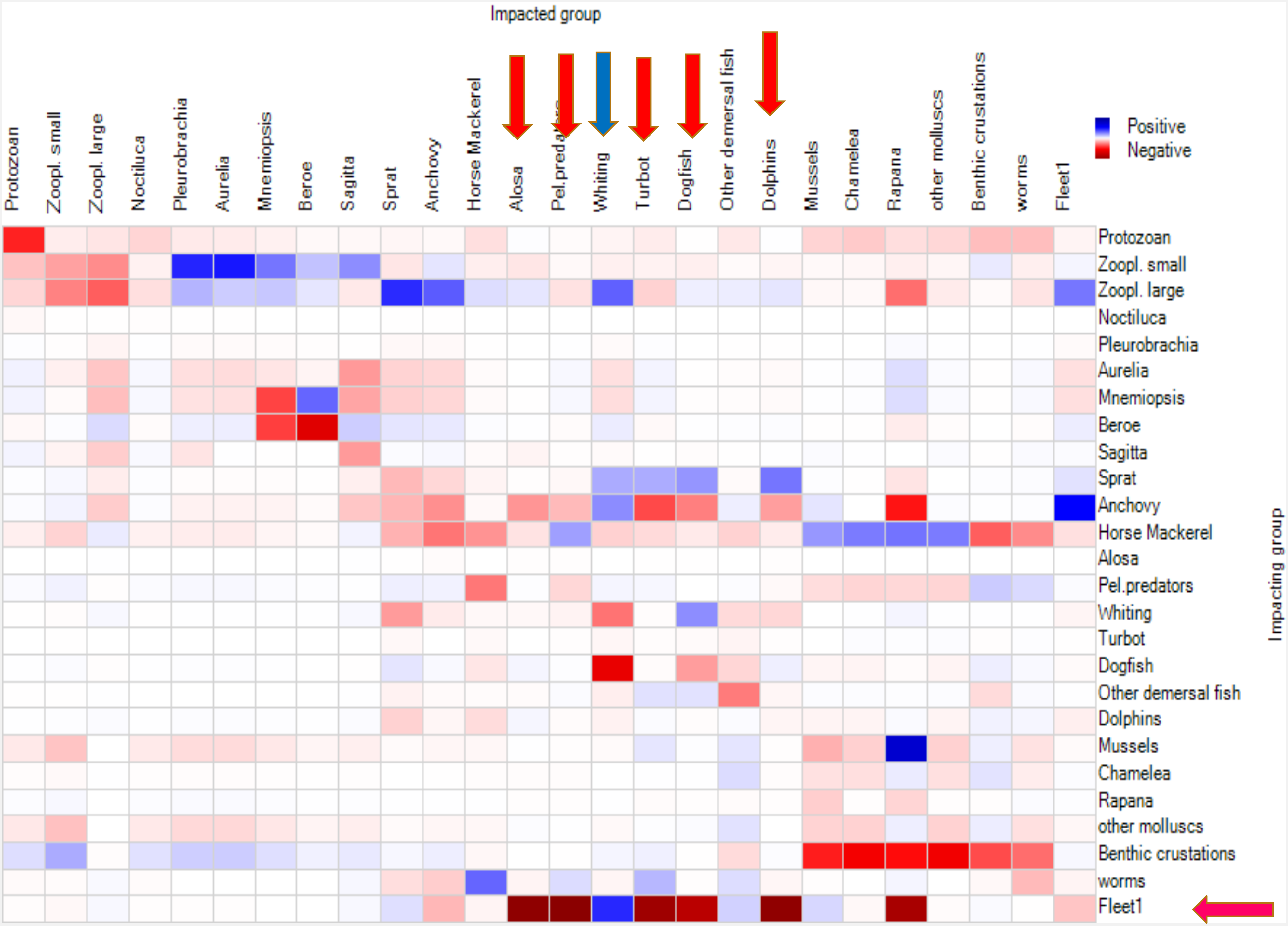

- Total mortality (Z) partitioned as: fishing mortality (F); predation mortality (M2); other mortality (M0), and (B.) proportions of F, M2, and M0 to the total mortality (Z), of the commercial marine bioresources, EwE, Black Sea, 1990-2010.




**Functional Group**

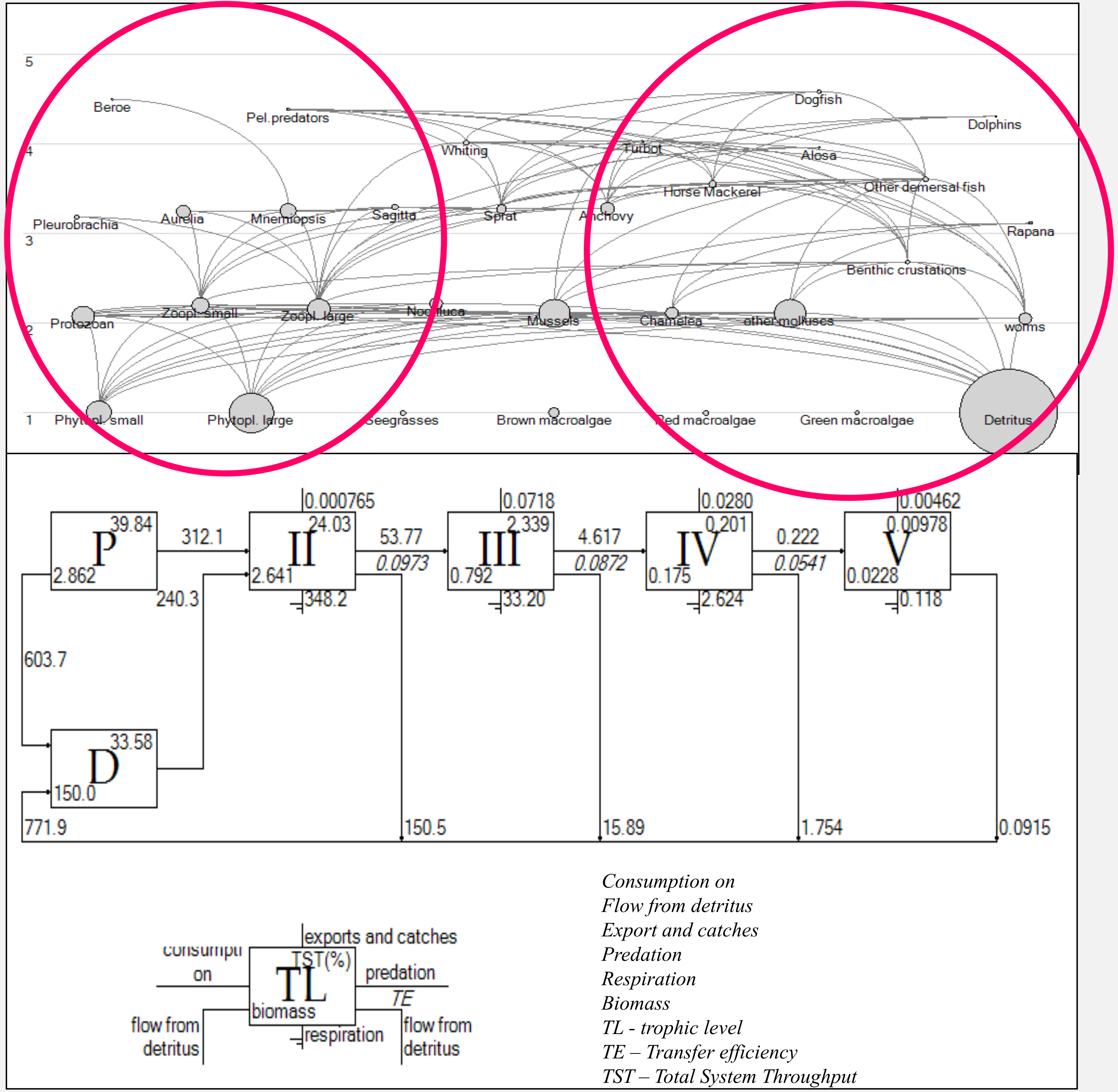
| | | | | | |
|---|---|---|---|---|---|
| 1 | PHYT.S | 10 | BER | 19 | DGS |
| 2 | PHYT.L | 11 | SAG | 20 | DEMFISH |
| 3 | PROTZ | 12 | SPR | 21 | DOLPH |
| 4 | ZOOPL.S | 13 | ANE | 22 | MUSSL |
| 5 | ZOOPL.L | 14 | HMM | 23 | CHAM |
| 6 | NOC | 15 | SHC | 24 | RPN |
| 7 | PLEUR | 16 | PELPRED | 25 | MOLLS |
| 8 | AUR | 17 | WHG | 26 | BCRUST |
| 9 | MNE | 18 | TUR | 27 | WORM |

- Keystoneness index and relative impact of the functional groups of the Black Sea ecosystem, EwE, 1990-2010



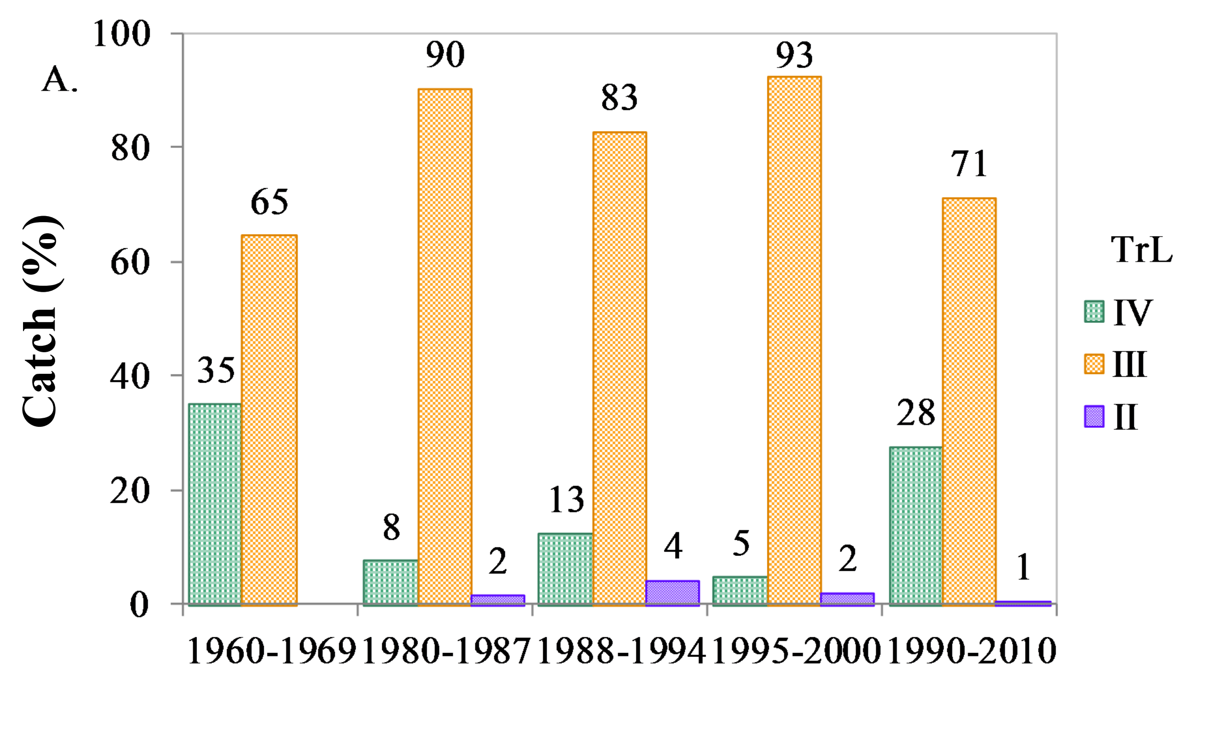

- Mixed trophic impact

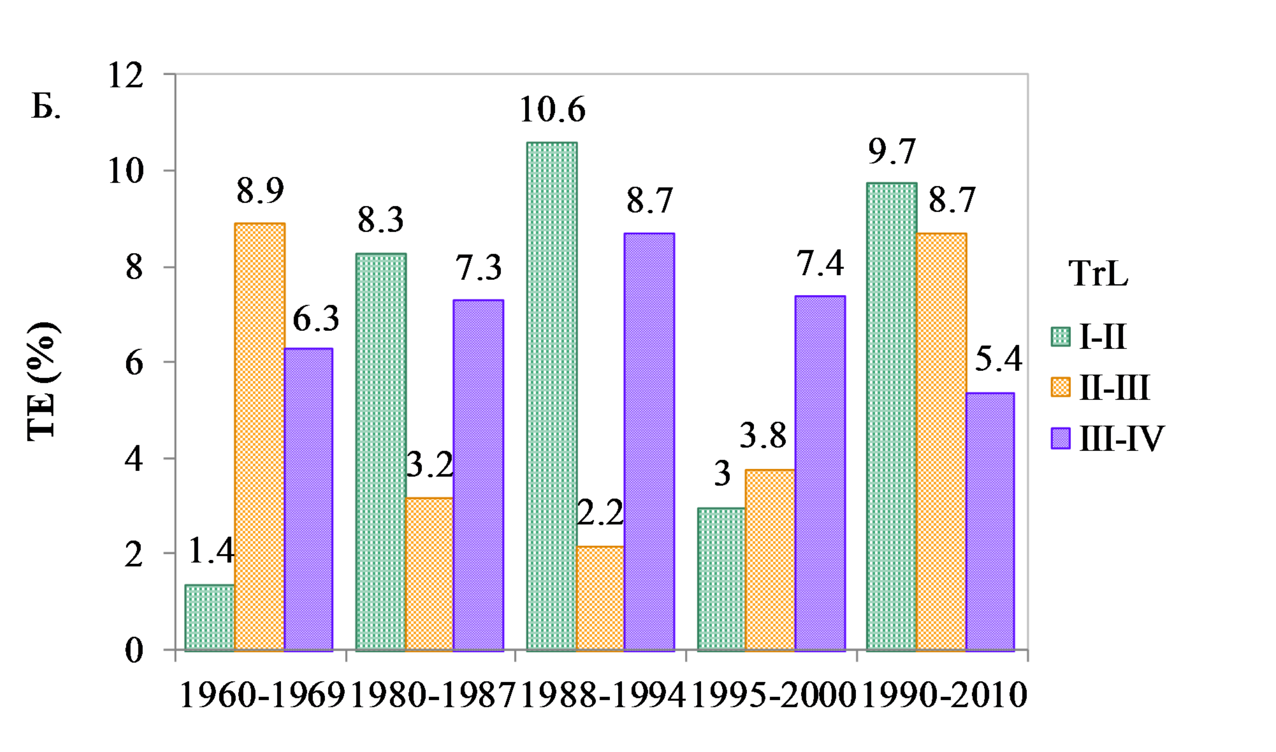
- Distribution of the trophic flows and matter in the Black Sea ecosystem, presented by (A.) flow diagram and (B.) Lindeman spine, EwE, 1990-2010. Abbreviations: P – primary producers and D - detritus – trophic level 1; II – trophic level 2; III – trophic level 3; IV – trophic level 4; V- trophic level 5.



| Indicator/Period | 1960-1969 | 1980-1987 | 1988-1994 | 1995-2000 | **1990-2010** |
|---|---|---|---|---|---|
| Sum of all consumption ($g\ C\ m^{-2}\ y^{-1}$) | 234.4 | 380.9 | 246.6 | 449.9 | **635.4** |
| Sum of all exports ($g\ C\ m^{-2}\ y^{-1}$) | 99.0 | 318.0 | 410.5 | 48.6 | **531.7** |
| Sum of all flows into detritus ($g\ C\ m^{-2}\ y^{-1}$) | 191.2 | 457.5 | 502.4 | 223.0 | **771.9** |
| Total System Throughput, TST ($g\ C\ m^{-2}\ y^{-1}$) | 681.7 | 1406.0 | 1316.6 | 1020.3 | **2323.1** |
| TPP/TR ($g\ C\ m^{-2}\ y^{-1}$) | 1.630 | 2.274 | 3.614 | 1.162 | **2.384** |
| Net system production ($g\ C\ m^{-2}\ y^{-1}$) | 98.9 | 317.9 | 410.4 | 48.6 | **531.7** |
| TPP/TB | 132.0 | 91.0 | 116.8 | 89.8 | **141.0** |
| System Omnivory Index | 0.072 | 0.122 | 0.115 | 0.116 | **0.135** |
| Finn's cycling index) | 9.4 | 6.239 | 4.860 | 3.867 | **5.198** |

- Ecosystem indicators describing the overall state of the Black Sea ecosystem



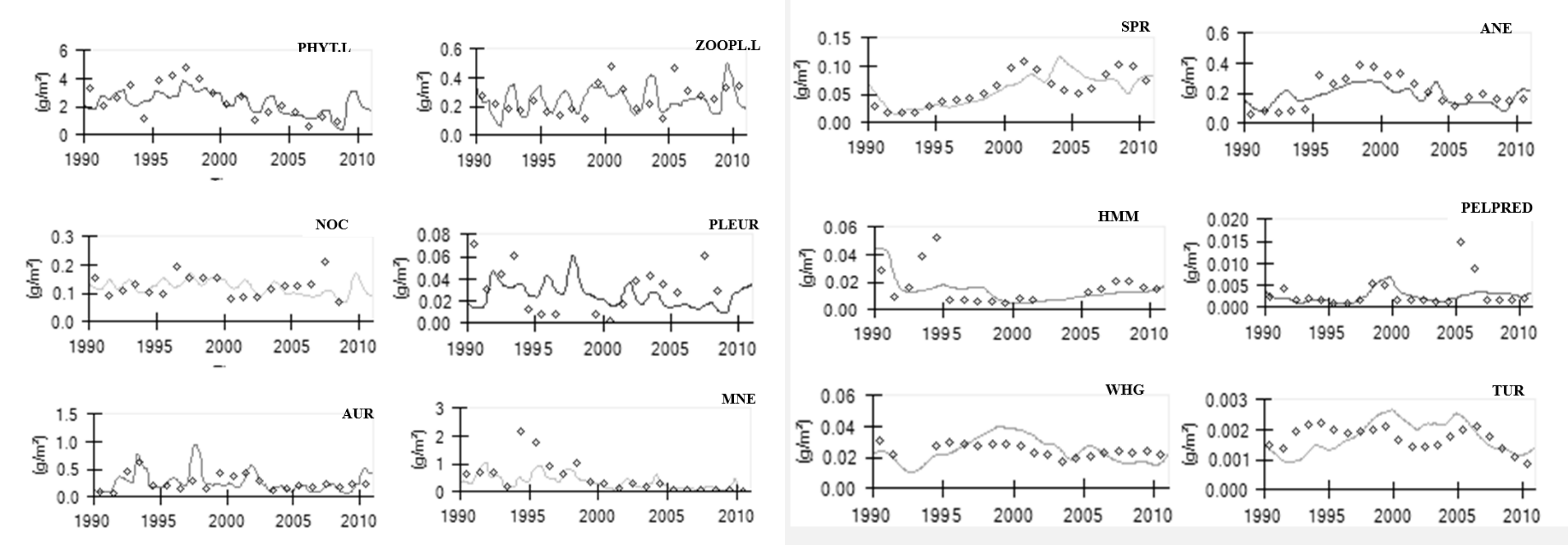




A.) Total catch and (B.) transfer efficiency (TE%) by trophic levels (TrL1→TrL2; TrL2→TrL3; TrL3→TrL4) for different periods of time, EwE models for the Black Sea. The data for the periods 1960-2000 are based on Akoglu et al. (2014).

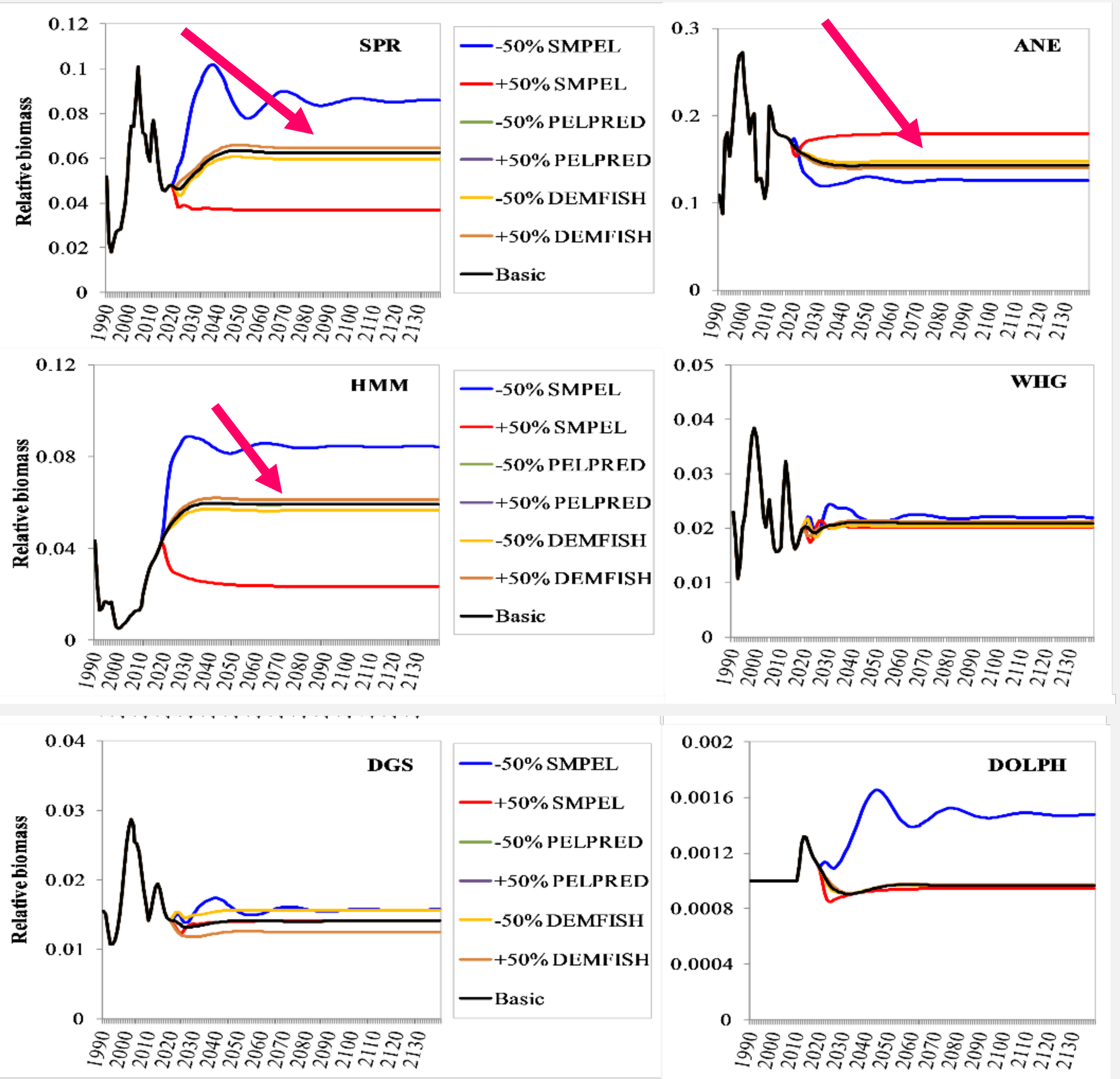
# Ecosim

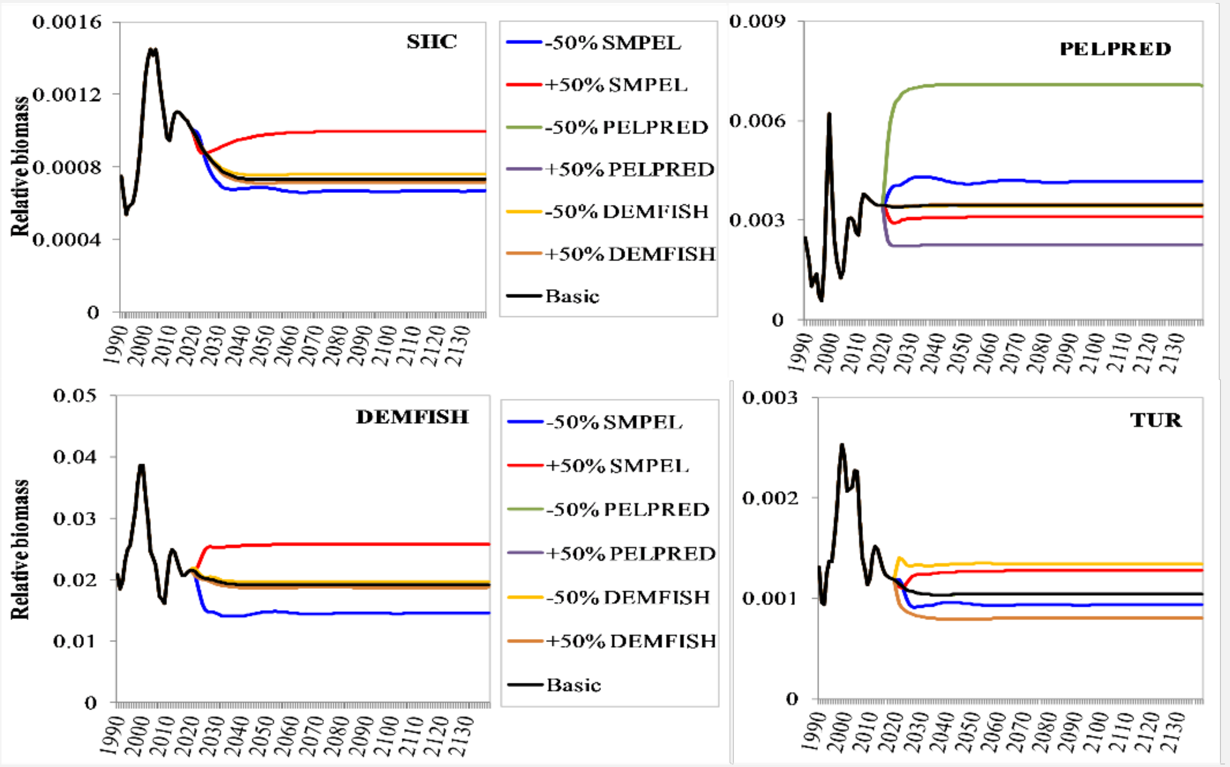
- Values of vulnerability parameter (vij) of the Ecosim model, Black Sea, 1990-2010.

| Predator/ Prey | | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | Скала |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | PHYT.S | 2 | <100 | 1 | 2 | | | | | | | | | 2 | | | | | | | 1 | 2 | | 1 | | 1 | |
| 2 | PHYT.L | 2 | <100 | 1 | 2 | | | | | | | | | | | | | | | | 1 | 2 | | 12.5 | | 2 | |
| 3 | PROTZ | 2 | <100 | <100 | 1 | | | | | | | | | | | | | | | | 2 | 2 | | <100 | | 2 | |
| 4 | ZOOPL.S | | 1 | <100 | | 1 | 1 | 1.5 | | 1 | <100 | 1 | | | | | | | | | <100 | 1 | | <100 | 2 | | |
| 5 | ZOOPL.L | | | | | 1 | <100 | <100 | | <100 | <100 | 3.7 | 100 | | | 1 | | | 2 | | | | | | 2 | | |
| 6 | NOC | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | PLEUR | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 8 | AUR | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 9 | MNE | | | | | | | | 1 | | | | | | | | | | | | | | | | | | |
| 10 | BER | | | | | | | | <100 | | | | | | | | | | | | | | | | | | |
| 11 | SAG | | | | | | <100 | <100 | | 2 | 1 | 1 | | | | | | | | | | | | | | | |
| 12 | SPR | | | | | | | | | | | | 1.2 | 2 | 1 | 1.5 | <100 | 1 | 2 | <100 | | | | | | | |
| 13 | ANE | | | | | | | | | | | | <100 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | | | | | | | |
| 14 | HMM | | | | | | | | | | | | | | 1 | | 2 | 100 | | <100 | | | | | | | |
| 15 | SHC | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 16 | PELPRED | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 17 | WHG | | | | | | | | | | | | | | 2 | 2 | 2 | <100 | | | | | | | | | |
| 18 | TUR | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 19 | DGS | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 20 | DEMFISH | | | | | | | | | | | | 100 | | 1 | 2 | 1 | 100 | 2 | | | | | | | | |
| 21 | DOLPH | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 22 | MUSSL | | | | | | | | | | | | | | | | 2 | | 2 | | | | 1 | | 2 | | |
| 23 | CHAM | | | | | | | | | | | | | | | | | | 2 | | | | 2 | | 2 | | |
| 24 | RPN | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 25 | MOLLS | | | | | | | | | | | | | | | | | | 2 | | | | 1 | | 1 | | |
| 26 | BCRUST | | | | | | | | | | | | <100 | | <100 | 2 | 1 | | 2 | | | | | | 2 | | |
| 27 | WORM | | | | | | | | | | | | <100 | | 2 | 2 | 1 | | 2 | | | | | | <100 | | |
| 28 | SEEGR | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 29 | BRMCALG | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 30 | RDMCALG | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 31 | GRMCALG | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 32 | DETR | 1 | <100 | 2 | 1 | | | | | | | | | | | | | | | | 1 | 1 | | <100 | 1 | 1 | |




- Time dynamic model estimates (black lines) of the main trophic groups in the Ecosim model 1990-2010, fitted to empirical data (dotes).




- Dynamic model biomass (Relative biomass) (Cg $m^{-2}$) estimates projected to from 1990-2139, as a results of the change in the fishing mortality. Commercial fish, Black Sea.

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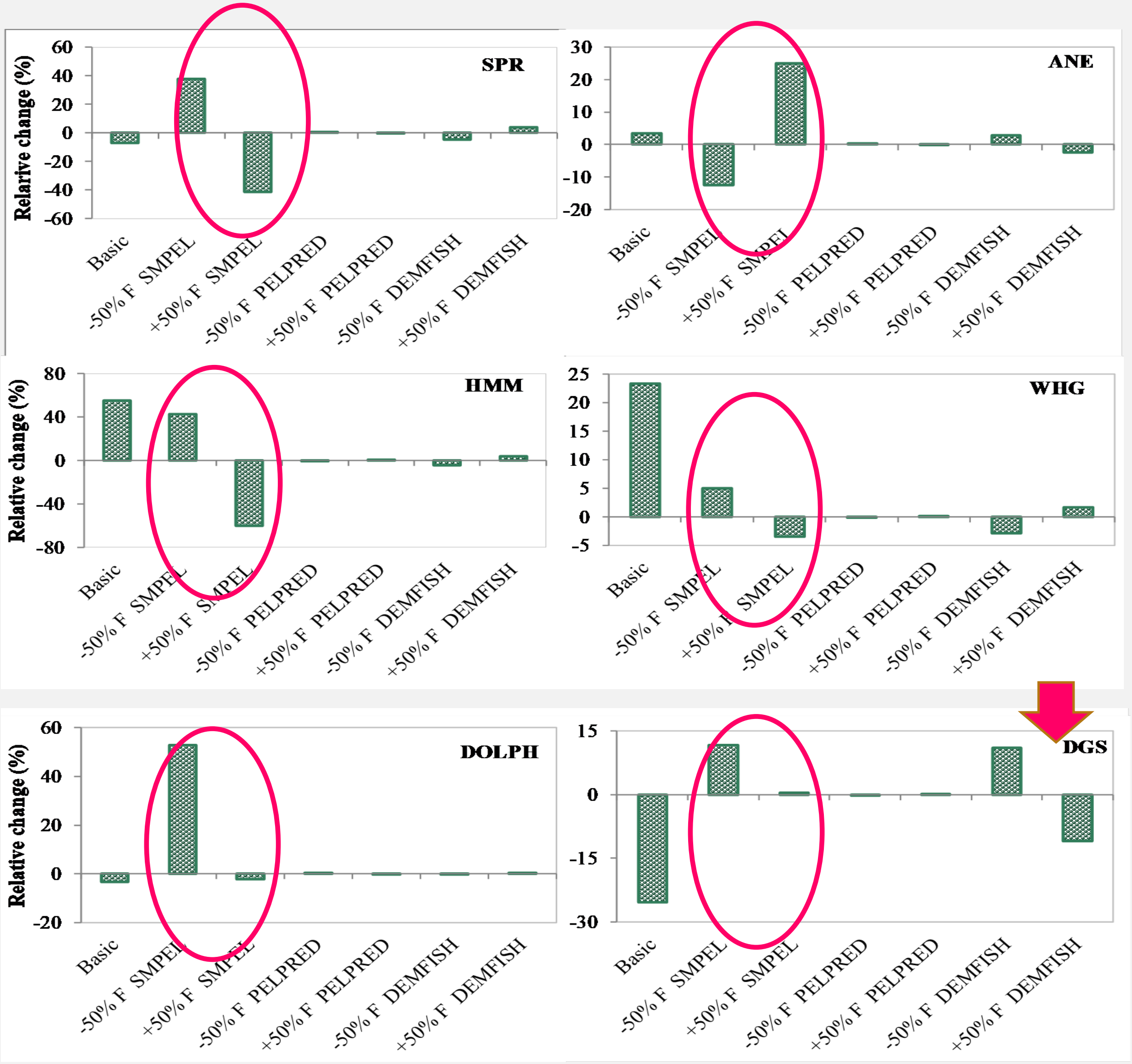


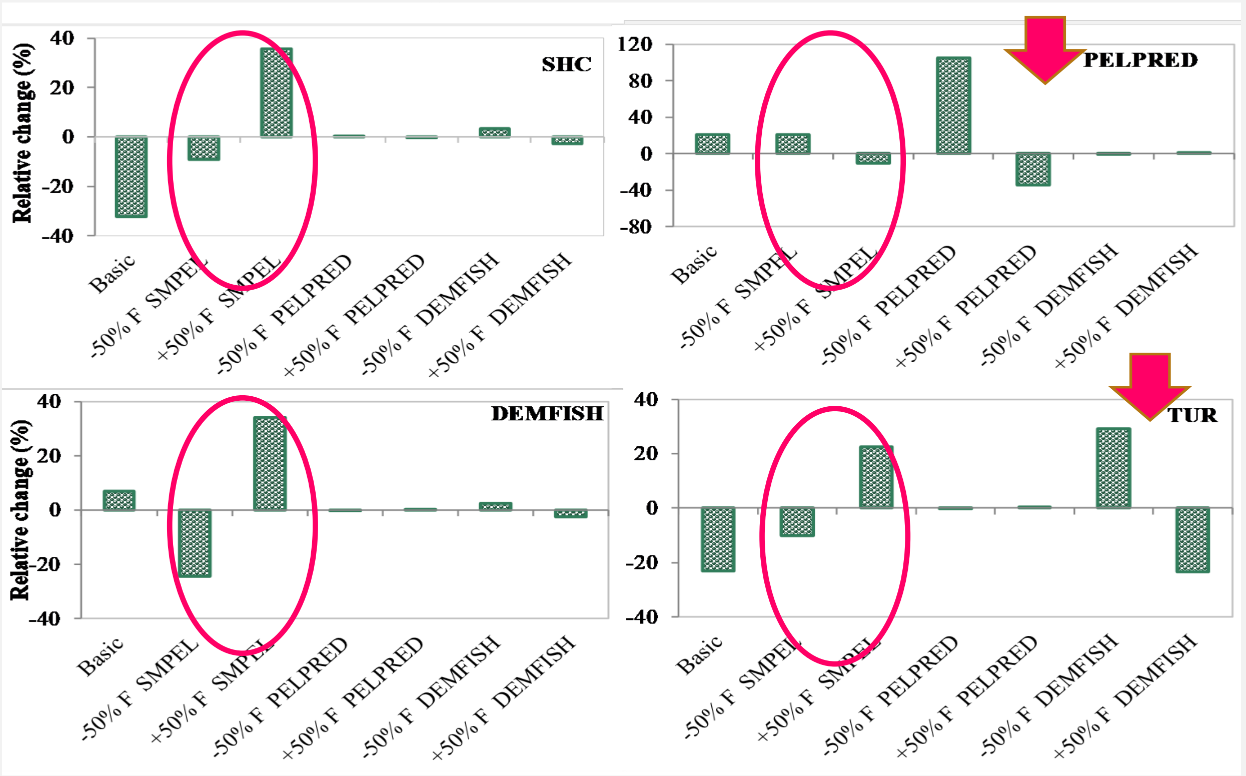


- Biomass change (%) in ecosystem forcing scenarios of the commercial fish species, Black Sea 2020-2140.

- The main energy flows in the Black Sea ecosystem originate from detritus group and primary producers. These two energy sources play an essential role in the functioning of the ecosystem and are considered to be the dominant components in the structure of the trophic chain.

- The groups of low trophic levels (TrL2 and TrL3) - benthic crustaceans and zooplankton play a key role in the trophic control (bottom-up) of the system, by linking the primary producers (phytoplankton and detritus) and the higher trophic levels (consumers), thus influencing a number of fish and invertebrate species with important ecological and commercial value.

- Fish groups would respond quickly to changes in fishing practices. These changes would be most pronounced when changing the exploitation rate of the small pelagics. Small pelagic fish (anchovy, sprat, horse mackerel) are an essential component of the Black Sea trophic pyramid. Located in the middle of the trophic web, the fluctuations in their biomass affect both the lower (top-down control) and upper (bottom-up control) trophic levels.

- The majority of commercial bioresources in the Black Sea are not sustainably exploited. The decreasing trends in the biomasses predicted by the EwE modeling (by keeping the current F) confirm the alarming results of the Black Sea fish stock assessments, according to which the priority fish species for the commercial fishery are in a state of overexploitation.

The results of this investigation showed the need of using different indicators when analyzing the state of marine ecosystems and its fish resources. The EwE model for the Black Sea is an example of the need to use multi-species models together with the single-species ones. Sometimes reducing the fishing pressure on a given resource is not enough to restore its stocks and abundance. The detailed investigation and understanding of the tropho-dynamic interactions between the species in a ecosystem are key factors to ensure their rational exploitation.

# Thank you for your attention!