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The coastal MPAs as a tool for implementing of sustainable fisheries management: a study of evaluation of the effects of MPAs on the recovery and distribution of the fish stocks in the Bulgarian Black Sea

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Title	The coastal MPAs as a tool for implementing of sustainable fisheries management: a study of evaluation of the effects of MPAs on the recovery and distribution of the fish stocks in the Bulgarian Black Sea
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INTRODUCTION

Many exploited fish and invertebrate species use coastal habitats during one or more life-history stages as spawning, feeding, nursery areas and migration; yet, the value of these habitats has not been adequately characterized (Seitz 2014). Coastal fish habitats are thus comprised of juvenile growth areas, foraging areas, reproduction areas and migratory routes. While the latter three are of direct importance for fisheries, by offering high catches or value per fishing effort (Airoldi and Beck, 2007; Seitz et al., 2014) (in Kraufvelin et al. 2018) the former one is a step required to produce recruits to replenish the fishery (Beck et al., 2001) (in Kraufvelin et al. 2018). With our rapidly expanding global population driving increasing demand for protein sourced from the sea, maximizing fisheries productivity is imperative (Unsworth et al. 2018).

Coastal habitats represent "home grounds" for coastal fish species throughout their lives and for other fish species during different life history stages when they are using the coastal zone (Kraufvelin et al. 2018). Major coastal fish habitats consist of: (1) coastal wetlands and shallow bays (including salt marshes, estuaries, river mouths, coastal lagoons and flads), (2) shallow vegetated areas (including seagrass meadows and macroalgal beds, but also freshwater plants in brackish water areas), (3) biogenic reefs and hard structures (including mussel beds, rockyshores, mariculture installations and other artificial substrates) and (4) unvegetated soft and sandy areas and shallow open water (modified from Seitz et al., 2014) (in Kraufvelin et al. 2018). Thus, basically, most types of shallow benthic and pelagic areas can function as coastal fish habitats.

1. The role of the coastal habitats for fishery yield

There are no sufficient information about the role of the coastal habitats for commercial fish population growth and production in the Black Sea. The most highly exploited fish species by the industrial Black Sea fishery are known to be: anchovy, sprat, horse mackerel, turbot, bonito, red mullet, bluefish (GFCM 2012; STEFC 2017). Their landings contribute the major part of the total Black Sea landing (Table.1.1). Some of these fish are schooling pelagics (anchovy, sprat, horse mackerel, bluefish, bonito), whereas others (red mullet, turbot) are demersal dwellers. Although the fish are highly mobile animals, and thus distributed in different parts (and depth) of the sea, all of the above mentioned species are closely connected with the coastal zone. Their reproduction, nursery grounds (distribution of fish eggs and larvae; protection from predators), forage arenas and migration routes are usually located in the near coastal area (Table 1.2.).

Table 1.1. List of the commercial fish species exploited by the Black Sea fishery, 2004-2014; FAO statistic (2016)

Species	Characteristic	Landings (%)
***Engraulis encrasicolus* (Anchovy)**	Endemic	74.2
***Sprattus sprattus* (Black Sea sprat)**	Endemic	19.7
***Trachurus mediterraneus* (Horse mackerel)**	Endemic	4.1
***Pomatomus saltatrix* (Bluefish)**	Migratory	1.6

***Sarda sarda* (Bonito)**	Migratory	<1
***Mullus barbatus* (Red mullet)**	Endemic	<1
***Scophtalmus maeotica* (Black Sea turbot)**	Endemic	<1
***Alosa pontica* (Pontic shad)**	Anadromous	<1

Table 1.2. Coastal habitat use of commercially important fish species in the Black Sea

Species	**Common name**	**Coastal zone**	**Depth range (m)**	**Reference**	
Alosa pontica	Pontic shad	F, M		Stoyanov et al. 1963	
Engraulis encrasicolus	Anchovy	S, F, M, N	0-25 m (eggs and larvae)	Stoyanov et al. 1963; Dechnik 1973	
Mullus barbatus	Red mullet	S, F, N	0-10 m	Stoyanov et al. 1963; Dechnik 1973	
Pomatomus saltatrix	Bluefish	S, F, M, N	0-10 m (eggs and larvae)	Stoyanov et al. 1963; Dechnik 1973	
Psetta maxima	Turbot	S, F, N	10-40 m	Stoyanov et al. 1963; Dechnik 1973	
Sarda sarda	Bonito	S, F, M, N	0-5 m (eggs and larvae)	Stoyanov et al. 1963; Dechnik 1973	
Sprattus sprattus	Sprat	S, F, N	0-100 m (0-50 m - eggs and larvae)	Stoyanov et al. 1963; Dechnik 1973	
Trachurus mediterraneus	Horse mackerel	S, F, M, N	0-10 m (eggs and larvae)	Stoyanov et al. 1963; Dechnik 1973	

(S) spawning area, (N) nursery area, (F) feeding area, and (M) migration route.

In temperate waters, shallow and wave-sheltered fish habitats are generally characterised by higher water temperatures, extensive macrophyte vegetation and a particularly high production of zooplankton and zoobenthic prey, thus providing excellent conditions for survival and growth of fish larvae and juveniles (Kraufvelin et al. 2018). Many habitats such as seagrass and macrophyte meadows, perennial macroalgal belts and mussel beds, also aid in maintaining fish populations by providing three dimensional benthic structures serving as more or less permanent habitats, temporary nursery areas, refuges/shelter from predation and rich feeding areas (Kraufvelin et al. 2018). In the case of the Black Sea, the benthic fauna (polychaetes, crustaceans) found in the horse mackerel 'stomachs (Georgieva et al. 2019) confirmed the fact that during its spring migration, the species being tolerant to warm water keeps close to the shore (up to 8-10 m of depth), were its spawning take place and where it can easily find accessible food (Stoikov 1978). The reported benthic invertebrates found in bluefish stomachs (Black Sea) also suggest that in the autumn the species migrates in the near coastal area (Georgieva and Daskalov 2019).

The coastal zone is not only an essential habitat for the survival - reproduction of the commercially important fish species, but also provide significant part of the industrial landings. For example, the major part of the Bulgarian sprat landings is located in the coastal area (10-20 m; up to 50 m) (Fig. 1.1). The concentration of fishing activity in the coastal zone is especially pronounced during spring-summer (April – June) months (Georgieva, Daskalov 2015; Stoyanov et al. 1963) when the sprat feeds actively in the shallow coastal waters (Stoyanov et al. 1963).

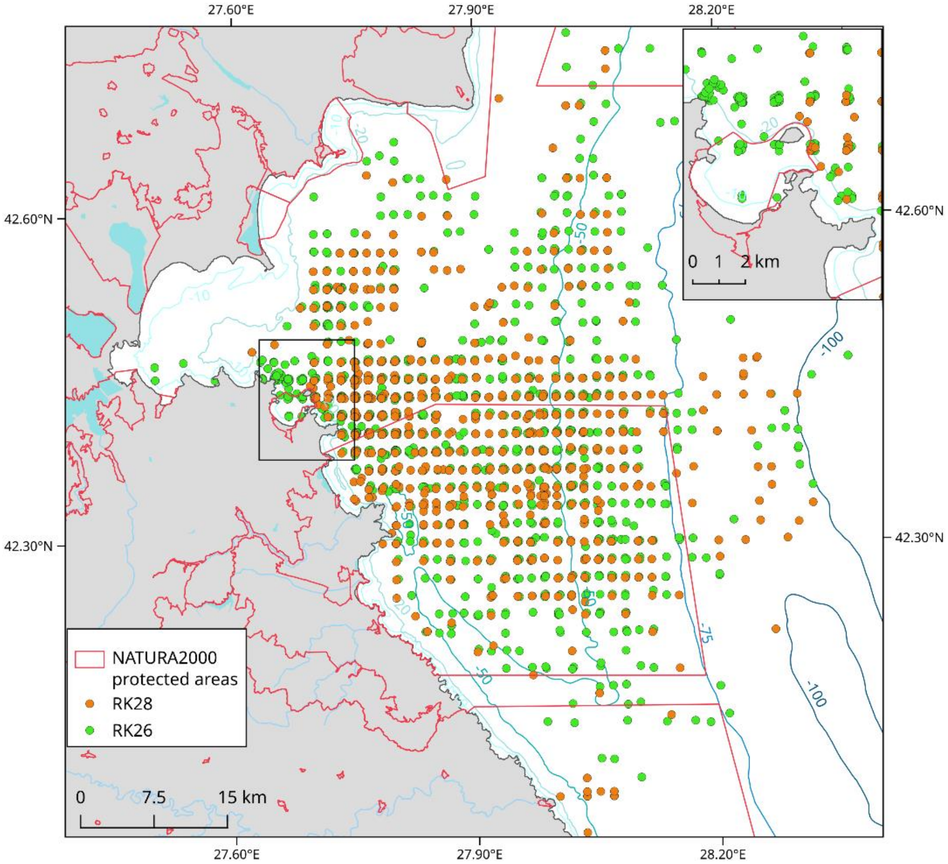

Figure 1.1. Fishing aquatory of two commercial fishing vessels (RK 26 and RK 28), operating for sprat in the Bulgarian Black Sea, 2006-2013. The black rectangle shows the region of Gradina-Zlatna ribka.

Figure 1.1 shows the fishing aquatories of two commercial fishing vessels (RK 26 and RK 28) trawling for sprat in the southern Bulgarian Black Sea. These fishing vessels were determined to have one of the highest fishing activities, expressed as fishing days and catches (Georgieva et al. 2017). The total landing for the period 2006-2013 of both of the vessels was recorded to be 5177.0 t (RK 26=2787.2t; RK 28=2389.8 t) (Table 1.3), while the sprat yield (2006-2013) fished only in the MPAs were calculated to be 2018.62 t on total (RK 26= 1121.106 t; RK 28=897.514 t) (Table 1.4). Hence, 39% of the total landing of both of the vessels (RK 26=40.2%; RK 28=37.5%) were conducted in the relevant MPAs. The highest yield of sprat was registered in the protected area of Ropotamo, followed by Strandja, Gradina- Zlatna ribka and Emine-Irakli regions (Table 1.4).

The index ”catch per unit of effort” (CPUE - an indirect measure of fish stock abundance or density); calculated for both of the vessels (RK 26 and 28) and for the whole fishing area and period (2006-2013), were registered to be on average 462 kg fish per hour (2006-2013) (Table. 1.3). Calculated only for the MPAs, the CPUE index showed its highest values for the zones of Strandja (RK 26=732 kg/h; RK 28=493 kg/h), Gradina-Zlatna ribka (RK26=664 kg/h) and Ropotamo (RK 26=526 kg/h; RK28=474 kg/h) areas (Table 1.5.).

Table 1.3. Total catch (C, tones) and average CPUE (kg/hour) of sprat for RK 26 and RK 28, 2006-2013, Bulgarian Black Sea

	RK 26	RK 28	total C, t/average CPUE, kg
C, t	2787.2	2389.8	5177.0
CPUE, kg/hour	486.7	437.4	462.1

Table 1.4. Total sprat landings (C, tones) for RK 26 and RK 28 fished in the MPAs, 2006-2013, Bulgarian Black Sea

MPA	Catch, t	
	RK 26	RK 28
Emine-Irakli	-	0.9
Emona	20.352	4.168
Plazh Gradina-Zlatna ribka	28.058	-
Ropotamo	1039.052	827.202
Strandzha	33.644	65.244
total C	1121.106	897.514

Table 1.5. Average sprat CPUE (kg/hour) for RK 26 and RK 28 fished in MPAs, 2006-2013, Bulgarian Black Sea

	CPUE, kg/hour	
	RK 26	RK 28
Emine-Irakli	-	300
Emona	398.25	272.75
Plazh Gradina-Zlatna ribka	663.6526	-
Ropotamo	525.5667	474.1758
Strandzha	731.9909	493.056

The traditional fishing methods can be classified as passive and active. Examples of passive gears are: trap nets, gillnets, long lines, seine nets; while fishing vessels as mid-otter trawlers and beam trawlers have been categorized as active ones. Generally, in the Bulgarian Black Sea, the fishery with passive gears is located in the very near coastal area (up to 20 m), while the active fishery could take place in the open/deeper sea region. The partitioning of the Bulgarian landings by passive and active gears showed that significant part of the fishery yield has been realized by passive activities (mainly trap net and gillnets) (Table 1.6) (EAFA 2016). This is especially pronounced for the species: turbot, bonito, red mullet and pontic shad (>40%). The importance of the coastal zone as fishing ground was also reported in a research concerning the ecosystem services in the Bulgarian Black Sea (FEMA Project). According to the investigation the highest fishing activity was registered in the coastal zone of the southern Bulgarian Black Sea (Burgas Bay) (Georgieva et al. 2017) (Fig. 1.2). This area is characterized by shallow waters (0-20 m), significant components of which are the sea grass and macroalgae meadows. These habitats provide favorable conditions as optimal sea water temperature, abundant food resources and shelters from predators – prerequisites for fish growth, survival and high fish productivity (Unsworth et al. 2018).

Table 1.6. Partitioning (%) of the Bulgarian commercial Black Sea landings by passive and active gears, 2013-2015, EAFA Statistics

Species	Passive Gears	Active Gears
Alosa pontica	43.4	56.6
Engraulis encrasicolus	22.5	77.5
Mullus barbatus	42.5	57.5
Pomatomus saltatrix	13.7	86.3
Sarda sarda	49.9	50.1
Scophtalmus maeotica	49.6	50.4
Sprattus sprattus	0.8	99.2
Trachurus mediterraneus	17.5	82.5

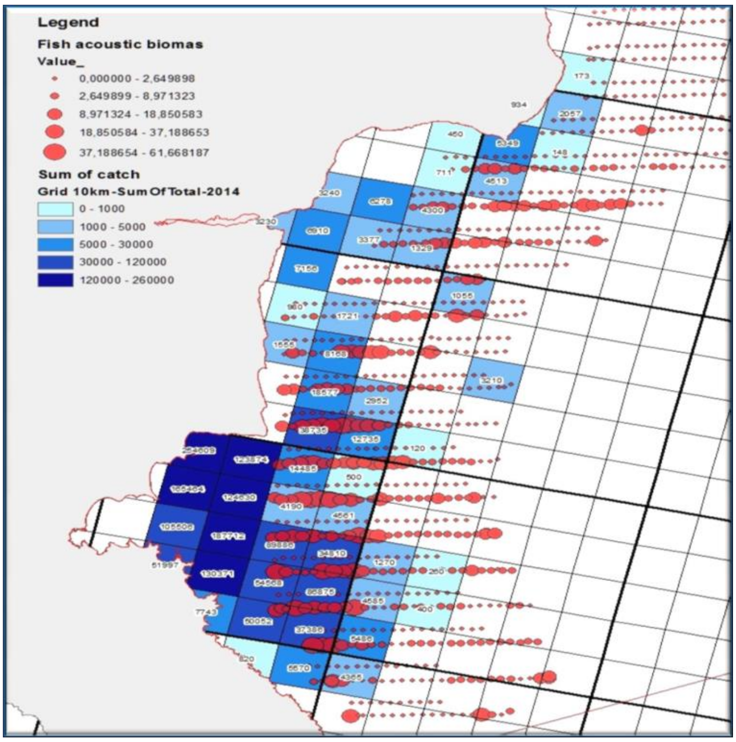

Figure 1.2. Mapping total fish landing (kg), Bulgarian Black Sea, 2013-2015

Compared with the modern period (1990-2010), in the past (1950-1980), the Black Sea landings were significantly higher (Fig.1.3). The combination of intensive coastal water eutrophication (1980s) together with overfishing has led to a drastic depletion of the commercial fish stocks in the 1990s. Since then, a partial recovery has taken place due mainly to decreased fishing capacity and improving environmental conditions (Daskalov et al. 2007), but this combination of uncontrolled fisheries and eutrophication has caused important alterations in the structure and dynamics of the Black Sea ecosystem (Daskalov

2002). These events have led not only to changes in species composition of fish, benthic invertebrate and macrophyte communities but also to the introduction of invasive species (Zaitsev 1997; Moncheva et al. 1995; Vinogradov et al. 1989; Bologa 2001). The environmental problems in the Black Sea as well as the climate change and coastal construction development emerge as real challenges for environmental management calling for integrated strategies focusing on both fish and their preferred environments (Borja et al., 2016; Uusitalo et al., 2016) (in Kraufvelin et al. 2018).

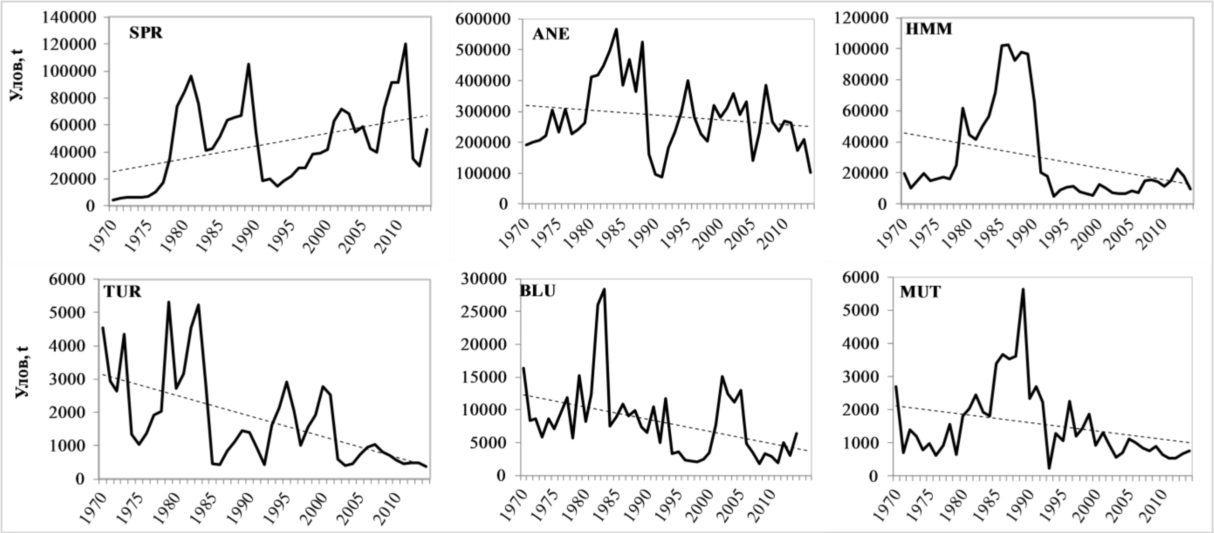

Figure 1.3. Landings (black line) and linear trends (dash line) of the Black Sea commercial fish species, 1970-2014, FAO Statistic (2016) (SPR - sprat; ANE – anchovy; HMM – horse mackerel; TUR – turbot; BLU – bluefish; MUT – red mullet).

This discussion demonstrates the use of coastal habitats by commercially (and ecologically) important species and thus suggests the importance of those habitats to population dynamics and fishery yield (Seitz et al. 2014; Unsworth et al. 2018). All of the investigated species utilizes coastal habitats during some portion of their life history, indicating the ecological value of coastal habitats. Moreover, these commercial fish using coastal habitats consist the majority (>95%) of the total Black Sea catch (GFCM 2012; STEFC 2017). Although management has attempted to ameliorate adverse effects of habitat degradation, to some extent, many management efforts do not go far enough in protecting these delicate habitats and the species that rely on them (Seitz et al. 2014). It is estimated that 85% of European coastlines are degraded (EEA, 1999), and public awareness of prolonged habitat losses is limited (Lotze, 2004) (in Seitz et al. 2014).

Since many species use coastal habitats as spawning, feeding, and nursery areas, and these life stages usually have very specific habitat demands, habitat availability may be a bottleneck for many fish populations (Fodrie and Levin, 2008; Sundblad et al., 2014) (in Seitz et al. 2014). The increased anthropogenic pressure on the coastal waters required management strategies for sustainable marine resources conservation. A fishery restriction in some coastal zones and periods is likely to contribute to increased catches both in the coastal areas (direct effect) and in the open sea region (indirect effect). Future fishery management efforts need to be directed not only at maintaining fish stocks, but also at preserving and restoring the habitats that are essential for fish and invertebrate populations, which is a major thrust of ecosystem-based management (Seitz et al. 2014).

2. The MPAs as a tool for implementing the Ecosystem Based Fisheries Management

Resource overexploitation and climate change are now recognised as considerable treats for the dramatically changing global environment and social systems around the world (Cury et al. 2008). With a growing body of evidence highlighting the parlous state of world fish stocks (e.g. Hutchings, 2000; FAO, 2002), new approaches to fisheries management that take account of how fishing and climate change affects ecosystem structure and function are being called for. Such principles are encapsulated in the Ecosystem Based Fisheries Management approach (EBFM, Botsford et al., 1997, Garcia & Cochrane, 2005).

In the Black Sea context the EBFM can be defined as a science based approach of managing of the human activities (e.g. fishing, fish stock enhancement, drivers of pollution) related to conservation and sustainable use of the biological resources. It is meant to deal with issues such as scientific assessment of the Black Sea ecosystem and fisheries, environmental change (e.g. climate), biological interactions (predator/prey), anthropogenic impacts (pollution, overfishing), conservation and recovery of biodiversity (habitats, populations), and social and economic impacts.

Marine Protected Areas (MPAs) are becoming increasingly considered an essential part of the EBFM. MPAs offer an appealing prospect to simultaneously act as a tool for fisheries management and biodiversity conservation (Allison et al. 1998; Gell and Roberts 2003). By protecting the whole community within a given area, MPAs can protect species that would otherwise not be covered under single species management plans. MPAs are therefore seen as an important tool within the EBFM as they can protect the whole community in the area, thus protecting ecosystem functioning in addition to focal species.

Fish are highly mobile organisms. Over their lifespan, they pass along significant distances, a fact especially pronounces for the migratory and the pelagic schooling fish species. There are strong communication between the different marine areas, as a result of the mobility of the fish populations. Hence, to consider a given fish stock strictly connected only to a particular marine area is completely wrong. In the Black Sea, the commercial fish stocks are shared between the riparian countries and an implementation of a cooperative fishery management system is needed to achieve sustainable exploitation of the fish recourses (Caddy 2008). In order to ensure a sustainable exploitation of a given stock, it is necessary to build not only an isolated MPA, but a complex network of MPAs where all kind of fishing activities to be prohibited. In the Bulgarian Black Sea, there is no ban for fishery in the MPAs.

Ecospace spatial ecosystem model (as part of the Ecopath with Ecosim modelling system, EwE Christensen et al. 2008), has been designed to evaluate effects of MPA on abundance and distribution of fish and associated fisheries and ecosystem changes (Walters et al. 1999, Le Quesne et al. 2008). Ecospace allows consideration of the effects of MPA establishment on all functional groups and fisheries within a system, rather than just considering the effects of MPA on a focal species, as has often been the case with previous model assessments of MPA effects (Guénette et al. 1998; Pelletier and Mahévas 2005). Ecospace simulations are strongly influenced by trophic interactions, a concept that lies at the heart of EBFM. This extends the evaluations of MPA based scenarios to encompass the wider ecosystem and socio-economic effects of MPA establishment.

Objective of this study is to evaluate effects of existing and potential MPAs in the Bulgarian Black Sea waters on fisheries and trophic interactions within the context of the EBFM. The study explores the range of ecosystem responses that occur following different scenarios of MPA establishment. It is based on originally build Ecospace spatial ecosystem model of the Bulgarian Black Sea waters. It is important to note, that Ecospace as a part of the EwE system, having being an ecosystem model including species interactions and some environmental influences, is centred on fish and as such its main predictions refer to fish stocks and fisheries. MPAs in Ecospace are defined as areas closed for fishing, and spatial simulations can be used to evaluate the use of MPA as a fisheries management tools.

3. Ecopath, Ecosim and Ecospace (EwE) model in Bulgarian Black Sea waters

Several models of EwE models of the Black Sea have been developed recently, including static time-dynamic and time-dynamic coupled with biogeochmical models (Daskalov 2002, Zavatarelli et al. 2013). An Ecospace model exploring the effects of MPAs in the Black Sea has been developed within the EU Coconet project (Sahyoun et al 2015). Here is presented the first space-dynamic Ecospace model developed in the Bulgarian Black Sea waters.

The ecosystem model is constructed using the well-established Ecopath with Ecosim approach (EwE, Christensen et al. 2008). The EwE approach provides a quantitative description of the average state of biomass organization and energy flows in a food web. Species are aggregated and represented in the model as ecological functional groups connected as predators and prey through a diet composition matrix. All components of the defined ecosystem are represented by user-defined functional groups. EwE has three main components: Ecopath, Ecosim and Ecospace. Ecopath can be used to produce a static (i.e. non-dynamic) trophic network model, while Ecosim simulates the Ecopath network behaviour over time and must be based on an existing Ecopath model, and Ecospace is a spatial simulation of the trophic network behaviour and must be based on an existing Ecosim model.

Ecospace relies on the Ecopath mass-balance approach for most of its parameterisation, it uses a cell-based format (cell size determined by Ecospace users) to describe the two-dimensional, spatial distribution of species under the influence of biotic and abiotic factors. Inputs include: (i) movement rates of fauna (used to calculate changes in species distribution) (ii) the settings (top-down vs. bottom-up control) also required for Ecosim (iii) habitat preferences (the influences of physical variables on spatial distribution of a species)

(iv) spatial distribution of fishing effort and (v) vulnerability to predators in the various specified habitats (Walters et al. 1999). Habitats in Ecospace are defined as sets of water cells sharing features affecting the movements, feeding rate and survival of the groups occurring therein (Christensen et al. 2008). Essentially, they are habitat parameters linked to the distribution of the faunal groups included in the model. The habitats are assigned based on knowledge of requirements of functional groups and observations of their main distribution areas. Functional groups are assigned to habitats which are known to match their main distribution areas.

The distribution of fishing fleet activity is specified by assigning fleets to habitats, (i.e. defining in which habitat(s) a fishing fleet may operate, the costs of fishing based on distance from port and whether a given fleet may operate within a restricted area. Fisheries restricted areas (e.g. MPAs) can be assigned by not allowing certain fleets to operate in them. During the simulation, the fishing mortality rates (F) of the fleets are distributed using a simple 'gravity model' where the proportion of the total effort allocated to each cell is assumed proportional to the sum over groups of the product of the biomass, the catchability, and the profitability of fishing the target groups (Caddy, 1975). Where costs or restricted areas are not prohibitive, the distribution of fishing fleets reflects the distribution of their target species.

Ecospace has been designed and is successfully applied to evaluate effects of Marine Protected Areas (MPA) on abundance and distribution of fish and associated fisheries and ecosystem changes (Walters et al. 1999, Le Quesne 2008, Daskalov et al. 2013).

3.1 Structure of input data, EwE settings and validation

The present EwE model was upgrading upon previous models by Daskalov 2002, Zavatarelli et al. 2013. The present model refers to the 1990s. The model structure is set to 32 trophic groups including phytoplankton (2 groups), macrophytobenthos (4 groups), protozoans (2 groups), invertebrates (zooplankton and zoobenthos, 11 groups), fish (9 groups), dolphins (1), and detritus groups (1 group, Fig 3.1.1). Fisheries consist of 4 fishing fleets (Fig 3.3.2).

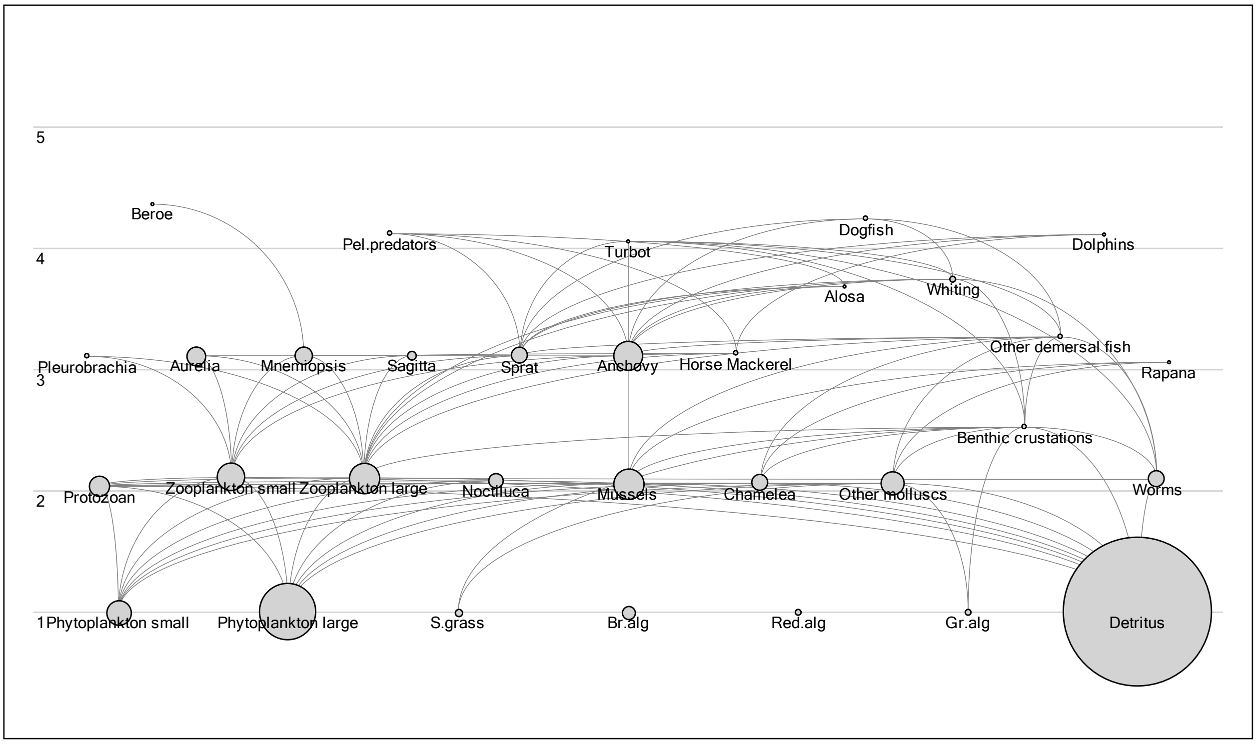

Figure. 3.1.1. Bulgarian Black Sea waters food web model structure: trophic groups size correspond to relative biomass, grops are ordered by trophic level (on Y axis)

Before starting Ecospace, a time-dynamic model Ecosim needs to be properly adjusted and validated by fitting to empirical time-series (Fig. 3.1.2). Ecosim is a dynamic trophic model structured from the mass-balance assessment carried out with Ecopath. Ecosim provides dynamic biomass predictions of each group as affected directly by fishing and predation, changes in available food, and indirectly by fishing or predation on other groups with which a group interacts (Walters et al., 1997; Christensen et al., 2008). The Ecosim model is validated by using empirical time series of biomass and catches (Fig. 3.1.2).

EwE can simulate a process termed “mediation,” in which a predator–prey interaction between two functional groups is influenced by a third (mediating) group (Christensen et al., 2008). Biogenic habitats (macrophytes, coral, seagrass, mussel beds) are important hiding and rearing habitats for many fish species (Armstrong and Falk-Petersen 2008), and recent EwE studies (Harvey 2014) have simulated the mediating role of biogenic habitat groups as refuge for prey from predators. Here, was simulated potential habitat mediation effects of black mussel beds for improving survival and production of mobile preys groups, and explore their impact on the food web structure and interactions, as well as the application of the current MPA network in Bulgarian Black Sea waters. It has been applied decreasing hyperbolic mediation function relating biomass and spatial distribution of black mussels to several mobile preys trophic groups, including Sprat, Anchovy, Horse Mackerel, Whiting, Other demersal fish, Benthic crustaceans and Worms. The expected effect of the application of such a function is that the vulnerability of affected groups to their predators will decrease with the increase of the mussel beds.

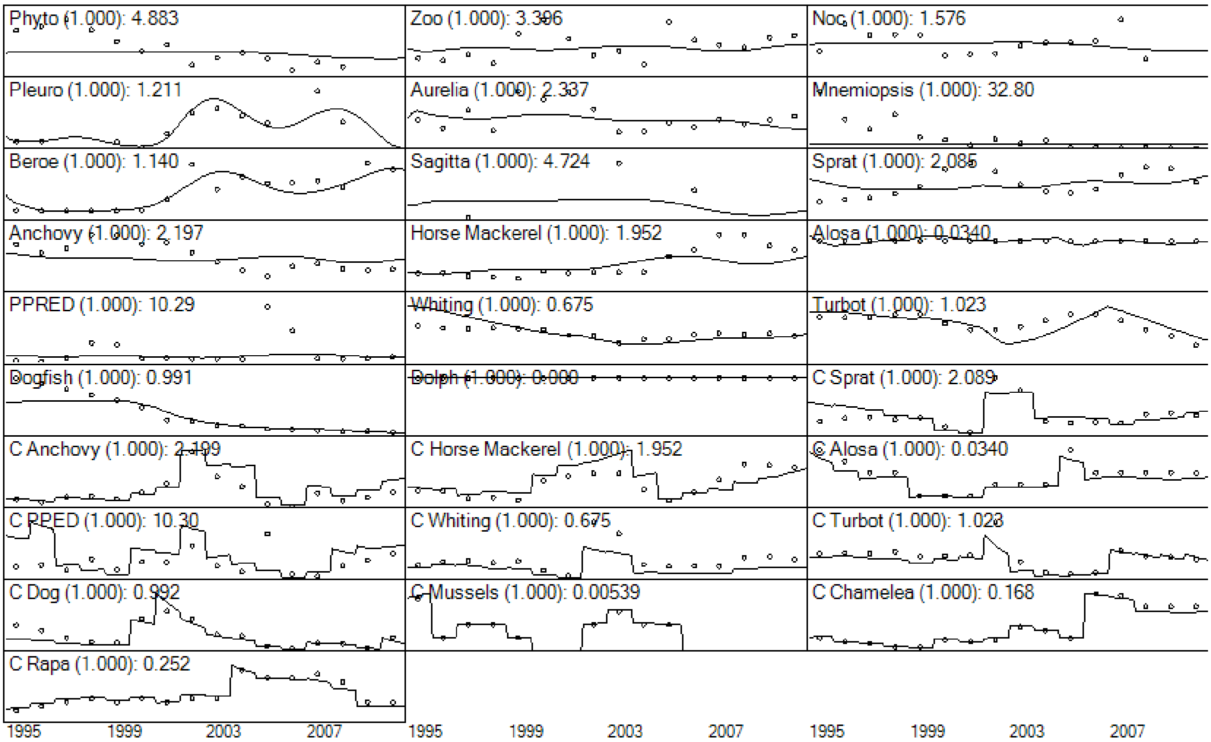

Figure. 3.1.2. Fitted Ecosim model: lines are estimated and dots are empirical time series of biomass and catches

3.2 Ecospace model

The Ecospace cell grid of the Bulgarian Black Sea waters model is set at 0.02 degree which resulted in 92 x 195 cells (Fig. 3.2.1). The habitats in the Ecospace model were defined based on depth and productivity: Habitat 1 (coastal waters), Habitat 2 (inner shelf), Habitat 3 (outer shelf), Habitat 4 (slope), Habitat 5 (deep sea). (Fig. 3.2.1). 12 different MPAs were set in the Ecospace model along the Bulgarian coast (Fig. 3.2.1, Table 3.2.1). Some of the model MPAs consist of few neighbouring smaller MPAs e.g. model MPA Ropotamo includes BG0001001 Ropotamo, Islands Saint Ivan and Saint Petar (Table 3.2.1).

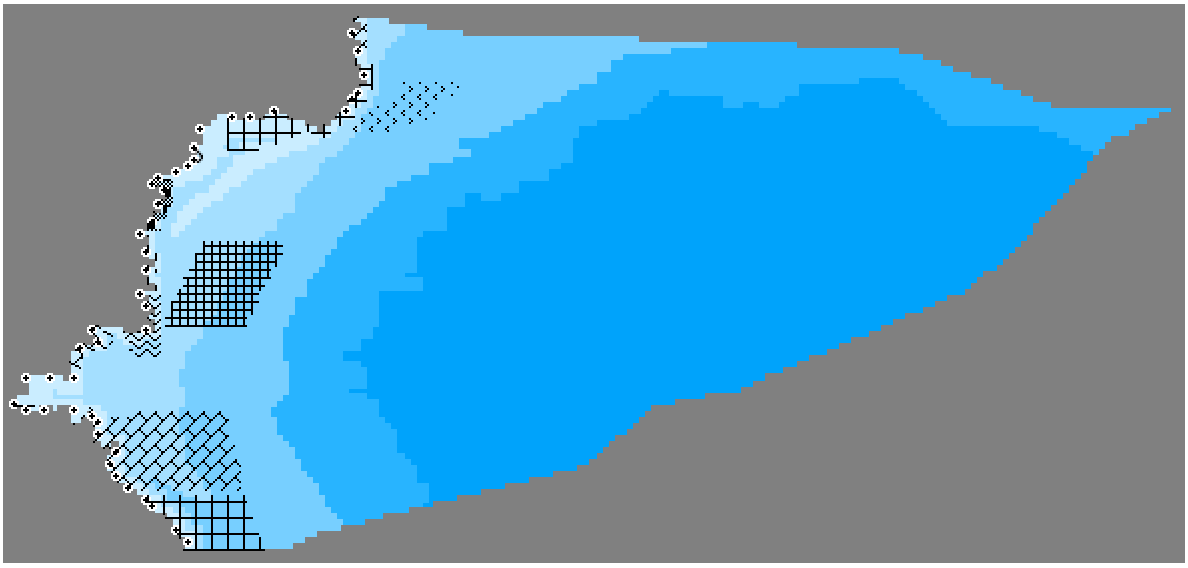

Figure 3.2.1. Representation of Bulgarian Black Sea waters Ecospace 'habitats': Habitat 1 (coastal waters), Habitat 2 (inner shelf), Habitat 3 (outer shelf), Habitat 4 (slope), Habitat 5 (deep sea). Gridded cells depict existing MPAs.

Table 3.2.1. Existing MPAs along the Bulgarian coast.

Modeled MPA	**MPA Name**	**Designation**	**Size in km^2**	**Type of MPA**
Strandja	BG0001007 Strandzha	Habitats/Bird Directive	391.53	Protected site
Ropotamo	BG0001001 Ropotamo	Habitats Directive	881.92	Reserve
	Islands Saint Ivan and Saint Petar	Habitats Directive	12.4	Protected site
Gradina	BG0000146 Plaj Gradina – Zlatna ribka	Habitats Directive	10.33	Protected site
Mandra	Mandra –Poda	Bird/Habitats Directive	0.61	Protected site
	Chengene skele	Bird /Habitat Directive	1.03	Protected site
	BG0001502 Otmanli	Habitats Directive	0.09	Protected site
Pomorie	Pomorie	Habitats /Bird Directive	11.26	Protected site
	Ravda- Aheloy-Nesebar	Habitats Directive	31.82	Protected site
	Nesebar State Game Breeding Station	Birds Directive	214.82	Protected site
Emine	BG0001004 Cape Emine-Irakly	Habitats/Birth Directive	76.75	Natural monument
	BG0001501 Emona	Habitats Directive	553.45	Protected site

Koketrays	Koketrays sand bank	Habitats Directive	7.6	Protected site/sand bank/
Kamchia	Kamchia	Habitats Directive	7.75	Strict Nature Reserve
	Shkorpilovtsi‖	Habitats/Bird Directive	112.76	Protected site
Galata	BG0000103 Galata	Bird/Habitats Directive	14.56	Protected site
Aladja	BG0001500 Aladja banka	Habitats Directive	6.7	Protected site
Kaliakra	BG0000573 Komplex Kaliakra	Habitats Directive	437.04	Protected site
Shabla	Lakes Shabla Ezeretz	Bird Directive	170.53	Protected site
	Lake Durankulak	Habitats Directive	37.88	Protected site

3.3 Ecospace results

Estimates of biomass, fishing effort, fisheries catches, and fishing mortality (catch devided of biomass) resulting from the Bulgarian Black Sea waters Ecospace model run, are presented in Table 3.3.1. and Figs. 3.3.1 – 3.3.5.

Table 3.3.1. Results of closing all MPAs for all fishing fleets. % change in biomass and catch compared to reference scenario of no closure, are shown in the whole area, and inside of the closed area (all MPAs), in the cases without and with applying mediation of Mussels on mobile prey groups. In the last column is % change in biomass in the overall area with applying mediation compared to the case without mediation (see the text for explanations).

	Without	**mediation**			**With**	**mediation**		**Biomass**
Functional groups	**Biomass change (%)**		**Catch**		**Biomass change (%)**		**Catch**	**change**
	All area	**MPAs**	**change (%)**		**All area**	**MPAs**	**change (%)**	**(%)**
Phytoplankton small	-0.011	-0.045			-0.005	0.008		2.252
Phytoplankton large	-0.005	0.053			0.014	0.030		-1.358
Protozoan	0.039	0.031			-0.007	0.009		2.080
Zooplankton small	-0.004	0.136			-0.030	-0.074		-4.979
Zooplankton large	0.010	-0.228			-0.054	-0.176		5.565
Noctiluca	0.034	0.099			-0.020	-0.020		-0.693
Pleurobrachia	0.016	-0.145			0.026	0.012		1.689
Aurelia	-0.003	-0.122			0.001	-0.033		-0.454
Mnemiopsis	0.008	-0.127			-0.008	-0.049		0.768
Beroe	0.015	-0.201			0.019	0.113		11.780
Sagitta	0.101	-0.424			-0.023	-0.014		24.609
Sprat	-0.218	3.988	0.418		1.420	5.845	-0.941	-61.267
Anchovy	-0.017	-0.194	-0.499		0.157	-0.177	-0.912	-16.056

Horse Mackerel	-0.120	0.472	4.107		-0.257	0.746	5.757	154.785
Alosa	0.469	3.060	-3.989		0.123	2.313	-4.470	-2.668
Pel.predators	-0.129	1.050	-0.120		0.034	0.855	0.165	-2.837
Whiting	0.036	2.901	-0.684		-0.726	2.497	2.048	187.365
Turbot	7.174	24.351	1.540		3.372	18.063	0.017	16.614
Dogfish	0.019	1.956	-0.525		-0.253	2.082	0.236	38.987
Other demersal fish	0.539	3.025	-5.846		0.424	2.920	-5.842	4.372
Dolphins	-0.001	0.008			0.000	0.005		7.102
Mussels	0.028	0.041	-1.076		-0.052	-0.024	-1.103	-1.349
Chamelea	-0.010	0.071	-17.772		-0.145	-0.070	-18.266	-3.030
Rapana	-4.780	-6.091	-11.851		-4.672	-5.409	-11.780	1.241
Other molluscs	0.013	0.072			-0.076	-0.041		-2.079
Benthic crustations	0.036	-0.007			-0.018	-0.019		0.401
Worms	0.052	0.046			-0.027	-0.023		-0.512
S.grass	0.000	0.000			0.000	0.000		-0.005
Br.alg	0.000	0.000			0.000	0.000		0.000
Red.alg	0.000	0.000			0.000	0.000		0.000
Gr.alg	-0.002	0.001			-0.001	0.000		-0.012
Detritus	0.054	0.083			-0.005	-0.004		-0.688
	0.053	0.083						-0.694
Planktivorous fish	-0.043	0.261	0.148		0.201	0.211	-0.604	-17.912
Pelagic predators	-0.084	1.271	-0.611		0.041	1.034	-0.498	-2.825
Demersal fish	0.259	3.525	-0.756		-0.601	2.829	1.213	147.262
Total fish	-0.033	0.395	-0.042		0.123	0.396	-0.031	-12.204

With no MPA restrictions, the spatial model ran over 15 years, predictions indicate increases in all fishes except the group of Other demersal fishes, as well as in Mussels and predatory gastropod Rapana (Fig. 3.3.1). Fisheries catches are also tend increase (Fig. 3.3.3), with fishing moratlity being especially high in Turbot (Fig. 3.3.4).

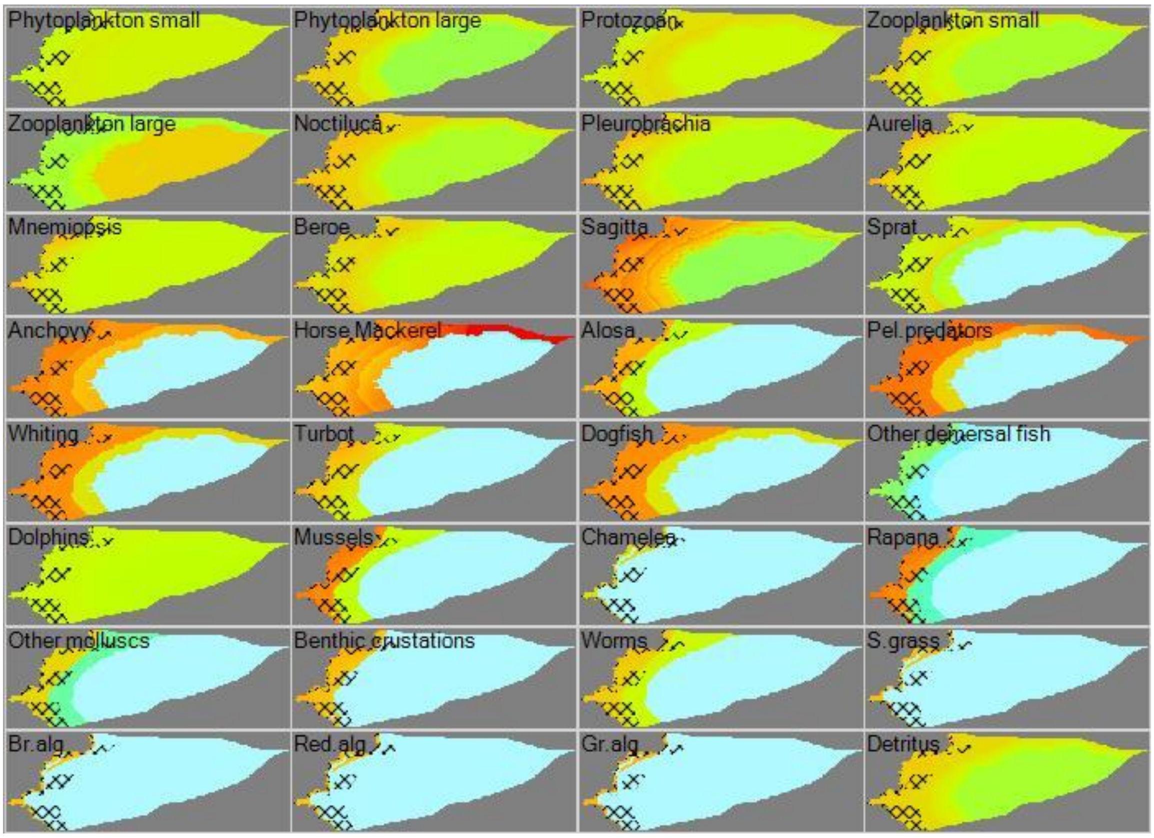

Figure 3.3.1. Ecospace model predictions of the spatial distribution of biomass of each function group in the Bulgarian Black Sea waters. Colours represent relative density in t/km^2, orange is high, green - intermediate, blue-low. Gridded cells depict existing MPAs

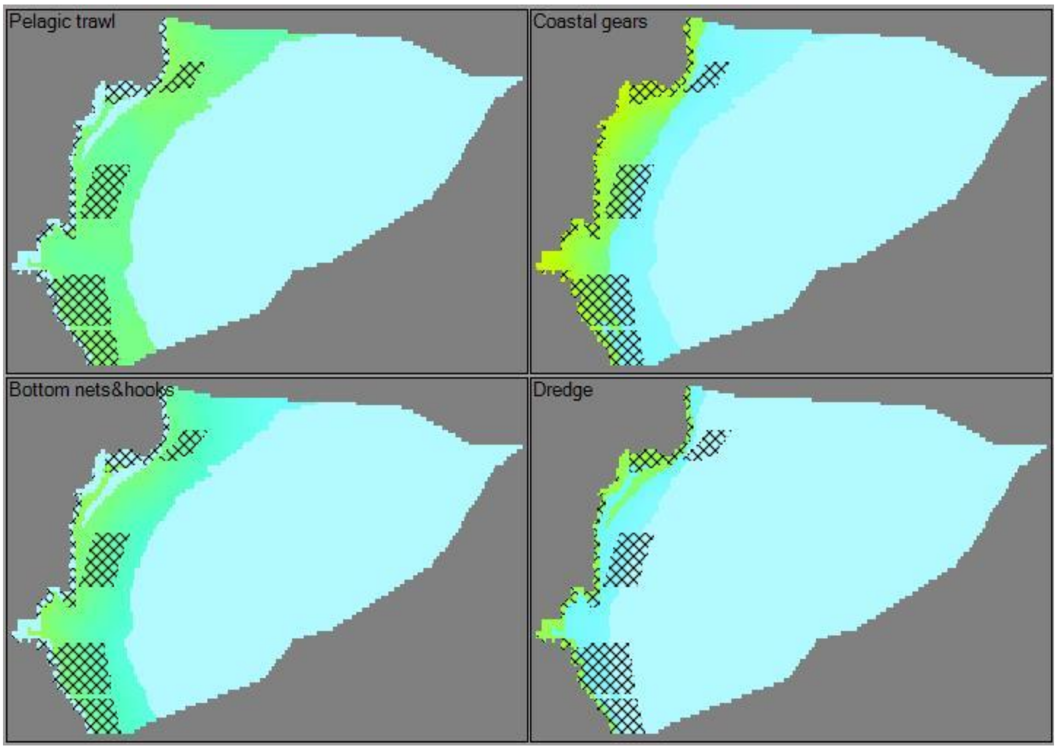

Figure 3.3.2. Ecospace model predictions of the spatial distribution of fisheries fleets in the Bulgarian Black Sea waters. Colours and grids are like in Fig. 3.3.1

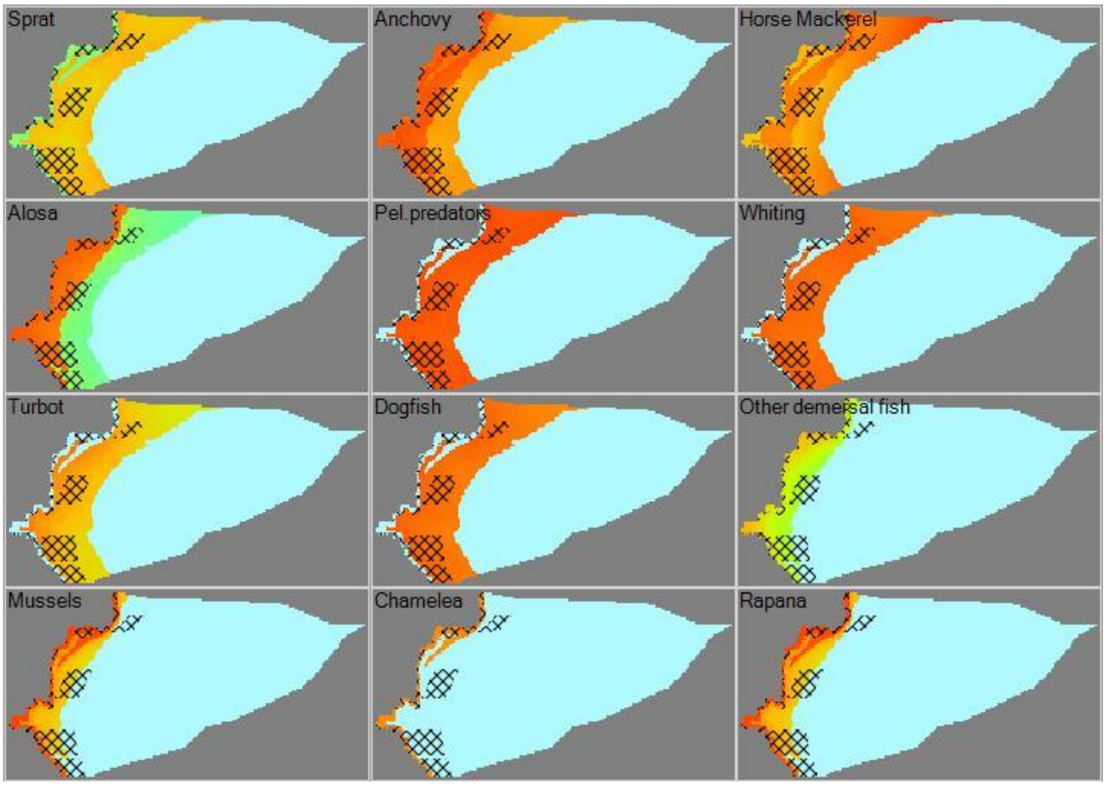

Figure 3.3.3. Ecospace model predictions of the spatial distribution of catch of fish and invertebrate stocks in the Bulgarian Black Sea waters. Colours and grids are like in Fig. 3.3.1.

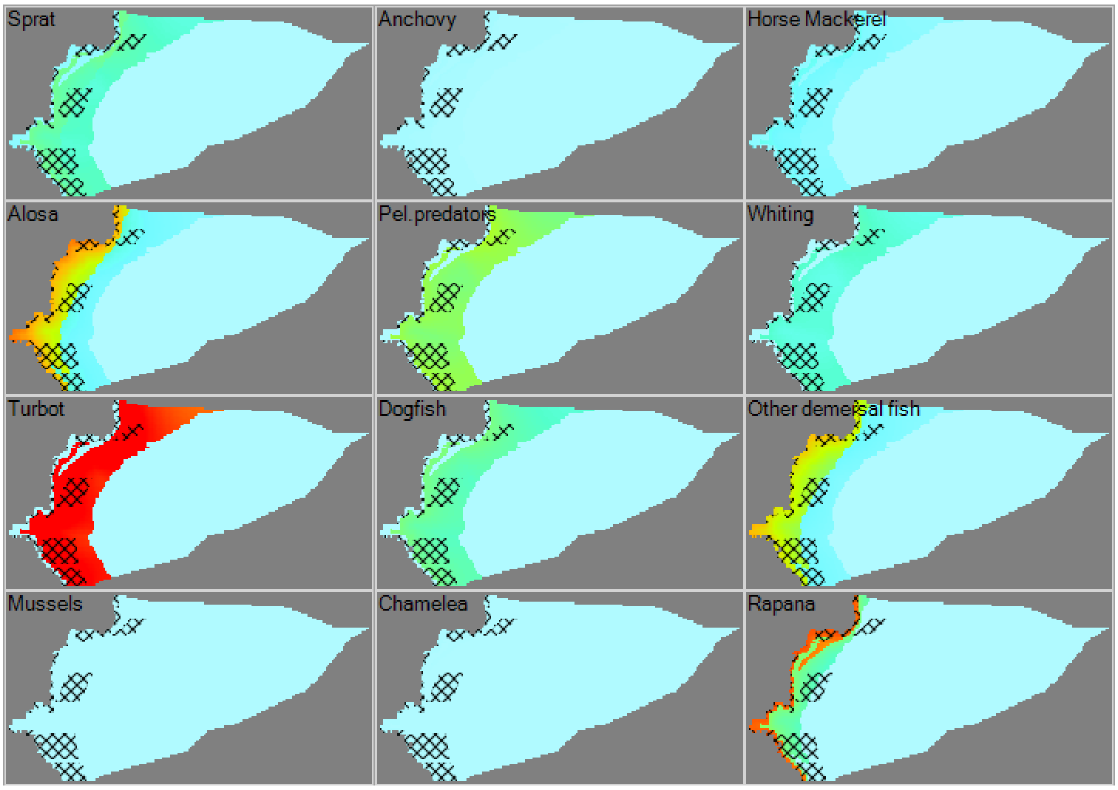

Figure 3.3.4. Ecospace model predictions of the spatial distribution of fishing mortality in the Bulgarian Black Sea waters. Colours and grids are like in Fig. 3.3.1.

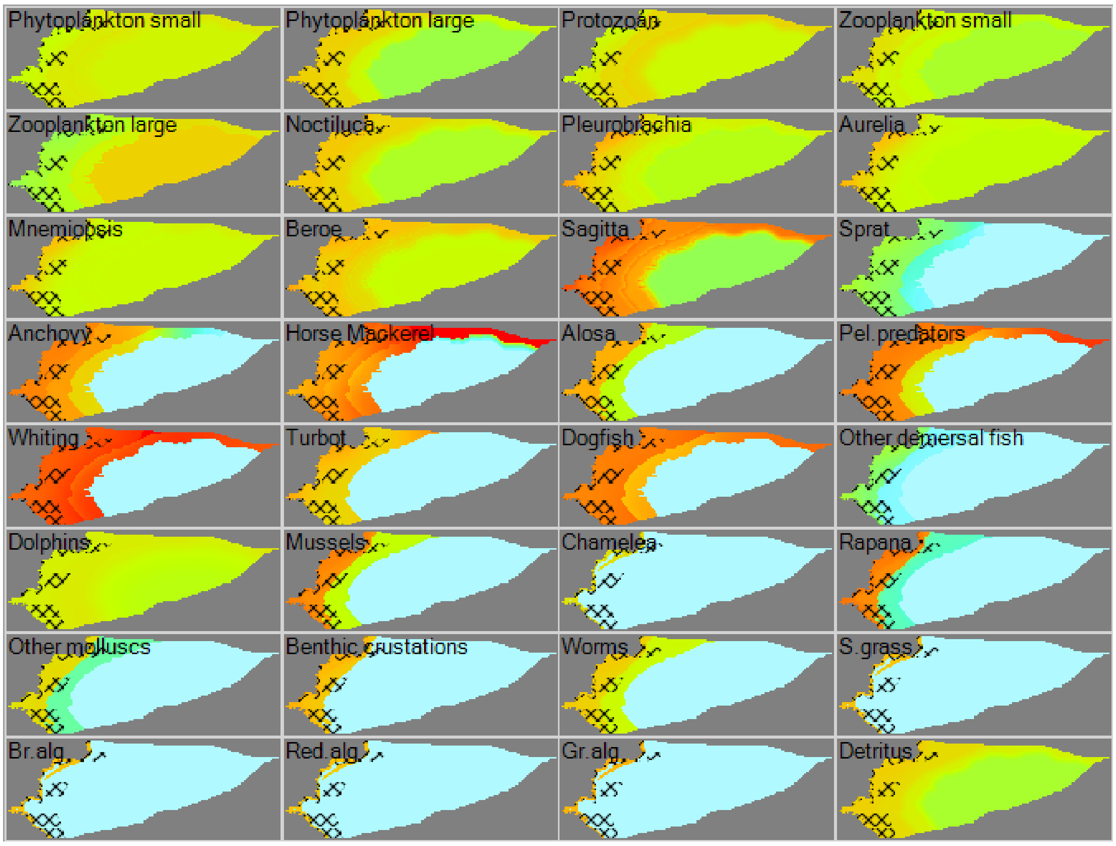

Figure 3.3.5. Ecospace model predictions of the spatial distribution of biomass of each function group in the Bulgarian Black Sea waters, with applying mediation of Mussels on mobile prey groups. Colours and grids are like in Fig. 3.3.1.

When fishing is prohibited within all MPAs along the Bulgarian coast, there is a clear increase in several, mainly fish groups, especially within the MPA areas (Table 3.3.1, Fig. 3.3.6, Fig. 3.3.8). The most positively affected is Turbot, increasing with about 7 and 24 % over the whole area and inside MPAs, respectively (Table 3.3.1, Fig. 3.3.8). Other fish groups also increase by up to about 4% inside of MPAs (Figs. 3.3.6, Fig 3.3.8), but there is a modest change in the overall modelled area due compensatory changes inside and outside of the MPAs (Table 3.3.1, Fig. 3.3.6, Fig. 3.3.8).

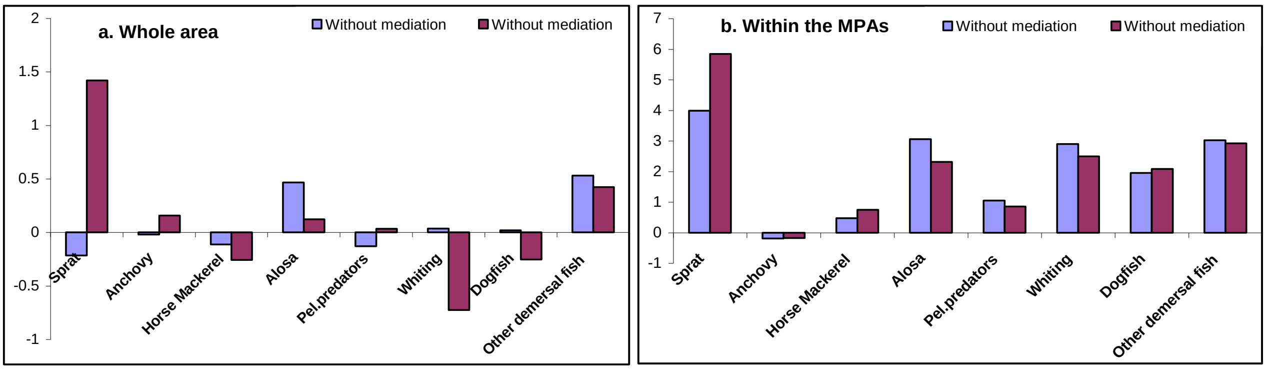

Figure 3.3.6. Biomass change (%) in various fish groups in scenarios described in Table 3.3.1.

Applying mediation of Mussels on some mobile prey groups, in order to simulate benefits of mussel beds as hiding and rearing habitats for fishes and invertebrates, results in increases up to 187 % in some groups (whiting, Table 3.3.1, Fig. 3.3.7). In general, the effect of mediation translate into the predatory groups, with some prey groups such as decreasing up to 61% (sprat, Table 3.3.1, Fig. 3.3.7). The mediation have variable effects when applied side by side with the closure of the fisheries in the MPAs (Table 3.3.1, Fig. 3.3.6).

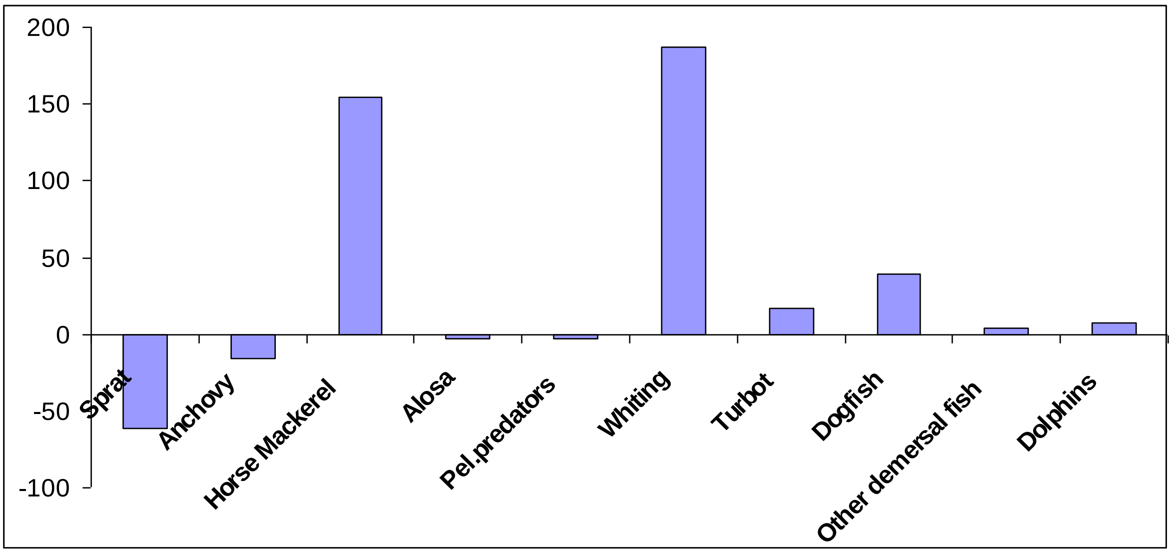

Figure 3.3.7. Biomass change (%) in various fish groups in the overall area when applying mediation compared to the case without mediation as in the last column of Table 3.3.1.

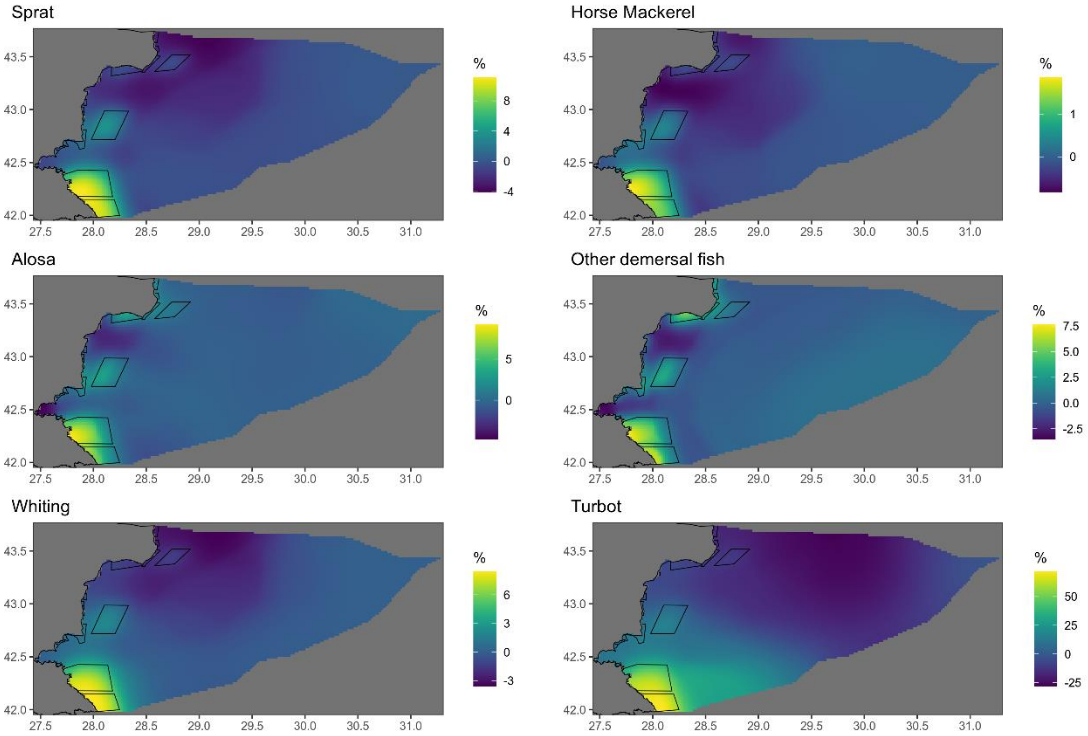

Figure 3.3.8. Spatial distributions of biomass change (%) in various fish groups in scenarios described in Table 3.3.1.

3.4 Discussion

This is the first attempt to build a spatial food web model (Ecospace) of the Bulgarian Black Sea waters, and to apply it for MPA scenario evaluation. Although this study is more about modelling and evaluating of existing MPAs, it also brings more general insights on spatial trophic interactions in the Black Sea.

Our results demonstrate that trophic interactions play a very important role in this system. Predation, competition for food and competitive compensation are evident as driving spatial biomass dynamics. Depending on biomass distributions and the interplay of predation and competition (top-down and bottom-up effects) trophic groups bring different responses to MPA simulations. Positive responses (increase in biomass) in various fish groups and areas and often compensated by decreases in other species and areas. Also, increase in stock biomasses in most cases needs to be traded-off against some decrease of fisheries catches.

Apart from planning recovery and biomass increase of target commercial fish stocks, the Ecospace approach allows for setting management goals aiming of improving environmental and ecosystem status and functioning, that prove its applicability in support to the EBFM.

Ecospace is an ecosystem food web model bringing together a large amount of information about ecosystem and trophic interactions and allowing the traceability and evaluation of various ecosystem traits (including ecosystem functions) out of MPA scenarios. The results of MPA scenarios indicated the potential of improving of damaged trophic structure in the Black Sea by recovery of depleted marine predators. They also indicated possible increases in biodiversity through local recoveries of depleted and endangered species such as endemic *Alosa* species, turbot and dogfish. EwE including Ecospace bring together environmental influences, trophic and fisheries interactions. It has the potential for coupling with biogeochemical models with the aim to build more realistic end-to-end models (Cury et al. 2008, Zavatarelli et al. 2013) that will further advance scenario based MPA simulations in support to the EBFM. Options have being developing, in the Ecospace system, for optimisation of the size, number and placement of MPAs in accordance to predefined economic or ecological constrains, which will allow in future to address specific conservation and management problems and evaluate the applicability of the MPA approach for solving them.

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