LONG-TERM ECOSYSTEM CHANGES AND THEIR IMPLICATIONS FOR FISHERY MANAGEMENT IN THE BLACK SEA

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Abstract

The long-term data from nutrient concentrations to pelagic piscivore catches delineated the successive ecological regime shifts towards alternating degraded states over the Black Sea in general, the northwestern shelf in particular. Following the major community-wide trophic cascade due to collapsed fish stocks and population outburst of invasive predators at the end of 1980s, the northeastern ecosystem was degraded to a very simplified food web structure having almost no predators for pelagic and benthic systems and was controlled effectively by mesozooplankton and polychaeta during the post-eutrophication period after the early 1990s. The northwestern shelf ecosystem continued to maintain a low-energy, ecotrophically inefficient food web structure that may hardly be considered as a tendency of improvement and restoration. The southern basin, on the other hand, has been able to functioning betterwith respect to the rest of the sea, and maintained sufficient resource production that sustained more favourable anchovy fishery. However, the last two decades of the Turkish fishery showed large oscillations that may be interpreted as a signature of weakly stable ecosystem behaviour and may demand further measures to retain the catch comparable to its maximum sustainable yield.

1. Introduction

The Black Sea has been impacted synergistically by the effects of climate-driven cooling/warming type strong decadal cycles, over-exploitation of fish resources, intense eutrophication, invasions by opportunistic species, and their density-dependent internal feedback processes in the 1970s and 1980s (BSC, 2009). These natural and anthropogenic pressures have exerted major transformations on the structure and functioning of the ecosystem as described by qualitative interpretation of the available data sets (Zaitsev and Mamaev 1997, Kideys 2002, Sorokin 2002, Yunev *et al.,* 2002, Daskalov 2003, Bilio and Niermann 2004, Oguz *et al.* 2006, Oguz and Gilbert 2007; Yunev *et al.*, 2009) and analysis of the modeling studies (Berdnikov *et al.*, 1999; Daskalov, 1999 and 2002; Gucu, 2002; Oguz 2007; Oguz *et al.*, 2008; Knowler, 2007; Oguz *et al.*, 2012a,b).

One of the notable changes encountered in the ecosystem structure has been large decadal-scale changes in fish stocks. For example, the basinwide small pelagics stock has increased almost five-fold from roughly 0.3 million tons in the mid-1960s to 1.5 million tons during the 1980s (Ivanov and Panayotova, 2001).

This period of stock increase has coincided with the transformation of ecosystem from a mesotrophic state into a critically eutrophic state due to a substantial increase of nutrient supply from the northwestern rivers (e.g. Danube, Dniepr, Dniester, Bug) and the subsequent increase in bottom-up resource enrichment (Zaitsev and Mamaev 1997). Degradation of the ecosystem due to intensification of eutrophication more predominantly supported gelatinous and opportunistic species *Aurelia aurita* and *Noctiluca scintillans* during the 1980s and *Mnemiopsis leidyi* at the end of 1980s in addition to the high forage fish stocks. Similarly, the benthic ecosystem has been under high predation pressure of the invasive species Japanese sea snail *Rapana venosa* (Knudsen *et al.*, 2010). As the total small pelagic stock declined abruptly to 0.3 million tons at 1989-1991, the ctenophore *Mnemiopsis leidyi* population, was outburst simultaneously (Ivanov and Panayotova, 2001).

The period after the early 1990s has been recognized as the post-eutrophication phase of the Black Sea ecosystem (Oguz and Velikova, 2010). The collapse of centrally-planned economies in the former Soviet Union and the eastern block countries led to a considerable decline in the antropogenic nutrient supply into the sea from the rivers discharging into the northwestern shelf (Mee *et al.*, 2005). Its consequence was to supply a more limited bottom-up resource to higher trophic levels with respect to the 1980s. The jellies continued to exert predation and food competition on forage fish eggs and larvae (Oguz *et al.*, 2008). The total small pelagic fish varied within 0.6-0.8 million tons range during this phase (Ivanov and Panayotova, 2001). Such changes however do not imply definitively rehabilitation of the ecosystem.

Below, we provide a summary of the mechanisms leading to these changes as inferred by the available observations and modeling studies. First, using the long-term (1960-2006) ecological data specific for the western shelf and the northeastern region, we document the successive trophic cascades took place successively under synergistic impacts of changing predator controls, climate change, species invasions, and eutrophication. We then focus on the changes in fishery in relation with the regional ecological changes and interpret them in terms of fishery management. The final section assesses our current scientific knowledge on the present state of ecosystem and proposes elaborations of the monitoring studies.

2. Trophic cascades and regime shifts in the Black Sea

Top-down controls and trophic cascades are interlinked processes to occur when the food web acquires a strong trophic flow directed from the highest to the lowest trophic level in the order of inverse abundance patterns, relative to bottom-up flow (Baum and Worm, 2009). The trophic cascade mechanism in the Black Sea has been first documented by Daskalov (2002) and elaborated later by Daskalov *et al.* (2007), Oguz and Gilbert (2007), Llope *et al.* (2010), and Oguz *et al.* (2012a). On the basis of composite data sets for the entire sea, the pelagic ecosystem was shown to experience the cascade mechanism first due to the collapse of large-bodied predatory fishes prior to the early-1970s and then collapse of the forage fishes at 1989-1991 (Daskalov *et al.*, 2007; Llope *et al.*, 2010. These trophic cascades might have not acted in isolation but supported by the nutrient enrichment, climatic effects,

and population explosion of invasive gelatinous species *Mnemiopsis leidyi* (Oguz and Gilbert, 2007; Oguz *et al.*, 2008; Oguz and Velikova, 2010). The benthic community structure around the sea, on the other hand, was heavily impacted by the opportunistic carnivorous gastropod species *Rapana venosa* in addition to that of *Mnemiopsis leidyi* (Shiganova *et al.*, 2008). They also introduced a regime shift in the northeastern Black Sea (Oguz *et al.*, 2012a).

2.1. Regime shifts in the western Black Sea

The available data from the western Black Sea shelf documented different trophic cascade structures during the last 50 years. The first series of decadal scale trophic cascades have developed within the fish-controlled food web of the 1960s - to - 1980s. The data set (Figure 1a-d) revealed relatively high piscivore catch and zooplankton biomass, moderate planktivore catch, relatively low biomass of phytoplankton before 1970. Thus, it represented a four trophic level cascade structure for a rather unperturbed, weakly productive, pre-eutrophication state as early as the 1960s (Figure 2a). In the presence of weak bottom-up resource supply, jellyfish *Aurelia* and redtide species *Noctiluca* have not sustained high biomass yet. The 1970s corresponded to an almost 50% reduction in piscivore fish catch (from ~7000 to ~3500 tons; Figure 1d) and roughly 30% increase in planktivours fish catch (from ~8000 to ~11000 tons; Figure 1d). They were accompanied with 50% decrease in zooplankton biomass (from ~150 to ~75 mg m^{-3}; Figure 1b) and an order of magnitude increase in phytoplankton biomass (from ~2 to ~15 g m^{-3}; Figure 1a). *Noctiluca* and jelly biomass have responded to these changes with few years phase lag by increasing from ~200 to ~800 mg m^{-3} (Figure 1b) and from ~40 to ~400 g m^{-2} (Figure 1c), respectively. The food web comprised the fish controlled trophic cascade characterized by decreasing trends of piscivore catch and zooplankton biomass and increasing trends of planktivore catch and phytoplankton biomass. The increasing trends in *Noctiluca* and jelly biomass up to their moderate levels followed closely interannual fluctuations of phytoplankton biomass, and characterized a bottom-up controlled jelly food chain (Figure 2a). The missing link between phytoplankton and *Aurelia*, not resolved by the present data set, should be the microzooplankton group on which *Aurelia* was predated heavily.

An order of magnitude increase in phytoplankton biomass in the 1970s could be hardly accounted by the change in top-down control alone and may indicate an additional contribution of bottom-up support in response to simultaneous five-fold increase in nutrient load from the River Danube (Oguz and Velikova, 2010). Such high phytoplankton biomass also provided necessary bottom-up resource supply for the development of jellies (e.g. *Aurelia aurita*) and opportunistic species (e.g. *Noctiluca scintillans*). The population/biomass size of *Noctiluca* was of critical importance in terms of the nature of trophic interactions and the form of trophic cascades at the lower part of the food web. The Ecosim model simulations also reproduced the observed cascading pattern better when intense fishery exploitation was combined with eutrophication effect (Daskalov, 2002).

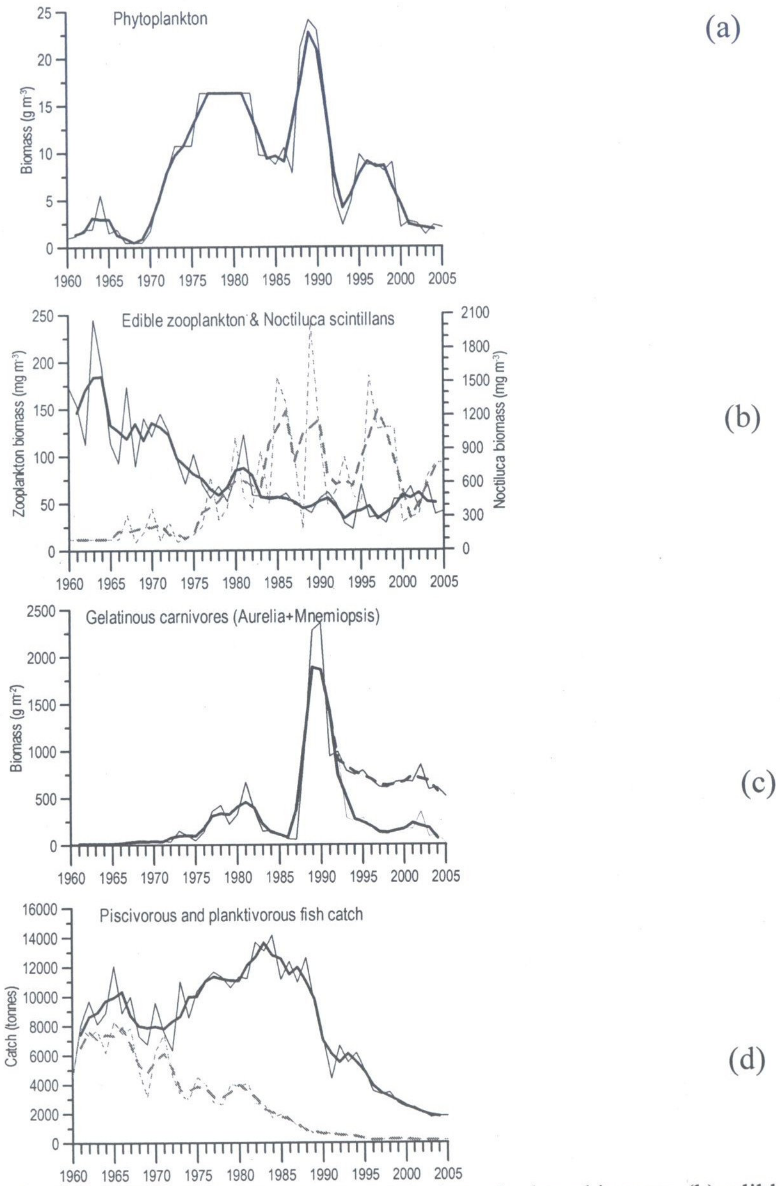

Figure 1. Time series of the annual mean (a) phytoplankton biomass, (b) edible zooplankton (continuous line) and *Noctiluca scintillans* (dash line), (c) the sum of gelatinous zooplankton species *Aurelia aurita* and *Mnemiopsis leidyi* withdash line representing their revised biomass estimate after the early 1990s, and (d) total planktivore (continuous line) and piscivore (dash line) catch representative of the western shelf. The thin lines represent the original data and the thick line as their 3 point moving average.

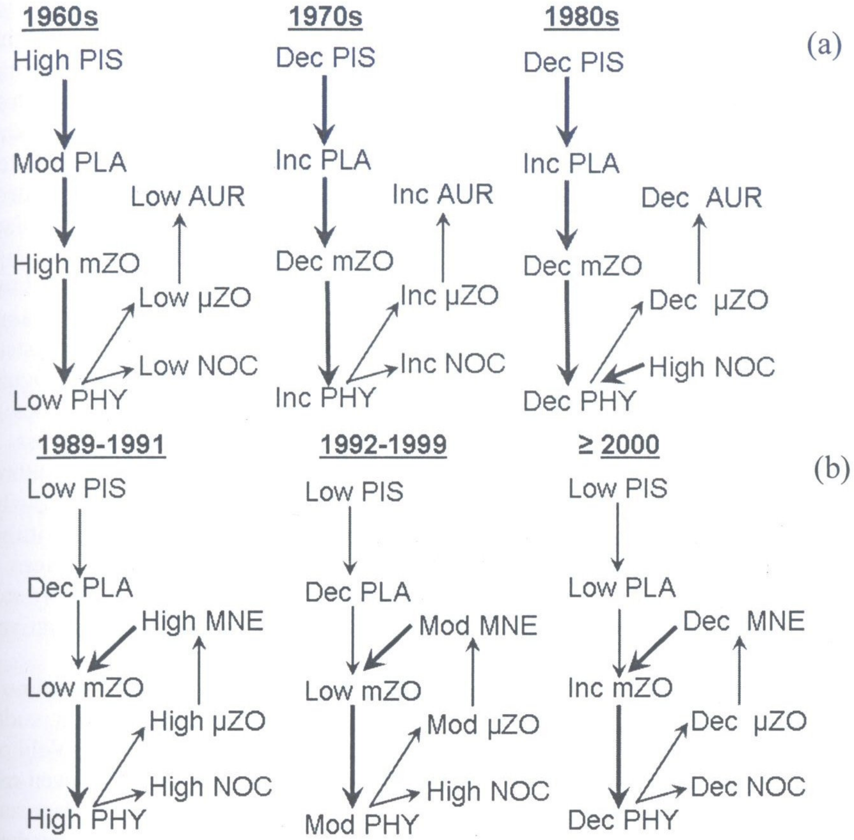

Figure 2. Trophic cascade formations developed within the western shelf (a) fish - controlled food webs during 1960-1980s, and (b) jelly- controlled food webs following the outbreak of ctenophore Mnemiopsis population during 1990s and 2000s. PHY, mZO, μZO, NOC, AUR, PLA, PIS refer to phytoplankton, mesozooplankton, microzooplankton, red tide species *Noctiluca*, jellyfish species *Aurelia*, planktivore and piscivore fish groups, respectively. Bold arrows represent the primary trophic cascade interactions. Inc, Dec, Mod refer to Increasing, Decreasing, Moderate.

During the 1980s, the prevailing cascade structure was modified slightly near the bottom of the food web. In the case of low biomass of herbivorous mesozooplankton due to their strong predation by planktivores, *N. scintillans* population preyed very efficiently on relatively high phytoplankton biomass and attained high biomass whereas phytoplankton biomass decreased considerably (Figure 1a,b) consistent with the mesocosm experiments. A more limited bottom-up resource supply due to lower phytoplankton biomass then caused a gradual decline of *Aurelia* biomass (Figure 1c). Thus, this trophic cascade involved elements of both fish and jelly food chains (Figure 2a).

In the absence of piscivores, the planktivore catch became subject to a sharp drop from 12,000 to 6,000 tons at 1989-1991 (Figure 1d). It coincided with an abrupt increase in the gelatinous carnivore biomass to its maximum level of about 2500 g m^{-2} due to the *Mnemiopsis* population outbreak (Figure 1c). As the strong planktivore predation was replaced by the jelly predation, zooplankton biomass remained at its low level and phytoplankton biomass experienced a short term increase up to ~25 g m^{-3} (Figure 1a) and *Noctiluca* responded to it by a strong biomass peak as well (Figure 1b). During 1989-1991, as planktivores were replaced with the ctenophore *Mnemiopsis* for both regions, the trophic cascade was changed to the jelly-controlled form characterized by high *Mnemiopsis* - low zooplankton - high phytoplankton (Figure 2b). It provides a unique trophic cascade example controlled by a predator different than a fish species in large marine ecosystems. According to the coupled plankton–anchovy population dynamics model (Oguz *et al.*, 2008), the decline of planktivore stock due to its overexploitation does not necessarily imply the simultaneous rise of *Mnemiopsis* abundance unless the environmental conditions are favourable. The *Mnemiopsis* population outbreak occured under favourable climatic conditions for their reproduction and growth at large populations, their competitive advantage of food consumption within a sufficiently enriched system, and reduced predation of prey abundances by planktivores. According to this scenario, *Mnemiopsis* outbreak and planktivore stock decline occured simultaneously, and both processes contributed to the planktivore-*Mnemiopsis* shift.

The food web structure was further changed by a strong decline of phytoplankton biomass during 1992-1993 (Figure 1a) in response to a sudden change of nutrient limitation from nitrogen to phosphorus (Oguz and Velikova, 2010). The new state that formed for 1992-1999 was characterized by an even more degraded structure involving the total absence of piscivore catch, decreasing planktivores - high *Mnemiopsis* - low zooplankton - high *Noctiluca* - moderate phytoplankton; this so-called jelly-controlled trophic cascade is depicted schematically in Figure 2b. This cascade structure was further modified after 2000 following introduction of the alien ctenophore *Beroe ovata* being the predator of *Mnemiopsis*. Decreasing *Mnemiopsis* biomass was accompanied by slight increases in zooplankton and Noctiluca biomass, and decrease in phytoplankton biomass (Figure 2b). The relatively low phytoplankton regime (also referred to as the post-eutrophication regime) prevailing after the early 1990s was not only caused by the reduction in anthropogenic nutrient load but also due to the interactions taking place within the food web under new trophic cascade structure.

2.2. Regime shifts in the northeastern Black Sea

The available data also pointed to the regime shifts in biomass and productivity towards lower trophic levels in the pelagic and benthic food webs of the northeastern Black Sea. Its degradation started with moderate level eutrophication commencing by the early 1970s in response to heavy fertilizers consumption in the Krasnodar region of the former Soviet Union. The fish landing (Figure 3a) showed a severe decline from ~100 ktons in 1986 to less than 25 ktons in 1990. Thereafter, it remained at ~10 ktons level during the 1990s followed by a slight increase to 25

ktons after 2000. The catch data therefore infer that fish community was not able to introduce any longer a notable predatory control on the lower trophic food web structure following the collapse at 1989-1990. The collapse has coincided with the *Mnemiopsis* population outburst with a mean value of 1000 individual per m^2 (Figure 3b), reaching at a maximum value of 7600 ind. m^{-2} ($\approx$ 4.6 kg m^{-2}) (Vinogradov *et al.*, 1999). According to the model simulations (Oguz *et al.*, 2008), the collapse initiated by the fishery overexploitation but then was reinforced by the predation by and food competion with Mnemiopsis population. Concurrently, the zooplankton biomass decreased and phytoplankton biomass increased considerably in 1991 and 1992 under heavy *Mnemiopsis* predation (Figure 3a, 3d). Starting by the exceptionally cold year 1993, zooplankton biomass remained fluctuating between 5 g m^{-2} and 10 g m^{-2} in accordance with interannual *Mnemiopsis* abundance changes during 1994-1999 (Figure 3a). These fluctuations were further accompanied with a weak decadal trend of zooplankton biomass increase. A general decreasing trend of the phytoplankton biomass from more than 20 g m^{-2} to less than 5 g m^{-2} during 1993-2002 (Figure 3d) may be associated with strong predation pressure due to increasing fodder zooplankton biomass. In addition, it is consistent with the warming trend of winter mean sea surface temperature giving rise to unfavorable physical conditions for promoting phytoplankton production (Figure 3d). Thus, in the absence of fish stocks, *Mnemiopsis* constituted an effective top predator species of the system, and introduced a trophic cascade that was further supported by the climatic warming trend during the 1990s. A similar system with much higher abundance of *Mnemiopsis leidyi* prevailed in the western region (Kamburska *et al.*, 2006; Oguz and Velikova, 2010), whereas the southern region maintained the small pelagic fishery together with a relatively low *Mnemiopsis* abundance (Oguz *et al.*, 2012a).

More noticeable increase in fodder zooplankton biomass occurred after 1999 up to more than 25 g m^{-2} at 2005-2008 in the northeastern region (Figure 3a). It apparently coincided with low *Mnemiopsis* abundance below 200 ind. m^{-2} (Figure 3b), implying weakening of top-down predator control of *Mnemiopsis* as a result of their extensive predation following the population outburst of *Beroe ovata* (Figure 3c) (Kideys, 2002). Relatively cold climatic conditions during 2003-2005 may also contribute to the low *Mnemiopsis abundance* (Vinogradov *et al.*, 2005). On the other hand, contrary to even stronger grazing pressure by zooplankton, phytoplankton biomass switched to an increasing mode after 2002. It may be explained by its positive correlation with the cooling cycle of winter mean sea surface temperature (Figure 3d) that indicates favorable winter vertical mixing conditions for the subsequent stronger spring and summer phytoplankton productions. As in the case of the warming trend in the 1990s, the cooling phase after 2001 thus appears to exert considerable modifications in the pelagic food web structure. The total catch and, possibly the total fish stock, are increased to some extent after 2001 once their competitor and predator Mnemiopsis population was reduced. Nevertheless, forage fishes appear to exert weak grazing pressure on the lower trophic levels. The biomass of jellyfish species *Aurelia aurita*, as a competitor of *Mnemiopsis*, increased during this period (Araskievich *et al.*, 2008). Its maximum value of about 600 g m^{-2} was however half of their observed biomass during the intense eutrophication period of the 1980s prior to the outburst of *Mnemiopsis* population (Shiganova *et al.*, 1998).

The *Mnemiopsis* population outburst also exerted a strong impact on the zoobenthic community starting by the early 1990s. An increase in the organic material sedimentation rate reinforced oxygen deficiency of the subsurface levels and thus brought the lower boundary of phytal zone to shallower depths (Alekseev and Sinegub, 1992). Heavy *Mnemiopsis* predation on bivalve larvae restricted the settlement of young bivalves whereas adult bivalves were consumed by the predator gastropod species Rapana. As a result, the native bivalve communities *Chamelea gallina* at the depth range of 20-30 m and *Mythilus galloprovincialis* at the depth range of 30-50 m disappeared completely leading to a serious degradation of macrozoobethic communities during the 1990s. At 1999, only few specimens of *Chamelea gallina* were recorded along the northeastern coast.

The dominant species at the depth 10-30 m range became the opportunistic bivalve species Anadara inequivalvis (Chikina and Kucheruk, 2005). It is a non-native species introduced into the Black Sea from the Indo-Pacific region around 1970, and competes for food (filter-feeder) and space with native species.

The reduction of *Mnemiopsis* population by its predator *Beroe ovata* introduced a transient cascade mechanism that resulted in replacement of mazrozoobenthos with the oportunistic polychaete species after 1999 (Figure 4). Reduction of Mnemiopsis predation strength allowed temporally for an order of magnitude increase in settlements (on the order of thousands) of *Chamelea gallina* larvae and juvenile at 10-18 m depth range and of *Anadara inaequivalvis* at 20-25 m in 2000. A consequence of such highly dense young bivalve community of ~ 400 g m^{-2} (*Chamelea, Anadara, Pitar rudis*) during 2000 - 2002 was their very slow growth rate due to the limited food availability to support their large population (Chikina and Kucheruk, 2005). At the same time, they have been exposed to heavy predation by *Rapana*, and their biomass reduced to ~ 100 g m^{-2} in 2003.

Subsequently, the population density of *Rapana* increased from its background value of 1 ind. per 10 m^2 to 8 ind. m^{-2} in 2001 and 100 ind. m^{-2} in 2002-2003 due to their massive grazing pressure on bivalve populations. Then bivalve biomass and abundance decreased abruptly from 470 g m^{-2} and 1292 ind. m^{-2} in 2002 to 35-45 g m^{-2} and 29-61 ind. m^{-2} in 2003-2004. The abrupt loss of bivalves degenerated the macrozoobethos community structure to an opportunistic deposit - feeding polychaete -dominated system, as encountered in the northwestern Black Sea during the 1980s. Their abundance increased from 300 ind. m^{-2} to 1500 ind. m^{-2} and biomass from 2.5 to 7.5 g m^{-2} in 2003-2004 (Chikina and Kucheruk, 2005). The lack of sufficient food for high *Rapana* population then caused a decline of their population to the background level in 2004-2005.

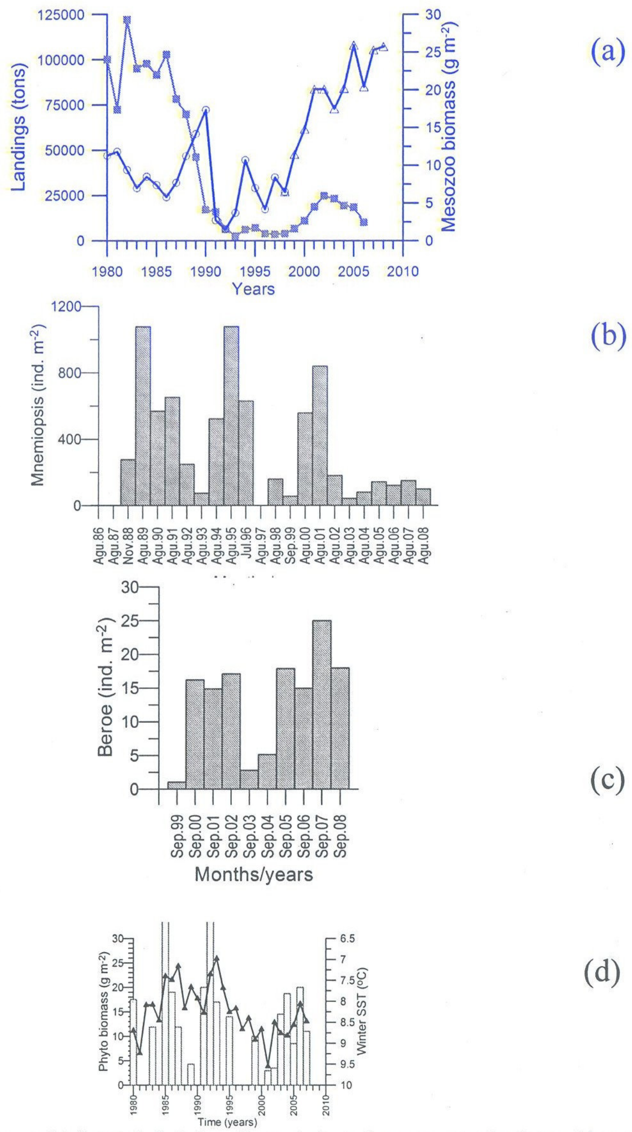

Figure 3. Variations of (a) total fish landings (■) and mesozooplankton biomass provided by Kovalev *et al.* (1998) (○) and Arashkevich *et al.* (2008) (Δ), (b) *Mnemiopsis* abundance (ind.m^{-2}) in August, (c) *Beroe* abundance (ind.m^{-2}) in September, (d) summer-autumn mean phytoplankton biomass integrated over the euphotic zone (g m^{-2}) (vertical bars), and the winter mean sea surface temperature (▲). "Agu" and "Sep" in (b) and (c) refer to August and September, and the subsequent two digit numbers to the last two digits of the years, respectively.

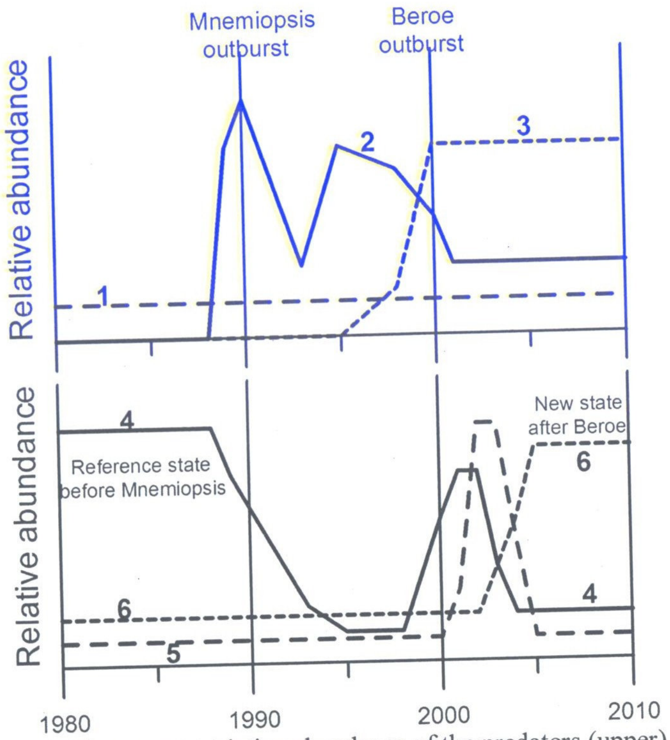

Figure 4. Time versus relative abundance of the predators (upper) and major elements of the benthic food web (lower) illustrating a conceptual model of the benthic trophic cascade and development of a new alternate state following the shift in predation pressure from the ctenophore *Mnemiopsis leidyi* to *Beroe ovata*. The numbers refer to the relative abundances of benthic fish (1), *Mnemiopsis* (2), *Beroe* (3), bivalve (4), *Rapana* (5), polychaete (6).

3. Temporal and regional variations of fishery

The past fisheries practices may be considered as a management failure because of the lack of a common and co-ordinated fishery policy among the Black Sea countries (Knudsen, 2003). The Black Sea fisheries convention signed at 1959 by Soviet Union, Bulgaria and Romania for rational exploitation of the Black Sea fish resources has been unsuccesful. This has been followed by other unsuccessful attempts because fishery resources have been considered as an easy way of cheep and high quality food supply, reducing unemployment, and securing economical profits (Knudsen, 2003; Duzgunes and Erdogan, 2008). These unpleasant past experiences, however, can be instructive for management agencies to develop more comprehensive and efficient management policies for the fishery sector. The adverse changes in fish stocks and complex trophic interactions among the food web components (Oguz and Gilbert, 2007) clearly demand an ecosystem-based management approach over the entire basin with the participation of all countries.

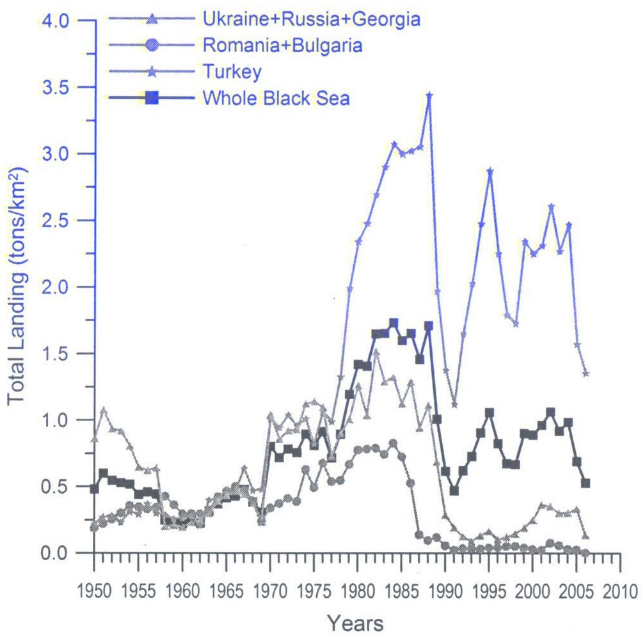

Figure 5. Time series of total annual landings in the former USSR countries (Georgia + Russia + Ukraine), the western sector of Bulgarian and Romanian waters, the southern sector of Turkish water, and the total landings over the entire basin.

The data highlighted significant regional and temporal differences in the Black Sea fishery since the begining of 1950s. It has been manipulated mainly by the former Soviet Union up to 1970, almost equally by the former Soviet Union and Turkey in the 1970s, and predominantly by Turkey afterwards (Figure 5). In the former USSR states, the large pelagic and demersal groups have experienced heavy harvesting even before the early 1950s due to the investment on technological advancement of industrial fishery (Figure 6a). Once they have been overexploited, the USSR fishery has been directed mainly on the small pelagic species starting by the 1950s. Their total landings declined from more than 200 ktons to less than 50 ktons with a major contribution from small pelagics (Figure 6a). They were accompanied with the changes in the MTL index from roughly 3.3 at the begining of 1950s to 3.1 a decade later at the time of small pelagics fishery (Figure 7). As suggested by (Prodanov *et al*, 1997), the large and middle-size valuable predatory species including marine mammals, sturgeon, tuna, bonito, turbot, large horse mackerel, and Black Sea mackerel disappeared by the end of 1950s, and the USSR fishery started to exploit primarily small pelagics as early as the 1950s (Figure 6a). On the other hand, the Turkish landing at 50 kton level included contributions from all functional groups of pelagics and demersals (Figure 6b) and covered a wider MTL range oscillating betwen 3.4 and 3.8 (Figure 7) with an average decreasing trend of 0.25 trophic levels per decade from 1955 to 1975. This level of reduction was one of the strongest among those reported in different parts of the world (Freire and Pauly, 2010) and represented unarguably a "fishing down" track (Pauly *et al.*, 1998). Such a strong decrease however does not appear in the overall Black Sea landings data suggesting that spatial aggregation of landings can seriously mask the fishing down effect (Pauly *et al.*, 2005).

Although the loss of predators introduced different temporal changes over the sea, the increase in landings occured concurrently and abruptly in both the Turkish and USSR sides during 1969-1970 and subsequent uniform level at 1970-1975 (Figure 6a,b), whereas the increase was more gradual in the western region (Figure 5). The Turkish and USSR landings increased, respectively, to 150 ktons and 250 ktons during the first half of 1970s with a major contribution from the small pelagic group (Figure 5). The landings in all three regions have been subject to further rise during the second half of the 1970s, but it was particularly notable in the Turkish side but low in the western region. Anchovy in the southern basin, sprat and anchovy together in the western and northern basins became the most abundant and commercially important target species and started acting as the main top predators in their regional ecosystems. Thereafter, the Turkish and USSR landings increased roughly 10-folds and five-folds, respectively, in terms of both total landings and landings per km^2. The medium pelagic landings also contributed to the Turkish fishery during this phase. The Turkish landing exceeded 500 ktons during the early 1980s, of which 350 ktons came from small pelagics (mostly anchovy), 50 ktons from small and medium demersals, 80 ktons from medium pelagics and 20 ktons from large pelagics (Figure 6b). The increase was however limited to the doubling of landing per km^2 in the Romania+Bulgaria region (Figure 5). On the other hand, the maximum USSR landing was 300 ktons and limited to small pelagics only (Figure 6a), as identified by the catch MTL index range of 3.15 - 3.25 (Figure 6). The increase in all regions was positively correlated with the increase in primary production in response to the basinwide eutrophication-induced bottom-up resource support (Oguz *et al.*, 2012a). The subsequent declining trend of the USSR landings started earlier than the Turkish landings and covered almost the entire 1980s, although they both attained a minimum at the end of 1980 (Figure 6a,b). The MTL index variations of the Turkish landings during the high catch phase of the 1980s were slightly better (3.25 - 3.35) because of the additional contribution of the medium size pelagics (Figure 7). The high catch phase of the Turkish fishery was characterized by a gradually decreasing contribution of the small pelagic landings that was however compensated by the gradual increase in the contribution of medium pelagic landings.

After 1991, on the average, 90% of the total landing of the Black Sea was captured by the Turkish fishery (Figure 6a). 80% of the total landings comprised small pelagics (mostly anchovy) and the rest is contributed almost equally by the medium and large pelagics and demersals (Figure 6b). This situation was reflected by a further reduction in the MTL index of the Turkish catches to ~3.15 (Figure 7). While the total landing in the Romanian and Bulgarian EEZs has been at negligibly low values, it increased from 25 kton at 1990s to 50-75 ktons range after 2000 over

the Ukrainian, Russian and Georgian EEZs that was totally dominated by small pelagics (anchovy+sprat) as in the previous phase (Figure 6a).

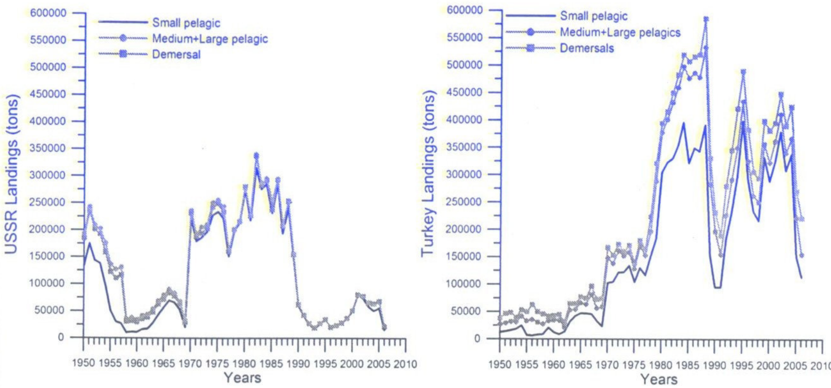

Figure 6. Time series of annual landings for small pelagics, the sum of medium and large pelagics, and total demersals in (left) the USSR EEZ, and (right) theTurkish EEZ. The landings in (left) and (right) are plotted in the form of cumulative sums.

One of the reasons for the notable increase in Turkish landings was the technological advancement of the fishing fleets and their geographic expansion as well as rapidly expanding large scale purse seine and mid-water trawl fisheries of small pelagic fish (anchovy, sprat, horse mackerel) (Bilgin, 2006). Purse seiners have been subject to seven-fold increase from about 40 at the begining of 1970s to about 280 at the end of the 1980s (Gucu, 2002). The trawl fishery fleet registered to Samsun province increased from 38 in 1988 to 123 in 2005 with an additional increase in engine power from ~10000 Hp to ~57000 Hp (Knudsen *et al.*, 2010). Turkey presently acquires 7308 fishing vessels in the Black Sea. That number is almost equal to 7269 vessels in the rest of the Black Sea countries, of which 1697 belongs to Bulgaria+Romania and 5572 to Ukraine+Russian Federation+Georgia (Duzgunes and Erdogan, 2008). It appears that the Black Sea countries presently maintain excessive fishing effort and overcapacity in the fishing fleet.

4. Fundamentals of the Black Sea ecosystem-based fishery management approach

The recovery and restoration efforts in degraded ecosystems require an efficient coordination between science, policy and practice, and demand integration of information from a wide range of disciplines, levels of ecological organization, and temporal and spatial scales. They also require an improved scientific understanding of the ecosystem structure and functioning, complex dynamical processes linked via feedback loops, and nonlinear ecosystem responses to changes and pressures (Walker and Meyers, 2004; Cochrane and de Young; 2008; Österblom *et al.*, 2010). Development of appropriate statistical and mathematical models and a long-term observational program form the backbones for a successful management program of marine fisheries. At the moment, to our knowledge, there is no dedicated ecosystem level systematic observations to collect data on the status of target species and bycatch, populations of the lower trophic levels, and indicators of ecosystem changes. Modeling is an essential scientific tool in developing ecosystem approaches for fishery management. Simple models limited to prey and predator interactions (Oguz, 2007) may be a good starting point, but they eventually need to incorporate nonlinear interactions among all components of the ecosystem (Oguz *et al.*, 2008). They also need to be able to assess the trade-offs among harvests of different fish species, relation between abundance of top predators and populations of prey species, and the amount of total primary production required to sustain ecosystem harvest. It however should be accepted a priori that ability of models to fully elucidate and predict a complex ecosystem behavior is limited for complex adaptive systems.

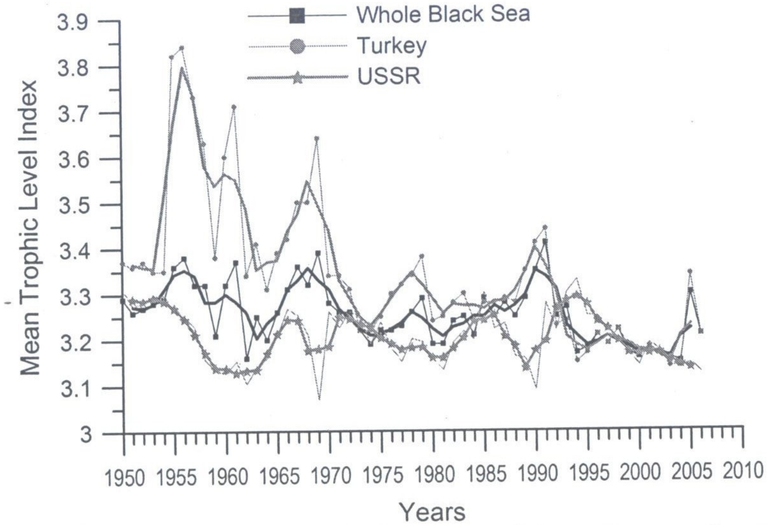

Figure 7. Time series of mean trophic level index of the catches over the entire basin and for the USSR EEZ and Turkish EEZ.

In general, the ecosystem-based management paradigm is designed for sustaining health and maintaining resilience of an ecosystem state that has not yet passed critical thresholds and shifted into an undesirable alternative state (Pikitch, *et al.*, 2005; Levin *et al.*, 2009; Kenneth, *et al.*, 2010). This concept, therefore, is not fully applicable for most of the Black Sea because its major part is characterized by an undesirable state of the collapsed fishery and degraded ecosystem structure and function. This implies some regional differences in the implementation of new ecosystem-based management approach depending on the regional peculiarities of the ecosystem and fishery conditions. The management agencies need to identify the approach that is best suited for their circumstances. But, to start with, a political decision need to be taken by the govermental agencies for coordinated actions to

reduce the effects of overfishing and eutrophication, to develop solutions for the restoration of regional ecosystems and recovery of their diverse fish stocks and to establish close cooperation with regards to the prevention, obstruction and the elimination of illegal, unregistered and undeclared fishing.

For the western and northern regions of the Black Sea, the mid- and long-term management objectives should be the focus on the recovery of fisheries starting by the small pelagics and restoring the ecosystem health to a desired new state. The recovery of a particular species involves setting its fishing mortality to much lower than its value for maximum sustaiable yield which in practice demands significantly decreasing or stopping fishery exploitation for a specified period of time, reducing degradation of benthic environments, and actively rehabilitating damaged habitats. These measures indeed identify main elements of the recovery trajectory for reaching the target stock status at a given period under some biological constraints. The recovery trajectory and period may be modified by management depending on new socio-economic, biological or ecological information during the course of time. A further critical ingradient of the recovery is to minimize energy loss to the opportunistic and gelatinous species and reverting the trophic flow once again towards the fish-dominated food web component. It is however unclear whether this type of rehabilitation process may occur gradually or in the form of an abrupt regime shift once the desired threshold conditions are met at a particular time. Moreover, rebuilding process of depleted stocks is expected to be vulnerable to climatic variations and related interannual changes in bottom-up resource supply. Rebuilding a new ecosystem state from a degraded one would also require coordination between fishery related sectors and goverment agencies. Engagement and participation of greater stakeholder groups are critical for successful implementation of the recovery process and to minimize economic hardship on fishers and community.

For the case of Turkish fishery, a critical requirement is to introduce a stringent control on fishing activity for stabilizing the anchovy catch by setting fishing mortality less than its value for the maximum sustainable yield for a certain period that will depend on the environmental conditions. During the 1980s, contribution of the small pelagic landings to the Turkish economy was around 200 millions US $, but the medium and large pelagic landings contributed as high as 400 millions US $ with much less landing size. The total income reduced more than half after the early 1990s when the fishery was limited only to the low cost anchovy in the absence of larger fish stocks. Therefore, promotion of the medium pelagic stocks at the expense of small pelagics appears to be an economically feasible management option.

5. Discussion

The cascade examples described in the present study illustrate how a food web structure may be altered quickly in response to perturbations at the highest trophic level once the ecosystem weakened its resilience to external stressors such as climate change, species invasions, and eutrophication. They support the view that top-down controls may vary depending on the intensity and nature of direct or indirect perturbations to predator abundances (Baum and Worm, 2009). At present the obvious science and policy question for the Black Sea, particularly for its western shelf, is to find a way to divert the main energy flow back to the planktivorous and piscivorous fish groups. This problem indeed is gaining a global relevance, as many coastal ecosystems around the world are presently exposed to rapid expansion of jellies and strong fishery overexploitation.

Table 1. Approximate ranges of major ecosystem properties for three regions of the Black Sea during the last decade following the introduction of gelatinous ctenophore species *Beroe ovata* into the Black Sea. The 5th column compares the alternate state of northeastern region during the 1980s with the recent one shown at 4th column. The values show approximate ranges and may involve some uncertainty due to conversion of the original data to common units for all regions. They allow for a gross comparision of ecological properties among the regions. The data are compiled from BSC (2008). The bold letters L and H within parantheses refer to the "Low" and "High" abundance/biomass, respectively.

Property	Northwestern region	Southern region	Northeastern region	Northeastern Region (before 1990s)	Unit
Fish landing	0.04 - 0.1	1.5 - 2.3	0.15-0.3 **(L)**	~ 1.3 **(H)**	tons km^{-2}
Aurelia+Mnemiopsis	> 500	< 100	<200 **(L)**	> 600 **(H)**	ind. m^{-2}
Noctiluca scintillans	< 15000	< 1000	<1000 **(L)**	> 1000 **(H)**	ind. m^{-2}
Zooplankton	5 - 10	< 3	25 **(H)**	< 10 **(L)**	g m^{-2}
Phytoplankton	3 - 6	< 0.5	<0.5 **(L)**	> 1.0 **(H)**	g m^{-3}
Polychaete	~ 5500	~ 500	~1500 **(H)**	~ 300 **(L)**	ind. m^{-2}

Table 1 documents differences between main elements of the recent ecosystem structure of the northeastern, western and southern regions. For example, in the western shelf ecosystem, the pelagic food web structure continued to acquire stronger predation controls by gelatinous ctenophore *Mnemiopsis leidyi* and the opportunistic heterotrophic dinoflagellate species *Noctiluca scintillans*, respectively, even after the introduction of *Beroe* and in the absence of forage fish stocks (Oguz and Velikova, 2010). The average *Mnemiopsis* abundance along the western shelf during 1998-2004 was roughly an order of magnitude higher than the northeastern region, even though the abundance became comparable for the open waters of the western basin (Kamburska *et al.*, 2006). They were complemented by the non-gelatinous mesozooplankton biomass varying around ~ 5 g m^{-2} depending on the warm/cold climatic winter conditions and the size of *Mnemiopsis* population. The bentic food web was dominated by polychaetes as in the case of northeastern region (Vorobyova and Bondarenko, 2009). On the other hand, the southern Black Sea was characterized by a relatively healthy structure (Table 1) in which the impact of opportunistic and gelatinous species is less critical. The Rapana stocks reduced considerably along the western and southern coastal waters due to their over-harvesting and commercial export to East-Asia. The southern region is able to provide roughly 85% of the total fish catch of the Black Sea that is however limited to the low commercial valued anchovy (Oguz *et al.*, 2012a). Even this regional

ecosystem structure, representing best of the Black Sea conditions, may be easily categorized as one of the worst observed cases at the global scale. The level of degradation of the northwestern and northeastern food webs may be considered rather exceptional cases among large marine ecosystems.

The lack of recovery of forage fish stocks in the presence of high food availability and the absence of gelatinous competitors during the last decade is an interesting feature of the ecosystem evolution in the northeastern Black Sea. One likely explanation is the impact of ongoing heavy fishery exploitation. Alternatively, it may signify resilience of the ecosystem to recovery due to complex internal dynamical processes in the case of alternative stable states. Comparison of the ecosystem properties during the 1980s and 2000s (see 4th and 5th columns in Table 1) documents clearly the presence of two alternate states before and after the community-wide trophic cascade introduced by *Mnemiopsis*. If that is really the case, then the recovery of fish stocks may delay until another community-level regime shift should bring the system back to a new fish-dominated state.

Assuming that the southern (Turkish) and northern (USSR) basins may have been exposed to an equally strong fishing pressure, maintenance of relatively high catch regime in the southern basin during the 1980s may be further related to its relatively more favourable spawning and overwintering grounds for the anchovy fishery and relatively less degradation of the ecosystem health. This view has been corroborated by the eggs and larvae surveys conducted starting by the early 1990s (Niermann *et al.*, 1994), but should be also valid for the 1980s for which the data do not exist. This view, however, opposes to the classical picture of migration routes and locations of spawning and overwintering grounds of anchovy (Ivanov and Beverton, 1985). The progressive expansion of the Turkish catch during the second phase (1975-1988) may be classified as a "fishing through" type fishery development although it does not exactly fit into its original definiton that states sequential addition of newly exploited species of low trophic level to the multi-species catch while keeping those of the higher trophic levels (Ivanov and Beverton, 1985).

Nearly 80% of the total catch in the Black Sea has been realized by the Turkish fleet after the early 1990s. Relatively weak *Mnemiopsis* pressure, better ecological and climatic conditions, and favorable spawning and overwintering grounds may be considered to be positive factors that prevented the Turkish fishery from shifting permanently into the low catch regime following the Mnemiopsis shock at the end of 1980s (Oguz *et al.*, 2008). The present Turkish landing capacity was, however, limited to the anchovy catch that was roughly comparable to its level prior to the decline with some fluctuations. Conditions of the Turkish fishery in the third phase (after 1992) characterizes the "fishing at the base of higher trophic food web" that represents the lowest level of "fishing down" type fishery, excluding those of invertebrates. The present level of exploitation of the Turkish fishery is twice higher than its sustainable level of about 200 ktons. The current unsustainable fishery exploitation is also evident by the comparable landing with the previous phase prior to the collapse even though the support by primary production was reduced by half. Such persistently high exploitation level likely reduces reproductive surplus of the system, and may push it closer to a threshold to switch finally to a low catch regime as in the case of other regions. The relatively uniform values of the FiB index during the second and the third phases indeed suggest no improvement in terms of fishery exploitation.

The ongoing high fishing pressure, illegal fishing, the use of destructive harvest techniques, and the lack of regional cooperative management of fisheries following socio-economic and administrative disintegration of the former Soviet Union system may be listed among the major threats for the fishery in Ukraine and Russian Federation after the early 1990s (Shlyakhov and Daskalov, 2009; Knudsen and Toje, 2008). It is quite likely that small scale fisheries have been harvesting more fishes than officially recorded and can be sustainably supported by the ecosystem. Similar problems also apply for the Bulgarian and Romanian fisheries.

A closer look at the Soviet landing data may also suggest two well-defined alternate regimes; the low stock/catch regime prior to the early 1970 and after the early 1990s, and the high stock/catch regime in between. The fishery was able to switch from the low catch regime prior to the early 1970s to the high catch regime following intensification of eutrophication (bottom-up resource enrichment). The strong competition and predation pressure of the ctenophore *Mnemiopsis* population as well as strong fishery overexploitation brought the system back to the low catch regime two decades later (Oguz, 2007; Oguz *et al.*, 2008). The present analysis however can not differentiate relative contributions of the ecological regime shift and badly managed fishery issues. This requires a more quantitative approach using a modeling study. It appears that they all together impose a strong resilience to the recovery (Hutchings, 2000).

Ecosystems damaged by human actions and mis-guided rehabilitation policies are usually subject to very slow recovery rate. For example, in spite of all efforts and progressive implementation of EU Directives, so far there has been only limited reduction in eutrophication of the Baltic and North Seas. Restoration of ecosystems is generally a long-lasting process that depends on the accomplishment of the conservation, protection and management measures both at national and regional level. In this respect, stress reduction interventions should be implemented in order to achieve improvement of environmental conditions in the coastal zone of the Black Sea and the sea itself. The most critical ones are the reduction of the terrestrial nutrient load from the catchment basin by investing in high technology waste-reduction projects and intensive agricultural practices, firm control on commercial fishery by effective regulation of trawls and dredges.

Moreover, the present assessment studies are hampered by some gaps in our knowledge due to the absence of sufficiently comprehensive and systematically sampled monitoring data. For the success of ecosystem restoration, routine monitoring of the key ecosystem indicators, e.g. set by EEA within the DSPIR framework, should be effectively implemented. This approach will further set a basis for the policy-relevant assessment of the state of the Black Sea environment in the EU context. The DSPIR protocol, however, may require some adaptations to the Black Sea conditions in terms of network of coastal stations, sampling frequency, and sampling depths in order to allow detection of temporal trends and inter-comparison of different areas. To this end, measurements of nutrients, oxygen, chlorophyll concentrations, as well as phytoplankton and zooplankton biomass, abundance and diversity need to be measured on monthly basis at some selected critical sites around of the basin. Also of critical importance is to monitor them not only in surface waters but also below the seasonal thermocline, and close to the bottom. Because majority of processes governing the pelagic ecosystem take place at time scales less than a month either in the surface layer or different parts of sub-surface layer, such high temporal resolution in observational strategy is indeed necessary. Either temporally, spatially and/or vertically coarse resolution measurements may be adequate for a stable ecosystem but will indeed carry a high risk of false assessments for the unstable Black Sea ecosystem.

Monitoring benthic communities needs to be designed to detect subtle changes in community structure through some indices and environmental conditions that drive these changes (e.g. sinking organic carbon flux, organic carbon content in sediments, deep-water oxygen concentration). The most practical approach is to choose some indicator species among the groups known to be opportunistic, disturbance-sensitive or insensitive. Great natural variability of the benthos requires seasonal monitoring at critical sections with many replicate samples. Monitoring chemical pollution level in sediments may be sufficient once a year. Large uncertainty exists on the amount of nutrients entering from the atmosphere and sediments, which therefore need to be monitored regularly around the basin as well.

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