



Current state of overfishing and its regional differences in the Black Sea

Temel Oguz*, Ekin Akoglu, Baris Salihoglu

Institute of Marine Sciences, Middle East Technical University, PO Box 28, 33731 Erdemli, Turkey

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ABSTRACT

Long-term (1950–2006) changes of fish landings in combination with some ecosystem indicators are used to evaluate the status and sustainability of the Black Sea fishery. Following the depletion of large pelagic predator and demersal fish stocks during the 1950–1960s, the main fishery was targetted on small and medium pelagics that declined abruptly to ~ 200 kton ($\text{kton} = 10^3 \text{ t}$) at 1989–1991 after a highly productive (~ 750 kton) but overfished state in the 1980s. Thereafter, total landings in all the Black Sea countries except Turkey remained at most 10% level of the previous phase. For Turkey, only the low cost anchovy fishery was able to maintain at the mean catch size of 368 ± 74 kton for 1992–2006 that however represented roughly twice of the maximum sustainable catch. The absence of fish within the western, eastern and northern regions and the presence of only a fluctuating heavily exploited anchovy fishery in the southern region during the last 20 years demand an immediate common ecosystem-based fishery management policy and actions by all the coastal states.

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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, 2008). 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; Daskalov, 2003; Bilio and Niemann, 2004; Daskalov et al., 2007; Oguz and Gilbert, 2007; Oguz and Velikova, 2010; Yunev et al., 2009) and analysis of the modeling studies (Daskalov, 1999, 2002; Gucu, 2002; Oguz, 2007; Oguz et al., 2008; Berdnikov et al., 1999; Knowler, 2007). 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 5-folds 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 *M. leidyi* population, being a food competitor and a predator of small pelagic eggs and larvae, 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 anthropogenic 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).

Several studies have described the changes in capture productions of different fish groups and/or species over the Black Sea during different phase of ecosystem organizations (Daskalov, 2003; Prodanov et al., 1997; Shlyakhov and Daskalov, 2008; Leonart,

* Corresponding author. Tel.: +90 324 521 2150; fax: +90 325 521 2307.
E-mail address: oguz@ims.metu.edu.tr (T. Oguz).

2008). But no assessment study has evaluated the level of sustainability of the Black Sea fishery at regional scale. The present study serves for this purpose and constitutes a part of our ongoing efforts devoted to a broad-based understanding of the Black Sea ecosystem dynamics. It brings together the available data for landings and some ecological indices to infer historical development of the Black Sea fisheries, to evaluate its present status in different regions, and to draw some general inferences on its sustainability.

Below, the data sets and features of their post-processing are presented in Section 2. Section 3 documents catch changes, and evaluates its variability in terms of bottom-up resource and top-down predator controls through changing percent primary production required and mean trophic level of the catches, respectively. It further assesses the ecologically sustainable maximum catch levels for the present ecosystem conditions. The latter analysis is primarily devoted to the Turkish fishery due to its overwhelming share with respect to the others. A critical interpretation of the results and conclusions are provided in Section 4.

2. Materials and methods

2.1. Data sets

Fishery in the Black Sea is conducted by six riparian countries (Fig. 1); the southern part is covered by the Turkish Exclusive Economical Zone (EEZ) (172,199 km²), the northwest and the north-central by the Ukraine EEZ (144,038 km²), the northeastern by the Russian Federation EEZ (66,854 km²), the southeast by the Georgian EEZ (22,765 km²), and the western by the Bulgarian (35,156 km²) and Romanian EEZ's (20,598 km²). The total EEZ of Georgia + Russia + Ukraine (the former Soviet Union countries) amounts to 233,657 km² that corresponds to 1.3 of the Turkish EEZ.

The yearly basinwide and country landings (ton y⁻¹) from 1950 to 2006 were obtained from the Sea Around Us project (SAUP) Global Fisheries Mapping database (Watson et al., 2004) provided at <http://www.seaaroundus.org>. They include (i) small pelagics with less than 30 cm body size (contributed mainly by anchovy *Engraulis encrasicolus*, sprat *Sprattus sprattus*, horse mackerel *Trachurus* spp), (ii) medium size pelagics with lengths between 30 cm and 90 cm (mainly Atlantic bonito *Sarda sarda*, mackerel *Scomber*

spp, blue fish *Pomatomus saltator*), (iii) large pelagics longer than 90 cm, (iv) demersals (mainly turbot *Scophthalmus rhombus*, red mullet *Mullus barbatus*, whiting *Merlangius m. euxinus*).

The SAUP database has disaggregated the Soviet Union catches prior to 1990 into national catches according to their EEZ. Making such a disaggregation may be problematic because the boats from different member states could easily cross borders and capture considerable amount of fish from waters of other member states (Knudsen and Toje, 2008). We therefore aggregated the Ukrainian, Georgian, and Russian landings again into what we call here the USSR landings covering the northern and eastern regions. We also aggregated the Romanian and Bulgarian landings for representing total fishery for the western region. The Turkish fleet was able to operate in Georgian waters after 1995 (Knudsen and Toje, 2008). Therefore, a part of the catch realized in the Georgian EEZ is likely included in the Turkish landings statistics.

The SAUP database also provides yearly values of the mean trophic level index of catches (MTL) (Pauly and Watson, 2005), the fishing-in-balance index (FIB) (Pauly and Watson, 2005), the percent primary production required index (%PPR) (Pauly and Christensen, 1995), and commercial values of different fish landings for all countries (Sumalia et al., 2007). A brief description of these data sets is given below. The indices are obtained by setting the trophic efficiency (TE) to 0.1 (Bilgin, 2006). Contrary to a slightly higher value of 0.14 suggested for the Mediterranean and Black Seas (Pauly and Watson, 2005), a choice of 0.1 may be more reasonable in the presence of jellies and opportunistic species diverting a part of resources to the jelly-dominated food web. However, the interpretations do not change for its different choices between 0.10 and 0.15. Unfortunately, the commercial landings can not be supported by true species abundance trends to more adequately analyze the changes in fish populations and communities (de Mutsert et al., 2008). Moreover, the official landings statistics may not be accurate enough because of the lack of reliable data on discards, under-reportings, and/or mis-reportings. Although the data sets used may involve some drawbacks, the findings of the present study may nevertheless form a basis for more detailed future ecosystem-based fishery management studies.

2.2. Description of indices

The mean trophic level (MTL) index of catches (Pauly and Watson, 2005; Pauly et al., 1998) gives a weighted average of the trophic levels of landings removed from an ecosystem. It is computed by weighting the trophic level (TL_i) of fished species ($i = 1, \dots, m$) by their catches (Y_i) for any year, i.e.,

$$MTL = \frac{\sum_{i=1}^m (TL_i \cdot Y_i)}{\sum_{i=1}^m Y_i} \quad (1)$$

Harvesting at different trophic levels has different ecological cost that increases for increasing trophic levels. This cost is expressed by the primary production required (PPR) (in ton C km⁻² y⁻¹) in terms of transfer efficiency (TE), catches of species (Y_i) and their trophic levels (TL_i) as

$$PPR = \sum_{i=1}^m \left[Y_i \cdot \left(\frac{1}{TE} \right)^{TL_i - 1} \right] \quad (2a)$$

Normalizing PPR by primary production (PP) yields the percent primary production required (%PPR) index (Pauly and Christensen, 1995) as a percentage of primary production in carbon units by

$$\%PPR = \frac{1}{9} \cdot \frac{PPR}{(PP \cdot 100)} \quad (2b)$$

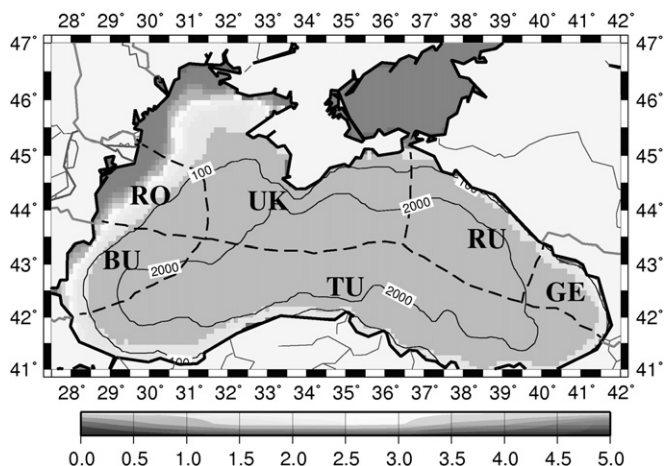


Fig. 1. The Black Sea map displaying approximately the exclusive economical zones of the riparian countries (dash lines). The background represents the decadal (1998–2008) mean chlorophyll concentration in mg m⁻³ and 100 m and 2000 m bathymetry contours. BU, GE, RO, RU, TU, UK refer to Bulgaria, Georgia, Romania, Russia, Turkey and Ukraine, respectively. The chlorophyll data are retrieved from 9 km monthly SeaWiFS products provided by <http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.seawifs.2.shtml>.

where the factor 9 allows conversion from the unit of wet weight to carbon. The %PPR changes evaluate how the catch changes respond to the accompanying changes in primary production and energy flow to higher trophic levels. For a given %PPR, a fishery at higher trophic levels becomes less disruptive than a fishery at lower trophic levels (Tudela et al., 2005). Also, for a given trophic level, a lower %PPR is less disruptive than the one with a higher %PPR. Thus, fisheries with relatively low %PPRs and high trophic levels represent better sustainably-fished ecosystem conditions.

The fishing-in-balance (FiB) index (Pauly and Watson, 2005) evaluates whether exploitations at different trophic levels are ecologically balanced over time by changes in the trophic levels of caught species with respect to a given reference condition. If that is the case, its value then remains to be zero. For example, for $TE = 0.1$, it occurs if catch increases by a factor of ten for each decline of one trophic level. In the case of higher catches, the *FiB* index increases or it decreases if increasing catches fail to compensate for a decrease in TL . The former case typically occurs due to an increase in primary production or geographic and technological expansions of the fishery. The decrease occurs if the fisheries withdraw so much biomass from the ecosystem due to strong fishery exploitation that gives rise to an impaired ecosystem functioning and eventually reduces fishery below the reference level. The *FiB* index is expressed by

$$FiB_i = \log \left[Y_i \cdot \left(\frac{1}{TE} \right)^{TL_i} \right] - \log \left[Y_0 \cdot \left(\frac{1}{TE} \right)^{TL_0} \right] \quad (3)$$

where TE is the transfer efficiency, Y_i , TL_i and Y_0 , TL_0 denote the catch and the mean trophic level of the catch in year i and 0, respectively, the latter referring to the reference condition taken as the first year of the data set (i.e. year 1950 for the present case).

The data for commercial values of fish landings are provided by the global fish price database. It is based on the observed prices of different species in different countries that were then adjusted for inflation to year 2000 real prices in US dollars (Sumalia et al., 2007).

2.3. Data processing

The original %PPR data retrieved from the SAUP database (hereinafter referred to as %PPR_{saup}), shown in Fig. 2, appear to involve errors from two particular sources. Firstly, it uses the primary production estimate of $830 \text{ mgC m}^{-2} \text{ d}^{-1}$ derived from the satellite (SeaWiFS) data. It is roughly twice higher than its alternative estimates from *in situ* measurements (Yunev et al., 2002) due to overestimation of the standard chlorophyll algorithm of the SeaWiFS sensor (Oguz and Ediger, 2006). The algorithm has been developed originally for open ocean conditions and needs to be corrected for the case two water conditions of the Black Sea (Finenko et al., 2010). Secondly, the primary production estimate of $830 \text{ mgC m}^{-2} \text{ d}^{-1}$ is assumed to be the same for the entire 1950–2006 period whereas its basin-average value obtained from *in situ* observations changes from $100\text{--}200 \text{ mgC m}^{-2} \text{ d}^{-1}$ during the first phase (prior to 1970) to $600\text{--}800 \text{ mgC m}^{-2} \text{ d}^{-1}$ during the second phase (1975–1990) and $200\text{--}400 \text{ mgC m}^{-2} \text{ d}^{-1}$ during the third phase (after 1990) (Fig. 3) (Yunev et al., 2002). The revised estimate (%PPR_{pw}) is therefore obtained first by dividing the original data with 830 and then multiplying with the temporally varying annual mean primary production values shown in Fig. 3. The resulting revised data is also depicted in Fig. 2.

Once the corrected percent primary production required values (%PPR_{pw}) are obtained, eq. (2b) allows to provide the corresponding values of the primary production required (PPR_{pw}) by multiplying them with the primary production (Fig. 3). Conversion of the

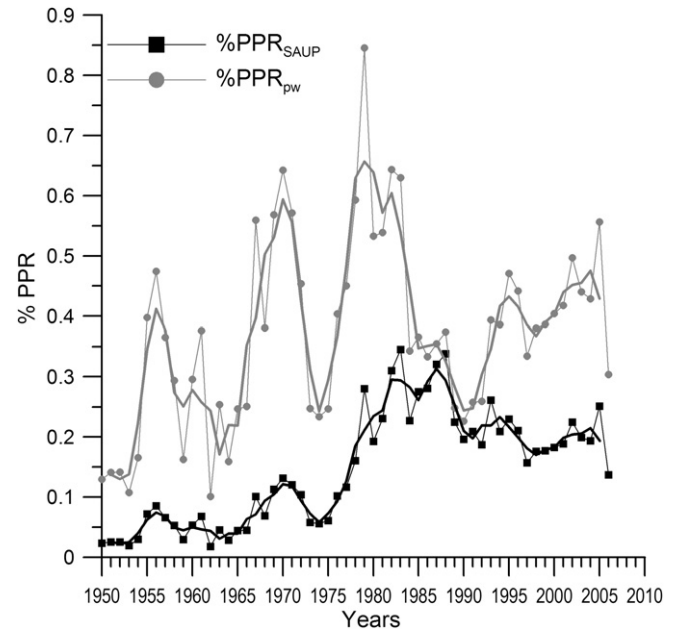


Fig. 2. Time series of annual mean %PPR changes of Turkish landings with the subscripts saup indicating the values provided by the SAUP database, and pw indicating the value deduced from the present work. The thick lines represent three-point moving averaging of the original data.

primary production required (PPR_{pw}) from the unit of primary production ($\text{ton km}^{-2} \text{ y}^{-1}$) to the unit of total landings (ton y^{-1}) requires its multiplication with the total fishing area that is however not known precisely and its choice directly affects the calculations. In the present study, in consistent with the computations provided by the SAUP database, we choose the country EEZs for the total fishing areas.

The %PPR_{pw} versus MTL changes evaluate the sustainability of fishery exploitation in terms of the bottom-up resource supply (%PPR_{pw}) and the top-down control effect (MTL index) using an empirically defined threshold curve that separates the sustainable

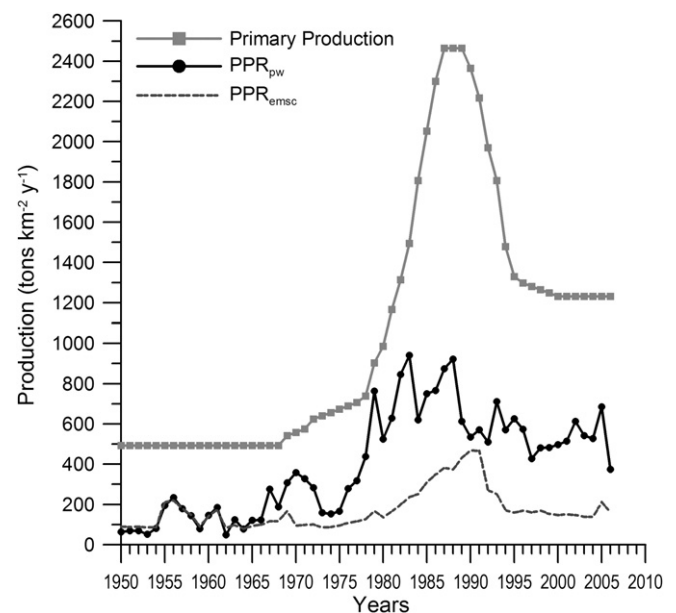


Fig. 3. Time series of the annual mean primary production and primary production required of the Turkish landings (PPR_{pw}) and its corresponding value for the maximum sustainable catch (PPR_{emsc}) for $EO_c = 0.00045$.

and unsustainable domains. The empirical relation is given by (Tudela et al., 2005)

$$\%PPR_{emsc} = EO_c \cdot MTL^{6.8391} \quad (4)$$

where EO_c is a constant parameter. The corresponding ecologically maximum sustainable catch ($EMSC$) may be estimated by (Pauly and Watson, 2005)

$$Y_{emsc} = \%PPR_{emsc} \cdot PP \cdot (TE)^{TL_c-1} = PPR_{emsc} \cdot (TE)^{TL_c-1} \quad (5)$$

where

$$PPR_{emsc} = \%PPR_{emsc} \cdot PP \quad (6)$$

as shown in Fig. 3. In eq. (5), Y_{emsc} depends on the primary production, the mean trophic level of the catches, and the transfer efficiency. It is expressed in $gC\ m^{-2}\ y^{-1}$, and converted to catch unit ($ton\ y^{-1}$) by multiplying 9 and the fishing area.

Defining

$$PPR_i^* = Y_i \cdot \left(\frac{1}{TE}\right)^{TL_i} \quad \text{and} \quad PPR_0^* = Y_0 \cdot \left(\frac{1}{TE}\right)^{TL_0} \quad (7a)$$

where the subscripts i and 0 refer to a particular year and its reference value (year 1950), respectively, eq. (3) can alternatively be written in terms of the annual mean primary production required and its reference value by

$$FiB_i = \log\left[PPR_i^* / PPR_0^*\right] \quad (7b)$$

The FiB index values computed with respect to an arbitrary choice of the reference value Y_0 in eq. (3) or PPR_0 in eq. (7) provides a poor measure of the fishery assessment (Fulton et al., 2005; Caddy et al., 1998). A more reliable approach is proposed in this study by replacing PPR_0 with PPR_{emsc} (given by eq. (6)) to describe the level of fishery exploitation with respect to a temporally varying reference level that is adjusted according to the changing ecosystem properties by

$$FiB_i = \log\left[PPR_i^* / PPR_{emsc}\right] \quad (8)$$

The revised definition of FiB index in eq. (8) can be computed for given annual values of landings (Y_i) and the mean trophic level of landings (TL_i), the transfer efficiency parameter (TE) and PPR_{emsc} . While its zero value (i.e. $PPR_i^* = PPR_{emsc}$) represents an ecologically balanced fishery, positive values imply exploitation and negative values underexploitation with respect to the level of $EMSC$.

3. Results

3.1. Temporal and regional variations of landings

The total landings over the basin and its fractions for the western Black Sea (Romanian + Bulgarian EEZs), the northern and eastern Black Sea of the former USSR states (Ukraine + Russia + Georgia), the southern Black Sea (the Turkish EEZ) reveal considerable interannual to decadal variability (Fig. 4a). The total basinwide landings reduced from 300 kton to 100 kton during the 1950s and switched afterward to an increasing trend up to ~350 kton during the first half of the 1970s, followed by a sharp increase up to a uniform level of 700–800 kton during the second half of the 1970s. The total landings then declined abruptly to 300 kton at 1990 and 200 kton at 1991. Soon after the decline, it increased again to 500 kton at 1995 and oscillated subsequently between two major lows at 300 kton during 1997–1998 and 250 kton at 2006, and two major highs at 500 kton during 1995 and 450 kton at 2001–2002.

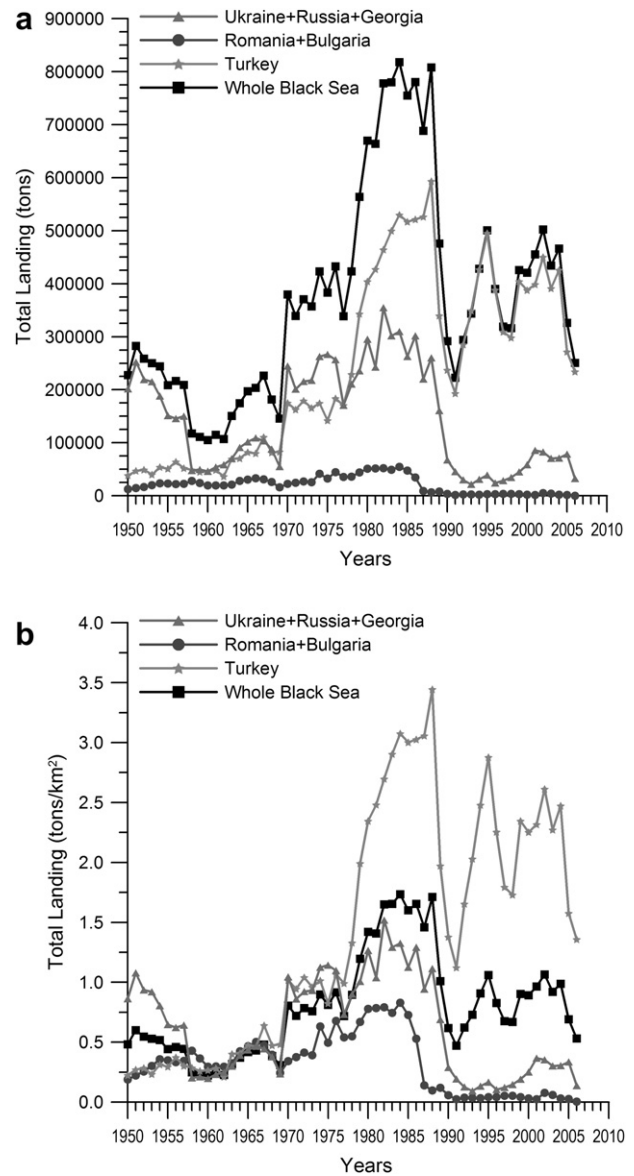


Fig. 4. Time series of (a) the total annual landings and (b) the annual landings per km^2 in the former USSR countries (Georgia + Russia + Ukraine), the western sector as the combination of Bulgaria and Romania, the southern sector of Turkish water, and over the whole Black Sea.

Contribution of the western region (Bulgarian + Romanian EEZs) to the total landings (Fig. 4a) has always remained at a negligible level (below 50 kton), but in terms of the landings per unit area it is roughly half of that in the former USSR and one-fourth of that in Turkish EEZ (Fig. 4b). A major exploitation of the fish resources took place in the former USSR countries during the 1950s as their total landings declined from more than 200 kton to less than 50 kton with a major contribution from small pelagics (Fig. 5a). They were accompanied with the changes in the MTL index from roughly 3.3 at the beginning of 1950s to 3.1 a decade later at the time of small pelagics fishery (Fig. 6). 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. On the other hand, the Turkish landings at 50 kton level included contributions from all functional

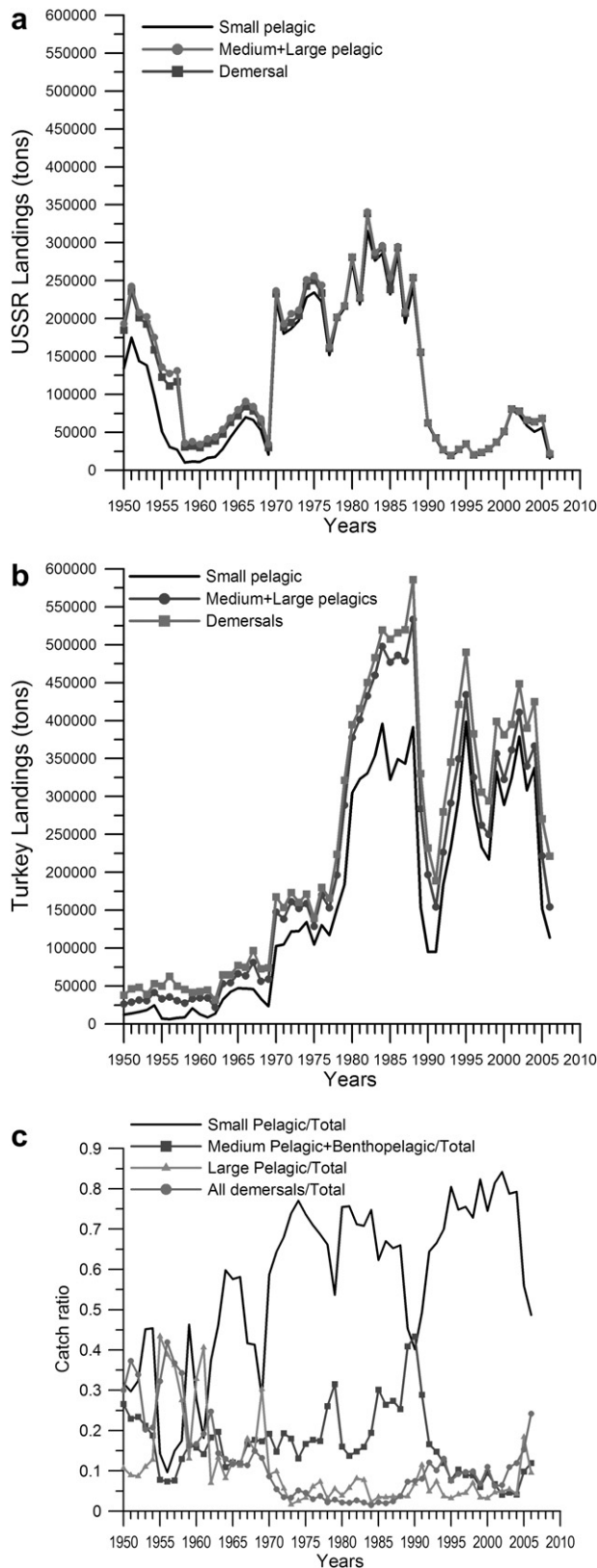


Fig. 5. Time series of the annual landings for small pelagics, the sum of medium and large pelagics, and total demersals in (a) the former USSR region (Georgia + Russia + Ukraine), (b) the Turkish EEZ, and (c) relative contributions of the total landings of small pelagics, medium pelagics + benthopelagics, large pelagics, total demersals with respect to the total landings within the Turkish EEZ. The landings in (a) and (b) are plotted in the form of cumulative sums.

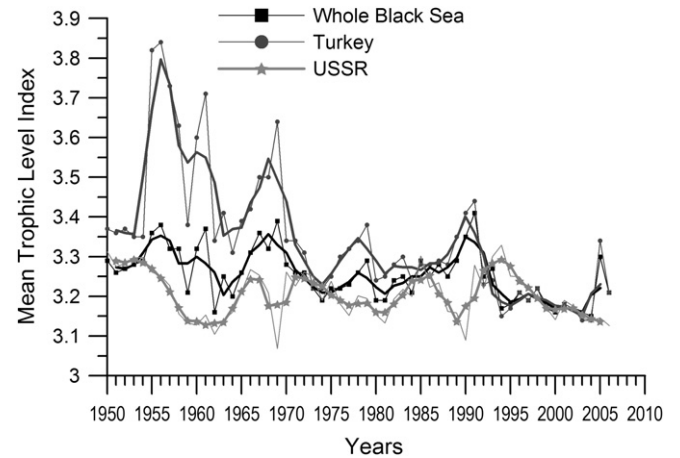


Fig. 6. Time series of mean trophic level index of the catches over the entire basin and for the USSR EEZ and Turkish EEZ. The thick lines represent three-point moving averaging of the original data.

groups of pelagics and demersals (Fig. 5b) and covered a wider MTL range oscillating between 3.4 and 3.8 (Fig. 6) with an average decreasing trend of 0.25 trophic levels per decade from 1955 to 1975. The MTL index changes for the overall Black Sea landings data however do not show such a strong decrease.

The Turkish and USSR landings increased, respectively, to 150 kton and 250 kton during the first half of 1970s with a major contribution from the small pelagic group (Fig. 4a). Following comparable landings of ~175 kton at 1977, the Turkish landings exceeded 500 kton during the early 1980s, of which 350 kton came from small pelagics (mostly anchovy), 50 kton from small and medium demersals, 80 kton from medium pelagics and 20 kton from large pelagics (Fig. 5b). On the other hand, the maximum USSR landings were 300 kton and limited to small pelagics only (Fig. 5a), as identified by the catch MTL index range of 3.15–3.25 (Fig. 6). 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 1990–1991. The Romanian + Bulgarian landings are also exposed to a similar gradual declining trend. 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. The high catch phase 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 (Fig. 5c).

The total landings in the Romanian and Bulgarian EEZs has been at negligibly low values after 1991 and, on the average, 90% of the total landings of the Black Sea was captured by the Turkish fishery (Fig. 4a). Over the Ukrainian, Russian and Georgian EEZs it increased from 25 kton at 1990s to 50–75 kton range after 2000 that was totally dominated by small pelagics (anchovy + sprat) as in the previous phase (Fig. 5a). In the Turkish EEZ, following the catch decline, 80% of landings comprised small pelagics (mostly anchovy) and the rest is contributed almost equally by the medium and large pelagics and demersals (Fig. 5b and c). This situation was reflected by a further reduction in the MTL index of the Turkish catches to ~3.15 (Fig. 6).

The temporal variation of landings per unit area (Fig. 4b) followed an identical abrupt rise at 1969–1970 and subsequent uniform level at 1970–1975 within the Turkish and USSR regions, whereas it was in the form of a gradual rise in the western region. 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. More interestingly, the landings first declined in the western region during 1986–1987 followed by the decline in the USSR at 1989–1990 and the Turkish EEZ at 1990–1991 (Fig. 4b).

The decline in the mean trophic level of the Turkish fishery from ~ 3.3 in the second phase to ~ 3.15 in the third phase has led to a great economical loss (Fig. 7). The economical value of 400 kton of anchovy captured within the Turkish EEZ during the 1980s was 2.5 times less than that of 100 kton medium pelagics landings. This was because the cost of 1 kg anchovy (0.5 US \$) was six times less than 1 kg medium pelagics of 3.0 US \$. During the third phase, Turkey continued to fish a similar amount of anchovy (Fig. 5c) and gained a similar income (Fig. 7), but the overall income from the Turkish fishery reduced more than half because of the reduction in the larger size fishery. At the same time, the investment and running costs of anchovy purse seiners kept increasing (Knudsen et al., 2010; Dincer et al., 1998; Celiker et al., 2006) due to increasing inflation rate.

3.2. State of the Turkish fishery in terms of ecosystem indices

As the fishery within the western and northern-northeastern regions has been in the collapsed state during the last 20 years, the analysis presented here will be focussed only on the Turkish fishery. The two different %PPR estimates (Fig. 2) offer very different interpretations for the development of Turkish fishery. %PPR_{saup} infers an ecologically well-balanced situation (<0.1) under sufficiently high (but falsely specified) primary production prior to 1970. On the contrary, %PPR_{pw} suggests a strong fishery exploitation as high as 50% of the primary production in the pre-eutrophication phase. The latter is indeed more consistent with the Turkish fishery data (Fig. 4a and b) and the corresponding MTL changes (Fig. 6). Furthermore, %PPR_{pw} reveals a major increase in the second half of the 1970s (up to 1982) that appears to happen prior to a major increase in primary production (Fig. 3) and therefore indicates a strong fishery exploitation (>0.6). On the other hand, %PPR_{saup} estimate is limited to <0.2 during the same period and represents once again an ecologically well-balanced fishery case. The subsequent decreasing trend of %PPR_{pw} from ~ 0.7 to ~ 0.35 during the 1980s points to the compensation of strong fishery exploitation by an equally strong and increasing primary production; i.e. strong fishery exploitation was able to be supported by a very strong

primary production. On the other hand, the corresponding %PPR_{saup} was maintained around 0.3 falsely reflecting a minor increase in fishery exploitation. The decreasing mode of primary production after 1990 emerges as an increasing trend in %PPR_{pw} (from 0.25 to 0.50), whereas %PPR_{saup} ≈ 0.2 suggests a steady and tolerable fishery exploitation. Thus, %PPR_{saup} data lead to quite different and indeed misleading interpretations on the state of Turkish fishery at all phases of the ecosystem transformation.

The plot for the %PPR changes of the Turkish fishery versus the MTL changes of landings (Fig. 8) separates the sustainably-fished and overfished ecosystem conditions for two alternative theoretical threshold curves depending on the values of the parameter EO_c . Here, the overfished ecosystem is defined by overall over-exploitation of marine resources, whilst sustainably-fished ecosystem is a non-disrupted one with main functioning and structure preserved (Murawski, 2000). The area below the threshold curve corresponds to the sustainably-fished ecosystem conditions and above to the overfished ecosystem conditions. For the choice of $EO_c = 0.00003$, that is the value provided on the basis of the analysis of many different ecosystem types over the globe (Tudela et al., 2005), the Turkish fishery has never been sustainable even during the 1950s and the overfishing has been particularly serious during the second and third phases. The unsustainable fishery during the first phase however seems to be not realistic according to the low values of landings on the order of 50 kton. If the value of EO_c is taken twice higher (i.e. $EO_c = 0.00006$) that implies extending the limit of sustainability to higher %PPR values, the first phase of Turkish fishery falls into the sustainable domain whereas the later phases into the unsustainable one. For an intermediate value $EO_c = 0.00045$, Fig. 3 shows that the %PPR_{pw} is compatible with its corresponding estimate of sustainably-fished conditions (%PPR_{emsc}) during 1950–1975 (except 1965–1970) reflecting an ecologically balanced fishery. We thus conclude the choice of an intermediate value, $EO_c = 0.00045$, may be an appropriate one for the Black Sea conditions.

FiB time series estimated from eq. (8) for $EO_c = 0.00003$ and $EO_c = 0.000045$ (Fig. 9) yield an ecologically sustainable fishery (i.e.

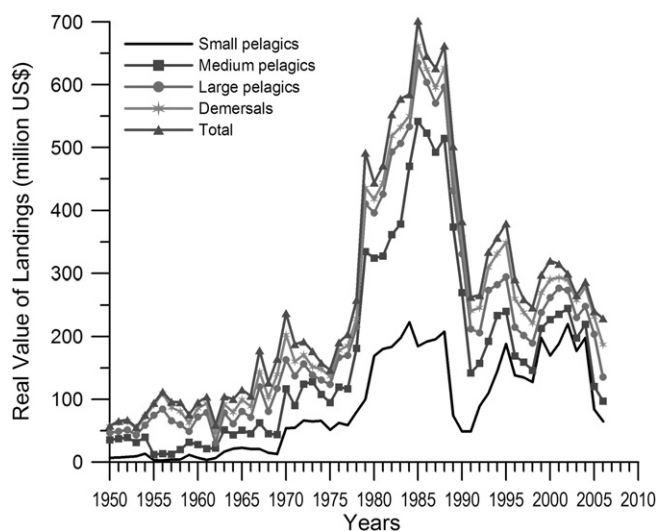


Fig. 7. Time series of the commercial values of small pelagics, medium pelagics, large pelagics, total demersals and total annual Turkish landings. The data are plotted in the form of cumulative sums.

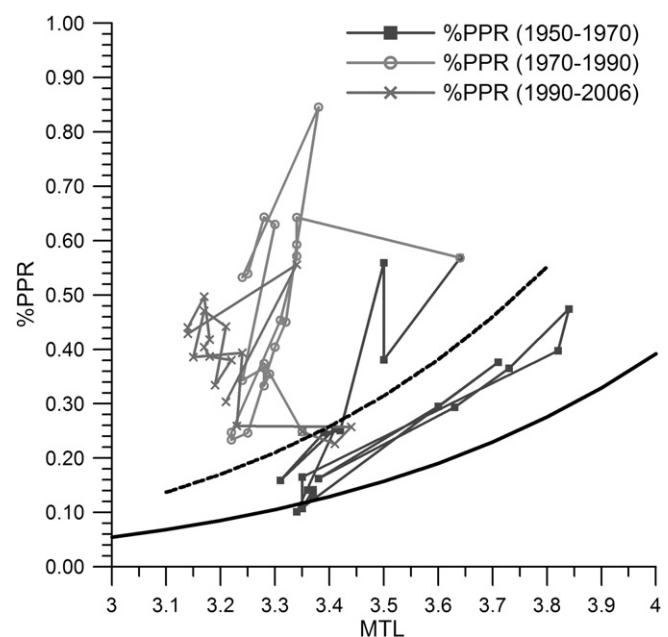


Fig. 8. %PPR versus MTL index plot shown in the form of three different ecosystem phases: 1950–1970 (■), 1970–1990 (●), 1990–2006 (*) for two threshold curves separating the sustainable fish and unsustainable fish conditions for $EO_c = 0.00003$ (straight line) and $EO_c = 0.00006$ (dashed line).

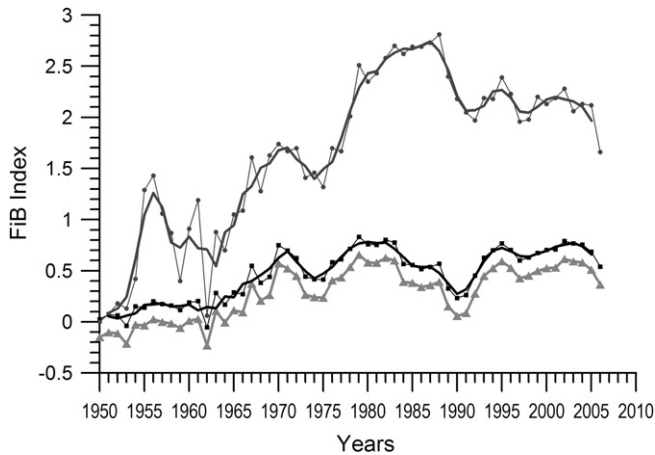


Fig. 9. Time series of fishing-in-balance index for the Turkish landings computed according to the classical definition given by eq. (3) (●) and the revised definition expressed by eq. (8) using two different reference levels of sustainable fished conditions with $EO_c = 0.00003$ (■) and $EO_c = 0.000045$ (▲). The thick lines represent three-point moving averaging of the original data.

$FiB \approx 0$) for 1950–1975 except for 1965–1970 as in the case of PPR_{emsc} . The sustainability is however better expressed with the latter EO_c value, as already deduced from Fig. 8. The exploitation level persisted around 0.5 afterward (i.e. unsustainable fishery) except some short periods of low %PPRs during the mid-1970s and the early 1990s. These changes are very different than those provided by the original definition of the FiB index computed by eq. (3) (Fig. 9). For example, its slightly lower FiB values for the third phase (after the early 1990s) may be interpreted as better fishery conditions than that of the 1980s. On the other hand, the revised definition offers an almost the same level of exploitation during the 1980s and 1990s and thus suggests no improvement.

The Turkish fishery exploitation index (Bilgin, 2006), defined as the ratio of fishing mortality to total mortality, persisted around 0.7–0.8 since the mid-1980s except its minimum values of about 0.5 at 1989–1991 due to the low catchability during the abrupt decline of catches (Fig. 10). With such high exploitation rates, small pelagic stocks are dominated by zero age class fish and only their small portion may survive to higher age classes. Assuming that 50% exploitation level, in general, reflects moderately sustainable fishery conditions, the low catch period 1989–1991 appears to correspond to the sustainable fishery conditions as further supported by the FiB index data in Fig. 9. According to Fig. 5b, the sustainable level of total Turkish landings in the third phase should

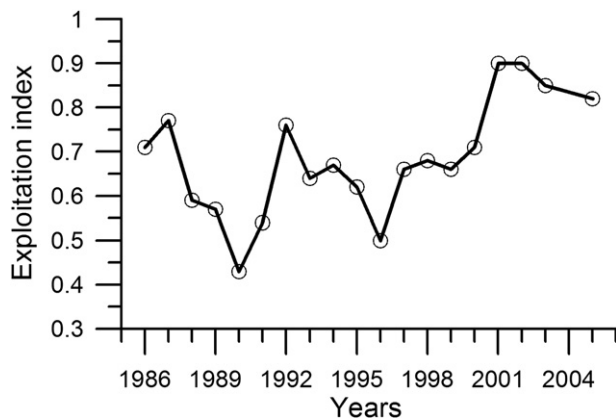


Fig. 10. Long-term variations of the exploitation index defined by the ratio of fishing mortality and total mortality in the southern Black Sea.

Table 1

The estimates of ecosystem-based maximum sustainable catches ($EMSC$) for the Turkish fishery during 1981–1988 intense-eutrophication and 1995–2006 post-eutrophication periods for the given values of the mean trophic index of catches (MTL), primary production (PP), primary production required (PPR) and percent primary production required (% PPR).

	1981–1988	1995–2006
MTL	3.28	3.19
PP (ton km ⁻² y ⁻¹)	1883	1214
% PPR	0.15	0.127
PPR (ton km ⁻² y ⁻¹)	284	159
$EMSC$ (kton y ⁻¹)	255	173

thus be about 175–200 kton. An alternative estimate may be achieved using the threshold PPR_{emsc} (eq. (6)). As given in Table 1, it yields the average ecosystem-based maximum sustainable Turkish catch ($EMSC$) of 173 kton y⁻¹ for 1995–2006 period and 255 kton y⁻¹ for the 1981–1988 period. These estimates therefore suggest that the Turkish fishery continues to exploit forage fish stocks twice more with respect to its sustainable level during the last 30 years. Furthermore, the maximum $EMSC$ value of 334 kton y⁻¹ at 1988 is close to the value of 325 kton y⁻¹ provided by Bingel et al. (1993) using the Schaeffer model of maximum sustainable yield.

These estimates may also be supported qualitatively by the landings data. In Fig. 5a, the total USSR landings increased by approximately 170 kton during 1977–1982. Assuming that the USSR fishery has already reached its geographic and technological expansions, this increase may be related mostly to the bottom-up resource enrichment mechanism in response to increased eutrophication. If we consider that the bottom-up resource enrichment is more or less uniformly distributed over the northern and southern basins and considering a smaller Turkish fishing area with respect to the USSR, 125 kton of the Turkish catch increase during the late 1970s should therefore be related to the eutrophication effect. This contribution, together with the additional contribution of 150 kton due to the decreasing MTL index, amounts to 275 kton of Turkish landings in the absence of geographic and technological expansion of the Turkish fishery. Once again, this value is consistent with the former estimates of the maximum sustainable yield for the 1980s.

4. Discussion and conclusions

The present study assesses interannual–decadal variations of the Black Sea fishery with a particular focus on the last two decades following the fish stocks collapse – the ctenophore *Mnemiopsis* population outburst at the end of the 1980s. The analysis comprises both reinterpretation of the classical landings data with an emphasis on the regional variability and more elaborate and novel analysis of the several ecosystem indices that combine landings information with those of bottom-up and top-down processes. The mean trophic level (MTL) index of catches is used to express a weighted average of the trophic levels of landings removed from an ecosystem. The % PPR index evaluates the catch quality and quantity in terms of primary production and energy flow to higher trophic levels. Its relatively low values at high trophic levels represent better sustainably-fished ecosystem conditions. The fishing-in-balance (FiB) index provides a measure for how fishery exploitation is ecologically balanced with respect to a given reference condition. Ideally, better sustainably-fished ecosystem conditions are characterized by relatively low % $PPRs$, high $MTLs$ and $FiBs$ close to its reference value. The present study note that the original forms of % PPR and FiB indices provided misleading interpretations on the state of fishery and therefore had to be modified

by introducing temporally varying primary production and reference state of ecologically maximum sustainable catch, respectively.

4.1. Main findings on the status of long-term Black Sea fishery

The data highlighted significant regional and temporal differences in the Black Sea fishery since the beginning 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 afterward. In the former USSR states, the large pelagic and demersal groups have experienced heavy harvesting even before the early 1950s due to the development of technologically advanced industrial fishery. Once they have been overexploited, the USSR fishery has been directed mainly on the small pelagic species starting by the 1950s. On the other hand, the Turkish fishery depleted the large pelagic and demersal fish at a rate of 0.25 trophic levels per decade from 3.8 at 1955–1956 to 3.3 at 1974–1975. 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 and Watson, 2005).

Although the loss of predators has had different temporal changes over the sea, the increase in landings occurred concurrently and abruptly in both the Turkish and USSR sides during 1969–1970, whereas the increase was more gradual 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 starting by the early 1970s. Thereafter, the Turkish and USSR landings increased roughly 10-folds and 5-folds, respectively, in terms of both total landings and landings per km². The medium pelagic landings also contributed to the Turkish fishery during this phase. The increase was however limited to the doubling of landings per km² in the Romania + Bulgaria region. 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.

The additional particular increase in Turkish landings was contributed by 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 7-folds increase from about 40 at the beginning 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 ~10,000 Hp to ~57,000 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.

Assuming that the southern (Turkish) and northern (USSR) basins may be 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 favorable 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 definition 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 (Essington et al., 2006).

The subsequent collapse of fish landings acquired different trajectories in different regions. It first declined during 1986–1987 in the western region. The USSR landings experienced a declining trend during 1982–1988 followed by an abrupt reduction at 1989–1990. The high catch state was however maintained until 1989 in the Turkish EEZ, and the collapse took place during 1990–1991. The more severe ecosystem degradation may have likely contributed to an earlier depletion of the fish stocks along the west coast. Nevertheless, almost simultaneous collapse of the fisheries all over the sea suggests concurrent role of overfishing and *Mnemiopsis* population outbreak (Oguz et al., 2008).

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) characterize 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 kton. The current unsustainable fishery exploitation is also evident by the comparable landings 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, 2008; 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 landings 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 over-exploitation 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).

4.2. Implications for the Black Sea ecosystem-based fishery management

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 unsuccessful. This has been followed by other unsuccessful attempts because fishery resources have been considered as an easy way of cheap and high quality food supply, reducing unemployment, and securing economical profits (Duzgunes and Erdogan, 2008; Knudsen, 2003). 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.

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 (Cochrane and de Young, 2008; Walker and Meyers, 2004; 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.

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., 2004; Hughes 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 governmental agencies for co-ordinated actions (i) to reduce the effects of overfishing and eutrophication, (ii) to develop solutions for the restoration of regional ecosystems and recovery of their diverse fish stocks and (iii) 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 (F) to much lower than its value for maximum sustainable yield (F_{msy}) 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 ingredient of the recovery is to minimize energy loss to the opportunistic and gelatinous species and reverting the trophic flow once again toward 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 government 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 $F < F_{msy}$. 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.

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