Trophic indicators to measure the impact of fishing on an exploited ecosystem

M. G. Pennino, J. M. Bellido, D. Conesa & A. López–Quílez

Abstract

Trophic indicators to measure the impact of fishing on an exploited ecosystem.— There is currently a global call for more use of an ecosystem approach to fisheries management (EAFM) to provide a holistic view of ecosystem–fisheries interactions. Trophic indicators could therefore be used to support the implementation of an EAFM by providing information on the state of the ecosystem. In this paper we propose a set of indicators such as the marine trophic index (MTI), the fishing in balance (FiB), the [cut]marine trophic index ([cut]MTI) and the pelagic/demersal index (P/D) to assess the dynamics and the trophic changes in the Black Sea large marine ecosytem from 1970 to 2005. Our analysis shows a heavily exploited ecosystem where overfishing and anthropogenic eutrophication are probably responsible. The decline of the MTI, [cut]MTI and FiB together with the rising trend of the P/D index could be interpreted as a fishing down marine food web process with a strong decrease in abundance of high trophic level species and a considerable increase of low trophic level species.

Key words: Trophic indicators, Ecosystem approach to fisheries management, Black Sea.

Resumen

Indicadores tróficos para medir el impacto de la pesca en un ecosistema explotado.— Cada vez son más frecuentes las iniciativas para la aplicación de un enfoque del ecosistema para la gestión de la pesca (*ecosystem approach to fisheries management*, EAFM) que proporciona una visión holística de las interacciones entre la pesca y el ecosistema. Los indicadores tróficos pueden ser herramientas ideales para la aplicación de EAFM proporcionando información sobre el estado del ecosistema. En este trabajo se propone un conjunto de indicadores tales como el índice trófico marino (MTI), el índice pesca en equilibrio (FiB), el índice trófico marino rebajado ([cut]MTI) y el índice pelágicos/demersales (P/D) para evaluar la dinámica y los cambios tróficos en el Mar Negro desde 1970 hasta 2005. Nuestro análisis muestra un ecosistema muy explotado, donde la pesca excesiva y la eutrofización antropogénica son probablemente los responsables. El decremento en la tendencia del MTI, el [cut]MTI y el FiB conjuntamente con el incremento de la proporción P/D, se podría interpretar como una situación de la red trófica marina debida a la sobrepesca (*fishing down marine food weeb situación*). Este fenómeno implica una fuerte disminución en la abundancia de las especies de alto nivel trófico y un considerable aumento de las especies de bajo nivel trófico.

Palabras clave: Indicadores tróficos, Enfoque del ecosistema para la gestión de la pesca, Mar Negro.

Maria G. Pennino & José M. Bellido, Inst. Español de Oceanografía, Centro Oceanográfico de Murcia, c./ Varadero 1, San Pedro del Pinatar, 30740 Murcia, España (Spain).– David Conesa & Antonio López–Quílez, Dept. Estadística e Investigación Operativa, Univ. de València, c./ Dr. Moliner 50, Burjassot, 46100 València, España (Spain).

Corresponding author: Maria G. Pennino. E–mail: grazia.pennino@mu.ieo.es

Introduction

The sustainability of the present fishery system is being questioned and failure of the traditional stock assessment and management is generally recognized (Garcia & De Levia Moreno, 2003). Sources of failure are many and varied for different types of fishing. In general, the failure can be attributed to the type of approach used, inadequate to capture multispecies and ecosystem effects (Cury et al., 2004). Considering factors that impact marine resource populations in a context beyond just the species level is one of the principal problems (Christensen et al., 1996). It has led to greatly simplify the nature and dynamics of resources, neglected the socio–economic dimensions of fisheries and the trophic relationships between species. The main consequence has been a series of ecological and economic collapses in numerous important fisheries in many parts of the world (Pauly et al., 2000a).

These considerations led to the new ecosystem approach to fisheries management (EAFM) which is a more holistic approach to resource allocation and management (Larkin, 1996). The FAO defined the EAFM as the extension and integration of conventional methods of management of marine resources, stressing the close interdependence between the welfare of humanity, the preservation of the environment and the need to maintain productivity of ecosystems for present and future generations (Ward et al., 2002; García et al., 2003).

The aim of an EAFM is to sustain an ecosystem in a healthy, productive and resilient condition so that it can continue to provide the services humans want and need (Link, 2002). To make this new type of ecosystem management possible, new viewpoints and tools must be developed to facilitate communication between managers, stake holders and scientists.

Acknowledging ecological interactions is a key point for an EAFM (Cury et al., 2003). The power of ecological processes such as trophodynamic interactions, i.e. predation and competition, has been identified as being of enormous importance in fish population dynamics (Bax, 1998). This involves two major problems in fisheries management. The first is the decrease in food resources on which some components of the ecosystem survive, necessitating the elimination of other localities or cause depletion (Link, 2002). The second is the indirect effect of decreasing fish biomass on the functioning of ecosystems (Cury et al., 2003).

Therefore, there is a need for descriptive indicators (Murawski, 2000) that reflect and describe the complex interactions between fisheries and marine ecosystems (Pauly & Watson, 2004).

Trophic indicators can help describe these in simpler terms that can be understood and used by non–scientists to make management decisions. Indicators could therefore be used to support the implementation of an ecosystem approach to fisheries management (EAFM) by providing information on the state of the ecosystem, the extent and intensity of effort or mortality and the progress of management in relation to objectives. Indicators should guide the management of fishing activities that have led to, or are most likely to lead to, unsustainable impacts on ecosystem components or attributes (Cury et al., 2005).

The potential danger of interpreting a single indicator may be that it does not analyze the causes of the observed trajectory or understand the dynamics of fisheries (Pennino et al., 2011). The application of a set of trophic indices could possibly resolve this problem. The weaknesses of one index are overcome by others that allow us to understand what has occured in past years in this ecosystem on a macro scale (Pennino et al., 2011).

In this paper we suggest a selection of indicators concerning TL to measure the impact of fishing on the Black Sea fish community, focusing on their meaning and sensitivity to fishing impacts.

Material and methods

The study area

The Black Sea is the world's most isolated sea, connected to the oceans via the Mediterranean Sea through the Bosphorus, Dardanelle and Gibraltar straits, and linked to the Sea of Azov in the northeast through the Kerch Strait (http://www.icpdr.org).

The Black Sea is a highly productive ecosystem (> 300 g / cm^2 year^1) with a continental climate. The fluvial discharge (Balkas et al., 1990), the natural winter production (Sur et al., 1994; Nezlin et al., 1999) the presence in summer of upwelling and a strong density stratification, make the Black Sea the largest anoxic basin of the global ocean (Sea Around Us, 2007). The deep waters do not mix with the upper layers of water that receive oxygen from the atmosphere. As a result, over 90% of the deeper Black Sea volume is anoxic water (Oguz & Ducklow, 1999). The most peculiar feature of the Black Sea is the absence of marine life at depths beyond 150–200 m, except for a few anaerobic bacteria (The Encyclopedia of Ukraine, www.encyclopediaofukraine.com). Living organisms are concentrated in the shallow waters of the continental shelf and river mouths along the northwestern coast. The number of alien species recorded at the regional level amounts to 217 (Sea Around Us, 2007). This number, together with the high level of pollution, suggests a serious impact on the native biological diversity in the he Black Sea and negative consequences for human activities.

The data set

In this study we used the fishery landings of the Black Sea large marine ecosystem (see www.lme.noaa.gov for more details) for the years 1970–2005.

Fishery data and TLs of the species were extracted from the database in http://www.seaaroundus.org. The data set consists of recorded nominal catches and does not include discarded species. Specific landings were grouped into 11 trophic groups taking their trophic level into account (table 1).

All indexes described were applied to this database to obtain an integrated vision of the environmental

Table 1. Trophic groups with trophic levels (TL) and standard errors (SE).

Tabla 1. Los grupos troficos con los respectivos niveles troficos (TL) y errores estándar (SE).

Groups	TL	SE
Bivalvia	2.02	0.03
Crustaceans	2.53	0.7
Molluscs	2.82	0.8
Engraulidae	3.11	0.45
Flatfishes	3.13	0.32
Cupleidae	3.15	0.19
Scorpionfishes	3.56	0.45
Carangidae	3.64	0.32
Percidae	3.66	0.19
Gadidae	4.05	0.68
Sharks and rays	4.15	0.79

and fishery problems of the Black Sea ecosystem and to test their performance.

Also, each series of indicators was smoothed using a locally weighted scatterplot smoothing, LOESS, which estimates a polynomial regression curve using local fitting (Cleveland, 1979). Bootstrap methodology was applied to assess variability. A 95% confidence band obtained from the bootstrapped samples was calculated for the original LOESS fit. Bootstrap (Efron, 1979) is a computer–intensive method that quantifies uncertainty for a large range of problems. It is based on resampling from an original sample of data to create replicate datasets and it provides inferences on the quantities of interest.

Finally, the standard error of the TL was included in the bootstrap procedure for the indicators derived from the TL, such as MTI, FiB, and the ^{cut}MTI.

All calculations were made with R (R Development Core Team, 2008).

Fishery ecosytem indicators

The marine trophic index – MTI
In February 2004, the Conference of the Parties to the Convention on Biological Diversity (CBD) recognized a number of indicators to observe the decrease in the current rate of biodiversity loss (CBD, 2004). The MTI is one of these indicators.

MTI is calculated from a combination of fisheries landings and diet composition data of the landed fish species. It is computed, for each year k from:

$$MTI_k = \sum_i (TL_i)(Y_i) / \sum_i Y_i$$

where MTI is the mean trophic level of landing in year

k, Y_i refers to the landings of trophic group i and TL is the trophic level of trophic group i.

Fishing often targets the highest predators, allowing individuals at the next TL to expand in numbers, leading to excessive grazing on the level below, reduced predation on the level below that, and so on, alternately, down to the base of the food chain. These 'trophic cascades' can, in extreme circumstances, be disastrous for marine ecosystems (Daskalov et al., 2007).

Pauly et al. (1998) showed the global declining trend of mean TL of catches from 1950 to 1994 based on the FAO dataset. The proposed explanation for this phenomenon, now widely known as 'fishing down marine food webs' (FDFW) is that the fishery catches are shifting from large, high–TL species to the small, low–TL species in response to their relative abundance in the ecosystem.

The fishing down marine food web effect has also been shown in Thailand (Christensen, 1998), Canada (Pauly et al., 2001), Greece (Stergiou et al., 2000), Iceland (Valtỳsson & Pauly, 2003) and in many others countries (Pauly & Watson, 2004). This phenomenon is widespread because the high–TL species (*e.g.*, large piscivorous fishes such as sharks, etc.), which are long–lived species with a low reproductive rate, are less resilient to overfishing and tend to be depleted quickly as compared to low–TL species, which are short lived and fast growing (Froese et al., 2004).

The ^{cut}marine trophic index – ^{cut}MTI
The use of mean TL as a measure of impact of fisheries on marine ecosystem was questioned by Caddy et al. (1998) who had in mind processes such as the eutrophication. This phenomenon of coastal areas may result in increasing abundance of planktivores, thus lowering mean TL. As a diffuse and general problem eutrophication can modify the ratio between predator and prey abundances, which could then be confused with effects of fisheries (Caddy, 1993). The analysis of this increase would lead by decreasing average calculated TL at a high inference TL fish depletion, although this cannot be reduced in absolute terms.

Pauly et al. (1998) noted a related problem due to fluctuations in the abundance of Peruvian anchoveta (*Engraulis ringens*), whose enormous catches strongly influence the mean TL of global catches.

To obviate this problem Pauly & Watson (2004) suggested that the MTI should in fact be based on time series that exclude low–TL organisms. This would lead to an indicator labeled ^{cut}MTI, with the 'cut' referring to the lowest (cut–off) TL value used in the computation. Pauly proposes the cut–off value of 3.25 ($^{3.25}$MTI). With a cut–off value of 3.25 all TL–levels lower than 3.25 are removed from the computation of the MTI, to eliminate the herbivores, detrivores and the planktivores whose biomass tends to vary widely in response to environmental factors (Pauly & Watson, 2004).

Fishing in balance index – FiB
Marine ecosystems operate as pyramids wherein the primary production generated at one TL is moved up toward the higher TL, with a huge fraction of that production being wasted in the process for the
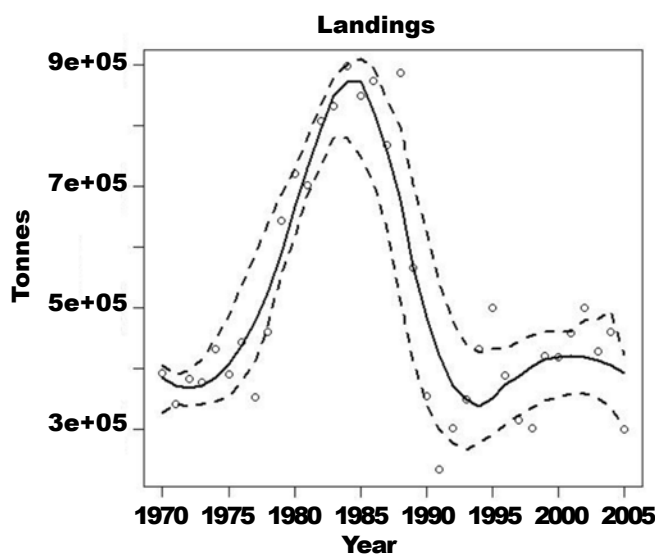
Landings

Fig. 1. Black Sea landings from 1970 to 2005. The continuous line represents the fit of the catch and the dotted lines represent the 95% confidence bands.

Fig. 1. Capturas en el Mar Negro desde 1970 hasta 2005. La linea contínua representa el ajuste de la tendencia de las capturas, mientras las lineas de puntos representan las bandas de confianza del 95%.

maintenance, reproduction and other activities of the animals in the systems (Pauly & Christensen, 1995). Thus, notwithstanding our preference for catching and consuming large predators, deliberately fishing down should enable more of an ecosystem's biological production to be captured by fishing. However, to avoid waste here as well, any decline in the mean TL of the fisheries catches should, in this case, be matched by an ecologically appropriate increase in these catches, the appropriateness of that increase being determined by the transfer efficiency (TE) between TL.

The average transfer efficiency between trophic levels in marine systems is c. 10% (Pauly & Christensen, 1995), Pauly et al. (2000b) predicted that a fall of 1 in the level at which a fishery operates would lead to a 10–fold increase in potential catches. To study this effect Pauly et al. (2000b) and Christensen (2000) introduced the fishing in balance (FiB) index as following:

$$FiB_k = \log [Y_k \cdot (1/TE)^{MTl_k}] - \log [Y_0 \, (1/TE)^{\,MTL_0}]$$

where Y corresponds to landings in year *k*, TL is the mean TL of the landings in year *k*, TE is the transfer efficiency (here set at 0.1 following Pauly et al., 2000a), and 0 refers to any year used as a baseline to normalize the index (Pauly et al., 2000; Christensen, 2000; Cury et al., 2005).

This index computes whether the increase in landings due to focusing on lower TL matches the ecological appropriate increase (determined by the transfer efficiencies between TL's). The FiB index remains constant if the TL–changes match 'ecological appropriate' changes in landings. When the FiB index

decrease this may indicate that fisheries withdraw so much biomass from the ecosystem that its functioning is impaired (Pauly & Watson, 2005). A decrease in FiB will also be observed if discarding that is not reflected in the reported catches takes place (Pauly & Watson, 2005). FiB requires the assumption that transfer efficiency is constant (and known sufficiently well) across trophic levels (Pauly et al., 2000c). Nevertheless, FiB is believed to provide a better indicator of ecosystem change than catch or catch composition, because of its integrative nature (Garcia & Staples, 2000).

Pelagic/demersal index – P/D
Changes in the trophic composition of marine communities can be tested in terms of large trophic groups such as planktivorous, benthivorous, or piscivorous animals (Caddy & Garibaldi, 2000). The expected effect of fishing (although not exclusive) is a decrease in the proportion of piscivorous fish. This is an easily understood indicator that can be estimated based on the knowledge of the biology of the species present in the community rather than on extensive diet data. A related index that has been proposed as an indicator for marine environments is the pelagic (P) to demersal (D) fish biomass ratio in fishery landings (Caddy, 2000; De Leiva Moreno et al., 2000).

However, the P/D ratio in fisheries catches is not exclusive in that it might be an indicator of eutrophication rather than exploitation (De Leiva Moreno et al., 2000).The pelagic fish are positively influenced by nutrient enrichment when it stimulates the plankton production (Caddy, 1993), while the demersal fish are influenced by the dynamics of benthic community,
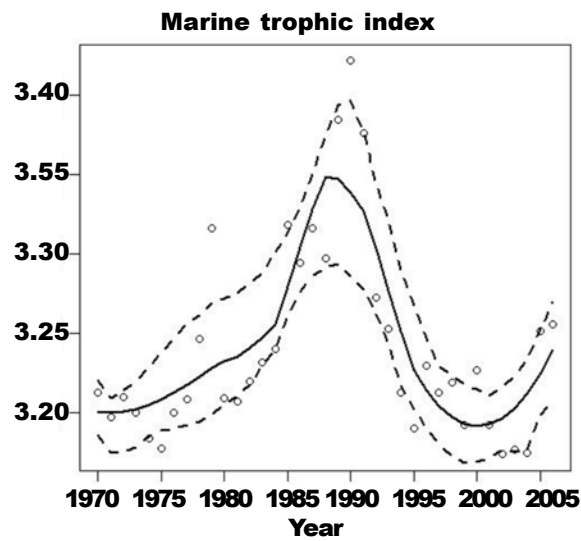
Marine trophic index

Fig. 2. Black Sea marine trophic index (MTI) between 1970 and 2005.

Fig. 2. Indice trofico marino (MTI) del las capturas en el Mar Negro entre 1970 y 2005.

which generally responds negatively to the conditions of excessive enrichment. It follows that a positive trend over time in the P/D index may depend both on the eutrophication both from the overexploitation of resources (Libralato et al., 2004). In addition, like other catch–based indicators, it will be sensitive to changes in the fishing targets and methods.

Results

Total reported landings in the Black Sea showed critical peaks and troughs, driven primarily by the fluctuation in the landings of European anchovy (*Engraulis encrasicolus*) with a peak landing of 790,000 tones recorded in 1984 (fig. 1). The landings increased
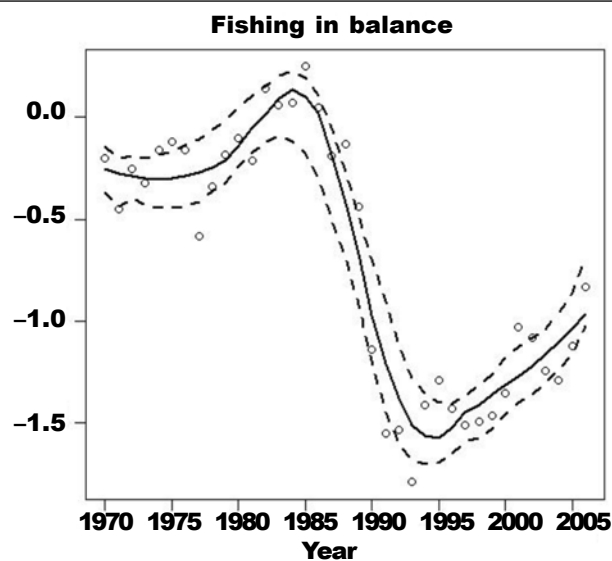
Fishing in balance

Fig. 3. Black Sea fishing in balance index (FiB) between 1970 and 2005.

Fig. 3. Indice de pesca en equilibrio (FiB) del las capturas en el Mar Negro entre 1970 y 2005.
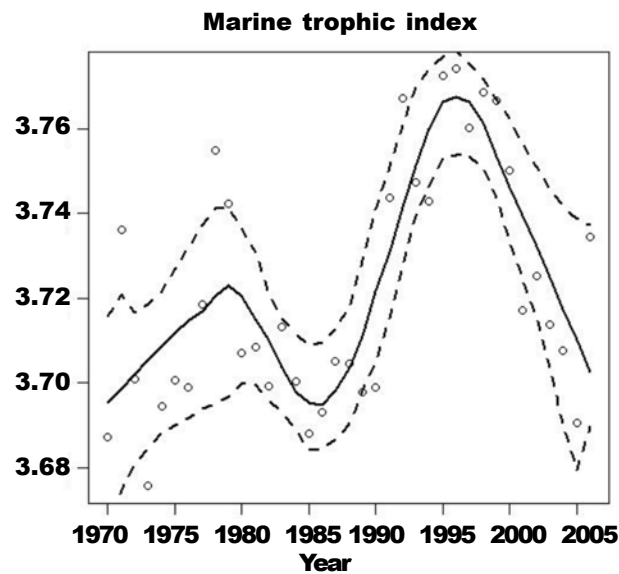
Marine trophic index

Fig. 4. Black Sea 3.25 marine trophic index ([3.25]MTI) from 1970 to 2005. The cut–off value of 3.25 removed from the computation of the index for all species whose biomass tend to vary widely in response to environmental factors.

Fig. 4. Indice trofico marino rebajado de 3,25 ([3.25]MTI) del las capturas en el Mar Negro desde 1970 hasta 2005. El corte del nivel trofico de 3,25 elimina del calculo del indice todas las especies cuya biomasa varia mucho en funcion de los factores ambientales.

following a precipitous decline from 1989 to 1991. However, they have not returned to the level achieved in the mid 1980s.

MTI showed an increase of 0.2 in the first two decades. In fact the values of MTI grew from 3.22 to 3.42 from 1970 to 1990 (fig. 2). In contrast, from 1990 to 2000 the MTI index showed an abrupt decline, with a decrement of 0.22 (fig. 2). Only in the last five years of the time series did the MTI index show a slight increase from a value of 3.20 to 3.25 (fig. 2).

The FiB index showed negative values in all 35 years of the series (fig. 3). The increase in the FiB index from the 1970s to the mid–1980s was driven by the increased reported landings during this period (fig. 3). In contrast, the decrease in the MTI values since 1990 was not countered by an increase in landings; thus the FiB index also declined in the early 1990 (fig. 3). After reaching the minimum value of –1.8, the FIB index increased by 0.5 from 1995 to 2005 (fig. 3).

The [cut]MTI showed a drastic decline in 1984, the same year that the landings of European anchovy peaked (fig.). In the mid–1990s the index increased from 3.69 to 3.77 in 1995 (fig. 4). In contrast, in the last five years the [cut]MTI index showed a strong decrease from 3.77 in 1995 to 3.69 in 2005 (fig. 4).

The P/D index showed positive values for all the times series (fig. 5). This trend showed a decreasing trend from the early 1970s until the minimum values recorded in 1990 (fig. 5). In the following years the index started to increase slowly, showing a maximum

value of 9.7 in 2002 (fig. 5). In contrast, the last three years of the time series showed a decrease in the index from 9.2 to 4 (fig. 5).

Discussion

The indices show a heavily exploited ecosystem where overfishing and the anthropogenic eutrophication are probably responsible (Daskalov, 2002). The decline of the MTI and of the FiB show a fishing down the marine food web situation in this ecosystem. Fishing down has been tested on Mediterranean large marine ecosystems (Pennino et al., 2011), but the speed with which changes occur in Black Sea fish communities is much higher.

Our results support previous studies that show strong changes in the fish community of the Black Sea in recent years (Lleonart, 2005; Daskalov, 2002).

The fishery eliminated the top predator during the 1970s (Daskalov et al., 2007); this led to reduced predation on planktivores, causing them to increase in the 1980s. Intense and unregulated fishing pressure in these years led to severe overexploitation of most major fish stocks (Black Sea Commission, 2002; UNEP, 2002).

The MTI and FiB decreases may indicate that fisheries withdraw so much biomass from the ecosystem that its functioning could be impaired (Pauly & Watson, 2005). The technological growth and demand
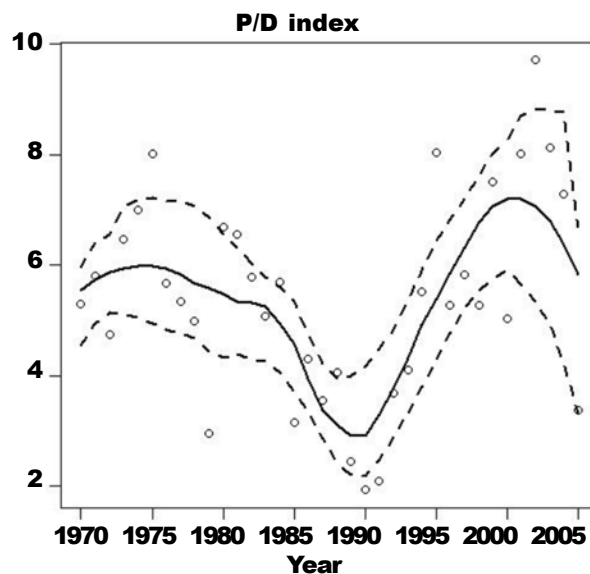
Fig. 5. Black Sea ratio of pelagic/demersal landings (P/D) from 1970 to 2005 (P/D index).

Fig. 5. Relación entre las capturas pelagicas y demersales (índice P/D) en el Mar Negro desde 1970 hasta 2005.

of fisheries in the 1980s has led to over–exploitation of marine resources, particularly for highest trophic demersal resources. This suggests that the changes in the food web could be influenced by the impact of advances in fishing technologies and changes in market–driven exploitation (Caddy & Garibaldi, 2000; Stergiou, 2002).

Indeed, the top predators, such as swordfish and tuna, were heavily exploited with the introduction of purse seining and through large scale surface longline and gill–net fisheries in the 1980s in this large marine ecosystem (Caddy, 1993). Some demersal species have pratically disappeared (Daskalov, 2002). This has been exacerbated by destructive fishing practices such as catching of under–sized fish (UNEP, 2002).

Furthermore, the invasion of the *Mnemiopsis leidyi* contributed to a catastrophic decline of fish stocks in the mid–1980s (Shiganova, 1998).

The trend of the [cut]MTI and P/D index confirmed this shift in the mid–1980s. The *M. leidyi* eats eggs and larvae of pelagic fish (Kube et al., 2007) and it caused a dramatic drop in fish populations.

The trend of the P/D index showed that the dramatic fall of the black sea fish catch was most pronounced for small pelagic species with a four–fold reduction in catches between 1988 and 1991, although the landings of these species have partially recovered over the past decade, as shown by the trend of the MTI.

The P/D index shows this increasing trend in recent years for the small pelagic species, which are *r* species with a higher turnover, especially in a highly eutrophic ecosystem such as the Black Sea. Also, this increase in small planktivorous species might have been a result of the transition of the ecosystem from an oligotrophic to eutrophic stae caused by nutrient enrichment (Caddy, 1993).

This phenomenon is confirmed by the decrease in recent years of the [cut]MTI index. This trend indicates that the resources with high TL, which correspond to the demersal fishes, are running out while the low TL species are increasing. Low TL species are usually small pelagic species.

The interpretation of trophic indicators is still very subjective. References points or limit values with which to unambiguously assess the results obtained with these indicators have not yet been established. These values cannot be established and standardised due to the sheer complexity of ecosystems. The tropic structure of each ecosystem is specific and unique.

However, we consider that jointly these indices are a good way to compare the dynamics of different ecosystems, since the important aspect for study of ecosystems is the trends in indices over times rather than the values they assume.

Sustainability, however defined, must imply some notion of permanence in at least some of the entities or processes being evaluated. Thus, if, in a given ecosystem, there is a clear trend of the relative abundance of high–TL to low–TL fishes, as indicated by declining MTI values, then this indicates the absence of sustainability and the need for intervention. Multispecies fishery can safely be assumed to be unsustainable if the mean TL of the species it exploits keeps going down (Pauly & Watson, 2005).

Furthermore, the indicators used are easily measurable and provide a clear understanding of complex processes that occur in an ecosystem. Like many other indicators, they do not detect changes induced by exclusive fishing, but they are, however, very sensitive to the dynamics of the fishes community. In conclusion we recommend the use of these indicators to analyze an ecosystem with a macro–scale approach and to obtain an overview of the ecosystem as a whole. The causes and the drivers that led to the changes highlighted by the analysis must be verified at the micro–scale, when and where better data are available.

We consider that ecosystem indicators are promising tools to assess ecosystem conditions because they are easy to standardize and to estimate with commonly available data. Application of the selected indicators to other marine ecosystems is encouraged so as to fully evaluate their usefulness for a broad selection of large marine ecosystems (LMEs), to assess their usefulness for an ecosystem approach to management and to establish international comparability.

Acknowledgements

References

Bax, N. J., 1998. The significance and prediction of predation in marine fisheries. ICES *Journal of Marine Science*, 55: 997–1030.

Balkas, T., Decheo, G., Mihnes, R., Serbanescu, O. & Unluata, U., 1990. Review of the State of the Marine Environmente of the Black Sea. United Nations Environment Programme, *Regional Seas Report and Studies*, 124: 201–218.

Black Sea Commission, 2002. State of the Environment of the Black Sea–*Pressures and Trends* 1996–2000. Istanbul, Turkey.

Caddy, J., 1993. Toward a comparative evaluation of human impacts on fisheries ecosystems of enclosed and semi enclosed seas. *Reviews Fisheries Science*, 1: 57–95.

Caddy, J. F., 2000. Marine Catchment Basin effects versus impacts of fisheries on semi–enclosed seas. *ICES Journal Marine Science*, 57: 628–640.

Caddy, J. F., Csirke, J., Garcia, S. M. & Grainger, R. J. R., 1998. How pervasive is 'Fishing down marine food webs?' *Science* (Washington, D.C.), 282: 1383.

Caddy, J. F. & Garibaldi, L., 2000. Apparent changes in the trophic composition of world marine haverests: the perspective from FAO capture database. Ocean Coastal Management. *Fisheries Research*, 72: 241–252.

CBD, 2004. Annex I, decision VII/30. *The 2020 biodiversity target: a framework for implementation.* Decisions from the Seventh Meeting of the Conference of the Parties of the Convention on Biological Diversity, Kuala Lumpur, 9–10 and 27 February 2004. Secretariat of the CBD, Montreal.

Christensen, N. L., Bartuska, A. M., Brown, J. H., Carpenter, S., D'Antonio, C., Francis, R., Franklin, J. F., MacMahon, J. A., Noss, R. F., Parsons, D. J., Peterson, C. H., Turner, M. G. & Woodmansee, R. G., 1996. The report of the Ecological Society of America committee on the scientific basis for ecosystem management. *Ecological Applications*, 6: 665–691.

Christensen, V., 1998. Fishery–induced changes in a marine ecosystem: insights from the models of the Gulf of Thailand. *Journal Fish Biology*, 53: 128–142.

– 2000. Indicators for marine ecosystems affected by fisheries. *Marine Freshwater Research,* 51: 447–450.

Cleveland, R. B., 1979. Robust locally–weighted regression and smoothing scatterplots. *Journal of the American Statistical Association*, 74: 829–836.

Cury, P. M., Mullon, C., Garcia, S. M. & Shannon, L. J., 2004. Viability theory for an ecosystem approach to fisheries. *ICSE Journal of Marine Science,* 62: 577–584.

Cury, P. M., Shannon, L. J., Roux, J–P., Daskalov, G. M., Jarre, A., Moloney, C. L. & Pauly, D., 2005. Trophodynamic indicators for an ecosystem approach to fisheries. *ICES Journal of Marine Science,* 62: 430–442.

Cury, P. M., Shannon, L. J. & Shin, Y.–J., 2003. The functioning of marine ecosystems: a fisheries perspective. In: *Responsible Fisheries in the Marine Ecosystem* (M. Sinclair & G. Valdimarsson, Eds.). CAB International, Wallingford.

Daskalov, G. M., 2002. Overfishing drives a trophic cascade in the Black Sea. *Marine Ecology Progress Series,* 225: 53–63.

Daskalov, G. M., Grishin, A. N., Rodionov, S. & Mihneva, V., 2007. Trophic cascades triggered by overfishing reveal possible mechanisms of ecosystem regime shifts. *Proceedings of the National Academy of Science.*

De Leiva Moreno, J. I., Agostini, V. N., Caddy, J. F. & Carocci, F., 2000. Is the pelagic–demersal ratio from fishery landings a useful proxy for nutrient availability? A preliminary data exploration for the semi–closed seas around Europe. *ICES Journal of Marine Science,* 57: 1091–1102.

Efron, B., 1979. Bootstrap methods: Another look at the Jacknife. *Annals of Statistics,* 7: 1–26.

Encyclopedia de Ukraine. Canadian Institute of Ukrainian Studies, Univ. of Toronto. www.encyclopediaofukraine.com.

Froese, R., Garthe, S., Piatowski, U. & Pauly, D., 2004. Trophic signatures of marine organisms in the Mediterranean as compared with other ecosystem. *Belgian Journal of Zoology*, 134: 25–32.

Garcia S. M. & De Leiva Moreno, J. I., 2003. Global overview of marine fisheries. In: *Sinclair:* 103–123 (G. M. Valdimarsson, Ed.). Responsible Fisheries in the Marine Ecosystem, CAB International,

Wallingford.

Garcia, S. M. & Staples, D. J., 2000. Sustainability reference systems and indicators for responsible marine capture fisheries: a review of concepts and elements for a set of guidelines. *Marine and Freshwater Research,* 51: 385–426.

Garcia, S. M., Zerbi, A., Aliaume, C., Do Chi, T. & Lassarre, G., 2003. *The ecosystem approach to fisheries.* FAO Rep 443, Rome.

Kube, S., Postel, L., Christopher, H. & Augustin, C. B., 2007. *Mnemiopsis leidyi* in the Baltic Sea – distribution and overwintering between autumn 2006 and spring 2007. *Aquatic Invasions*, 2: 137–145.

Larkin, P. A., 1996. Concepts and issues in marine ecosystem management. Reviews in *Fish Biology and Fisheries*, 6: 139–164.

Lleonart, J., 2005. Mediterranean an Black Sea, Fao statistical area 37. In: *FAO Marine resources Service, Fishery Resources Division, Review of the state of the world marine fishery resources. FAO Fisheries Technical Paper*, 457: 220–221.

Libralato, S., Pranovi, F., Raicevich, S., Da Ponte, F., Giovanardi, O., Pastres, R., Torricelli, P. & Mainardi, D., 2004. Ecological stages of the Venice Lagoon analysed using landing time series data. *Journal of Marine Systems,* 51: 331–334.

Link, J. S., 2002. What does ecosystem–based fisheries management mean? *Fisheries Management*, 27: 418–21.

Murawski, S. A., 2000. Definitions of overfishing from an ecosystem perspective. *ICES Journal of Marine Science*, 57: 649–658.

Nezlin, N. P., Kostianoy, G. & Gregorie, M., 1999. Patterns of seasonal and interannual changes of surface chlorophyll concentration in the Black Sea revealed from the remote sensed data. *Remote Sensing of Environment*, 69(1): 43–55.

Oguz, T. H. & Ducklow, W., 1999. A physical–biochemical model of plankton productivity and nitrogen cycling in the Black Sea. Deep Sea Research Part I: *Oceanographic Research Papers*, 46(4): 597–636.

Pauly, D. & Christensen, V., 1995. Primary production required to sustain global fisheries. *Nature*, 374: 255–257.

Pauly, D., Christensen, V., Dalsgaard, J. P. T., Froese, R. & Torres, F., 1998. Fishing down marine food webs. *Science,* 279: 860–863.

Pauly, D., Christensen, V., Froese, R. & Palomares, M. L., 2000a. Fishing down acquatic food webs. *American Scientist*, 88: 46–51.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T. J., Sumaila, U. R., Walters, C. J., Watson, R. & Zeller, D., 2002. Towards sustainability in world fisheries. *Nature*, 418: 689–695.

Pauly, D., Christensen, V. & Walters, C., 2000b. Ecopath, ecosim, and ecospace as tools for evaluating ecosystem impact of fisheries. *ICES Journal of Marine Science*, 57: 697–706.

Pauly, D., Froese, R. & Rius, M. J. F. D., 2000c. Trophic pyramids. In: *Fishbase 2000: Concepts, Design and Data Sources:* 203–204 (R. Froese & D. Pauly, Eds.). ICLARM, Manila.

Pauly, D., Palomares, M. L., Froese, R., Sa–a, P., Vakily, M., Preikshot, D. & Wallace, S., 2001. Fishing down Canadian aquatic food webs. *Canadian Journal of Fisheries and Aquatic Science*, 58: 51–62.

Pauly, D. & Watson, R., 2004. Fisheries impact on global marine diversity and ecosystems: inferences from large heterogeneous data sets. *Ocean Biodiversity Informatics*. 29 Nov–1 Dec.

– 2005. Background and interpretation of the 'Marine Trophic Index' as a measure of biodiversity. *The Royal Society,* 360: 415–423.

Pennino, M. G., Bellido, J. M., Conesa, D. & López–Quílez, A., 2011. Fishing down the Mediterranean Large Marine Ecosystem. Submitted.

R Development Core Team, 2008. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3–900051–07–0. URL http://www.R–project.org.

Sea Around Us, 2007. A Global Database on Marine Fisheries and Ecosystems. Fisheries Centre. University British Columbia, Vancouver, Canada. www.seaaroundus.org.

Shiganova, T. A., 1998. Invasion of the Balck Sea by the ctenophore *Mnemiopsis leidyi* and recent changes in pelagic community structure. *Fisheries Oceanography,* 7: 305–310.

Stergiou, K. I., 2002. Overfishing, tropicalization of fish stocks, uncertainty and ecosystem management: resharpening Ockham's razor. *Fisheries Research*, 55: 1–9.

Stergiou, K. I., Koulouris, M., 2000. Fishing down the food webs in the Hellenic Seas. *CIESM Workshop Series*, 12: 73–78.

Sur, H. I., Ozsoy, E. & Unluata, U. 1994. Boundary current instabilities, upwelling, shelf mixing and eutrophication processes in the Black Sea. *Progress in Oceanography,* 33: 249–302.

UNEP, 2002: Stolberg, T., Borysova, O., Sukhorukov, G. & Kideys, A., 2002. Black Sea, GIWA Regional Assessment 22, *Scaling and Scoping Report*. Univ. of Kalmar, Kalmar, Sweden.

Ward, J. V., Robinson C. T. & Tockner, K., 2002. Applicability of ecological theory to riverine ecosystems. *Verhandlungen des Internationalen Verein Limnologie,* 28: 443–450.