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APPLYING THE MARINE TROPHIC INDEX IN THE NORTH LEVANTINE SEA

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Abstract

The Marine Trophic Index (MTI) is a biodiversity indicator of ecosystem health mainly measuring the effects of fishing and fisheries on ecosystems, which relies on the mean weighted trophic level of fisheries landings, but excludes low trophic level species (those below trophic level of 3.5). The annual landings statistics were extracted from the General Fisheries Commission for the Mediterranean (GFCM) dataset for all available records since 1970 for the Levantine Sea (GFCM area 3.2). The MTI of the North Levantine Sea landings generally increased between 1970 and 1985 indicating that fisheries were geographically and bathymetrically expanding and that new stocks were exploited. Following 1985, the MTI declined rapidly to a lowest value of 3.74 in 2005. The rate of decline in the North Levantine Sea for the period 1985-2005 was 0.07 per decade, far exceeding the declining rates calculated so far for the entire Mediterranean Sea. MTI decline indicates that the larger, higher trophic level species are removed from the fishery at higher rates compared to the small-bodied lower trophic level ones. Thus, the landings are progressively dominated by small-bodied species and their mean weighted trophic level declines, a phenomenon termed fishing-down. The species replacement as revealed by the MTI decrease demonstrates biodiversity loss in the North Levantine Sea, while the process of fishing-down is an indicator of absent sustainability and ecosystem health in the area.

Introduction

A number of important scientific findings have been documented over the past decade concerning to the functioning of marine ecosystems. Recent achievements in marine research include the description of long-term patterns of change (climate change) with reference in inter-decadal cycles, teleconnections and regime shifts (for a review see [1]) and/or trophic cascades [2], food webs [3], biodiversity [1] and overfishing [e.g. 3, 4].

Overfishing has long been recognized as a leading environmental and socioeconomic problem, which has reduced biodiversity and modified ecosystem functioning [5]. Selective exploitation can change the size and age structure of populations if the frequency of extraction is shorter than the generation time of some of the species involved. Changes in the mean size of the fish caught and the mean trophic level (TL) of fisheries landings as a consequence of the sequential removal of top predators and the selective character of fisheries are well documented [3]. Moreover, the global ocean has lost more than 90% of large predatory fishes [6]. The same time global catches declining [7], fishery-induced [8] top–down effects are evident in coastal [4] and shelf [9] ecosystems, with the open oceans ecosystems being not well studied because of the lack of information [6]. Additionally, commercial fisheries discard large quantities of dead fish annually, a practice that may severely affect the energy flow in marine ecosystems documenting the cascade through the food chain of fishing impacts on marine ecosystems [1].

The extensive and non-sustainable exploitation of fisheries resources during the last century (after the industrial revolution and the modernisation of fleet and gear [10]) have catastrophic consequences and provide enough information to document habitat degradation, population declines and extinctions, as well as ecosystem changes [3, 4, 11-14]. Industrial fishing over the past half-century has depleted the top predators in aquatic food chains [14] and consequently fisheries are increasingly relying on the smaller, short-lived fishes and on the invertebrates from the lower parts of both marine and freshwater food webs [15] with the mean TL of the species declined from 1950 to 1994 [3].

For the evaluation of the status of fisheries as well as their ecological footprint, an established method is to test for the existence of fishing down the marine food webs. Ecologically, fishing down can be explained based on the relationships between fishing, sizes of organisms fished, and their TLs [16]. In general, fishing selectively removes the largest organisms. Since TLs in marine organisms generally increase with size, intense fishing lowers the relative catch contribution of large-sized, high TL organisms [16]. As a result, landings are progressively dominated by small-sized fishes (i.e., the mean TL of the catches declines) [16]. Fishing down can be put into practice using the Marine Trophic Index (MTI) [15], which actually is the mean TL of landings for a cut-off value of TL (i.e., MTI emphasizes changes in the relative abundance of the high TL species that are generally more threatened by fishing) [16].

This contribution is the first attempt to highlight management practices of fisheries resources in the area of Levantine Sea. We test the hypothesis that the mean trophic level of fisheries landings has declined based on the Marine Trophic Index [15, 17] and the Fishing-in-Balance index (FiB) [18], as measures of marine biodiversity and fisheries assessment.

Materials and methods

The Conference of the Parties to the Convention on Biological Diversity (CBD) identified the Marine Trophic Index (MTI) as one of the eight indicators for "immediate testing" of their ability to measure and monitor progress toward reaching the target to "achieve by 2010 a significant reduction in the current rate of biodiversity loss" [15, 17]. The term "MTI" is in fact the CBD's name for the mean trophic level (TL) of fisheries landings, originally used to describe the fishing down phenomenon [3]. The index is a measure of the richness and abundance of large, higher-trophic-level fish species and finally measures overall ecosystem health and stability, but also serves as a proxy measure for overfishing.

The mean weighted mean trophic level of the fish landings [15] for each year (k) was estimated in the fishing subareas using the landings of all species and their trophic levels:

$$\overline{TL_k} = \frac{TL_i \sum_{i=1}^{m} Y_{ik}}{\sum_{i=1}^{m} Y_{ik}}$$

where Yi refers to the landings of a species (or group of species) i, and TL is the trophic level. The trophic levels were taken from studies [19, 20] that provide estimates for Mediterranean fishes, and when not available, from FishBase [21] (www.fishbase.org). As a cut-off MTI value we used 3.5, the trophic level threshold which excludes small- and medium-sized pelagic species (i.e. European anchovy *Engraulis encrasicolus*, European sardine *Sardina pilchardus*, round sardinella *Sardinella aurita*). This is because the landings of these species fluctuate greatly and may be affected by climatic perturbations [e.g. 22]. Low TL species (cut-off MTI value 3.5) with rapid life history strategies (rapid growth, early maturation, short generation time, short lifespan and small body size) are known to respond quickly and be affected the most by climate fluctuations (Perry et al. 2005). Because of their rapid population characteristics, small pelagic species are among the most susceptible groups of fish to climatic and environmental changes (Blaxter & Hunter 1982; Cole & McGlade 1998). Higher TL species (TL > 3.5) are not affected since the species-specific reactions may be immediate or time-lagged (McCarty 2001) depending on the rate of population turnover. The effects of climate change on the ecology of aquatic organisms may vary from direct (through temperature and precipitation) to indirect (through habitat modification and food supply).

The Fishing in Balance index (FiB), which complements the MTI analysis, was calculated per year (k) as follows [18]:

$$FiB = \log\left[\frac{\left(\sum_i Y_{ik} 10^{TL_i}\right)}{\left(\sum_i Y_{i0} 10^{TL_i}\right)}\right]$$

where Y is the catches, TL is the mean trophic level of the catch, and the subscript 0 refers to the first year in a time-series that is used as a baseline. FiB attains a value of 0 for the first year of the series and does not vary in periods in which trophic level and catches change in opposite directions. Increasing or decreasing FiB values indicate a geographic expansion or contraction (or collapse) of the fishery in concern, respectively [18].

The annual landings statistics were extracted from the General Fisheries Commission for the Mediterranean (GFCM) dataset [23] for all available records since 1970 for the Levantine Sea (GFCM area 3.2). The landings of the North Levantine Sea (Cyprus, Lebanon, Syria, and Turkey) were included in the analysis and the landings of the southern part of the sea (Egypt, Israel, and Palestine) were excluded. The dataset accounted only for the landings actually derived from area 3.2 and ignored the catches of the above countries that were taken elsewhere.

Results

The MTI of the North Levantine Sea landings generally increased between 1970 and 1986. For that period, the lowest value of MTI was recorded in 1975 (3.68) and the highest in 1986 (4.01). The increase was strongly linear (r^2=0.79) and the rate of MTI increase was 0.2 per decade (Figure 1). The higher MTI values were recorded in 1980-1985 and suggest that the fisheries were geographically and bathymetrically expanding in that period and that new stocks were exploited. Following 1986, the MTI declined rapidly to a lowest value of 3.74 in 2005. The decline was again strongly linear (r^2=0.46). The rate of decline in the North Levantine Sea for the period 1985-2005 was 0.07 per decade, far exceeding the declining rates calculated so far for the entire

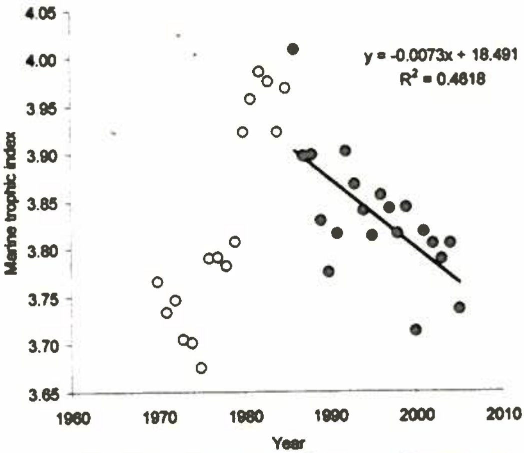

Figure 1. The Marine Trophic Index variability for the period 1970-2005. Open circles refer to the ascending part of the dataset and solid ones to the descending one on which the trend line was fitted.

Mediterranean Sea (Figure 1).

The fishing-in-balance index (FiB) increased for the period 1971-1992 exhibiting interannual variations and gradually declined thereafter. Its lower value (-0.171) was recorded in 1972 and its higher (0.715) in 1992 (Figure 2). Following the FiB decline, its most recent value was 0.322 in 2005. The declining trend of FiB was steeper compared to the increasing trend.

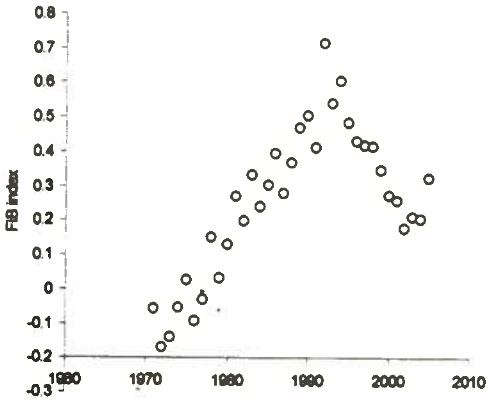

Figure 2. The fishing in balance (FiB) variability for the period 1970-2005.

Discussion

The main threat to marine biodiversity is exploitation, which has resulted in habitat degradation, population declines and extinctions and ecosystem changes [3, 4, 11-13, 16]. Because fishing is a recognized cause of biodiversity loss, indicators of marine biodiversity are needed to support conservation and fisheries management [11, 15]. Biodiversity indicators must summarize in a single number a variety of complex processes that are otherwise hard to apprehend and must also allow for communication and, ideally, for intervention [11, 15, 24]. MTI satisfies all characteristics of a biodiversity indicator as it summarizes complex and disparate sets of data and thereby simplifies information, it is based on comparable scientific observations and statistical measures, and provides a message that can be communicated and used by decision makers, stakeholders and the general public [25-27].

The MTI was applied here for a cut-off MTI value 3.5 which excludes low TL species such as small pelagics. Climate fluctuations affect directly (through temperature and precipitation) or indirectly (through habitat modification and food supply) the ecology of marine organisms. Low TL species (cut-off MTI value 3.5) with rapid life history strategies (rapid growth, early maturation, short generation time, short lifespan and small body size) are known to respond quickly and be affected the most by climate fluctuations [28]. Because of their rapid population characteristics, small pelagic species are among the most susceptible groups of fish to climatic and environmental changes [22, 29]. Higher TL species (TL > 3.5) are not affected since the species-specific reactions may be immediate or time-lagged [30] depending on the rate of population turnover [22].

MTI decline in the North Levantine Sea indicates that the larger, higher trophic level species are removed from the fishery at higher rates compared to the small-bodied lower trophic level ones. Thus, the landings are progressively dominated by small-bodied species and their mean weighted trophic level declines. The species replacement as revealed by the MTI decrease demonstrates biodiversity loss in the North Levantine Sea, while the process of fishing-down is an indicator of absent sustainability and ecosystem health in the area. The lack of fisheries sustainability was confirmed by the rapid decline of FiB index after 1992.

In the Mediterranean, the trophic level variability has been well documented [31]. In the Western Mediterranean, significant decrease in anglerfish, demersal sharks, anchovy and sardine has been shown, while there was an increase in red mullet, flatfish, juvenile hake and horse mackerel [32]. Intense fishing activity during the period from 1978 to 2003 in the South Catalan Sea (NW Mediterranean) was an important driver of the structural and functional changes in the marine ecosystem, in conjunction with environmental factors [32]. Ecosystem changes in the South Catalan Sea from 1978 to 2003 included a change in the biomass of several commercial and non-commercial species, the proliferation of non-commercial species, the decrease of the mean TL of the community and of biomass diversity, and the increase of total flow to detritus and the demersal/pelagic ratio [32].

Furthermore, a recent study demonstrated that the Mediterranean is being "farmed up" and revealed the masking of the full extent of "fishing down" in the Mediterranean [33]. In the eastern Mediterranean, a study from the Hellenic Seas (Aegean, Cretan and Ionian Seas) [34] showed that in the main part of the Aegean Sea the mean TL of the landings has decreased during the period from 1964 – 1997. The Aegean fisheries resources were not sustainable as previous results of both field and catch-effort studies [35] indicated. Similar results documenting fishing down phenomenon have been published for the Ionian Sea [34], the Adriatic Sea [36, 37] and the Venice Lagoon [38]. The Levantine Sea is not yet reported to be fished down, as well as the North Levantine which includes Cyprus waters.

This is the first study that reveals that "fishing down the marine food web" has been common the last years in the area of North Levantine waters. The decline in MTI documented here (Figure 1) indicates the absence of sustainability of fisheries resources exploitation, as well as in management system. To further test this phenomenon and provide the best scientific information to decision and policy makers, management bodies and the public in general, further research in the fields of trophic ecology and trophic interactions among marine food webs, is needed. The estimation of fractional trophic levels from stomach content and diet data [19, 20], as well as from stable isotopes [39, 40] will provide the basis to i) confirm the findings and recommendations of the present study, ii) to check whether TL estimations provided by FishBase [www.fishbase.org; 21] can be applied in Levantine Sea, which is described as an ultra-oligotrophic region [41] due to phosphorus limitation, and iii) to apply MTI in lower spatial and temporal resolution checking among other variables the trophic signatures [42, 43] of fishing fleet and gear. Furthermore, empirical knowledge regarding fisheries resources availability around Cyprus waters could be tested putting in practice fisheries trophic ecology and biology, biological oceanography and modelling ecosystem functioning and interactions using the "Ecopath with Ecosim" [18] approach with the above only being applicable through cooperation between scientists in Turkish- and Greek-Cypriot communities.

Management system in the studied area must be adapted so as to be sustainable. Lessons from the past, as well as from other areas in the world must be taken into consideration. The failure of traditional management approaches has led to a growing interest in "ecosystem-based management" as a promising alternative strategy [19, 44-47].

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