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Fisheries impact on trophic levels: North of the Persian Gulf case study, 2002-2011

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There are few documented reports about the trophic structure and catch composition of trawl fishery in the Persian Gulf. In this study, the changes in the marine food webs in the North of Persian Gulf along the Bushehr province coastal water of Iran was determined based on the estimates of the two indicators, mean trophic level (MTI) and Fishing in Balanced (FiB) index for the last decade (2002-2011). The data indicated an increase in total landings (of 49 exploited species), and moderate increasing trend in both MTL and FiB-index was observed. Even though the Iranian coastal fishing has increased over time, it has a low impact on the trophic structure of marine communities in this region. The study suggested that it may be due to occurrence of ‘‘fishing up’’ phenomenon in this area and there is a need to expand fishing to offshore and deep waters for discovery of new and high-TL species.

[**Keywords:** Mean trophic level; Fishing-in-balance; Fishing effects; North of the Persian Gulf]

Introduction

In ecology, the key indicator for monitoring changes in marine ecosystems is the mean trophic level (MTL) of the species groups that was proposed by Pauly[1] as an index of the impact of fishing. The trophic levels range from 0 to 5, from primary producers to second -level consumers or top carnivores[2]. The MTL has been designated by the conference of the parties to the Convention on Biological Diversity (CBD)[3], and measured by base on fisheries landings and species richness.

The high MTL indicates higher marine biodiversity and its long-term decline reflects gradual transition in landings from long-lived, high trophic level, top predator fish toward short-lived, low trophic level invertebrates and planktivorous pelagic fish[1]. When fish communities are exposed to intensive exploitation, it leads to fundamental reduction in the abundance of target species and changes in species composition. Large or slow-growing species with late maturity increase species abundance in respect of smaller, faster-growing species[4]. Higher trophic levels can lead to a decline in the mean trophic level of exploited fish communities[5]. It shows that changes in the composition of landings frequently changes the structure of underlying fish communities[6]. Some elements that are considered an agent of overfishing of marine resources are: Increasingly world catches[7], the fisheries impact on ecosystems[8-10] and low management in traditional stock assessment[11].

The long-term decline in marine food webs, in the MTL is considered as theory of “fishing down the marine food web”[12], that potentially alters trophic flows in an ecosystem[1,13]. But, to explain the observed patterns in human impact, a conceptual typology is used to classify the MTL declin in ecosystems into four types: Predators collapse (‘‘fishing down’’), low-trophic-level fisheries expand (‘‘fishing through’’), addition of new and high-TL species to catches over time (‘‘fishing up’’), and general expansion of fisheries leading (‘‘ecosystem overfishing or fisheries expansion’’)[14]. Another indicator used to track the status of marine ecosystems is the fishing in-balance (FIB)-index which can be used to draw on the sustainability of fisheries[15], and based on transfer efficiency between trophic levels (with a mean value of 10%), enables us to assess whether a fishery is ecologically balanced or not[16-17].

The strategic position of the Persian Gulf in comparison with other regions is more subject to overfishing and scarcity of resources. Also, according to reports of the Iranian Fisheries Research Organization (IFRO)[18], all commerical fishing resources in the Persian Gulf are believed to be in an entirely exploited or over-exploited condition. However, there is little biological information about

industrial and small-scale fishing and management, especially in the Northern coasts of Persian Gulf. Therefore, this study was aimed to determine and compare the impact of local fishing on changes in mean trophic level in shallow waters of the North of Persian Gulf (Boushehr Province) in ten years (2002 to 2011).

Materials and Methods

Landing data collection

Landings and fishery data for the coastal waters of the North of the Persian Gulf along the Bushehr province shoreline from the last decade (2002-2011) were collected from the Iranian National Organization of Fisheries. The studied area located between latitudes 29° 08′ 05″-29° 34′ 45″and longitudes 50° 30′ 30″- 50° 41′ 15″ (Fig. 1).

Landings are detailed by species in term of quantity (tones), which comprise about 90-95% of the total annual landings in the study period. A trophic level is defined as the position of an organism in the food chain and ranges from a value of 0 for primary producers up to a level of 5 for marine mammals and humans. In this study, based on their diet composition, me trophic level estimates for 49 species were found using two database Fish Base (www.fishbase.org), the global online database on fish, and Sea Around Us (see www.seaaroundus.org) database (Table 1). The mean trophic levels of the exploited groups are given in Table 1. The data were aggregated into 17 functional group categories with further subdivisions into sub-groups at species level to the total of 49 statistical categories, which were used in analyses.

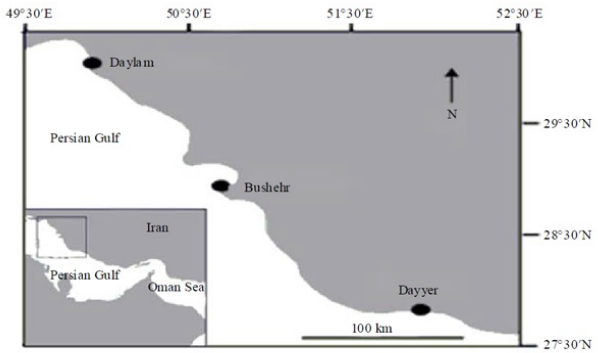


Fig. 1 — Map of study area, the Persian Gulf, showing the location of the Bushehr inshore water.

Marine trophic index (MTI)

Marine Trophic Index (MTI) is calculated from a combination of fisheries landings and diet composition data of the landed fish species. Their values are set as a definitional trophic level (TL) of 0 for primary producers, TL of 1 for microscopic plants and detritus, TL of 2 for herbivores and detritivores (first level consumers), TL of 3-5 for second-level consumers and higher order carnivores, and trophic omnivory or non-integer trophic levels for animals that feed on more than one trophic level. So, real consumers, which tend to have general diets, do not usually have TL with integer values[2]. The equation corresponding to TL for any consumer species i is:

$$TLi = 1 + \Sigma j\ (TLj.DCij), \quad \ldots (1)$$

where TLj is "fractional" (i.e., non-integer) trophic level of the prey j, and DCij represents the fraction of j in the diet of i[2].

The mean trophic index for each organism in landings was calculated for each year using:

$$MTI = \sum Yik.TLi / \sum Yik, \quad \ldots (2)$$

Where TLi is the trophic level of species (groups) i in year k, and Yik is their catches. MTI was calculated twice for each year: once for all species and a second after removal of species (groups) with TL< 3.25. In this study, following Pauly and Watson[19], $^{cut\ off}$ MTI was determinate[19]. Cut off is related to low trophic level species or groups that get eliminated from the analysis to emphasize the relative frequency of high trophic level species and ignore low trophic level species. The decline, if any, in the MTL over the years is considered as "fishing down the marine food web". The MTL trend was interpreted by plotting the MTL against years. Then regression analyses were performed, i.e., regression lines were fitted to MTI series against time and correspondingly for the correlation.

The fishing-in-balance (FiB) index

The fishing-in-balance (FiB) index[17] is used to indicate whether fisheries in the ecosystem are balanced in ecological terms. The FiB index was also estimated as follows:

$$FiB = \left[log\left(Yk.\left(\frac{1}{10}\right)^{TLk}\right) - \log\left(Y0.\left(\frac{1}{10}\right)^{TL0}\right)\right], \quad \ldots (3)$$

Where Y_k is the catch in year k, TL_k and TL_0 the mean trophic level of the catch in year k and 0,

Table 1 — Trophic level (TL) of the main species, landed from the North of the Persian Gulf (Bushehr province), 2002 - 2011, derived from FishBase and Sea around US database.

Common name	Scientificname	TL	Groups
Black tip sardinella	*Sardinella melanura*	2.9	**Small pelagics**
Skinny cheek lanternfish	*Benthosema pterotum*	3.1	
Blochs gizzard shad	*Nematalosa nasus*	2.7	
Indo-pasific king mackerel	*Scomberomorus guttatus*	4.3	**Medium pelagics**
Trigate tuna	*Auxis thazard*	4.3	
Hilsa shad	*Tenualosa ilisha*	2	
Wolf-herring	*Chirocentrus nudus*	4.2	**Large pelagics**
Talang queen fish	*Scomberoides commersonnianus*	4.5	
Indian mackerel	*Rastrelliger kanagurta*	3.2	
Mahimahi / common dolphinfish	*Coryphaena hippurus*	4.4	
Black skipjack	*Euthynnus affinis*	4.5	
Narow- barred Spanish mackerel	*Scomberomorus commerson*	4.5	
Yellowfin tuna	*Thunnus albacares*	4.3	
Longtail tuna	*Thunnus tonggol*	4.5	
Skipjack tuna	*Katsuwonus pelamis*	4.3	
Pickhandle barracuda	*Sphyraena jello*	4.5	
Black king fish	*Rachycentron canadum*	4	
Mullet	*Liza macrolepis*	2.6	**Demersals**
Southern meager	*Argyrosomus hololepidotus*	3.8	
Gaint trevally	*Caranx ignobilis*	4.2	
Cuttle fish	*Sepiidae*	3.6	
Silver pomfret	*Pampus argenteus*	3.1	
Gulf parrotfish	*Scarus persicus*	2	
Tigerthooth croaker	*Otolithes ruber*	3.6	
Javelin grunter	*Pomadasys kaakan*	3.5	
Spangled emperor	*Lethrinus nebulosus*	3.31	
Safi fish	*Siganus*	2.11	
Spotted sicklefish	*Drepane punctate*	3.3	
Yellowfinseabream	*acanthopacrous*	3.2	
Black pomfret	*Parastromateus niger*	2.9	
John’s snapper	*Lutjanus johnii*	4.2	
Red snapper	*Lutjanus erythropterus*	4.5	
Fourfingerthreadfin	*Eleutheronema tetradactylum*	4.3	
Japanese threadfin bream	*Nemipterus japonicas*	3.8	
Bartail flathead	*Platycephalus indicus*	3.6	
Greater lizardfish	*Saurida tumbil*	4.4	
Indian halibut	*Psettodes erumei*	4.4	
Orangespot grouper	*Serranidae*	3.9	
Bigeye croaker	*Johnius* spp.	3.65	
Indian pompano	*Trachinotus mookalee*	3.7	
Roundsnoutsea cat fiah	*Arius maculatus*	3.48	
Largeheadhairtail	*Trichiurus lepturus*	4.5	
Giant guitarfish	*Rhynchobatus djiddensis*	3.6	**Chondrichthians**
Green sawfish	*Pristis zijsron*	4	
Sharks or rays and chimaeras	rays	4	
Sharks or rays and chimaeras	Sharks	4	
Spiny lobsters	*Palinurus*	2.7	**Mollusks Crustaceans**
Swim crabs	*Portunus*	3.4	
Shrimps and prawns	Shrimps and prawns	2.7	

respectively, TE is the mean transfer efficiency (0.1), and 0 refers to the year used as a baseline year[17]. The FiB assesses if changes in the mean trophic level were compensated by changes in catches[17]. The FiB index remains constant (FiB=0) if the TL–changes match 'ecological appropriate' changes in landings. When the FiB index decrease (FIB<0) this may indicate that fisheries withdraw so much biomass from the ecosystem that its functioning is impaired. An increase in FIB (FiB>0) indicates expansion of a fishery beyond the initial ecosystem to stocks not previously exploited or only lightly exploited or that bottom-up effects have occurred[17].

Piscivory index

Piscivory index is the ratio of the sum of catches of piscivorous fishes (p) to the sum of catches of piscivorous (p) plus planktivorous fishes (Z), was computed.

$$\text{Piscivory index} = \sum Pk/(\sum Pk + \sum Zk), \quad \ldots (5)$$

Where P_k is the catch of piscivorous fishes in year k and Zk is the catch of planktivorous fishes in year k[20].

Results and Discussion

In the study area, Persian Gulf (Bushehr province shoreline), there are few documented reports about catch composition of trawl fishery and so few case studies have been mainly investigated about by-catch and discard[21-25]. Based on the past reports of The United Nations Environment Programme, the abundances of major target species in the Persian Gulf, including shrimps, mackerels, and various perciformes fishes, are slowly declining[26-27]. But now, despite little information available about the changes in species composition and mean trophic level status of the Persian Gulf, it is predicted that due to the immense pressure on the environment of this area, such as highest concentration of oil and gas extraction, rapid industrialization, coastal development, land-based pollution, high maritime traffic, overfishing and other unsustainable forms of resource use[28], the abundances of target species is decreased.

Table 1 shows the specimens collected from Bushehr province (N, Persian Gulf), and TL of landings over 2002-2011, derived from FishBase and Sea Around Us databases. In the coastal waters from Bushehr province (N, Persian Gulf), one of the important functional groups is large pelagic fishes with the most abundant species in landing such as Black skipjack and Longtail tuna, 71111 and 40213 tons, respectively. The landings in fisheries of the Iranian province of Bushehr increased from 41730 tons in 2002 to 54905 tons in 2008, and after that descended in 2009 and then exhibited an upward trend to 2011 with 53003 tons (Fig. 2). Also, the Planning and Programming Department[29] landing data of fishes indicated 21% reduction from110,000 in 2002 to 87,240 tons in 2003, in the Persian Gulf. The total landings by major trophic groups with and without the key species ($^{cut\ off}$ MTI), during 2002-2011, are shown in Figure 3 and 4. This analysis of landings data showed that the catch increases in the time series (2002 to 2011) were probably due to a

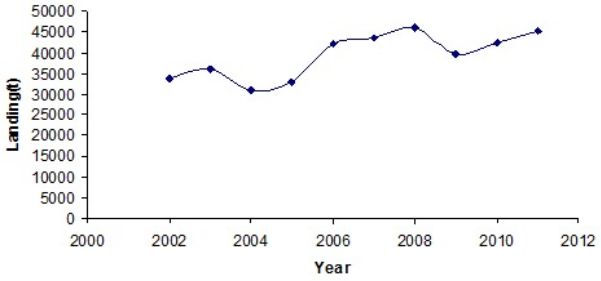
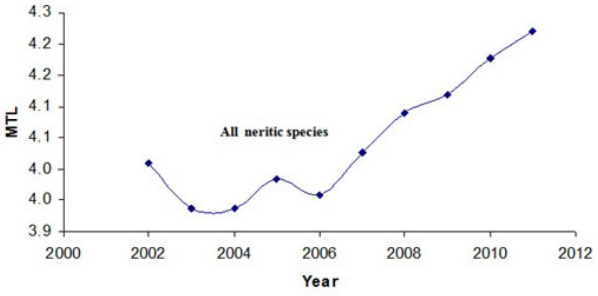
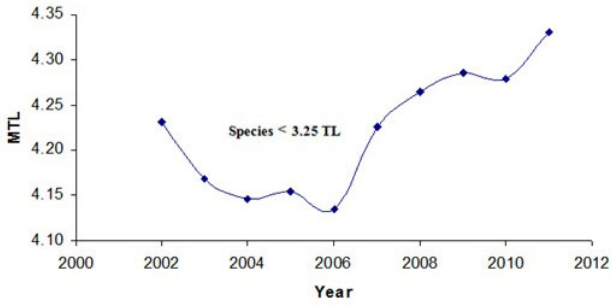


Fig. 2 — Annual landings of total fishing in Bushehr province (N, Persian Gulf).



(A)



(B)

Fig. 3a — MTL of landings b) MTL of landings (with TL < 3.25) in the Persian Gulf, Bushehr province over the period, 2002–2011.

spatial (offshore) expansion to deep waters and catch of the large pelagic species especially tuna fishes. As this species is found in offshore waters (www.fishbase.org), it is abundance in landings indicates that the fisheries in Bushehr coastal waters have developed to offshore waters. We found that the increased total landings in part may be related to technical innovation and the development of new fishing gear designs.

The MTI of Bushehr landings (all neritic species) exhibits a decreasing trend for the period 2002 to 2004 as well as 2005 to 2006, and increased trend from 2004 to 2005 as well as 2006 onward (Fig. 3a). With the moderate increasing trend in the catch to 2011, the mean trophic level also increased (Fig. 3a,b). The results suggest an increasing trend in MTI since 2006 onward during the time periods, due to variation in species group landing composition in the total landings, as the high-level carnivores and large pelagic fishes (e.g., Black skipjack, Longtail tuna, and Narrow-barred Spanish mackerel) make greater contributions to the total landings than detritivores and mid-level carnivores during the time periods. Following Pauly and Watson (2005), MTI were calculated twice for each year: Once for all species and a second time after removal of species groups with TL< 3.25 to eliminate the masking effect of highly variable and abundant small pelagic fishes (Fig. 3a,b). Asadi[30-31] has reported that the proportion of juvenile and adult commercial finfish (by TL< 3.25) from total catch is 50% in the catch composition of shrimp trawls from Bushehr waters (N. Persian Gulf). Used a cut off of 3.25 don't have an error masking effect on the fishing downtrend in this study, Using as the major species of the Bushehr landings pertains to large pelagic species with high-trophic-level (e.g., Tuna) and after that some small pelagic species with larger fraction of the catch and low-trophic-levels (e.g., Mullet and Hilsa shad) makes little contribution to the catch (Fig. 3b). Figure 3 shows that the MTL after removal of species (groups) with TL < 3.25, decreased from 2002 to 2006, and an increasing trend was observed from 2006 to 2011. These findings indicate a clear increasing trend in MTI of the Bushehr coastal waters, since 2006 onwards. This situation did not provide a sign of fishing down occurrence in this marine area (Fig. 3a,b) and showed that fishing activities had no impact on the trophic structure of the Bushehr coastal waters. So following Shannon[14], may be related to addition of new and high-TL species to catches by technical issues over time and classified in ''fishing up'' category. This observation is confirmed by the data found for Piscivory index of Bushehr landings that indicated an upward trend for the period 2002–2011 (Fig. 5). As noted by Caddy[32] and Caddy and Garibaldi[33], MTL could be sensitive not only to fishery-induced changes at the ecosystem level, but also to economic and technological factors. Further, changes in the environment, modifications of some migration patterns, epidemic diseases, in addition to fishing activities have a vigorous impact on distribution and abundances of fish species and structure of an ecosystem[34]. Nonetheless, it has been unclear that this general increase in MTI of landings and high trophic level species fishing is caused by the development of technology and or due to alteration of the marine ecosystem. The exploited species in total landings were separated into three categories: Large pelagic fishes, demersal fishes, and small and medium pelagic fishes. The high-level carnivores and top predators (TL>3.25, such as large pelagic fishes and demersal) make higher contributions to the total

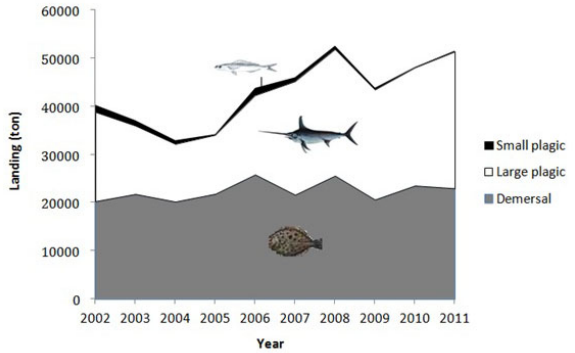


Fig. 4 — Annual landings (t) in Bushehr province coastal water: Landing of species groups (demersal, large pelagic and small pelagics).

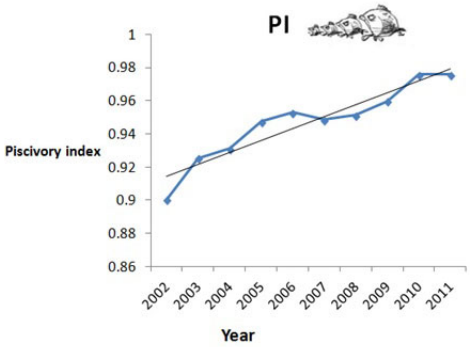


Fig. 5 — The trend of Piscivory index in catches from Bushehr province coastal water, 2002 to 2011.

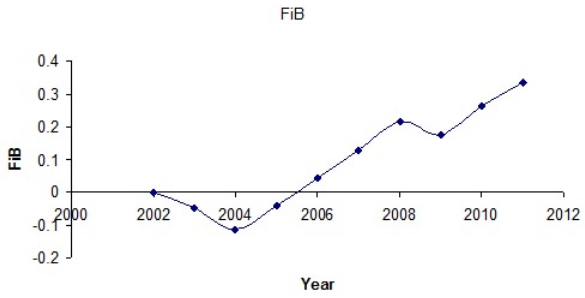


Fig. 6 — The Persian Gulf, Bushehr province fishing in balance index (FiB) over 2002 to 2011.

landings than detritivores and omnivores and mid-level carnivores (TL<3.25, such as small and medium pelagic fishes) (Fig. 4). The FiB index, which enables an assessment of whether the fishery is balanced in ecological terms or not, increases (FiB >0), if either a ‘‘bottom up effect’’ occurs (e.g., increase in primary production) or if a geographic expansion of the fishery occurs[17,35]. In this study, the amounts of FiB were variable from a range of -0.11 to 0.33 with the maximum amount observed in 2011. The FiB index has negative values for the year 2003 to 2005, and positive values and an upward trend from 2004 to 2011 along the coasts of Bushehr, indicating that the fisheries practice has increased, and may have developed to offshore and deep waters (Fig. 6). Further, this trend may be caused via bottom-up effects under the control of climate-mediated changes in the availability of lower trophic levels having knock-on consequences for higher trophic levels[36-37].

Conclusion

This study shows that fishing has a low impact on the ecosystem structure in Bushehr coastal waters, because the moderately increasing trend in both MTL and FiB index reflects increasing catches and is not attributed to shift from high-level carnivores and top predators fishes to low trophic level invertebrates and small pelagic fish, suggesting low probability of ‘‘fishing down’’ process. But ‘‘fishing up’’ phenomenon may have occurred in the North of Persian Gulf along the Bushehr province shoreline. We suggest that, in the long-term using ecosystem-based approach and fishing management programs, this trend should be controlled.

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