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A Bio-economic Study of the Trophic Structure of the Omani Fish Catch

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Abstrak: Kajian ini telah dijalankan untuk mendapatkan anggaran indeks biologi dan ekonomi untuk struktur trofik penangkapan ikan Omani, iaitu aras trofik min (MLT), indeks penangkapan ikan yang seimbang (FiB) dan indeks harga relatif (RPI). Secara umumnya, MLT telah berkurangan dari 1995 hingga 2010, menunjukkan penangkapan ikan menurun dalam web trofik marin. Indeks FiB telah meningkat, menunjukkan ketidakseimbangan dalam perikanan. Indeks ekonomi, RPI telah menurun dari 1994 hingga 2007, menunjukkan bahawa nilai spesies aras trofik (TL) bawah telah meningkat secara relatif kepada spesies TL atas.

Kata kunci: Aras Trofik, Indeks Penangkapan Ikan yang Seimbang, Indeks Harga Relatif

Abstract: The present study was conducted to obtain estimates of certain biological and economic indices of the trophic structure of the Omani landed fish catch, namely, the mean trophic level (MTL), the fishing-in-balance (FiB) index and the relative price index (RPI). The MTL generally decreased from 1995 to 2010, indicating a fishing-down of the marine trophic web. The FiB index increased, indicating an imbalance in the fisheries. An economic index, the RPI, decreased from 1994 to 2007, indicating that the values of lower trophic level (TL) species increased relative to those of higher TL species.

Keywords: Trophic Levels, Fishing-in-Balance Index, Relative Price Index

INTRODUCTION

The intensive exploitation of fish communities is a main reason of substantial decrease in the abundance of target species changing the species composition (Greenstreet & Hall 1996) which in turn reflect changes in the structure of the underlying fish communities (Gulland 1987). The study of fish trophic levels (TLs) is of practical and theoretical significance. Fishing-down in marine food webs worldwide was initially documented using Food and Agriculture Organization (FAO) landings data from 1950 to 1994 with estimates of TLs extracted from recorded mass-balance trophic models (Christensen 1995; Pauly & Christensen 1995; Christensen & Pauly 1993; Pauly & Christensen 1993).

The average transfer efficiency between TLs in marine systems is 10% (Pauly & Christensen 1995) and 10-fold in potential catches increases with 1 level decrease of fishery operation (Pauly *et al.* 2000). To study this effect, Pauly *et al.* (2000) and Christensen (2000) introduced the fishing-in-balance (FiB) index. If catches increase 10-fold for every full TL decrease, the FiB index will remain constant, and fishing can be deemed ‘in balance’. The Convention of Biological Diversity's (CBD) Marine Trophic Index was developed (CBD 2004),

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based on the contribution of Pauly *et al.* (1998), on the assumption that a decline in the mean trophic level (MLT) of the fishery catch is generally due to a fisheries-induced reduction of the biomass and hence of the biodiversity of the vulnerable top predators.

Fishery preferences change due to economic forces. Inside this context the values of the species determine what species the fishermen are targeting and to what extent they are ready to invest their money to catch it. According to previous studies [Organisation for Economic Co-operation and Development (OECD) 1997; Murawski & Serchuk 1989] the average market price of a species will increase with its rarity .According to Sumaila (1998) markets may give a good value to previously undesirable fish when target species disappear. The average price of low TL species increased between 1952 and 1994 relative to the price of high-TL species (Sumaila 1998). To measure this effect in Omani fisheries, we followed the method of Pinnegar *et al.* (2002) based on the estimation of the relative price index (RPI). Pinnegar *et al.* (2002) claimed that that constant RPI leads to constant relationship between the prices of low and high TL species, although prices may have increased in absolute terms due to inflation. The principal objective of the current work is to describe the TL structure with the temporal changes in the landed catch and to examine the degree of balance in the fishery by estimating the FiB index. Another objective is to describe the economic effect of the change in the TL structure by measuring the change in the prices of various TLs relative to each other.

MATERIALS AND METHODS

The weights in metric tonnes (mt) and values in Omani Real (RO) of the landed catch were obtained for 1995–2010 from the compilation of fishery statistics (Omani Ministry of Agriculture and Fisheries Wealth). The TLs of the landed species (Table 1) were retrieved from the Fishbase web site (Froese & Pauly 2012). From this information, we identified three groups of TLs: group 2+ (herbivores and detritivores), which includes species at TLs ranging from 2.00 to 2.99; group 3+ (carnivores which feed only on herbivores and/or detritivores), which includes species at TLs ranging from 3.00 to 3.99; and group 4+ (top predators), which includes species at TLs ranging from 4.00 to 4.99. This classification was made according to Pauly *et al.* (1998) and Froese and Pauly (2012).

Mean Trophic Level (MTL)

According to Kleisner and Pauly (2011), the MTL is calculated as follows:

$$MTL = \Sigma (Y_{ik} \times TL_i) / \Sigma (Y_{ik})$$

where Y_{ik} is the catch of species i in year k and TL_i is the TL of species (or group) i.

Table 1: TLs of various fish species in Omani catch (modified from Froese & Pauly 2012).

Fish species	Common name	TL
Sphyraena barracuda	Barracuda	4.50
Sphyraena jello	Barracuda	4.50
Trichiurus lepturus	Ribbonfish	4.40
Euthynnus affinis	Kawakawa	4.50
Seriphus politus	Queenfish	4.50
Istiophorus platypterus	Sailfish	4.45
Thunnus albacares	Yellowfin tuna	4.30
Auxis thazard	Frigate tuna	4.35
Rachycentron canadum	Cobia	4.00
Thunnus tonggol	Longtail tuna	4.50
Platybelone argalus platyura	Needlefish	4.50
Scomberomorus commerson	Kingfish	4.50
Sarda orientalis	Striped bonito	4.21
Katsuwonus pelamis	Skipjack	4.30
Lutjanus malabaricus	Snapper	4.45
Carcharhinus leucas	Shark	4.34
Carcharhinus melanopterus	Shark	3.94
Sphyrna lewini	Shark	4.08
Megalaspis cordyla	Small jacks	4.00
Decapterus kurroides	Small jacks	3.40
Epinephelus tauvina	Grouper	4.13
Epinephelus areolatus	Grouper	3.90
Epinephelus chlorostigma	Grouper	3.99
Pristipomoides typus	Jobfish	4.20
Caranx ignobilis	Large jacks	4.22
Caranx heberi	Large jacks	3.70
Alectis indicus	Large jacks	4.09
Elagatis bipinnulata	Large jacks	3.59
Gnathanodon speciosus	Large jacks	3.84
Arius jella	Catfish	4.00
Lethrinus nebulosus	Emperor	3.75
Lethrinus lentjan	Emperor	3.87
Argyrops filamentosus	Seabream	3.95
Atractoscion aequidens	Croaker	3.60
Aetomylaeus nichofii	Rays	3.76
Himantura uarnak	Rays	3.67
Rhynchobatus djiddensis	Rays	3.60
Rhinoptera javanica	Rays	3.28

(*continued on next page*)

Table 1: (*continued*)

Fish species	Common name	TL
Atractoscion aequidens	Sweetlips	3.60
Sepia pharaonis	Cuttlefish	3.44
Encrasicholina punctifer	Anchovy	3.43
Rastrelliger kanagurta	Indian mackerel	3.20
Sardinella longiceps	Sardine	3.00
Siganus canaliculatus	Rabbitfish	2.21
Penaeus indicus	Shrimp	2.65
Panulirus homarus	Lobster	2.60
Valamugi seheli	Mullets	2.39
Haliotis sp.	Abalone	2.27

Fishing-in-Balance Index (FiB)

According to Pauly *et al.* (2000) and Christensen (2000), the FiB index for any year k is computed as follows:

$$FiB = \log [Y_k \times (1/TE)^{MTL_k}] - \log [Y_0 \times (1/TE)^{MTL_0}]$$

where Y is the catch, TE is the mean energy-transfer efficiency between TLs (assumed to be 10%) and 0 refers to the first year in the time series that is used as a baseline.

Relative Price Index (RPI)

The average prices of landed fish species (in RO per ton) landed in the Omani fisheries between 1995 and 2010 were estimated as value (RO) divided by landings (mt). Note that data after 2007 were excluded because data for abalone were missing. The relationship between prices and TLs was examined for each year using a linear regression. The slope of the regression (*b*) was taken as the RPI for each year (Pinnegar *et al.* 2002). The decrease in the RPI means that the prices of lower TL species have increased relative to those of the higher TL species (Sumaila 1998); conversely, when the RPI increase, this means that the top predators have increased in value relative to the low TL species.

RESULTS

Present study showed that the Omani fish catch includes three groups of TLs: 2+ (herbivores and detritivores), 3+ (carnivores feeding only on herbivores and/or detritivores) and 4+ (top predators). It appears that trophic group 3+ dominated the catch during most fishing seasons and that the catch of this trophic group increased continuously, followed by the species belonging to trophic group 4+, whose catch showed a general decrease. Fish belonging to trophic group 2+ were sparsely represented in the catch (Fig.1).

Our investigation showed a general decrease in the annual MTL (Fig. 2) and obvious increases in the total landed catch (Fig. 3) and FiB index (Fig. 4). The MTL generally decreased from 1995 to 2010 (Fig. 2). Initially, an increase in the MTL occurred from 1995 to 1997, followed by a marked decrease until 2001 and then an increase until 2003 at a rate of 0.07 TLs year^{-1}, followed by a gradual decrease.

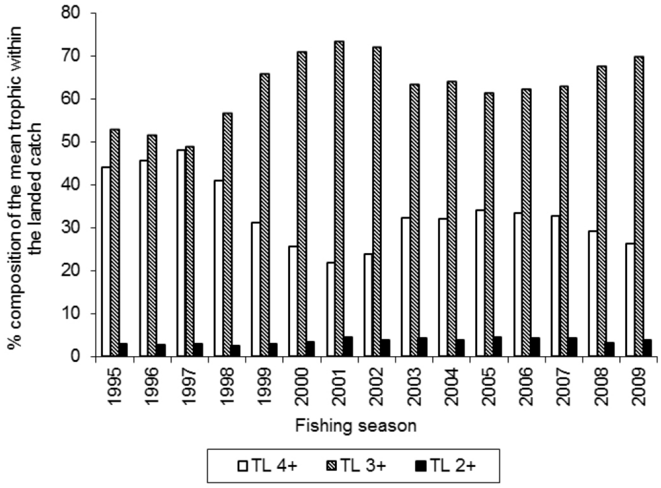

Figure 1: Percentage composition of various groups of TLs in Omani catch.

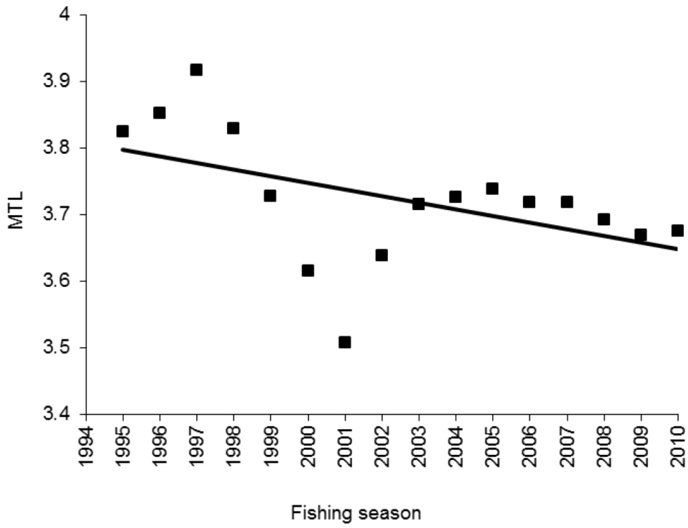

Figure 2: Seasonal changes in MTL of Omani landed catch from 1995 to 2010.

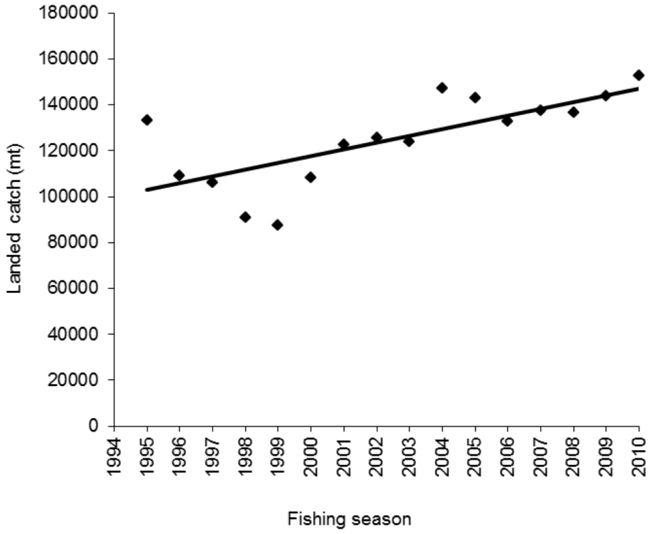

Figure 3: Seasonal change in total landed catch.

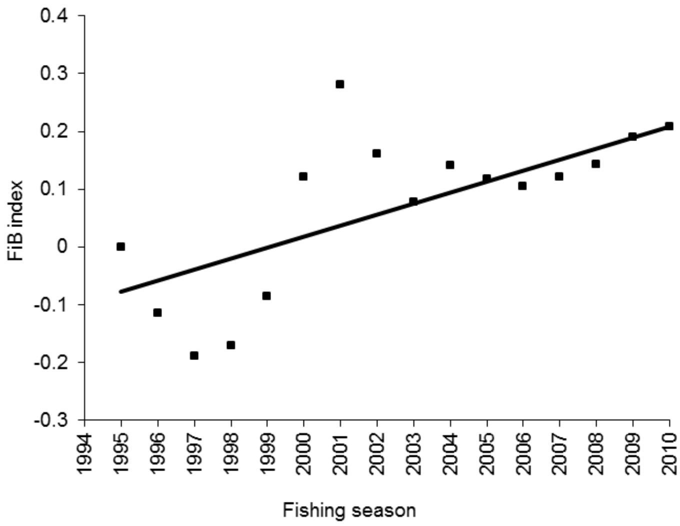

Figure 4: Seasonal changes in FiB index.

Economic Analysis

An examination of the economic contribution of various trophic groups in the catch (Fig. 5) showed that the contribution of trophic group 3+ was generally greatest, followed by group 4+ in certain seasons and 2+ in certain other seasons.

The results of the present study show an increase in the value of the total catch (the summation of the values of all TLs) from 1995 to 2010 (Fig. 6). In contrast, the RPI generally decreased (Fig. 7).

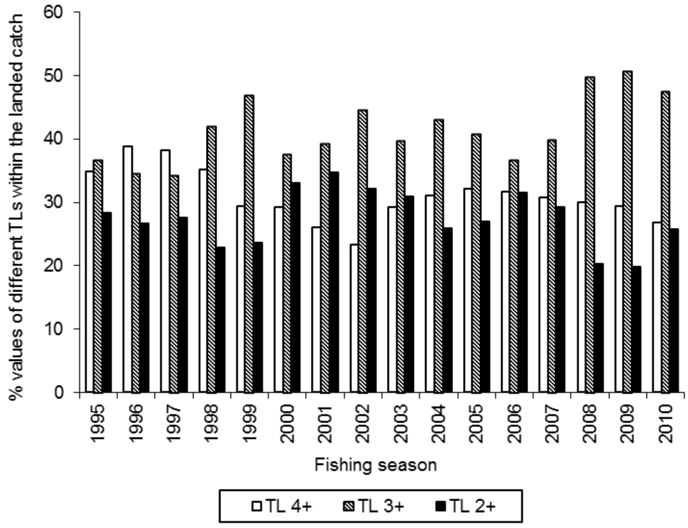

Figure 5: Economic contribution (% values) of various groups of TLs in the catch from 1995 to 2010.

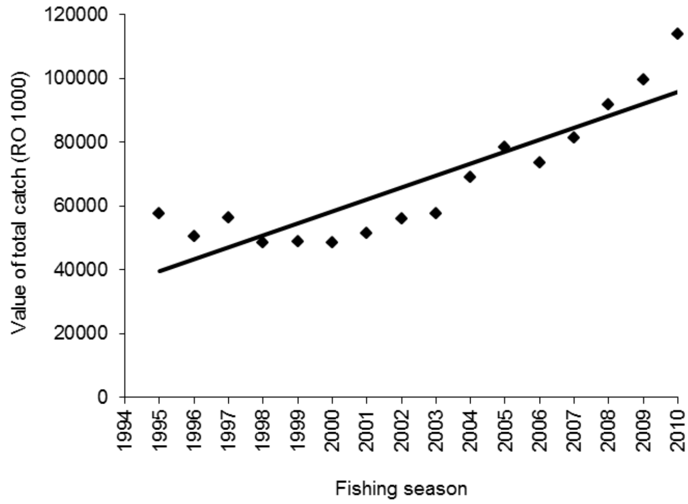

Figure 6: Seasonal changes in values of total landed catch of Oman.

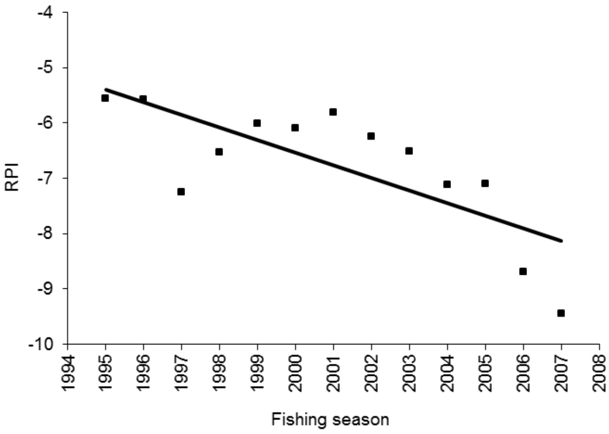

Figure 7: Temporal change in RPI of the TL structure within the Omani landed catch (from 1995 to 2007).

DISCUSSION

In the present study, the TLs of the fish constituting the Omani catch were retrieved from the Fishbase website (Froese & Pauly 2012). The Fishbase data showed that the TLs of fish, non-fish vertebrate groups and invertebrate groups in the Omani ecosystem ranged from 2.20 to 4.50. The analysis of these data showed that the catch includes three groups of TLs: 2+ (ranging from 2.21 for rabbitfish to 2.65 for shrimp), 3+ (ranging from 3.00 for sardine to 3.96 for seabream) and 4+ (ranging from 4.00 for catfish and cobia to 4.50 for barracuda and ribbonfish). These groups were classified according to Pauly (1998), who mentioned that TL 1 includes that plants and organic matter (detritus), TL 2 includes exclusive plant or detritus feeders (herbivores, detritivores) and TL 3 include carnivores which feed only on herbivores and/or detritivores. He claimed that carnivores do not necessarily have TLs of exactly 3 or 4 but may have intermediate values due to consuming mixture of prey. Due to this effect of mixed diets, top predators in marine ecosystems rarely exceed TL 5. These high values includes only in transient killer whales and polar bears, because they exclusively feed on marine mammals (which themselves prey on piscivorous fish) (Pauly *et al.* 1998). Moreover, although certain fish reach TLs in excess of 4.00, the majority have TLs between 2 (in herbivorous species such as anchovies and in most commercial invertebrates) and 4 (in cod, snappers, tuna and other predators).

The present study showed a general decrease in the MTL of the Omani fish catch by approximately 0.01 TLs year^{-1} as the total catch increased. The decrease in MTL is usually attributed to the fishing pressure on the higher TLs at the start of the fishery, which is then replaced by pressure on the lower TLs as the abundance of the high TL species declines (Kleisner & Pauly 2011; Pauly *et al.* 1998) due to fisheries-induced reductions of the biomass and biodiversity of these top predators. This principle explains the decrease found by this study in the abundance of several important high TL species and the increase of lower TL species in the Omani catch from 1995 to 2010. The present study showed a decrease in the abundance of yellowfin tuna, ribbonfish and sharks to approximately one-half of the catch recorded for the first year of the database. In contrast, the abundance of fish with a TL of 3+, such as sardine, emperor and sea bream, increased to approximately twice the level of their catch recorded at the beginning of the time series. Additionally, the catch of mullet and shrimp, with a TL of 2+, also doubled. The above discussion documents the occurrence of fishing-down in the marine food webs of the Omani ecosystem. This trend was clear from 1997 to 2001 and was characterised by a marked decrease in the MTL, followed by a period of increase until 2005 and a subsequent decrease. The occurrence of fishing-down in food webs has been documented and validated by numerous studies on a large number of marine and freshwater ecosystems (Kleisner & Pauly 2011; Stergiou & Tsikliras 2011; Pauly 2010; Jaureguizar & Milessi 2008; Morato *et al.* 2006; Frank *et al.* 2005; Pauly 2005; Arancibia & Neria 2005; Bellwood *et al.* 2004; Hutchings & Reynolds 2004; Myers & Worm 2003; Jackson *et al.* 2001; Pauly *et al.* 1998). The increase in the MTL from 2001 to 2005 may indicate a geographic expansion of the fishery (Kleisner & Pauly 2011) as a result of modernisation and the increase in numbers of fishing boats due to the increase in the Fishermen's Encouragement Fund. Morgan (2004) reported that the Fishermen's Encouragement Fund, implemented at the end of the 1990s and the beginning of the 2000s, produced an extensive upgrading of fishing vessels. Support from the Fund allowed the boats to be equipped with depth finders, fish detection systems, communication gear and miscellaneous equipment, as well as outboard engines. Thus, we might expect that further fishing grounds were explored and that the catches included the high TL species whose catches had previously declined. This explanation was previously discussed for Australian fisheries by Kleisner and Pauly (2011). They stated that the modernisation of the Australian fishing fleets in the 1960s allowed the spatial expansion of fishing effort by these vessels into deeper waters farther from shore.

The FiB index was developed to explain what may occur if the decline in mean TL is attributable to a deliberate choice to target low TL species because biological production is greater at low TLs (Pauly *et al.* 2000). If the choice to fish lower in the food web is deliberate, an increase in the catch commensurate with the decline in the mean TL would be expected (Kleisner & Pauly 2011). This pattern was clear in the present study of the Omani catch. The catch increased from 1995 to 2010. The present study showed a continuing imbalance in the fishery, as the value of the FiB index never remained constant (Pauly *et al.* 2000). Actually, the FiB values in the present study showed a series of fluctuations, including both increases and decreases, but the FiB index generally increased from the first year of the time series to the last year. Pauly *et al.* (2000) explained decreases in the FiB index in terms of the discarding of unwanted fish or an impairment of ecosystem function due to the removal of excessive amounts of biomass. The increase in the FiB index may be due to bottom-up effects, such as an increase in primary production (Kleisner & Pauly 2011; Pauly 2005; Pauly *et al.* 2000; Caddy *et al.* 1998), or to the extension of the fishery to new waters, which, in effect, expands the ecosystem exploited by the fishery (Kleisner & Pauly 2011; Pauly *et al.* 2000).

The economic analysis performed in the present study showed an increase in the value (in RO) of the total landed catch. The values of the species belonging to trophic group 3+ appeared to increase with time relative to the values of the high TL predator species (group 4+). This pattern may be due to the temporal decrease in the catch of certain important top predators such as ribbon fish, yellowfin tuna and sharks, which was accompanied by an increase in the catch of diverse lower TL species including sardine, emperor, sea bream and grouper. This result can be clarified by examining the estimates of the RPI, following (Pinnegar *et al.* 2002). According to these authors, a decrease in the RPI implies that the prices of lower TL species have increased relative to those of higher TL species (*sensu* Sumaila 1998); conversely, an increase in the RPI implies that the top predators have increased in value relative to the low TL species. The present study demonstrated a clear temporal decrease in the RPI and an increase in both the total landed catch (by amounts and values) and the 3+ TL species (by amounts and values). These results may suggest that the prices of the 3+ TL species increased relative to those of the 4+ TL species. Species belonging to the lowest TLs (group 2+) had the lowest values because their weights in the catch were always very much lower than those of the upper TL species (groups 3+ and 4+). Sumaila (1998) reported that low TL species have become more valuable relative to high TL species, and this would result in decline of the global RPI.

CONCLUSION

The results and discussion of the present study offer perspectives on the TL structure of the Omani landed catch and the associated temporal bioeconomic changes. It was clear that the Omani catch contained TLs ranging from 2.27 to 4.50, with three principal levels, 2, 3 and 4. The study found a clear decrease in the MTL of the total catch, indicating the fishing-down of the marine food web. The study also found a temporal increase in the FiB index. This increase was attributed to a bottom-up effect or to the geographic expansion of the fishery. Economically, there was a clear decrease in the RPI, indicating an increase in the prices of the species at TL 3 relative to the top predator species.

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