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Changes in the trophic level of Portuguese landings and fish market price variation in the last decades

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ABSTRACT

Fishing can alter the structure of marine food web by selective removal of some species. Changes in marine food webs in Portuguese waters were evaluated based on estimates of the annual mean trophic levels (TLm) and fishing-in-balance index (FiB) of mainland, Azores, Madeira and total Portuguese marine fisheries landings for the period between 1970 and 2006. The log-relative-price-index (LRPI), that translates the relationship between the logarithm of prices of low and high trophic level species, was also calculated for each year. TLm of mainland landings showed a decreasing trend, reflecting changes in the structure of marine food webs, whereas in Azores and Madeira TLm increased. FiB index also showed a downward trend and negative values in mainland waters, which may be associated with unbalanced fisheries. In the period studied LRPI increased, indicating that high trophic level species had become more valuable in relation to species feeding at lower trophic levels. It is likely that the persistence of present trends will compromise the sustainability of fisheries. A better management is needed in order to reverse this decreasing trend in TLm in the long-term using an ecosystem-based approach.

1. Introduction

Since fishing can alter the structure of marine ecosystems by selectively removing some species and by changing the physical support for the communities (Goñi, 1998), analysing its effects on the ecosystem has become a thrust area of investigation in recent years (Vivekanandan et al., 2005). An ecosystem-based approach has been suggested as a complement to the traditional fisheries stock assessment and management (Sinclair et al., 2002; Pauly et al., 2003; Pikitch et al., 2004). Ecosystem indicators (Rochet and Trenkel, 2003; Trenkel and Rochet, 2003) and ecosystem models have, therefore, been proposed to detect and describe the effects of fishing in marine ecosystems (Hollowed et al., 2000; Shannon et al., 2000).

Fisheries tend to first remove large, slow growing long-lived predatory fish. As the fishery develops there will be a shift to smaller species with faster turnover (Jennings et al., 1998; Pauly et al., 1998a,b; Pauly and Palomares, 2005). Consequently, the mean trophic level (TLm) of the fish communities remaining in the system is reduced, eventually leading to declining trends of TLm in the catches extracted from an ecosystem, a process known as “fishing down marine food webs” (Pauly et al., 1998a). Because the number of links in marine food webs is finite, and because few commercially attractive species are positioned near the base, Pauly et al. (2000b) argued that current practices will lead to the collapse of fisheries in many areas.

The TLm of landings of a particular area has been proposed as an indicator of the fishery-induced impacts in food webs structure (Pauly et al., 1998a,b, 2001, 2002; Rochet and Trenkel, 2003). This indicator is a useful way of describing the state of fisheries because: it reflects complexity; it is largely related to the size of target species, which is linked to their fecundity and thus to their scope for recruitment; it tends to reflect other types of stress, such as pollution; it allows the development of new approaches to the analysis of aquatic food webs and to obtain a series of TLm values of fish and invertebrates landed by fisheries that can be used to evaluate their impacts on marine ecosystems (Stergiou and Polunin, 2000).

TLm of fisheries landings (total marine and freshwater landings) appear to have globally declined in recent decades at a rate of about 0.1 per decade, without the landings themselves increasing substantially. At a regional, ocean-specific scale this decreasing trend was also observed, especially in the Northern Hemisphere. According to Pauly et al. (1998a), TLm of landings in the Northeast Atlantic has declined since the late 1960s. The “fishing down marine food webs” hypothesis triggered fisheries scientists to start searching for similar patterns at smaller scales and several studies have confirmed this theory at regional and local scales (Stergiou and

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Koulouris, 2000; Pauly et al., 2001; Pinnegar et al., 2002; Laurans et al., 2004; Sala et al., 2004; Sánchez and Olaso, 2004; Milessi et al., 2005; Vivekanandan et al., 2005).

Changes in fishery preferences are often driven by economic reasons. The value of a species will determine the investment that fishermen are willing to make in order to catch it, and thus how heavily it is targeted even at low abundance (Pinnegar et al., 2002, 2006). In general, large fish species with a high trophic level command higher prices in the market than small low trophic level fishes or invertebrates (Pinnegar et al., 2006). In general average market price of a species will increase as it becomes scarce (Murawski and Serchuk, 1989).

Portuguese waters include the Exclusive Economic Zone (EEZ) sub-area of mainland Portugal and the two EEZ sub-areas of the Autonomous Regions of Azores and Madeira. All three areas are in the subtropical/boreal transition zone of the Eastern Atlantic. As a result of their high biodiversity, there are several distinct fleets (métiers) characterized by the use of different fishing gear types targeting different commercially important species. In mainland Portugal fisheries focus on a high number of resources existing in fishing grounds located a short distance from shore, whereas in the autonomous regions, due to their oceanic nature, pelagic species are the most exploited.

The Portuguese fishing fleet can be divided in three segments: seine, trawl and multigear. The purse seine fishery targets mainly small pelagics like sardines [*Sardina pilchardus* (Walbaum, 1792)], the most important species in terms of total landings in Portugal, Atlantic horse mackerel [*Trachurus trachurus* (Linnaeus, 1758)] and chub mackerel [*Scomber japonicus* (Houttuyn, 1782)]. Trawl fisheries comprise two distinct fleets: one that targets fish such as Atlantic horse mackerel and European hake [*Merluccius merluccius* (Linnaeus, 1758)], and cephalopods, whilst the other targets crustaceans. The multigear fleet is the largest segment and catches a wide variety of species as it is made up of boats that are usually licensed to operate with gillnets, trammel nets, longlines and traps.

The impact of Portuguese fisheries in biological interactions, especially along the food web, remains poorly understood. The present study describes changes in Portuguese landings over time, analyses whether the TLm of landings is declining as a function of time and examines if these changes are reflected in the relative market price of living marine resources in Portuguese waters. The result of this study should provide valuable information for the future management of the Portuguese marine ecosystems.

2. Materials and methods

Landings in Portuguese waters and fleet composition between 1970 and 2006 were obtained from the National Statistical Institute database (INE). For the period between 1992 and 2006 statistics were also obtained from the General-Directorate for Fisheries and Aquaculture (DGPA) since these present a better taxonomic resolution. The DGPA data is comprised of 389 species or groups of species (316 fish, 31 crustaceans, 41 molluscs, 1 equinoderms) whilst the INE data aggregated the same data but only for 60 species or groups of species (42 fish, 6 crustaceans, 12 molluscs). For an enhanced interpretation of possible trends and patterns in the data and subsequent analysis, Portuguese waters were divided in mainland Portugal (hereafter referred to as mainland), Azores and Madeira. Also the evolution of Portuguese fishing fleet composition and landings by fleet segment were analysed.

Trophic level (TL) of each species was obtained from information in feeding studies and FishBase (Froese and Pauly, 2008), in the case of fish, and from TrophLab (Pauly et al., 2000b), in the case of invertebrates. When available, data for Portuguese waters were used primarily; otherwise, data for neighbour areas or for the species in general were used. Landings and trophic levels of each species were subsequently used to calculate the annual mean trophic level (TLm) of landings as follows:

$$\mathrm{TLm} = \frac{\sum \mathrm{TL}ij\mathrm{Y}ij}{\sum \mathrm{Y}ij},$$

where TLm is the mean trophic level of landings in year *j*, Y*ij* denotes the landing of species *i* in the year *j* and TL*ij* is the trophic level of species *i* in the year *j*. The rate of TLm increase or decrease over time was calculated as the slope of a linear trend line.

Landings composition was analysed considering the species or groups of species with higher landings individually – sardine, horse mackerel, chub and Atlantic mackerels (*Scomber scombrus* Linnaeus, 1758), silver [*Lepidopus caudatus* (Euphrasen, 1788)] and black scabbardfishes (*Aphanopus carbo* Lowe, 1839) – and the other species grouped into ISCAAP (International Standard Statistical Classification of Aquatic Animals and Plants).

Moving down the food web may be the result of a deliberate choice, for which justification may be found in the ever-increasing, world wide demand for animal protein. As biological production increases about 10 times as one moves down one trophic level in typical marine ecosystems (Pauly and Christensen, 2002), a fair evaluation of the impacts of a fishery should not be based on an index that declines as a fishery moves down the food web of a particular ecosystem. A good evaluation index should only decline when catches do not increase as expected, and, therefore, an index that allows us to assess whether a fishery is balanced in ecological terms or not (Pauly et al., 2000a) was used in the present paper. The fishing-in-balance index (FiB) for any year i in a time series is defined by:

$$\mathrm{FiB} = \log\left(\mathrm{Y}i\left(\frac{1}{\mathrm{TE}}\right)^{\mathrm{TL}i}\right) - \log\left(\mathrm{Y0}\left(\frac{1}{\mathrm{TE}}\right)^{\mathrm{TL0}}\right),$$

where Y*i* corresponds to landing in year *i*, TL*i* is the mean TL of the landing in year *i*, TE the trophic efficiency (here set at 0.10 following Pauly et al., 2000a), and Y0 and TL0 the landing and mean TL, respectively, of the first year of the series. The FiB index changes its value only when a decrease in TL is not matched by a corresponding increase in catch, and conversely for increasing TL. Values of FiB < 0 may be associated with unbalanced fisheries, i.e. a lower catch than that theoretically predicted based on the productivity of the food web (Pauly et al., 2000a). An increase in FiB indicates expansion of a fishery (geographically, or expansion beyond the initial ecosystem to stocks not previously exploited, or only lightly exploited) or that bottom-up effects have occurred, e.g. increased primary production. Conversely, a decrease indicates geographic contraction of the fisheries, a collapse of the underlying food web (impairing the ecosystem functioning) (Pauly and Palomares, 2005; Pauly and Watson, 2005). A decrease in FiB will also be observed if discarding takes place that is not reflected in the reported catches (Pauly and Watson, 2005).

Within each year the relationship between log price (€ kg^{-1}) and TL of each fish species was calculated using linear regression, considering the slope of the regression as the log-relative-price-index (LRPI; Pinnegar et al., 2006) for that particular year. For this analysis only fish species that had a complete time series of price estimates for the period between 1970 and 2006 were used. The logarithm of fish prices was used because inflation acts non-linearly, which results in larger absolute increases in the price of high-value species compared to lower-value species. If the LRPI decreases, then the relative price of high TL species has declined or low TL species are becoming relatively more valuable and conversely if the LRPI increases then the price of high TL species has increased (above inflation) or the price of low TL species has declined. If the LRPI remains constant then this infers that there has been no significant

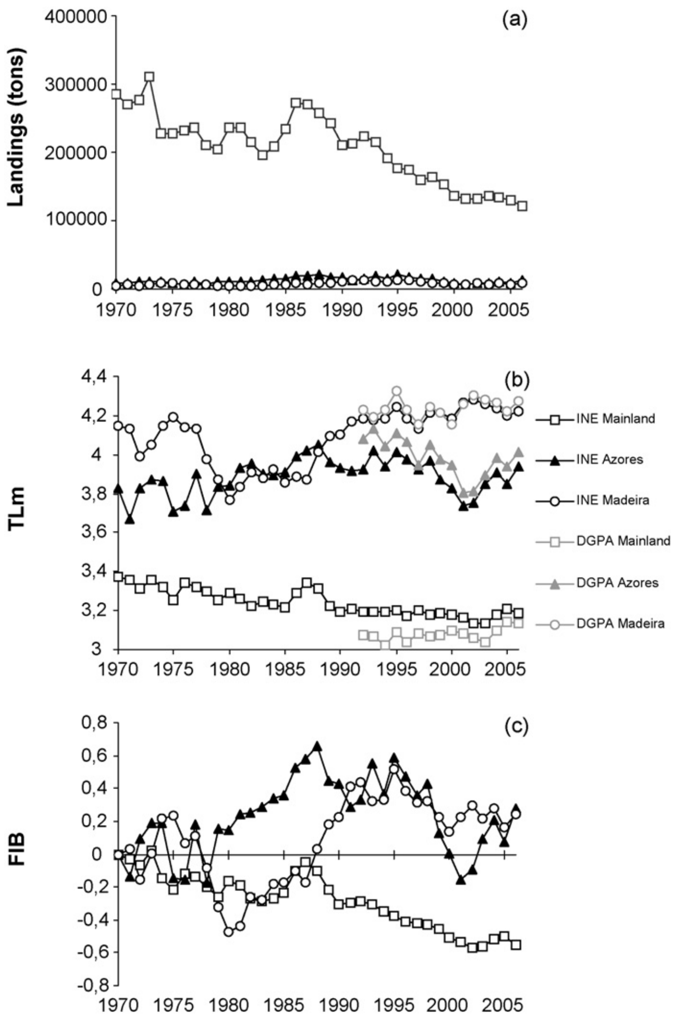

Fig. 1. (a) Annual landings, (b) mean trophic level of landings and (c) FiB index from Portuguese waters for the period between 1970 and 2006.

redistribution of prices and that the price of each species has simply increased in line with inflation. The rate of the LRPI increase or decrease over time was calculated as the slope of a linear trend line.

3. Results

In the last decades total landings from Portuguese waters have shown a downward trend (Fig. 1a). Nowadays, its values (145,593 tons) represent no more than half the value of the landings in 1970 (298,756 tons). During the analysed period, landings from the Azores were always higher than those of Madeira, however, the overall contribution of these two autonomous regions to the total Portuguese landings was small, in such a way that mainland landings made up more than 85% of the total landings. In effect, the mainland landings showed a decreasing trend, which was only inverted between 1983 and 1986, whilst landings from the Azores and Madeira were very similar in the beginning and in the end of the analysed period.

The TLm of the landings from Portuguese waters during 1970–2006 is shown in Fig. 1b. Despite the observed fluctuations, TLm of mainland landings presented an overall decreasing trend in the order of 0.005 units per year (s.e. 0.035). In 1970 TLm of landings from mainland attained approximately 3.37. This maximum value was reached once more in 1987, subsequent to the increase verified between 1985 and 1987. After that TLm continued to show a downward trend, although, in the last three years, this trend appeared to be slightly inverted, attaining the value of 3.19 in 2006.

Contrary to what succeeded in mainland, TLm of landings of both autonomous regions landings increased between 1970 and 2006, more pronouncedly in Madeira (0.007 per year; s.e. 0.091) than in the Azores (0.003 per year; s.e. 0.125). Values of TLm attained in these regions, and their variations over time, were larger than those from mainland. In 1970 TLm of Azores' landings was 3.82, reaching its maximum value (4.04) in 1988. Between 1998 and 2001 it showed a marked decrease, followed by an increase until reaching 3.94 in 2006. TLm of Madeira's landings decreased from 4.15 in 1970 to 3.76 in 1980, increasing again to its maximum value in 2002 (4.30) and attaining 4.21 in 2006.

Considering the DGPA data for the period between 1992 and 2006 (Fig. 1b), TLm for all considered regions' landings showed the same trend, however, TLm obtained with these data were lower for mainland waters and higher for both autonomous regions than those obtained with INE data.

A clear decrease in FiB index was observed for mainland landings between 1970 and 2006 with values always below zero (Fig. 1c). The exception was only between 1984 and 1987. FiB index of the Azores' landings showed wide variations over time but rarely attained values below zero. In the 1980s FiB increased whilst at the end of the 1990s it decreased sharply to negative values; in the recent years FiB index has had an increasing trend. FiB index for Madeira's landings also presented a high variability during the analysed period: after a marked decrease at the end of 1970s, when it reached less than zero, an upward trend has been observed until now, with positive FiB values since 1987.

There was a concordant trend between TLm and landings in all analysed areas (Fig. 2) with the highest values of TLm associated to the highest landings values. During the analysed period, TL versus landings plot for mainland presented a decline of TL accompanied by a decline in catches. For the Azores there is an increase both in catches and TL until 1990, after which both decline until 2000 when they start to rise again. In Madeira, despite landings not showing a significant increase, TL increased since 1980 until nowadays.

The decrease in TLm in mainland waters coincided with changes in landings' composition (Fig. 3). Sardine was the most caught species in mainland waters, with highest landing values attained in the mainland. In 1970, this resource represented approximately 24% of total mainland landings (69,158 tons). Its importance increased in the next years, attaining a maximum value of 48% of total landings in 1981 (113,572 tons). After 1985, sardine catches decreased, with the minimum value achieved in 2006, even though its relative importance in the national landings increased (48,021 tons; 39% of total landings). From 1970 to 2006, the most caught resources in both autonomous regions were tunas; Madeira also had high landing values of black scabbard fish. In all the three analysed regions, horse mackerel and chub and Atlantic mackerels occupied top positions in landings.

Between 1970 and 2006 the Portuguese fleet was reduced to almost half the vessels, however, the three segments of the fleet kept their relative proportions (Table 1). In mainland, where the reduction was greater, the three segments of the fleet can be effectively identified throughout the studied period, although the multigear was always the most important segment. This was also the only region where there is a trawling fleet. The proportion of landings correspondent to each of the segments in the mainland did not change much over time (Fig. 4). In the 1970s catches from the trawl fleet corresponded to around 20%, decreasing over time to around 15%; seine and multigear fleets' contributions have remained at around 55% and 30%, respectively. In the Azores, multigear is the only segment present and even though in Madeira there was a seine fleet the number of vessels is reduced.

Table 1
Fishing fleet composition in mainland Portugal, Azores and Madeira.

Year	Total (number of vessels)	Mainland				Azores			Madeira			
		Multigear (%)	Seine (%)	Trawl (%)	Total (number)	Multigear (%)		Total (number)	Multigear (%)		Seine (%)	Total (number)
							Tuna			Tuna		
1970	17,583	96.59	2.51	0.90	15,375	100.00	2.46	1,708	100.00	7.80	0.00	500
1980	19,326	98.18	0.91	0.91	16,772	100.00	1.66	1,623	99.46	2.90	0.54	931
1990	16,582	98.21	0.82	0.97	13,988	100.00	1.96	1,892	99.29	19.09	0.71	702
2000	10,750	96.80	1.96	1.23	8,601	100.00	1.03	1,649	99.00	25.60	1.00	500
2006	9,603	96.94	1.80	1.26	7,551	100.00	0.76	1,584	98.93	19.44	1.07	468

Along the analysed period LRPI increased at 0.004 per year (s.e. 0.051), although between 1976–1979 and 2001–2005 it decreased (Fig. 5).

4. Discussion

Although short-term fisheries management objectives may be partially fulfilled in the absence of ecosystem information, long-term strategies necessarily require placing fisheries in their

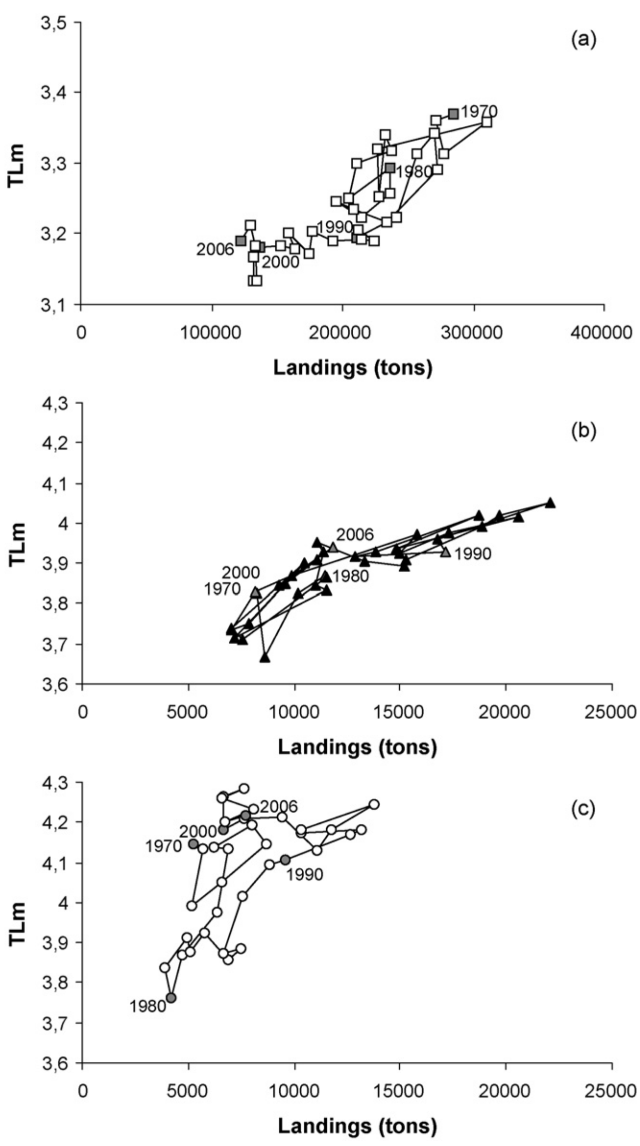

Fig. 2. Mean trophic level of landings versus landings for (a) mainland Portugal, (b) Azores, and (c) Madeira, for the period between 1970 and 2006.

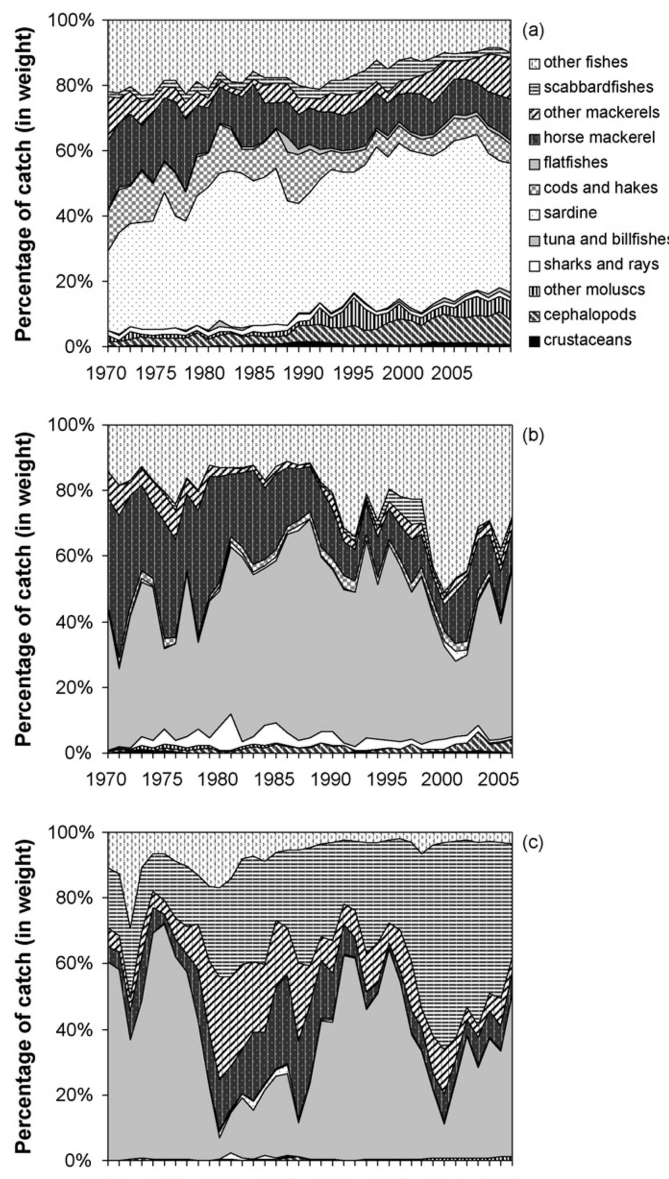

Fig. 3. Landings composition for mainland Portugal (a), Azores (b) and Madeira (c) between 1970 and 2006. Landings were divided considering the species or groups with higher landings – sardine, horse mackerel, chub and Atlantic mackerels, silver and black scabbardfishes – and the other species grouped into ISCAAP (International Standard Statistical Classification of Aquatic Animals and Plants)—crustaceans, mollusks subdivided into cephalopods and other mollusks, sharks and rays, tuna and billfishes, cods and hakes, flatfishes, and other fishes.

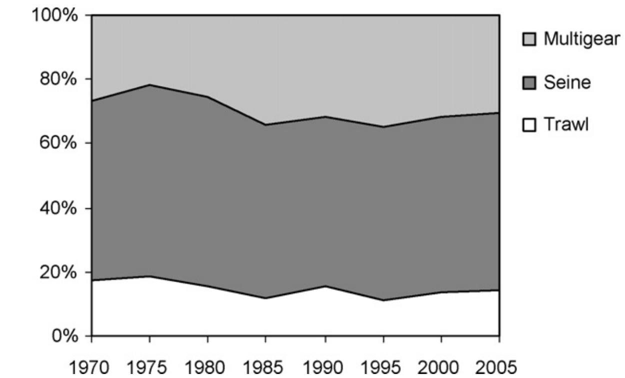

Fig. 4. Landings by fleet segment – multigear, seine and trawl – in mainland Portugal between 1970 and 2006.

ecosystem context (Christensen et al., 1996; Sinclair et al., 2002). The analyses carried out in the present paper, using an ecosystem indicator which describes a major aspect of the complex interactions between fisheries and marine ecosystems (Pauly and Watson, 2005), demonstrated marked changes in the structure of fisheries landings and fish communities from Portuguese waters in the past 36 years.

In the last decades, Portuguese landings have shown a downward trend, mainly due to the decrease of mainland's landings. Upon joining the European Union in 1986, Portuguese fisheries' management became based on the Common Fisheries Policy (CFP) and the policies and management measures undertaken since then seem to be the most important factors that contributed to this trend. At the same time TLm of landings from Portugal mainland waters has also decreased at a rate of about 0.005 per year, whilst the TLm of landings registered in the autonomous regions showed an upward trend (0.003 per year in Azores and 0.007 per year in Madeira). In the three areas the highest landings were not associated with the lowest trophic levels, as the "fishing down marine food webs" theory would predict; instead TLm declines were accompanied by declining catches.

Based on Pauly et al. (1998a) hypothesis that landings data can be used as ecosystem indicators, with changes in TLm of the catch a reflex of the changes in the ecosystem, the decreasing trend found in the mainland data may be interpreted as a result of a decrease in abundance of high trophic level species relative to low trophic level ones in the ecosystem. Since mainland fleet works not only

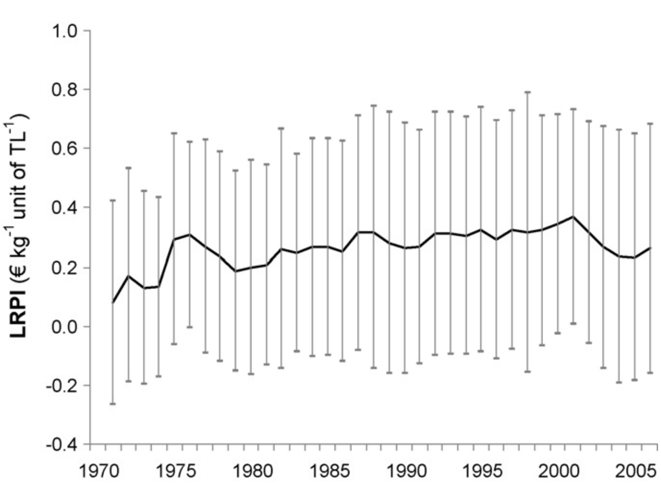

Fig. 5. Log-relative-price-index (LRPI), that translates the relationship between log price (€ kg^{-1}) and mean trophic level of fish species, and respective confidence intervals for the period between 1970 and 2006.

in its EEZ but in the whole national EEZ, this decrease in TLm can be seen as representative of the entire national EEZ. Our results support the statement of Pauly et al. (1998a) that there have been great changes in fish communities in all marine areas, including the northeast Atlantic, although the decrease observed in our data (0.05 per decade) was lower than that estimated by these authors for northeast Atlantic (about 0.2 per decade) or on a global scale (0.1 per decade).

Decreasing trends in TLm of landings and fish communities, due to fishing, have been described for different locations: Aegean Sea marine communities (Stergiou and Koulouris, 2000), Canadian landings (Pauly et al., 2001), Celtic Sea (Pinnegar et al., 2002), Senegal and Guinea (Laurans et al., 2004), Gulf of California (Sala et al., 2004), Cantabrian Sea (Sánchez and Olaso, 2004), Uruguayan waters (Milessi et al., 2005), Indian coastal communities (Vivekanandan et al., 2005) and Argentinian–Uruguaian Common Fishing Zone (Jaureguizar and Milessi, 2008). On the contrary, Pérez-España et al. (2006) showed that the TLm in Mexican fisheries has increased in the last decades. Jennings et al. (2002), after analysing two long time series, concluded that there was no trend in the TLm of the demersal community of the North Sea. The observed changes differ both in direction and intensity, suggesting that responses of marine communities to exploitation or habitat degradation are the result of complex interactions and feedback mechanisms (Goñi, 1998).

The "fishing down marine food webs" phenomenon observed in mainland landings is also supported by the decreasing trend observed in FiB index, which suggests that the functioning of the foodweb that underlies fisheries is impaired. The application of FiB index to the North Atlantic (Pauly et al., 2000a) indicated that the observed decrease in TLm, though initially matched by an increase in catches, eventually led to decreasing FiB indices, i.e. the decrease in catches did not compensate for the decrease in TLm. Pauly and Watson (2005) considered that this effect also occurs in world catches as a whole.

The positive values of FiB in autonomous regions and its increase during the 1980s suggest an expansion in fisheries beyond its traditional fishing area (or ecosystem) and that fisheries would not have yet reached their maximum catch level. Subsequently the decrease in FiB observed for Azores could be pointing out a heavy withdraw of biomass from the ecosystem, impairing its functioning. Madeira's FiB remained more or less constant, highlighting that TLm changes were accompanied by "ecologically correct" changes in the catch (Pauly and Watson, 2005).

The lack of "taxonomic resolution", i.e. the over-aggregation of species under a higher taxonomic unit, also influences the estimation of TLm: whereas mainland's TLm values were lower when the landing statistics used were more detailed, the opposite occurred for the autonomous regions. According to Pauly et al. (1998b), the better the taxonomic resolution, the stronger the effect of "fishing down the marine food web" phenomenon. However, data of the present study suggest that finer taxonomic resolution contributes to higher accuracy of trends, whether they are increasing or decreasing.

The composition of historical landings may be affected by phenomena such as natural oscillations in species abundance, changes in fishing technology and economic factors which are likely to have influenced TLm of the landings (Caddy et al., 1998; Caddy and Garibaldi, 2000).

The influence of environmental factors on abundance and distribution of marine organisms is not quite clear in Portuguese waters (Santos et al., 2001b). Sardine has been presenting fluctuations in its abundance with consequences in the catch level (Mendes and Borges, 2006) that are believed to be associated with environmental factors and climatic changes. Since 1970s sardine population has been decreasing as a result of a winter upwelling phenomenon with negative consequences to the primary productivity and juveniles' survival (Dickson et al., 1988; Santos et al., 2001a; Borges et al., 2003). This change on primary productivity can also influence other species of lower trophic levels, since these react more rapidly to environmental changes (Laurans et al., 2004), and then propagate the effect up the foodweb. Despite this, species with low trophic level have gained importance in Portuguese landings.

Despite the reduction of the Portuguese fishing fleet to almost half the number of vessels between 1970 and 2006, the three fleet segments kept their relative proportions throughout the analysed period. Even if the reduction in the number of vessels was accompanied by a maintenance or even increase of the fishing power, the proportion of total landings for each fleet segment did not change much over time. Portuguese fishing practices have suffered few changes in the last decades and the fishing fleet is an aging fleet: nowadays about 62% of mainland vessels and 42% of trawlers are over 20 years old.

Also the establishment of TACs, mainly set on higher trophic level species, could have resulted in changes in landings composition. Most of the species landings declined in the last decades, however, this reduction does not appear to have been greatest for species subject to TAC in comparison to those that are not. Despite fluctuations, landings for many of these species have remained at similar levels to those recorded before the entry into the EU with some even increasing, namely blue whiting, Atlantic mackerel, monkfish and tunas. Thus, changes in landings TLm seem more related to changes in the exploited fishing community than to changes in fishing practices.

Fish prices are significantly influenced by changes in consumer income and preferences, the price of alternative products, their availability in the environment, catch restrictions, technologic innovation as well as weather (Ludicello et al., 1999) and fuel prices (Pinnegar et al., 2006). The present study revealed that the relative distribution of fish market prices in Portugal has changed over the past decades, with high TL species experiencing greater price rises than lower TL species. As species of higher TL become less abundant, their prices increased. At the same time for species of lower TL landings increased. Similar results were obtained by Pinnegar et al. (2002, 2006) for the Celtic Sea fish community. In the Italian fish market the LRPI remained remarkably stable but as a result of widespread expansion in fin-fish aquaculture (Pinnegar et al., 2006). Sumaila (1998) suggested that globally, low TL species have become more valuable in relation to high TL species over the past 50 years, since markets are good at giving value to previously undesirable fish when target species become unavailable, therefore masking the real economic effects of changing trophic levels in marine ecosystems.

Results obtained in this study can be considered as good indicators of fishery-induced impacts on the marine community structure of Portuguese waters, highlighting the unsustainability of Portuguese fisheries resources. Achieving sustainable use of marine fisheries and ecosystems is not easy, but it can be enhanced by a better recognition of the scope and magnitude of the problems to be solved, to which this study presents a significant contribution. However, more studies on the ecosystem's structure and functioning are still required to promote better management solutions to address and attempt to reverse in the long-term the decreasing trend found in TLm through ecosystem-based approaches.

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References

Borges, M.F., Santos, A.M.P., Crato, N., Mendes, H., Mota, B., 2003. Sardine regime shifts off Portugal: a time series analysis of catches and wind conditions. Sci. Mar. 67, 235–244.

Caddy, J.F., Garibaldi, L., 2000. Apparent changes in the trophic composition of world marine harvests: the perspective from the FAO capture database. Ocean Coast. Manage. 43, 615–655.

Caddy, J.F., Csirke, J., Garcia, S.M., Grainger, R.J.R., 1998. How pervasive is "fishing down marine food webs?". Science 282, 1383–1385.

Christensen, N.L., Bartuska, M., Brown, J., Carpenter, S., D'Antonio, C., Francis, R., Franklin, J., MacMahon, J., Noss, R., Parsons, D., Peterson, C., Turner, M., Woodmansee, R., 1996. Report of the Ecological Society of American Committee on the scientific basis for ecosystem management. Ecol. Appl. 6, 665–691.

Dickson, R.R., Kelly, P.M., Colebrook, J.M., Wooster, W.S., Cushing, D.H., 1988. North winds and production in the eastern North Atlantic. J. Plankton Res. 10 (1), 151–169.

In: Froese, R., Pauly, D., (Eds.), 2008. FishBase. World Wide Web Electronic Publication (www.fishbase.org, version 09/2008).

Goñi, R., 1998. Ecosystems effects of marine fisheries: an overview. Ocean Coast. Manage. 40, 37–64.

Hollowed, A.B., Bax, N., Beamish, R., Collie, J., Fogarty, M., Livingston, P., Pope, J., Rice, J.C., 2000. Are multispecies models an improvement on single-species models for measuring fishing impacts on marine ecosystems? ICES J. Mar. Sci. 57, 707–719.

Jaureguizar, A., Milessi, A., 2008. Assessing the sources of the fishing down marine food web process in the Argentinean-Uruguayan Common Fishing Zone. Sci. Mar. 72, 25–36.

Jennings, S., Greenstreet, S.P.R., Hill, L., Piet, G.S., Pinnegar, J.K., Warr, K.J., 2002. Long-term changes in the trophic structure of the North Sea fish community: evidence from stable-isotope analysis, size-spectra, and community metrics. Mar. Biol. 141, 1085–1097.

Jennings, S., Reynolds, J.D., Mills, S.C., 1998. Life history correlates of responses to fisheries exploitation. Proc. R. Soc. Lond. B 265, 333–339.

Laurans, M., Gascuel, D., Chassot, E., Thiam, D., 2004. Changes in the trophic structure of fish demersal communities in West Africa in the three last decades. Aquat. Living Resour. 17, 163–173.

Ludicello, S., Weber, M., Wieland, R., 1999. Fish, Markets and Fishermen: The Economics of Overfishing. Earthscan, London.

Mendes, H., Borges, M., 2006. A sardinha no século XX: capturas e esforço de pesca. Relat. Cient. Téc. IPIMAR 32, Série digital (http://ipimar-iniap.ipimar.pt).

Milessi, A.C., Arancibia, H., Neira, S., Defeo, O., 2005. The mean trophic level of Uruguayan landings during the period 1990–2001. Fish. Res. 74, 223–231.

Murawski, S.A., Serchuk, F.M., 1989. Mechanized shellfish harvesting and its management: the offshore clam fishery of the eastern United States. In: Caddy, J.F. (Ed.), Marine Invertebrate Fisheries: Their Assessment and Management. John Wiley & Sons, New York, pp. 479–506.

Pauly, D., Christensen, V., 2002. Primary production required to sustain global fisheries. Nature 374, 255–257.

Pauly, D., Palomares, M.L., 2005. Fishing down marine food web: it is far more pervasive than we thought. Bull. Mar. Sci. 76, 197–211.

Pauly, D., Watson, R., 2005. Background and interpretation of the 'Marine Trophic Index' as a measure of biodiversity. Phil. Trans. Roy. Soc. Lond. B 360, 415–423.

Pauly, D., Alder, J., Bennett, E., Christensen, V., Tyedmers, P., Watson, R., 2003. The future for fisheries. Science 302, 1359–1361 (Pauly, D., Christensen, V., Froese, R., Palomares, M.L., 2000b. Fishing down aquatic food webs. Am. Sci. 88, 46–51).

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., Torres, F., 1998a. Fishing down marine food webs. Science 279, 860–863.

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, 689–694.

Pauly, D., Christensen, V., Walters, C., 2000a. Ecopath, ecosim and ecospace as tools for evaluating ecosystem impact of fisheries. ICES J. Mar. Sci. 57, 697–706.

Pauly, D., Froese, R., Christensen, V., 1998b. Response to Caddy, et al., 1998. How pervasive is "fishing down marine food webs"? Science 282, 1383–1385.

Pauly, D., Froese, R., Sa-a, P., Palomares, M.L.D., Christensen, V., Rius, J., 2000b. The TrophLab Manual (www.fishbase.org).

Pauly, D., Palomares, M.L., Froese, R., Sa-a, P., Vakily, M., Preikshot, D., Wallace, S., 2001. Fishing down Canadian aquatic food webs. Can. J. Fish. Aquat. Sci. 58, 51–62.

Pérez-España, H., Abarca-Arenas, L.G., Jiménez-Badillo, M.L., 2006. Is fishing-down trophic web a generalized phenomenon? The case of Mexican fisheries. Fish. Res. 79, 349–352.

Pikitch, E.K., Santora, C., Babcock, E.A., Bakun, A., Bonfil, R., Conover, D.O., Dayton, P., Doukakis, P., Fluharty, D., Heneman, B., Houde, E.D., Link, J., Livingston, P.A., Mangel, M., McAlister, M.K., Pope, J., Sainsbury, K.J., 2004. Ecosystem-based fishery management. Science 305, 346–347.

Pinnegar, J.K., Hutton, T.P., Placenti, V., 2006. What relative seafood prices can tell us about the status of stocks. Fish Fish. 7, 219–226.

Pinnegar, J.K., Jennings, S., O'Brien, C.M., Polunin, N.V.C., 2002. Long-term changes in the trophic level of the Celtic Sea fish community and fish market price distribution. J. Appl. Ecol. 39, 377–390.

Rochet, M.J., Trenkel, V.M., 2003. Which community indicators can measure the impact of fishing? A review and proposals. Can. J. Fish. Aquat. Sci. 60, 86–99.

Sala, E., Aburto-Oropeza, O., Reza, M., Paredes, G., López-Lemus, L.G., 2004. Fishing down coastal food webs in the Gulf of California. Fisheries 29, 19–25.
Sánchez, F., Olaso, I., 2004. Effects of fisheries on the Cantabrian sea shelf ecosystem. Ecol. Model. 172, 151–174.
Santos, A.M.P., Borges, M.F., Groom, S., 2001a. Sardine and horse mackerel recruitment and upwelling off Portugal. ICES J. Mar. Sci. 58, 589–596.
Santos, F.D., Forbes, K., Moita, R., 2001b. Mudança Climática em Portugal. Cenários, Impactes e Medidas de Adaptação—SIAM. Sumário Executivo e Conclusões, Gradiva, Lisboa.
Shannon, L.J., Cury, P., Jarre, A., 2000. Modeling effects of fishing in the southern Benguela ecosystem. ICES J. Mar. Sci. 57, 720–722.
Sinclair, M., Arnason, R., Csirke, J., Karnicki, Z., Sigurjonsson, J., Rune Skjoldal, H., Valdimarsson, G., 2002. Responsible fisheries in the marine ecosystems. Fish. Res. 58, 255–265.
Stergiou, K.I., Koulouris, M., 2000. Fishing down the marine food webs in the Hellenic Seas. In: Stergiou, K.I., Polunin, N. (Eds.), Fishing Down the Mediterranean Food Webs, CIESM Workshop Series 12, pp. 73–78.
Stergiou, K.I., Polunin, N., 2000. Executive summary. In: Stergiou, K.I., Polunin, N. (Eds.) Fishing Down the Mediterranean Food Webs, CIESM Workshop Series 12, pp. 7–15.
Sumaila, U.R., 1998. Markets and the fishing down marine food webs phenomenon. EC Fish. Coop. Bull. 11 (3–4), 25–28.
Trenkel, V.M., Rochet, M.J., 2003. Performance of the indicators derived from the abundance estimates for detecting the impact of fishing on a fish community. Can. J. Fish. Aquat. Sci. 60, 67–85.
Vivekanandan, E., Srinath, M., Kuriakose, S., 2005. Fishing the marine food web along the Indian coast. Fish. Res. 72, 241–252.