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Original Article

Towards coherent GES assessments at sub-regional level: signs of fisheries expansion processes in the Bay of Biscay using an OSPAR food web indicator, the mean trophic level

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Using the Bay of Biscay (BoB) as a case study, we conducted a transnational assessment of the mean trophic level (MTL, Ospar FW4) indicator at sub-regional level, over the last three decades. Our results confirm the apparent recovery of BoB's bentho-demersal system**,** as shown by trends in the MTL indicator based on survey data. However, they also point at a concomitant "fishing through" process where the apparent stability revealed by the MTL indicator based on landed catch data may be masking the expansion of demersal fisheries to deeper waters, and an over-exploitation of resources (particularly abundant pelagic species). Moreover, they show how the combined examination of independent surveys and fishery landings allows the identification of ecological trends in ecosystem studies. In addition, our results confirm that analysing MTL at various threshold levels helps discerning the causality of trends in this indicator, especially if analyses for pelagic and demersal species are run independently. Further studies, at smaller (i.e. local) spatial scales, need to be conducted to ascertain our results and suggest appropriate management strategies aimed at regulating fisheries expansions in the area.

Keywords: Bay of Biscay, ecology, environmental status, fisheries expansion, fishing through, food webs, mean trophic level, MSFD, OSPAR indicators

Introduction

The suitability of trophic indicators to detect patterns in ecosystems subjected to fishing pressure remains controversial (Fulton *et al.*, 2004; Piet and Jennings, 2005; Branch *et al.*, 2010; Hornborg *et al.*, 2013), mainly due to the historical preference of size-based indicators in this type of status assessments. The mean trophic level (MTL) indicator, in particular, has a long history of applications in the understanding of the influence of fishing pressure on marine food webs (Pauly and Watson, 2003; Branch *et al.*, 2010; Butchart *et al.*, 2010). Nevertheless, its operationality is still questioned due to: (i) the difficulty in establishing reference values or targets directly linking it to fisheries management, and (ii) the complications implicit in the establishment of accurate trophic level values for the main species involved. These limitations have posed questions regarding the reliability of the MTL as an indicator overall. Moreover, the

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shortcomings associated with the calculation of MTL fluctuations based on catch data have often been raised and extensively documented (Branch *et al.*, 2010; Hornborg *et al.*, 2013; Shannon *et al.*, 2014; Gascuel et al., 2016), survey data being recommended instead as better accounting for ecosystem status variations. Despite this, most comprehensive studies on its utility conclude that MTL can help to gain insight on the effects of fisheries impacts at ecosystem level. This is especially true if various data sources and cut-off levels are considered, and if results are interpreted at regional or local level, observing the specific pressures and environmental history occurring in the respective study areas (Hornborg *et al.*, 2013; Shannon *et al.*, 2014; Reed *et al.*, 2017).

The rationale behind the MTL, the concept of "fishing down marine food webs" (FD), is that when MTLs of the catch start decreasing, it is a sign that fisheries are relying on smaller sized fish and that stocks of the larger predatory fish are beginning to decline. Since large and slow-growing species with higher TLs and late maturities decline in abundance more rapidly, fishing is expected to reduce the MTL of exploited fish communities. The resulting shorter food chains render marine ecosystems increasingly vulnerable to natural and human induced stresses, eventually reducing the overall supply of fish for human consumption (Pauly and Watson, 2003). The MTL has been extensively utilized and successively refined, its concept serving as inspiration to subsequent indicators and metrics aimed at assessing the effects of (mainly) fisheries in ecosystems. Thus, various data sources and cut-off levels have been combined to better understand the effect of top-predators and lower trophic levels in ecosystem dynamics (Cury *et al.*, 2005; Pauly and Watson, 2005; Branch *et al.*, 2010; Shannon *et al.*, 2014; Bourdaud *et al.*, 2016). The FD process theory has been later complemented by other concepts, which incorporate the serial addition of new resources, low ("fishing through", Essington *et al.*, 2006) or high ("fishing up", Stergiou and Tsikliras, 2011) in the food web, and/or new fishing grounds, as elements to disentangle the effect of fisheries on MTL trends. In fact, the link between food web status and the pressure exerted by fisheries, together with the more holistic rationale behind the MTL (Rombouts *et al.*, 2013), has led this indicator to be included as a food web indicator in the OSPAR list of common indicators, used for the assessment of the European Marine Environmental Status (www.ospar.org). However, despite all efforts to make the indicator operational, it has only been accepted as common within OSPAR in region IV (BoB and Iberian coast), the main obstacles hampering its operationality at a wider level being ascribed, again, to the difficulties implied in establishing appropriate target levels for Good Environmental Status (GES) assessment.

To this end, regional cooperation has been deemed essential. Member states are encouraged to conduct joint assessments of their shared waters to obtain coherent and integrative perspectives of their environmental status, and to be able to define those boundaries at which the effects of pressures (basically fisheries) in the values/trends of the indicator would require management measures or increased research. The MTL indicator is particularly appropriate for this type of integrated assessments since the concept is transferable across regions and it can be easily estimated on a regional/sub-regional scale using existing biomass data from landed catch data and scientific surveys, which already share a common methodology (e.g. IBT surveys). However, an integrated assessment of its evolution at a regional or sub-regional level has never been conducted.

Here, we perform the first assessment of the MTL indicator conducted in European waters at the sub-regional level, employing the most complete data sets available for the BoB. This area has been historically subjected to strong fishing pressure and has witnessed periods of stock decline for several commercial species in line with those observed in the rest of the Northeast Atlantic (Lassalle *et al.*, 2011; Lorance, 2011). Some of these periods even culminated in extended fishing bans such as the 2005–2010 anchovy ban set forth after the collapse of the stock in the Bay of Biscay (BoB). As in wider oceanic areas (Cardinale *et al.*, 2013), the enforcement of such specific fisheries regulations during the last decades, seems to have triggered the recovery of many of the stocks, a reduced mortality of the main commercial species (Modica *et al.*, 2014), and an overall better status of bentho-demersal communities (Fernandes and Cook, 2013; Gascuel et al., 2016; Arroyo *et al.*, 2017a, b). This should have redounded in an increase in the MTL of the affected communities.

The aim of this study was threefold:

(i) to test the operationality of the indicator at the sub-regional level in relation with fishing pressure evolution in the BoB;

(ii) to progress in the definition of pressure - state relationships using the MTL indicator and other food web related indicators;

(iii) to ascertain whether generalized global patterns of MTL decrease can be extended to the BoB or the observed trends confirm the reported recovery of the bentho-demersal assemblages in the BoB.

Material and methods

Study area

The BoB

The BoB is a temperate regional Sea in the North-East Atlantic (OSPAR region IV, Figure 1), which comprises ICES subdivisions 27.8.a, b, c, and d, and 27.9 a (Figure 1). For this study, two separate areas have been considered: on the one hand, the northern BoB (French continental shelf: subdivisions 27.8.a and 27.8.b) and on the other, the southern part, comprising the Cantabrian Sea and Galician waters (Spanish part, subdivisions 27.8.c and 27.9.a-north).

In these areas, the topography from the continental shelf to the abyssal plain is very variable, and characterized by the presence of seamounts, banks and canyons and a diversified coastline. Specifically, the northern and southern BoB differ notably in the structure of their continental platforms, the French one being much broader and uniform in terms of bathymetry and types of substrate, while the Spanish one is much narrower and heterogeneous as regards topography, types of substrate and depth ranges (Figure 1).

Data sources

Landed catch data

Landings data (i.e. catch data without considering discards) for the Southern BoB (hereafter, Cantabrian Sea) consisted of the data compiled by the SAP project of the Spanish Institute of Oceanography (hereafter IEO, by its Spanish acronym), based on

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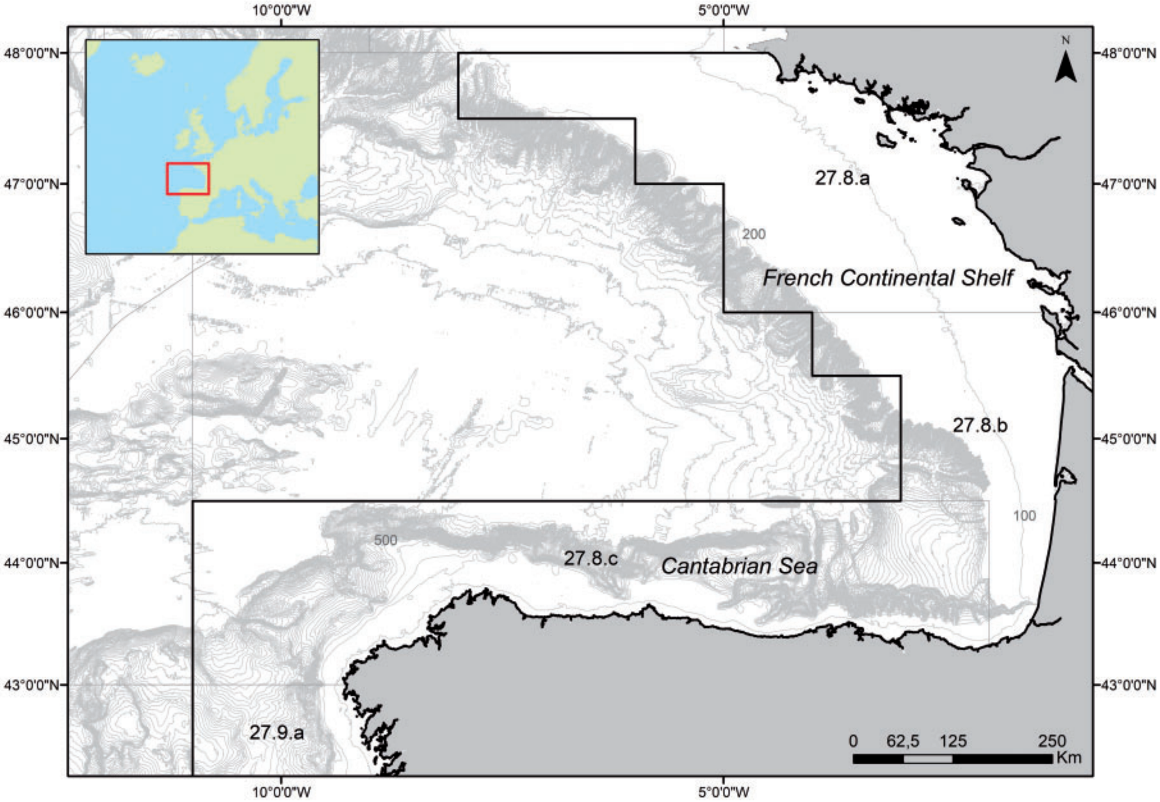

Figure 1. Map of the Study Area: BoB and northern Iberian coast (ICES sub-divisions 27.8.a,b,c and 27.9.a-north).

log-book information for ICES subdivisions 27.8.c and 27.9.a north. In this case, data covered the temporal range 1994–2015.

For the northern BoB (French continental shelf), landings data consisted of IFREMER landings data compiled for ICES subdivisions 27.8. a and b, over the 1983–2014 period.

Survey data

Survey data came from random stratified bottom trawl surveys, which are conducted for demersal fishery assessments in the study area every year during autumn (IEO Demersales and EVHOE surveys for the Cantabrian Sea and French parts, respectively), following IBTS (International Bottom Trawl Surveys) standards (ICES, 2012). Data for the Cantabrian Sea covered the period 1992–2015 and were obtained from the IEO repository. In the northern BoB, data run from 1997 to 2014 and were downloaded from the DATRAS database for bottom trawl scientific survey EVHOE (http://www.ices.dk/marine-data/data-portals/Pages/DATRAS.aspx).

Trophic-level data

The trophic level of 24 consumer species was calculated with stomach content data collected during "Demersales" surveys over the period 1990–2013 (Supplementary Material S1). For each fish species, the percentage contribution (% volume) of each prey item during each year was calculated (see Olaso, 1990 for details) and the trophic level derived with the formula (1):

$$TL_i = \sum_j TL_j \cdot DC_{ij} \qquad (1)$$

where TL_j is the fractional TL of prey j, and DC_{ij} represents the fraction of j in the diet of i (Christensen and Pauly, 1992). The space-time variability in diets results in trophic levels being slightly variable. This uncertainty around the mean TL value of a given species was reported as a standard error.

The TL assigned to the prey for calculating the predators' TL values, based on their stomach contents, were obtained from the literature or from the Sea Around Us Project (www.fishbase.org and www.sealifebase.org, for fish and invertebrates, respectively). When no specific TL value for a given species was available, a standard TL was assigned, following those suggested in the TrophLab tool (www.fishbase.org).

Trophic levels for species/taxa for which no stomach content data were available, were obtained from estimations made in relevant publications from the same or similar habitats in the area (Le Loc'h *et al.*, 2008; Lassalle *et al.*, 2011, 2014; Chouvelon *et al.*, 2012), or from the Sea Around Us Project, as above. When TLs based on isotopic data reported by the various studies differed, we used those values pertaining to studies in which a wider area (higher prey variability) was prospected, as follows: Chouvelon *et al.* (2012) >Lasalle *et al.* (2014) > Le Loc'h *et al.* (2008) > Lasalle *et al.* (2011). A list of the compiled TL values and their sources is shown in Arroyo *et al.* (2017b).

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Ecological indicators

Mean trophic level

MTL values were derived for landings and survey data in parallel. In both cases, taxa identified with a lower resolution than family level, for whom an accurate trophic level could not be given, were excluded from the analyses. In the case of landings data, all species coming from aquaculture were also eliminated from the data matrix prior to the analyses.

Mean TLs for each year *k* were calculated with the formula (2):

$$TL_k = \sum_i (TL_i) \cdot (Y_{ik}) / \sum_i Y_{ik} \tag{2}$$

Where TL_i is the assigned TL per species and Y_{ik} refers to the biomass of species/group *i* in year *k*, as included in landings or in survey data.

In order to account for uncertainty in MTL values, a bootstrap was applied to the MTL calculation. Randomization was applied to annual TL values and their standard error, performing 500 permutations of the original data. Hence, the final MTL corresponds to the mean value obtained after bootstrapping the original annual data, while the uncertainty is given by its standard deviation. The uncertainty around the MTL model was thus linked to the uncertainty of the TL estimations.

We established three different thresholds on TL values: MTL_2 (including all sampled/landed heterotrophic elements of the food web), $\mathrm{MTL}_{3.25}$ (including only those elements with a $\mathrm{TL} > 3.25$, i.e. higher consumers), and MTL_4 (including only top-predators, mainly large fish and some cephalopods).

Further, since IBT surveys target primarily demersal species, MTL trends for the various thresholds (MTL_2, $\mathrm{MTL}_{3.25}$, and MTL_4) were analysed both considering the whole set of species appearing in each of the data sets and excluding the pelagic ones. Pelagic species are not well sampled by these surveys and their high biomass may overwhelm the total ecosystem biomass, masking the actual status of the demersal communities. This procedure was also maintained when analysing landed catch data, to account for variations in MTL as a function of the main species targeted.

Primary production required and FiB

To further understand the results obtained regarding MTL trends and trends in landings observed in the BoB, two additional trophic ecological indices relating trophic structure with fishing pressure were calculated, and their trends analysed over time.

The primary production required (PPR), as proposed by Pauly and Christensen (1995), gives an estimation of the PPR to generate the catches of species at a particular trophic level and is computed from (3):

$$PPR = \sum_{i=1}^{n} \frac{C_i}{CR} \times \left(\frac{1}{TE}\right)^{TL_i} - 1 \tag{3}$$

where C_i is the catch of species *i*, *CR* is the conversion rate of wet weight to carbon, *TE* is the trophic transfer efficiency, TL_i is the trophic level of species *i* and *n* is the number of species caught. We applied a 9:1 ratio for *CR* and 10% for *TE* (Pauly and Christensen, 1995).

The Fishing-in-Balance (FiB) index evaluates whether a change in the MTL is balanced by a corresponding change in catch levels, in such a way that a decreasing MTL is compensated by an increase in the catches of lower TLs (FiB = 0), as required given the loss of energy from low to higher trophic levels. It is thus an estimate of the TE between TLs, also requiring the assumption that TE is constant across them (Pauly *et al.*, 2000). It gives an account of the expansion and contraction of fishing fleets over time as reflected by the level of the catches (Pauly *et al.*, 2000), an increase in FiB (FiB > 0) indicating a geographic or stock expansion of a fishery or an increase in primary production (bottom-up effects) in the study area. A decrease (FiB < 0) would point at a geographic contraction of the fisheries, a collapse of the underlying food web, or at a non-reflection of discarding in catch reports (Cury *et al.*, 2005).

The FiB index is computed as (4):

$$FiB = \log\left[\frac{\left(\sum_i Y_{ik} 10^{TLi}\right)}{\left(\sum_i Y_{i0} 10^{TLi}\right)}\right] \tag{4}$$

where Y_{ik} refers to the landed catch of species/group *i* in year *k*, TL_i is the trophic level of species *i* and the subscript 0 refers to the year at the start of a series, which serves as an anchor (Pauly *et al.*, 2000). Both in the Cantabrian Sea and the northern BoB, the anchor year was established as the first year of the series, i.e. 1994 and 1983, respectively.

Trend analyses

Trends in MTL, PPR, and FiB were analysed using linear regression except in those cases in which the assumptions of normality (Shapiro-Wilkins tests), homoscedasticity (Harrison McCabe test) and/or independence (Durbin-Watson test) were not met, in which case Mann Kendall trend analyses for non-correlated and/or correlated data were conducted. All analyses were performed using R statistical language (R Core Team, 2017).

Results

Trends in landed catch MTLs

In the Cantabrian Sea the biomass of nominal landings (kg of live weight equivalent landed catch) has been increasing over the time series analysed, though that of the species representing 85% of the landed catch has remained more or less stable throughout the historical series (Figure 2a and b). Altogether, eight species, namely mackerel (*Scomber scombrus*, 25%), horse mackerel (*Trachurus trachurus*, 18.6%), blue whiting (*Micromesistius poutassou*, 13.8%), sardine (*Sardina pilchardus*, 12.7%), Atlantic chub mackerel (*Scomber colias*, 5.6%), hake (*Merluccius merluccius*, 4.7%), anchovy (*Engraulis encrasicolus*, 3.7%) and monkfish (*Lophius* spp., 1.6%) accounted for 85% of the total landed catch over the analysed time period, pelagic species dominating the bulk of the landed catch over time (Figure 2b), though a shift into more demersal species in later years can be observed (Figure 2c). Catch landings declined markedly in 2003, and there was an outstanding peak in 2009, following changes in the landed catch of mackerel. Large mackerel catches lasted until 2011, when a continuous decline was observed in all *Scomber* species, reaching a critical point in 2013, after which catch landings of these species have been increasing. The biomass of caught *T. trachurus* has been declining considerably from 2011 onwards, whilst that of *M. poutassou* has shown the opposite trend.

Throughout the historical series considered, landed catch $\mathrm{MTL}_{3.25}$ values including both pelagic and demersal species ranged from 3.89 in the years 2001–2002, to 3.97 in 2011. No

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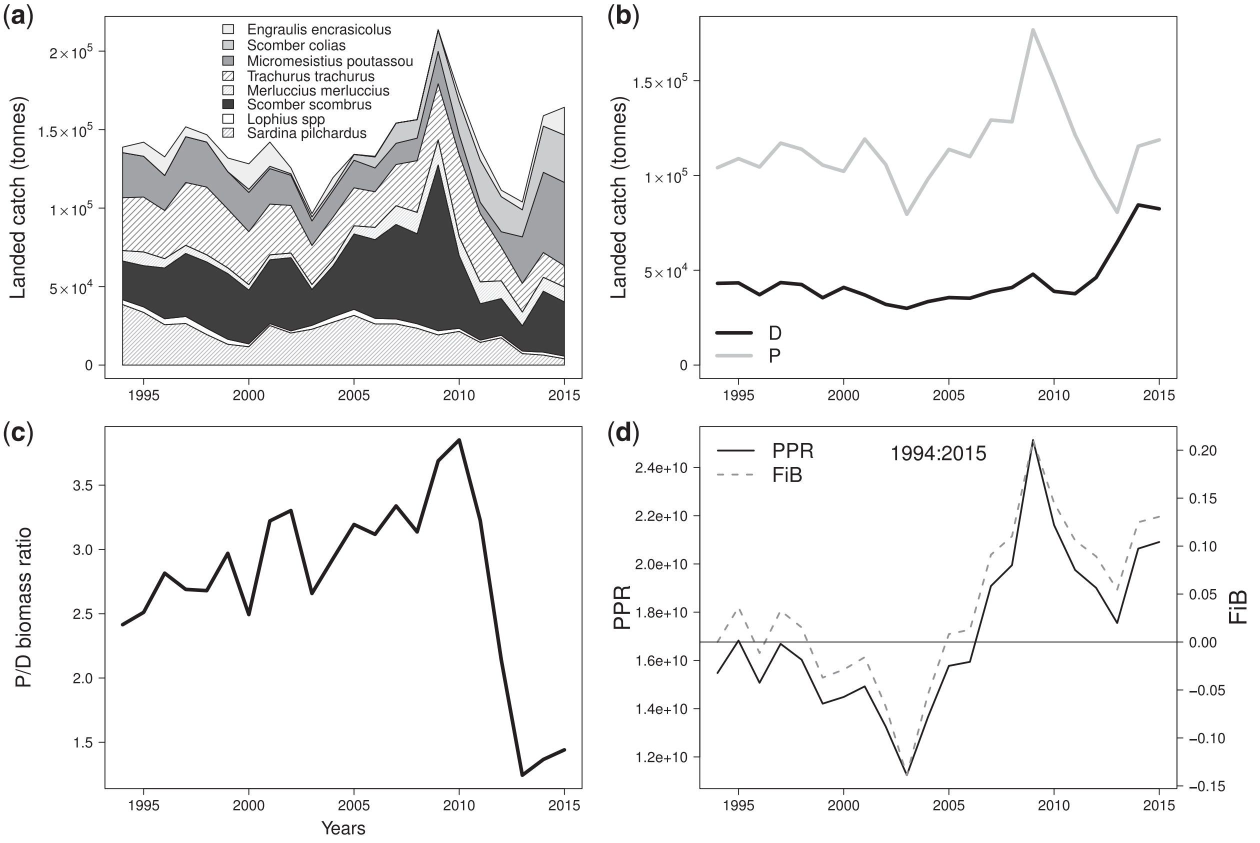

Figure 2. Trends in the biomass of species accounting for 85% of landed catches in the Cantabrian Sea (a) and in the biomass of the various landed catch compartments (b, D, demersal; P, pelagic,) over the study period. Pelagic/demersal landed catch ratio overtime (c), and FiB and PPR trends in the Cantabrian Sea (d) over time.

significant trends, over the total period, were observed for cut-off levels MTL_2 (MK, $Zc = -0.92$; $pc > 0.05$) or $MTL_{3.25}$ (MK, $Zc = 0.70$; $pc > 0.05$) (Figure 3a), despite the decrease in values from 2011 onwards reflecting variations in mackerel and horse mackerel over the last period. However, a significant increasing trend was obtained when using the cut-off level of MTL_4 ($Zc = 2.20$, $pc < 0.05$, Figure 3a). A high standard error around the TL was observed for MTL_2 and $MTL_{3.25}$, mainly due to the high uncertainty around the TL of *S. scombrus* (S1) which is the main landed species in this area.

When pelagic species were excluded from the analyses (Figures 3a), the trend was of a non-significant decrease in MTL_2 ($Zc = -1.30$, $pc > 0.05$) and $MTL_{3.25}$ ($Zc = -1.31$, $pc > 0.05$), and a significant increase in MTL_4 ($Zc = 2.20$, $pc < 0.05$), the latter as that observed when including all species.

In the northern BoB, the landed catch has also been increasing over the time series analysed, especially due to a constant increase in the catches of pelagic species (Figure 4a and b). The 10 main species landed over time have been hake (12%), sardine (12%), horse mackerel (10%), anchovy (7.5%), mackerel (6%), *Lophius* spp. (5%), cuttlefish (*Sepia officinalis*, 4%), common sole (*Solea solea*, 4%), Norway lobster (*Nephrops norvegicus*, 3.5%), and European conger (*Conger conger*, 3%) (Figure 4a). The landed catch of anchovy declined dramatically around the year 2005 and recovered from 2010 onwards. On the other hand, the landed catch of horse mackerel has been declining during the time series, as in the Cantabrian Sea. Bentho-demersal species dominated the bulk of the landed catch in the northern BoB until the mid-1990s and, since then, both pelagic and demersal species were equally landed (Figure 4b). It is interesting to note that demersal catch landings were constant over the analysed time series but, the pelagic/demersal ratio increased constantly, driven by the increase in pelagic species catches (Figure 4c). Although increasing biomasses of demersal species have been observed in later years in the Cantabrian Sea, the opposite occurs in the northern BoB, where pelagic species continue dominating the bulk of the landed caught biomass.

The analysis of MTL trends including the early 80's, from 1983 onwards (ICES historical Data), showed no significant trend except in the case of $MTL_{3.25}$, which showed a significant decreasing trend (Figure 3b). $MTL_{3.25}$ values, corresponding to landed catches including all species, ranged from 4.09 in 1989 to 3.97 in 2007.

Trends in surveys MTLs

In the Cantabrian Sea, the main species contributing to demersal survey biomass over time (Figure 5a), were blue whiting (37%), horse mackerel (12%), and the pelagic crab *Polybius henslowii* (11%), followed by catshark (*Scyliorhinus canicula*, 4%) and hake (3%). The biomass of surveys has been augmenting over time, with a notable increase over the last years (especially blue whiting), and significant oscillations in the abundance of particular

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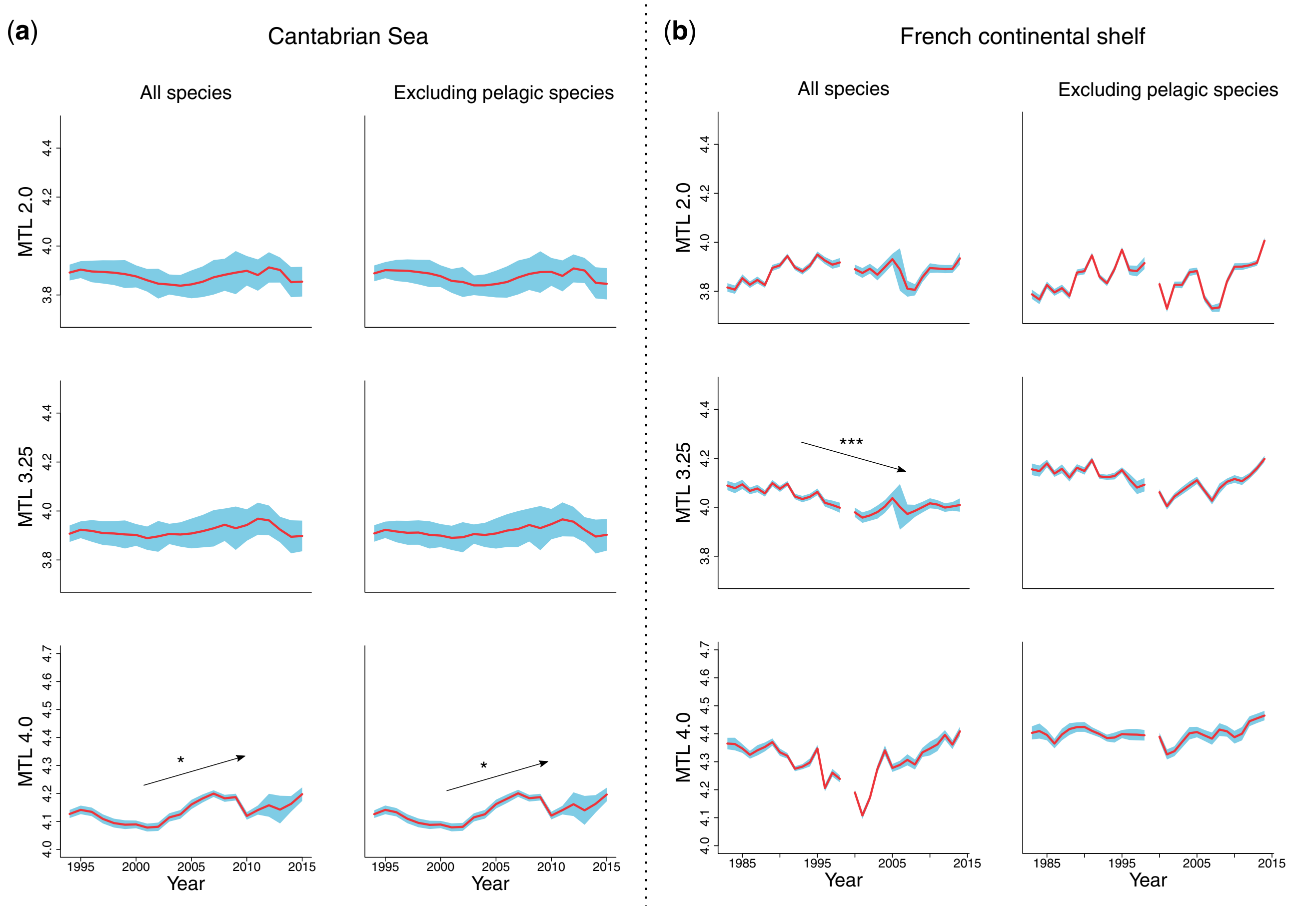

Figure 3. Trends in the mean trophic level of landed catches based on (a) IEO data for ICES divisions 27.8.c, and 27.9.a north (1994–2015), and (b) ICES data for divisions 27.8.a and b (1997–2014) at the various cut-off levels analysed, including all species and excluding pelagic ones from the analyses. Arrows indicate increasing/decreasing trends. *, significant at $p < 0.05$, ***, significant at $p < 0.001$. Shading indicates uncertainty (as standard deviation) around MTL values.

species (e.g. *Macrorhamphosus scolopax* were very abundant during the first years of study, but practically disappeared afterwards).

Survey $\mathrm{MTL}_{3.25}$ values including all species in the Cantabrian Sea ranged from 3.77 in 1994 to 4.00 in 2008, when the collapse in blue whiting biomass caused an increase in the influence of other higher TL predators. In general, trends revealed significant changes only for $\mathrm{MTL}_{3.25}$ without considering pelagic species ($F = 4.7$, $t = 2.2$, $p < 0.05$), showing an increase in the MTL of demersal predators but no major variation in MTLs over time (Figure 6a).

In the northern BoB, the total biomass from the Datras Evhoe survey data revealed no specific trend during the studied period (i.e. 1997–2014) (Figure 5b). An important peak was observed in 2003, which was mainly due to an important biomass of mackerel that year. Pelagic species had the highest relative biomass compared with their demersal counterparts. Two main species, mackerel and horse mackerel represented >60% of the total biomass surveyed. As in landings data, horse mackerel displayed an important constant decrease in biomass between 2002 and 2013, whereas hake almost quadrupled its biomass between 1997 and 2014.

Regarding trends in survey MTL values, increasing ones were found above the 3.25 and 4.0 thresholds (Figure 6b), but not for MTL_2, due to the high interannual variations in boarfish (*Capros aper*) biomass. Significant increasing trends were mainly driven by the biomass of hake, which has increased significantly in northern BoB's continental shelf during the last decade.

PPR and FiB trends

In the Cantabrian Sea, both PPR and FiB values exhibited a parallel varying trend over the studied period, which was also similar to the one shown by the catches of the pelagic compartment (Figure 2d). Both indices revealed a somewhat stable but decreasing trend until 2002, when a marked drop was accounted for until 2003. Then, the trend was reversed in 2004 and followed a steady increase with a peak in 2009 (coinciding with the peak in catches). Thereafter, a notable decreasing trend followed until 2013, concomitant with the decrease in mackerel catches, when again the tendency was reversed (Figure 2d).

In the French BoB, the evaluation of these indicators was conducted over a longer period and revealed three very marked periods: from the eighties until the 2000s, a period characterized by

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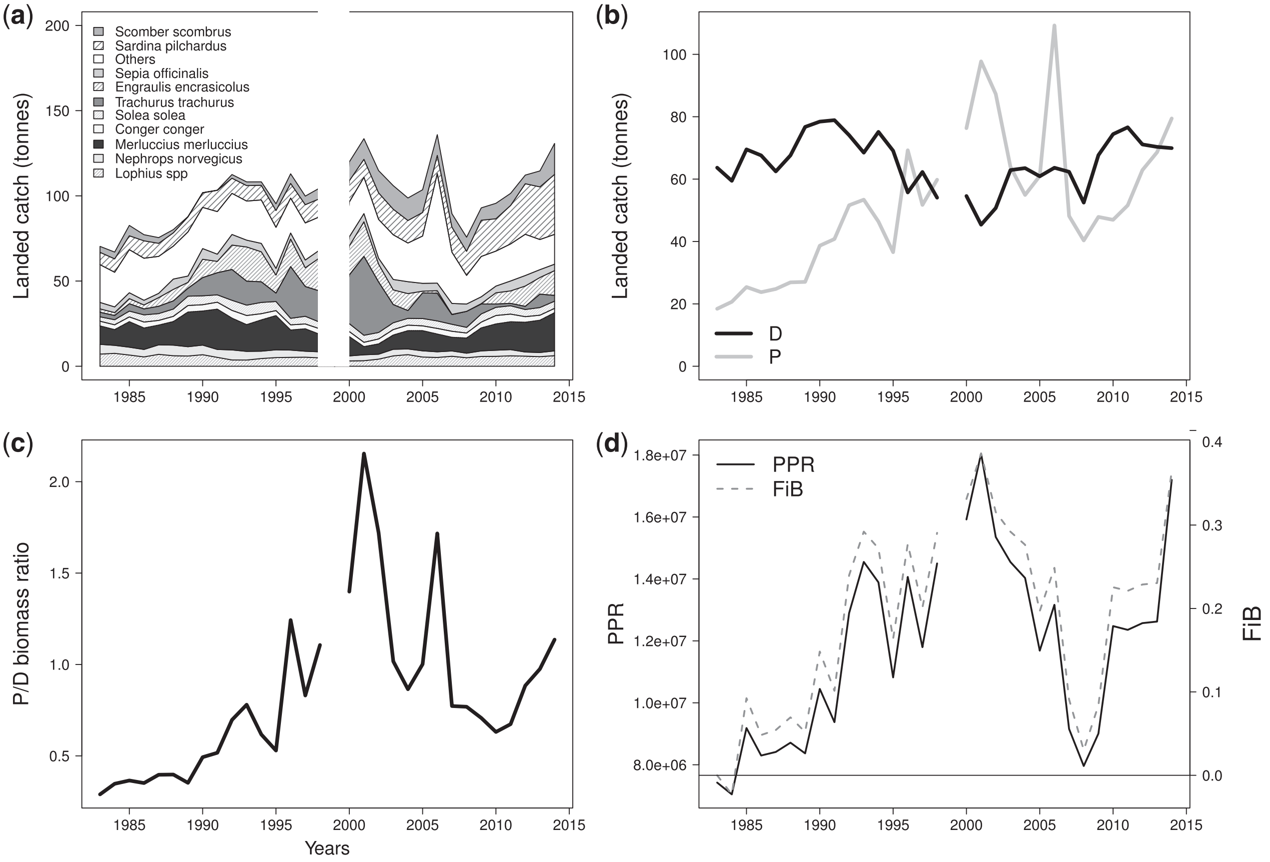

Figure 4. Trends in the biomass of species accounting for 85% of the landed catch in the Northern BoB (a) and in the biomass of the various landed catch compartments (b, D=bentho-demersal, P=pelagic) over the study period. Pelagic/demersal biomass ratio overtime (c), and FiB and PPR trends in the Northern Bay of Biscay (d) over time. "Other species" include, in decreasing order of biomass (percentage of total landed biomass over the study period): *Conger conger* 3%, *Trisopterus luscus* 2.3%, *Cancer pagurus* 2.1%, *Merlangius merlangus* 2%, *Dicentrarchus labrax* 1.9%, *Trachurus spp* 1.4%, *Thunnus alalunga* 1.4%, *Pollachius pollachius* 1.4%, *Loliginidae* 1.3%, *Raja naevus* 0.9%, *Molva molva* 0.9%, *Lepidorhombus spp* 0.8%, *Maja squinado* 0.7%, *Scyliorhinus canicula* 0.7%, *Raja spp* 0.6%, *Spondyliosoma cantharus* 0.6%.

an increasing trend, thereafter until 2008 a steeply declining trend, and again an abrupt increasing trend afterwards (Figure 4d), coinciding with the increase in pelagic catches.

Discussion

No single indicator can capture the complexity of the changes observed in an ecosystem, or in the fishing strategies exploiting it. Food web and trophodynamic indicators are considered valuable tools, which provide a broad and holistic vision of the state of ecosystems and the interactions between the various compartments inhabiting them (Cury *et al.*, 2005; Hornborg *et al.*, 2013; Shannon *et al.*, 2014; Reed *et al.*, 2017), but whose direct linkage to pressures and therefore direct management applicability is often difficult to establish (Shepard *et al.*, 2015). Despite these shortcomings, they are being increasingly put forth as able to provide an improved and holistic vision of the dynamics of ecosystems, and therefore, valuable tools within monitoring and assessment schemes such as the MSFD (Rombouts *et al.*, 2013).

Our results confirm the ability of the MTL indicator to give a clear picture of the trends followed by the communities and their response to fishing pressure at a sub-regional level, especially when combining results from landings and surveys and analysing trends including and excluding pelagic species. Indeed, while survey data provided a good image of changes occurring (mainly) in the demersal compartment of the food web, landed catch trends reflected the pressures exerted over the various compartments by the main fisheries in the area. The complementarity of these data sources when examining trends in the MTL and other trophic-based indicators has been highlighted before (Laurans *et al.*, 2004; Shannon *et al.*, 2014; Gascuel *et al.*, 2016; Reed *et al.*, 2017), and suggests a way in which assessments should incorporate the information provided by them in addition to a good contextualization of the fisheries history, fish production and the evolution and interactions of the various compartments of marine ecosystems in a specific area (Cury *et al.*, 2005; Hornborg *et al.*, 2013; Reed *et al.*, 2017).

On the one hand, the evolution of survey MTLs, with a significant increasing trend of the indicator under most thresholds, especially on the French continental shelf, indicates that the demersal community seems to be on a recovering trend, with an increase in the biomass of high TL predators both in the northern and southern parts of the BoB. This is in accordance with recent studies showing an increase in the biomass of the main predators and groups associated with demersal–benthic habitats in the Cantabrian Sea (Modica *et al.*, 2014; Punzón *et al.*, 2016; Arroyo *et al.*, 2017a, b; Hidalgo *et al.*, 2017) and the northern BoB

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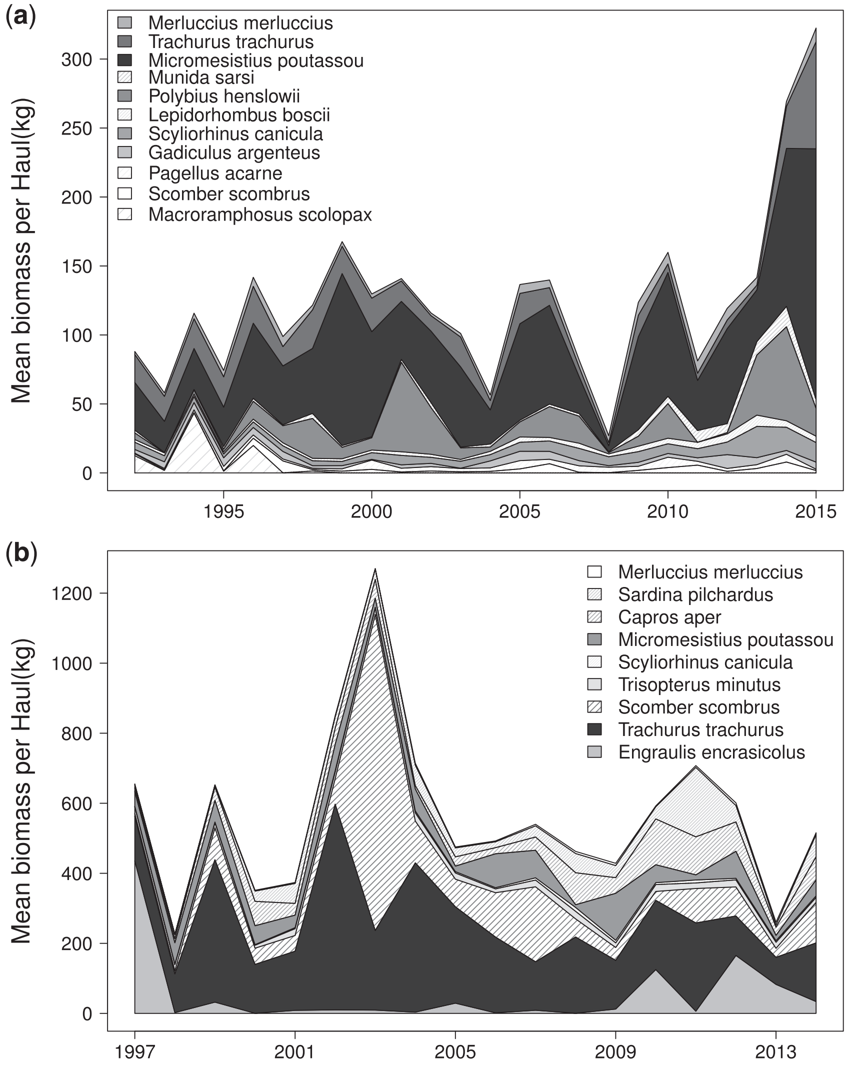

Figure 5. Trends in IEO Demersales (a) and EVHOE DATRAS (b) survey biomass data for the Cantabrian Sea and the French continental shelf, respectively, overtime. Graphs are based on species accounting for 95% of the global biomass sampled overtime.

(Gascuel *et al.*, 2016), as well as with the recovery trends of many stocks in the eastern North Atlantic (Fernandes and Cook, 2013). Specifically, in the French continental shelf, Gascuel *et al.* (2016), showed an improving trend of the large fish indicator in the area, when analysing Evhoe survey data over the period 1997–2010, which seemed to reflect a recovery of the fish community size structure following a decrease in fishing mortality. These authors also reported a general decrease in mean maximum length (MML) across Europe, which they ascribed to a growing predominance of smaller size and lower trophic-level species among landed biomasses, which we have detected also. An increase in landings of pelagic species has been noted in the whole BoB, even after the anchovy ban in 2005, the sardine stock being at its minimum historical levels (ICES, 2016). The relative stability in landings MTL$_{3.25}$ (and its decline in the northern BoB when pelagic species were considered) could be a confirmation of these processes, illustrating the concomitant increase in the catches of all trophic levels (the "fishing through process"), and particularly, pelagic ones (Essington *et al.*, 2006; Branch *et al.*, 2010; Collie *et al.*, 2017). Similar results were reported by Cury *et al.* (2005), who found an apparent stability in catch MTLs in the northern Benguela ecosystem, which they attributed to the continuing decline of small pelagics in the catches, and the partial replacement of hake by horse mackerel during a period of general decline in overall catches.

The sharp drop in catches in the Cantabrian Sea in 2003 was due to the fisheries regulations enforced after the Prestige oil spill, which took place in November 2002. The increase in landed catch MTL$_4$ thereafter could have been the result of fisheries exploiting new and deeper (un-banned) grounds where the biomass of high TL species was larger (Essington *et al.*, 2006; Shannon *et al.*, 2014). In fact, a shift to deeper grounds was reported directly after the Prestige oil spill for fisheries targeting monkfish (Abad *et al.*, 2010), their landings increasing markedly as of 2003 (Figure 7). The transfer of fishing effort from shallower (100–200 m) to deeper (200–500 m) areas during the ban was maintained after the prohibition was lifted (Abad *et al.*, 2010), though whether the new exploited fishing grounds have been maintained further in time needs specific analyses. The ban on the main fishing grounds in 2003 after the Prestige oil spill might have

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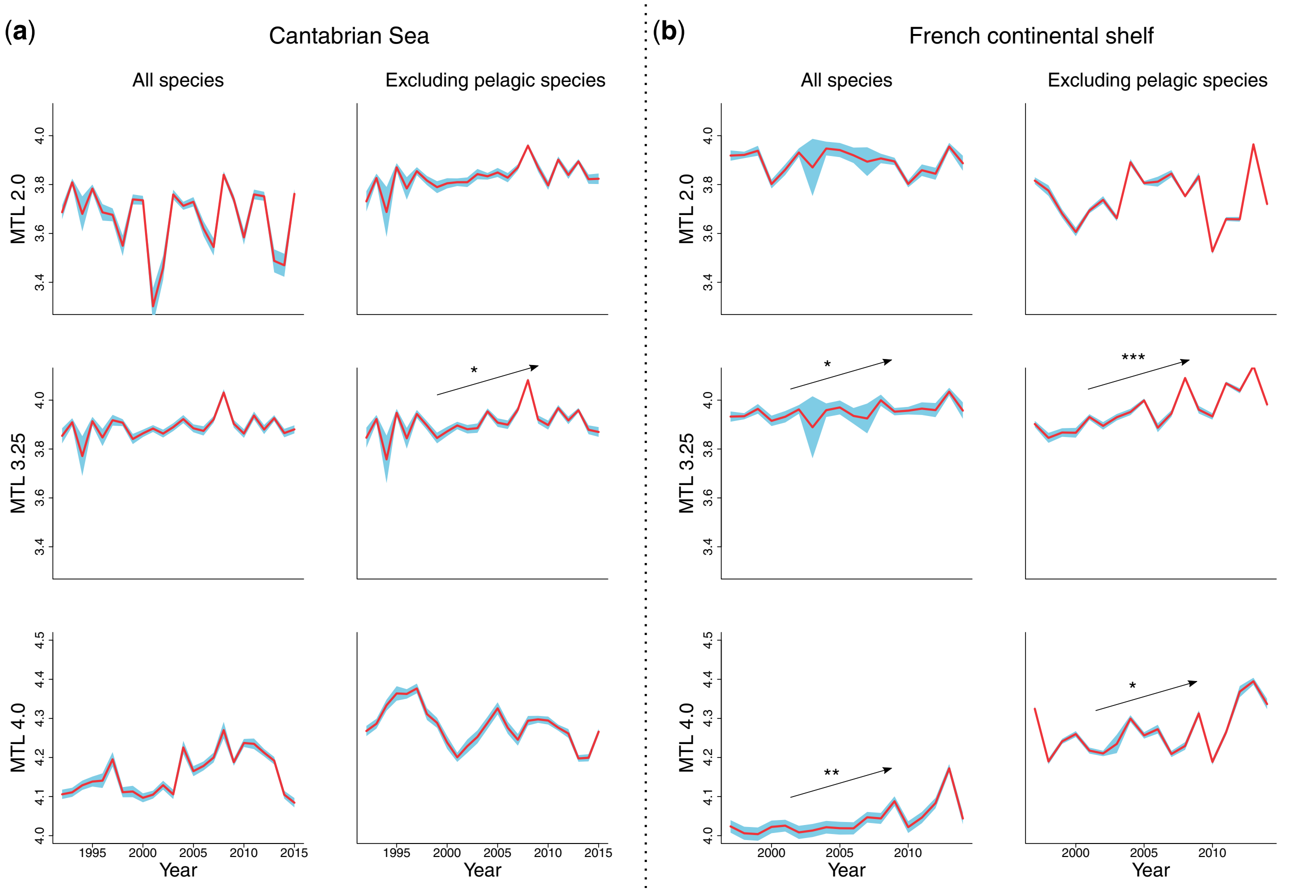

Figure 6. Trends in MTL level of (a) IEO Demersales survey data for the Cantabrian Sea and (b) DATRAS EVHOE survey data for the French Continental Shelf at the different cut-off levels including all species identified to family, genus or species level at the various cut-off levels analysed, and excluding pelagic species from the former data base. Arrows indicate increasing/decreasing trends. *, significant at $p < 0.05$, **, significant at $p < 0.01$, ***, significant at $p < 0.001$. Shading indicates uncertainty (as standard deviation) around MTL values.

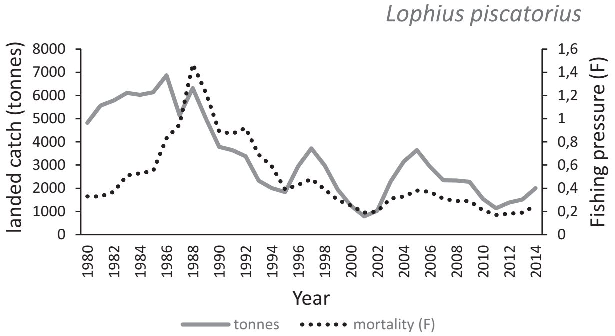

Figure 7. Trends in the landed biomass (solid line) and fishing pressure (mortality, dotted line) exerted over White anglerfish (*Lophius piscatorius*) in ICES Divisions VIIIc and IXa (Cantabrian Sea, Atlantic Iberian Waters) over time. Source: ICES stock assessment (2015).

triggered the observed recovery of bentho-demersal populations both directly, by releasing them from being fished and indirectly, by sending fishermen to deeper waters. These trends were reflected in an increase in the FiB and PPR indices after 2003. Despite the fact that our catch data did not include discards and these results should be interpreted with caution, the higher PPR values pointed at an increased cost for the ecosystem caused by larger catches including higher TL predator species (Pauly and Christensen, 1995; Watson *et al.*, 2014), while the increase in FiB confirmed the likelihood of an expansion of the fishery to deeper waters. Fisheries expansion is a well-documented phenomenon worldwide (Essington *et al.*, 2006; Watson *et al.*, 2014) causing many paradigms in fisheries assessments to be now re-evaluated (Frank *et al.*, 2018). Indeed, the apparent recovery of stocks in surveyed areas were management strategies have now been on-going for decades, might be masking the depletion of deeper, off-shore areas where no control or fisheries regulations are being imposed. These ecosystems are often less known, fragile and less productive and their recovery may take longer than that of shallower areas (Norse *et al.*, 2012), their resilience and robustness to growing pressures being still far from understood.

In contrast, in 2003, after the oil spill, there was a very important fall in the effort of the handline fishery, which is the main fishery exploiting the southern component of the Northeast Atlantic mackerel stock. The drop in mackerel landings during this year can also be attributed to fisheries regulations, but contrary to the former transfer of effort to deeper areas, it only caused a change in landing ports, which was not extended after the ban (Abad *et al.*, 2010). Quite oppositely, an increase in

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landings of mackerel thereafter has been registered in both the northern and southern parts of BoB. The same has been observed for sardine and anchovy. The declining trends in PPR and FiB in the northern BoB seem to be particularly eloquent in reflecting this overexploitation of pelagic resources, despite an apparent stability of landed catch MTL values in later years.

Finally, environmental factors should not be overlooked and may also be behind some trends observed. Shifts in productivity are known to affect fish communities in decadal time scales (Beaugrand, 2004) and the more gradual effects of global warming are now becoming increasingly apparent (Poulard and Blanchard, 2005; Collie *et al.*, 2008; Punzón *et al.*, 2016). These drivers are temporally confounded and interact with fishing, making the impacts of various pressures difficult to disentangle and the setting of targets and thresholds even more problematic.

This shortcoming is particularly momentous in the frame of the MSFD (whose requirements oblige the definition of targets and thresholds defining GES), and probably the main bottleneck placing trophic-level based indicators still under the category of surveillance indicators (Shephard *et al.*, 2015). The increasing number of studies concentrating on the evolution of MTL trends under varying scenarios, thresholds and theories is undoubtedly contributing to give an idea of the variation of the indicator under different pressure levels (Reed *et al.*, 2017), which will probably help in understanding its variability, and meeting such requirements. Specifically, our study contributes to build on the growing evidence indicating that no trend in landings $MTL_{3.25}$ is no direct sign of stability but could indicate an over-exploitation of resources, and particularly, a decline in the biomass of abundant pelagic species, which often have an important role as forage for higher trophic levels (Preciado *et al.*, 2008; López-López *et al.*, 2012). In this regard, more focussed spatial approximations in areas of high fishing pressure may help to identify the indicator values suggestive of a continuous pressure (Preciado *et al.*, 2019), while analyses of less exploited, pristine or Marine Protected Areas could provide a clearer image of long-term targets to be achieved.

Our study also confirms that trends inevitably need to be interpreted in parallel with other indices and knowledge/evaluations of the fisheries history and the surveyed biomass trends of the main commercial species. Still, it clearly shows how a detailed assessment of MTL trends can provide a sound overall idea of the status of food web status over time. Nevertheless, further studies need to be conducted to ascertain the trends observed here and suggest appropriate management strategies aimed at regulating fisheries expansions, especially in deeper areas.

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Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

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