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Evaluation of status of commercial fish stocks in European marine subareas using mean trophic levels of fish landings and spawning stock biomass

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ABSTRACT

Most of the fish stocks in the world, including European fish stocks, are threatened by overfishing and/or degraded environmental conditions. Although the Common Fisheries Policy (CFP) is the main policy instrument managing fish stocks in Europe, there is continued concern as to whether commercial fish stocks will achieve Good Environmental Status (GEnS) in 2020 in accordance with the Marine Strategy Framework Directive (MSFD). In this context, the evaluation of the status of fish stocks in the subareas of FAO fishing area 27 was carried out using mean trophic levels (*MTL*) in fish landings and spawning stock biomass (*SSB*). Comparisons were made before and after 2008 to establish whether the trend is positive or negative. The main data sources for landings and *SSB* were the International Council for the Exploration of the Sea (ICES) advisory reports. *MTL*s in landing and *SSB* were determined for each subarea and the subareas were categorized into four groups, according to *MTL*s after 2008. The first group (subareas I + II, V) had higher *MTL* in landings and higher *MTL* in *SSB* after 2008. Therefore, fisheries in these subareas appear sustainable. The second group was subareas VIII + IX, for which the fish stocks have higher *MTL* in landings but low *MTL* in *SSB*, indicating that *SSB* was being overfished. The third was subarea (VI), where fish stocks have lower *MTL* in landings than those in *SSB* after 2008, which may indicate that fish stocks are recovering. Fish stocks in the fourth group (subareas III, IV and VII) had low *MTL* in landings and the *MTL* in *SSB* was lower than that of landings before 2008. This may be due to heavy fishing. In addition, we estimated the harvest rate (*HR*) of the fish stocks before and after 2008. The results showed that most of the fish stocks have lower *HR* after 2008, indicating that the status has improved, perhaps due to improvements in the implementation of CFP. However, some fish stocks showed high *HR* even after 2008, so that new management options are still needed. Other factors such as eutrophication, seafloor disturbances, marine pollution, invasive species etc., influence *SSB* ecosystem health options and should also be incorporated in the management criteria. Most of these environmental pressures are of high priority in the MSFD, and therefore the findings of this study will be useful for both CFP and MSFD.

1. Introduction

The Common Fisheries Policy (CFP) is the main policy document to manage European fisheries resources. It was adopted in 1983 and has since been revised every 10 years (Aanesen et al., 2012). The latest version was approved by the European Parliament in 2013 (Pastoors, 2014). The main *modus operandi* of the CFP for managing fisheries is to decrease the fishing capacity (Villasante, 2010; Gascuel et al., 2011). However, the very high fishing pressure exerted by EU fishing fleets has been insufficiently reduced by the CFP to achieve healthy stocks and maximum sustainable yield

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(MSY) (Villasante, 2010). Furthermore, the EU has a legal responsibility under the United Nations Convention on the Law of the Sea (UNCLOS) to restore fish stocks by maintaining fishing mortality at a level of producing MSY that reached a critical milestone in 2015 (Froese and Proelß, 2010). As a further governance response, the European Marine Strategic Framework Directive (MSFD) was established in 2008 by European nations with coastal boarders (EU, 2008). The main objective of MSFD is to achieve good environmental status (GEnS) by 2020 through 11 qualitative descriptors (Borja et al., 2010; Foley, 2013). Descriptor number three (D3) addresses populations of commercially exploited fish/shellfish emphasizing that these should be within safe biological limits, while exhibiting population age and size distribution pertaining to healthy stocks (EU, 2008). Furthermore, Member States are responsible to conserve, improve and restore the marine ecosystems, including fish populations, to achieve the UNCLOS milestone in conjunction with the CFP and MSFD.

Both the CFP (EU, 2013; Prellezo and Curtin, 2015) and MSFD (EU, 2008) use ecosystem-based management approaches. Garcia et al. (2003), Browman and Stergiou (2004) and Pauly et al. (2002) have shown the importance of ecosystem-based fisheries management (EBM) to obtain a sustainable harvest from marine fish stocks. Additionally, Brodziak and Link (2002) stated that maintaining a healthy trophic structure (food web) is one of the main objectives of EBM. Furthermore, trophic level based indicators are useful to understand complex interactions between fisheries and marine ecosystems (Pauly and Watson, 2005).

Pitcher et al. (2001) suggested that reinventing fisheries management where and when the fisheries are in a crisis, such as the current situation in European Regional Seas. The contention is that EBM directed towards fisheries sustainability should rebuild fish communities, whereas the conventional fisheries management approaches do not reverse the depleted fisheries because of the over-exploitation of species of higher trophic levels (Pitcher et al., 2001). Thus, a fish community trophic level approach, in accordance with the EBM, would better fulfil the objectives of both the CFP and MSFD.

The present study was focused on how trophic level based indicators of fisheries can be used to assess and manage EU fish stocks in marine subareas of FAO area 27, through the evaluation of the status of some commercially exploited fish stocks. The main objective of the study was to determine whether the adoption of new policy instruments (MSFD and CFP) are successfully reversing the negative trend of fisheries. One difficulty is to set the threshold date for comparison of “before” and “after” effective implementation of policy instruments. Any date is arbitrary since the adoption of a policy is not the same as its effective implementation. However, we opted to compare pre and post 2008 data for the purposes of this study. After adoption of the MSFD, member states were mandated to draw up cost-effective plans by 2015, prior to the full implementation of the MSFD (Long, 2011). Additionally, the latest version CFP is effective from 1st January 2014, and hence we used data until 2013, to show the status of fish stocks prior to the new version of the CFP. The findings of the present study may thus be useful to monitor the progress due to both the CFP and MSFD implementation.

The present study addresses the following research questions:

(i) Is there a change in fishing pressure over trophic levels in the context of the implementation of the policy instruments?
(ii) Are fish stocks showing signs of recovery since 2008?

2. Materials and Methods

2.1. Area, fish stocks and data sources

2.1.1. Study area

Sub areas of FAO fishing area 27 (Baltic and NE Atlantic) were selected for the present analysis (Fig. 1). Table 1 describes the marine subareas considered in this analysis.

2.1.2. Selection of fish stocks and data sources

Commercially important fish stocks that are listed in the International Council for the Exploration of the Sea (ICES) advisory reports were selected for the present analysis. The species evaluated were cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), saithe (*Pollachius virens*), herring (*Clupea harengus*), sole (*Solea solea*), plaice (*Pleuronectes platessa*), whiting (*Merlangius merlangius*), hake (*Merluccius merluccius*) and sprat (*Sprattus sprattus*). These stocks represent about 25% of the fish stocks in the European region. They are considered as the most important in European commercial fisheries and these data are considered to be rich and reliable by ICES (Cardinale et al., 2013).

Data on fish landings and spawning stock biomass (*SSB*) of concerned fish stocks from the ICES scientific advisory reports for 2014 (http://www.ices.dk/community/advisory-process/Pages/Latest-advice.aspx) were accessed on 20.10.2014 and used in the study. In these reports, catch data were available up to and including 2013.

2.2. Data analysis

2.2.1. Mean trophic levels in SSB and fish landings in different subareas

Mean trophic levels (TL_i) of fish communities were calculated based on the feeding habits of constituent species and according to Equation (1) (Pauly and Palomares, 2005), which are reported in www.fishbase.org (Froese and Pauly, 2014).

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

where TL_j is trophic level of the prey j and DC_{ij} is the fraction of j in the diet of i. For the present analysis, TL_i values for the spawning stock biomass and landings of constituent species in the fishing areas (Table 1) were extracted from the www.fishbase.org (Froese and Pauly, 2014). Accordingly, TL_i values used in the analysis were 4.29 for cod, 3.56 for haddock, 3.61 for saithe, 3.29 for herring, 3.30 for sole, 3.23 for plaice, 3.57 for whiting, 3.84 for horse mackerel, 4.30 for hake and 3.01 for sprat (Jayasinghe et al., 2015).

Seven subareas (I + II, III, IV, V, VI, VII, VIII + IX) were considered, based on the availability of ICES advisory reports. For each area, the Mean trophic level for year y (MTL_y) was computed from 2009 to 2013 to observe whether there are any trends before and after the 2008. The fish stocks that were considered for each subarea for *MTL* analysis are given in Table 2. The data availability of each fish stock was inconsistent, and therefore, the analysis was performed for the periods when data were available for all fish stocks in several consecutive years before and after 2008. Accordingly, the analysis was for the periods commencing in 1960, 1991, 1990, 1987, 1992, 1987, and 1992 for the I + II, III, IV, V, VI, VII and VIII + IX subareas respectively, and until 2013. The formulae are given below.

$$MTL_y = \sum_i (TL_i \cdot Y_{iy}) \Big/ \sum_i Y_{iy} \tag{2}$$

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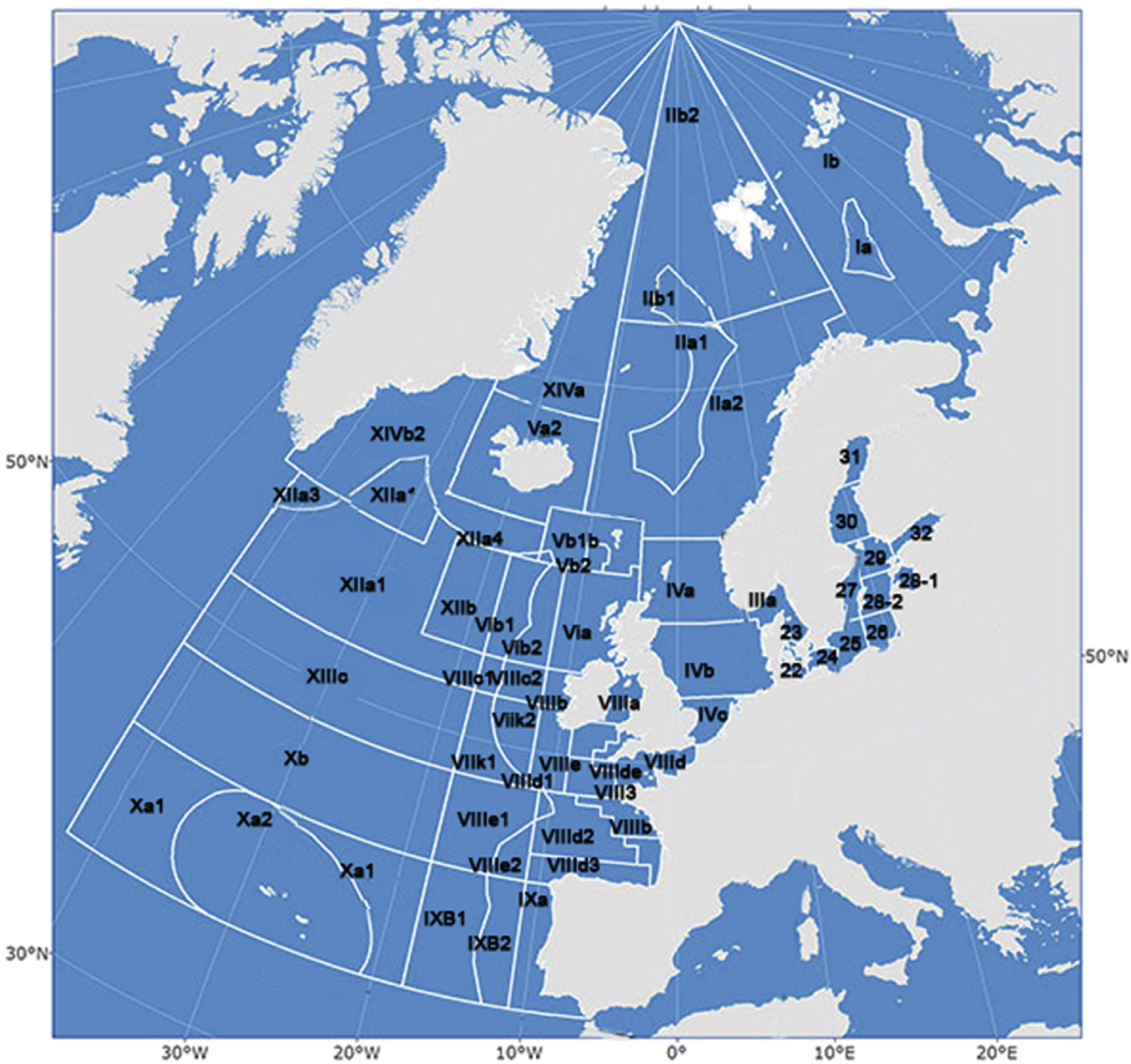

Fig. 1. Map of the FAO 27 area showing subareas where different fish stocks analysed (modified after http://www.fao.org/fishery/area/Area27/en).

Table 1
Fishing subareas (FAO 27) considered for data gathering from FishBase online database, and ICES advisory reports.

Area name	Sub area number as shown in Fig. 1
Barents Sea	I
Norwegian Sea (IIa); Spitsbergen, and Bear Island (IIb)	II
Skagerrak and Kattegat (IIIa); Sound, Belt Sea (III b, c) and Baltic Sea (IIId 24–32); the Sound and Belt (IIIc 22) together known also as the Transition Area	III
North Sea (Northern IVa); (Central Vb); (Southern IVc)	IV
Iceland (Va); Faroes Grounds (Vb)	V
Northwest Coast of Scotland and North Ireland or West of Scotland (VIa); Rockall (VIb)	VI
Irish Sea (VIIa); West of Ireland (VIIb); Porcupine Bank (VIIc); Eastern (VIId) and Western (VIIe) English Channel; Bristol Channel (VIIf); Celtic Sea North (VIIg) and South (VIIh); and Southwest of Ireland – East (VIIj) and West (VIIk)	VII
Bay of Biscay (North VIIIa); (Central VIIIb); South (VIIIc); Offshore (VIIId); (West VIIIe)	VIII
Portuguese Waters (East IXa); (West IXb)	IX
Azores Grounds	X
North of Azores	XI
East Greenland (North XIVa); (South XIVb)	XIV

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where Y_{iy} is the catch of species i.

Similarly, the *MTL* in *SSB* was estimated using Equation (3).

$$MTL(SSB)_y = \sum_i (TL_i \cdot SSB_{iy}) \Big/ \sum_i SSB_{iy} \quad (3)$$

where SSB_{iy} is the *SSB* of species i (obtained from ICES advisory reports) in year y.

The *MTL* in fish landings (L) is given by Equation (4).

$$MTL(L)_y = \sum_i (TL_i \cdot L_{iy}) \Big/ \sum_i L_{iy} \quad (4)$$

where L_{iy} is the landings of species i (obtained from ICES advisory reports) in year y.

To determine whether the *MTL* in landings was high or low in each subarea after 2008, a reference level of *MTL* in 3.75 (Christensen et al., 2003) was used.

2.2.2. Difference between mean trophic levels in SSB and fish landings

The difference of *MTL* (*D*) in fish landings [$TL(L)_y$] and SSB [$TL(SSB)_y$] was determined by following equation:

$$D = MTL(L)_y - MTL(SSB)_y \quad (5)$$

Subareas showing higher *MTL* in *SSB* than that in landings after 2008 were identified.

2.2.3. Categorization of fishing subareas

The subareas were grouped based on the *MTL* in landings (high or low) and the difference between *MTL* in *SSB* and *MTL* of landings after 2008.

2.2.4. Distribution of MTL among SSB and fish landings (L) before and after 2008

The following equations were used to analyze the effect of adopting the *MSFD* on tropic levels in *SSB* and fish landings (L).

TL_i for *SSB* before *MSFD*

$$Mean\ SSB_{TL_i} = \sum SSB_{TL_{i(y1-2008)}} \Big/ n_y \quad (6)$$

TL_i for *SSB* after *MSFD*

$$Mean\ SSB_{TL_i} = \sum SSB_{TL_{i(2009-2013)}} \Big/ n_y \quad (7)$$

where SSB_{TL_i} is *SSB* of fish with trophic level i, $y1$ is first data available year and n_y is number of years.

TL_i for fish landings before *MSFD*

$$Mean\ L_{TL_i} = \sum L_{TL_{i(y1-2008)}} \Big/ n_y \quad (8)$$

TL_i for fish landings after *MSFD*

$$Mean\ L_{TLi} = \sum L_{TLi(2009-2013)} \Big/ n_y \quad (9)$$

where L_{TL_i} is landings of fish with trophic level i, $y1$ is first data available year and n_y is number of years.

2.2.5. Harvest rate of fish stocks before and after2008

The Harvest rate (*HR*) of fish stocks was calculated (Piet et al., 2010) for fish stocks before and after 2008.

Table 2
Fish stocks considered for mean trophic level analysis in each subarea.

Area (s)	Fish stocks
I + II	Cod, Haddock, Saithe
III	Cod (SDs 22–24), Herring IIIa and (SDs 22–24)
	Herring IIId (SD 30), Herring IIId (SDs 25–29)
	Herring IIId (28.1), IIId (SD 31), Sole IIIa
IV	Cod (IV,VIId, IIIa), Haddock (IV,IIIA (West)),
	Herring (IV, VIId, IIIa West), Sole, Plaice, Whiting (IV, VIId), Sprat
V	Cod, Haddock, Saithe, Herring
VI	Whiting (VIa), Herring (VIa North), Haddock (VIb)
VII	Cod (VIIe-k), Cod (VIIa), Herring (VIIa)
	Sole (VIId), Sole (VIIf,g), Plaice (VIIe)
VIII + IX	Sole (VIIIa,b), Horse Mackerel (IXa)
	Hake (VIIIc, IXa)

Note: fish stocks were allocated to each subarea following Cardinale et al. (2013).

$$HR \text{ for before 2008 } (HRy1 - 2008) = \sum L_{i(y1-2008)} \Big/ \sum SSB_{i(y1-2008)} \quad (10)$$

$$HR \text{ for } 2009 - 2013\ (HRy2009 - 2013) = \sum L_{i(2009-2013)} \Big/ \sum SSB_{i(2009-2013)} \quad (11)$$

3. Results

3.1. MTL in fish landings and SSB

Higher *MTL* values (>3.75) in the landings after 2008 were found for fishing subareas I + II, V and VIII + IX (Fig. 2). Lower values of *MTL* (<3.75) in landings since 2008 were found in subareas III, IV, VI and VII (Fig. 2).

In addition, Fig. 2 illustrates that in most cases, the *MTL* in landings were higher than the *MTL* in *SSB*, showing the high fishing demand for fish species of higher trophic levels. Nevertheless, the *MTL* in *SSB* exceeded the *MTL* in landings in some instances, in the subareas I + II, IV, V, VI and VII (Fig. 2).

3.2. Differences between MTL in fish landings and SSB

In Fig. 3, various levels of differences between *MTL* in fish landings and *SSB* can be seen for the subareas. Moreover, subareas such as I + II, V and VI (Fig. 3) had higher *MTL* in *SSB* than that of landings after 2008, while other subareas (III, IV, VII and VIII + IX) did not have higher *MTL* in *SSB* than of landings (Fig. 3). Furthermore, Fig. 3 indicates that *MTL* in landings in subareas III, VIII and VIII + IX were always higher than *MTL* in *SSB*. Also, the difference of *MTL* of these two mean trophic levels was remarkably large in subareas VIII + IX (Fig. 3), especially after year 2005.

3.3. Categorization of fishing subareas based on MTL in landing and differences between MTL in SSB and landings

The fishing subareas could be classified into four groups based on the *MTL* in landings (high or low) and the difference between *MTL* in *SSB* and *MTL* in landings after 2008 (Table 3).

3.4. Distribution of SSB and landings among different trophic values (before and after 2008)

3.4.1. Subareas I + II

In subareas I + II, cod was the main species in *SSB* and landings.

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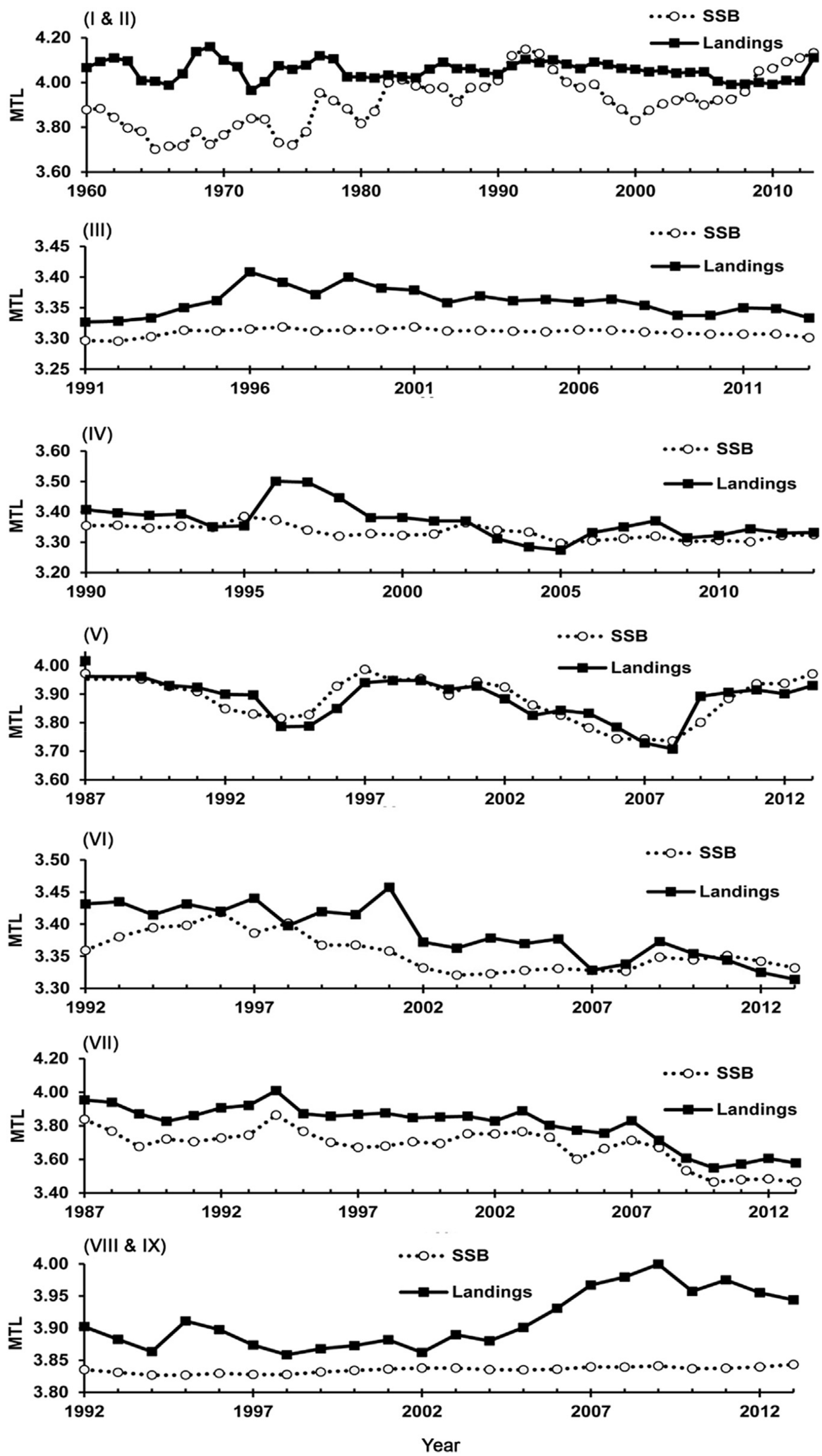

Fig. 2. Variations of Mean trophic levels (*MTL*) of fish spawning stock biomass (*SSB*) and landings in fishing subareas I + II, III, IV, V, VI, VII and VIII + IX.

The rise of *SSB* in cod after 2008 was significant and landings for cod also increased after 2008 (Fig. 4).

Please note: Section 3.4 is annexed (Annex 1) with this manuscript with similar figures (Figs. 5–9) which illustrate Mean fish *SSB* (a) and landings (b) in tonnes (horizontal axis) in different trophic levels (vertical axis) before and after 2008 for subareas I + II, III, IV, V, VI, VII and VIII + IX.

3.5. Harvest rate of fish stocks

Among the fish stocks used for the analysis, the majority had a lower harvest rate after 2008, (Table 4). However, harvest rate did

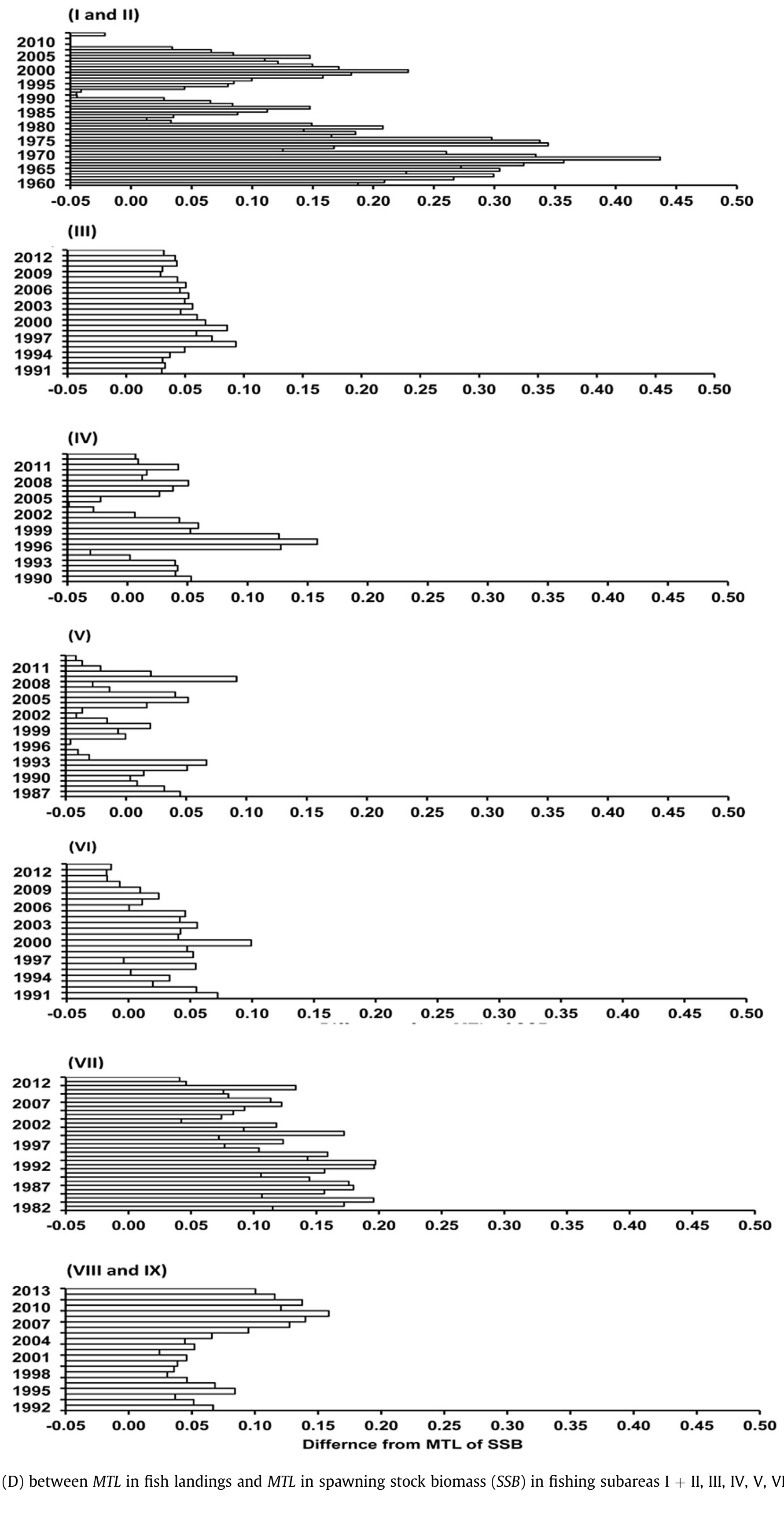

Fig. 3. Difference (D) between *MTL* in fish landings and *MTL* in spawning stock biomass (*SSB*) in fishing subareas I + II, III, IV, V, VI, VII and VIII + IX.

Table 3
Categorization of fishing subareas and fish stocks based in *MTL* in the landing and differences between *MTL* of *SSB* and landings after 2008.

	High $MTL_{(L)}$	Low $MTL_{(L)}$
$MTL_{(SSB)}>MTL_{(L)}$ 2008–2013	I + II: Cod, Saithe, Haddock V: Cod, Saithe, Haddock, Herring	VI: Whiting (VIa), Haddock (VIb), Herring (VIa North)
$MTL_{(SSB)}<MTL_{(L)}$ 2008–2013	VIII + IX: Hake (VIIIc, IXa), Horse Mackerel (IXa), Sole (VIIIa,b)	III: Cod (SDs 22–24), Sole (IIIa), Herring in IIIa and (SDs 22–24), IIId (SD 30), IIId (SDs 25–29), IIId (28.1) IV: Cod (IV,VIId, IIIa), Whiting (IV,VIId), Haddock (IV,IIIA (West), Sole, Herring (IV, VIId, IIIa West) Plaice, Sprat, VII: Cod in (VIIa), (VIIe-k), Sole in (VIId), (VIIf,g) Herring (VIIa), Plaice (VIIe)

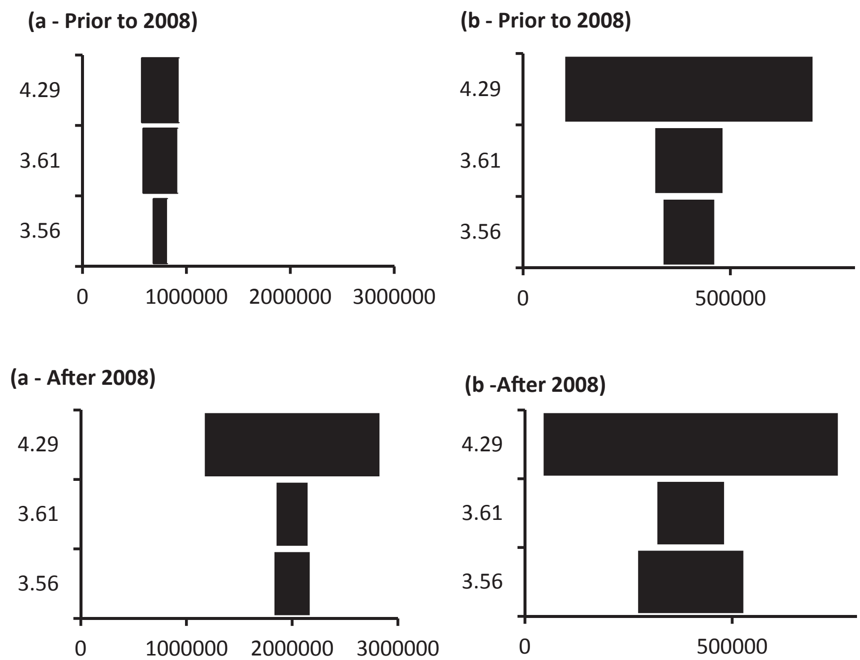

Fig. 4. Mean fish *SSB* (a) and landings (b) in tonnes (horizontal axis) in different trophic levels (vertical axis) in before and after 2008 in subareas I + II.

increase in some fish stocks. The highest harvest rates were found in cod fisheries in the North Sea (subarea IV) before and after 2008.

4. Discussion

SSB and landings are considered as important indicators in evaluating the status of commercial fish stocks. Trophic level based indicators are also useful indicators to understand complex interactions between fisheries and marine ecosystems (Pauly and Watson, 2005). In the present study, we attempted to use trophic status of *SSB* and landings to categorize marine subareas in Europe.

Our analysis showed that the *MTL* of landings in subareas I + II, V and VIII + IX were higher, while other subareas (III, IV, VI and VII) had lower *MTL* landings. Additionally, Jayasinghe et al. (2015) found similar results for these subareas while evaluating environmental status based on trophic levels and life history information on fishes. As a step forward, we computed *MTL* in *SSB* in each subarea to compare with those of fish landings. The study revealed that subareas I + II and V had higher *MTL* in landings as well as higher *MTL* in *SSB* than *MTL* in landings after 2008.

In the first group of subareas (I + II and V), the anthropogenic stresses on the fish stocks such as shipping, sea bed disturbances are not excessive (EEA, 2015), and perhaps these conditions may have supported the increase of fish biomasses. Subareas where higher *MTL* in *SSB* and landings are evident appear to be "safe" in terms of fisheries.

The second group (Subareas VIII + IX) had high *MTL* in landings, but not in *SSB* after 2008. This is probably due to by a severe dependence of the fishery on new recruits, a majority of immature individuals in the landings, inhibition of breeding and recruitments because of overexploitation over the past decades (Guénette and Gascuel, 2012). Here, the landings of high trophic level species, such as hake, increased after 2008. Guénette and Gascuel (2012) reported that extremely heavy fishing mortality in Bay of Biscay area (subarea VIII) before 2008, and it seems that fishing pressure towards hake in these subareas is still high. In addition, the estimated harvest rate for hake in these subareas was 1.10 (present analysis) signifying that this stock is being overfished.

Subarea VI was grouped in the third category, which was having low *MTL* in *SSB* and landings. However, in this subarea after 2008, *MTL* of *SSB* has been higher than in landings perhaps due to the drop of landings specially whiting. Though the *MTL* in landings low, increasing *MTL* in *SSB* is a positive sign of recovery of fish stocks in this subarea.

The last category of subareas (III, IV and VII) had low *MTL* in both landings and *SSB* after 2008. As such, these subareas can be considered as the poorest status of fish stocks in terms *MTL*s. The *SSB* has not improved during the recent years and high trophic level species also was dominant in the landings. In these subareas, there was no prominence of *SSB* for cod, but for herrings both *SSB* and landings increased after 2008, showing a dominance of low trophic species in subarea III. Similarly, subarea IV also had larger

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Table 4
Harvest rates (*HR*) of fish stocks before and after 2008 and stock status.

Subarea	Fish stock	HR		Stock status
		Before 2008	2009–2013	
I + II	Cod	1.688	0.429	Improved
	Saithe	0.499	0.547	Not improved
	Haddock	0.955	0.759	Improved
III	Cod (SDs 22–24)	1.156	0.462	Improved
	Sole IIIa	0.364	0.320	Improved
	Herrings			
	IIIa and (SDs 22–24)	0.752	0.471	Improved
	IIId (SD 30)	0.139	0.423	Not Improved
	IIId (SDs 25–29)	0.286	0.724	Not Improved
	IIId (28.1)	0.408	1.604	Not Improved
IV	Cod (IV,VIId, IIIa)	2.018	1.032	Improved
	Whiting (IV,VIId)	0.200	0.098	Improved
	Haddock (IV,IIIA (West)	0.631	0.226	Improved
	Sole	0.519	0.343	Improved
	Herring (IV, VIId, IIIa West)	0.298	0.142	Improved
	Plaice	0.601	0.240	Improved
	Sprat	0.814	0.434	Improved
V	Cod	0.332	0.196	Improved
	Saithe	0.627	0.535	Improved
	Haddock	0.553	0.413	Improved
	Herring	0.249	0.120	Improved
VI	Whiting (VIa)	0.419	0.123	Improved
	Haddock (VIb)	0.650	0.269	Improved
	Herring (VIa North)	0.245	0.249	Not improved
VII	Cod (VIIa)	0.809	0.159	Improved
	Cod (VIIe-k)	0.806	0.512	Improved
	Sole (VIId)	0.420	0.386	Improved
	Sole (VIIf,g)	0.421	0.331	Improved
	Herring (VIIa)	0.458	0.053	Improved
	Plaice (VIIe)	0.023	0.017	Improved
VIII + IX	Hake (VIIIc, IXa)	1.173	1.110	Improved
	Horse Mackerel (IXa)	0.075	0.080	Not Improved
	Sole (VIIIa,b)	0.426	0.295	Improved

proportions of low trophic level fish species such as herring, plaice and sprat both in *SSB* and landings. The high tropic level species (cod) showed overfishing status even after 2008. Shannon et al. (2014) and Emeis et al. (2015) reported that most of high trophic level species in the North Sea have already been fished out. In subarea VII, even though landings of cod have dropped after 2008, no improvement could be seen in *SSB*. This is probably due to some other factors affecting recruitment and mortality of fishes like physical damage of sea floor (EEA, 2015), which is common in subarea VII (Foden et al., 2011). Furthermore, eutrophication is also common in this subarea (EEA, 2015), and has negative impacts on fish populations (HELCOM, 2009).

In the present analysis, we illustrated that *MTL* in *SSB* of fish species can be considered as an ecosystem-based indicator for assessing trophic structure of commercially important fish communities (Rombouts et al., 2013). However, growth, development, reproduction, recruitment, migration, predation and natural mortality also affect *SSB* in fish stocks. According to the EEA (2015), in addition to fishing pressure, various qualitative descriptors of MSFD such as eutrophication (Descriptor 5), habitat separation, disturbances to sea floor (Descriptor 6), invasive species (Descriptor 2), and contaminants (Descriptor 8) cause negative impacts on fish populations. Moreover, global climatic changes have impacts on fish stocks (Brander, 2010; Arnason, 2012) affecting *SSB* and landings. Importantly, most of these pressures are being considered as qualitative descriptors of MSFD which will be helpful to improve environmental health.

Harvest Rate (*HR*) is considered as one of the best indicators assessing status of *SSB* of fish stocks (Probst and Oesterwind, 2014). Piet et al. (2010) mentioned that *HR* is suitable for commercial catches (landings) too. Most of the fish stocks in the present analysis had lower *HR* after 2008 than before, indicating that management strategies implemented by ICES such as TACs, controlling fishing effort etc. have resulted in positive signs for rebuilding the fish stocks. However, some fish stocks are being harvested with *HR* of greater than unity, indicating that immature individuals are present in the landings. Even though some *HR* of fish stocks in some areas (like subareas VIII and IX) had improved after 2008, the *MTL* of landings and *SSB* still recorded low. Therefore, further improvement of fish stocks status is still needed. From the present analysis, it is possible to postulate that *MTLs* in *SSB* and landings are also useful to be considered for implementing new management strategies. This is of particular importance because there are difficulties in assigning reference levels for indicators like *HR* (Piet et al., 2010). Nevertheless, Rosenberg (1995) suggested that 0.20 of fishing rate of current level is appropriate to avoid declining of fisheries after maximum harvest. Cardinale et al. (2013) have also given some suggestions and strategies to improve fish stocks in Europe, such as creating large marine reserves, specific fishing gear regulations, integrated maritime management, balanced harvesting and banning discards, etc.

Pauly and Palomares (2005) have shown that “fishing down marine food webs” is a widespread trend in many fisheries of the world, and European marine areas are no exception. This trend has been shown to take place in Portuguese seas (Baeta et al., 2009); Icelandic waters (Valtysson and Pauly, 2003); Spain (Sánchez and Olaso, 2004) and the UK (Molfese et al., 2014). Prior to 2008, fishing pressure was high on higher trophic level species in some subareas of FAO Area 27, which resulted in the dominance of low trophic level species. The North Sea (sub area IV), where excessive fishing has occurred in the past (Emeis et al., 2015), is an example in this study.

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The study was mainly based on *MTL* in fishes to understand the status and the trends of fish stocks in the European marine subareas. *MTL* has been widely used as an indicator of fisheries sustainability (Branch et al., 2010; Fey-Hofstede and Meesters, 2007; Pauly et al., 1998) and biodiversity status (Foley, 2013; Pauly and Watson, 2005). In addition, *MTL*-based indicators are widely used to assess various marine environments (Baeta et al., 2009; Jayasinghe et al., 2015). These indicators are listed as one of the indicators in European Environmental Agency-EEA (Foley, 2013) and other regional marine assessments (HELCOM, OSPAR). EEA demonstrated that *MTL* (or Mean Trophic Index) as an inexpensive, simple and clear demonstration of environmental status that may be applied in all European seas (EEA, 2010). Even though *MTL* is not listed as an indicator in MSFD (EU, 2010), EEA suggested that *MTL* would be an appropriate indicator to be used with the implementation of MSFD (EEA, 2010). In fisheries research, most of the previous studies used the landings data alone for *MTL*-based studies. Shannon et al. (2014) and Gascuel et al. (2014) have shown the importance of *MTL*-based studies combining with other variables and approaches together with landings. Our analysis also showed possibility of using *MTL* of both *SSB* and landings to assess the status of the marine fisheries. Furthermore, the present approach is more realistic because it covers combined information of several commercially important fish species than the conventional fisheries assessments which deal with "single species context" in fisheries management.

5. Conclusions

In the Introduction we posed two research questions that were addressed in this study.

(i) Is there a change in fishing pressure over trophic levels in the context of the implementation of the policy instruments?

Fishing pressure towards high trophic level species seems to be decreasing in subareas I + II and V. This is apparent from the recoding of higher values of *MTL* in landings and higher *MTL* values in *SSB* than *MTL* in landings after 2008. On the other hand, subareas VIII + IX had higher *MTL* in landings, but lower *MTL* in *SSB* than in landings after 2008. It seems this area is being highly overfished. Low values of *MTL*s subareas III, IV and VII could be considered as overfished stocks in these subareas.

(ii) Are fish stocks showing signs of recovery since 2008?

The fishing subareas were categorized according to the *MTL* in landings and *SSB* of the fish stocks after 2008. This study showed the importance of considering *MTL* of both landings and *SSB* while evaluating environment and fish stocks. Most of the fish stocks have increased *SSB* and harvest rate decreased since 2008 showing previous management plans were working on fisheries. Fish stocks appear to be recovering since 2008 in subarea VI. This is supported by values of high *MTL* values in *SSB* than in landings after 2008. However, no recovery is apparent in subareas III, IV and VII where low *MTL* in landings and lower *MTL* in *SSB* than in landings after 2008 were reported. We identified some marine subareas were having low *MTL*s in landings, *SSB* and some fish stocks higher *HR*.

Contribution to fisheries and marine management

Both CFP and MSFD have provisions to work for improving environmental status of seas in order to achieve healthy fish stocks. The study demonstrates that Ecosystem Based Management should incorporate mean trophic levels of fish landings and spawning stock biomass in the assessment of commercial species of fish. Further, using this approach continuous evaluation of major fish populations can be carried out in a robust way, with *SSB* and landings data. A future evaluation (2021) using our approach should show whether the implementation of CFP and MDFD improved the populations of commercial species of fish. This will be a good indication that these policy instruments whether they are delivering the desired results towards improving the status of commercially important fish populations. The starkness of the approach presented in this study is therefore of importance for evaluating fish stocks based on longer time series data before and after implementation of a nowel approach as presented in this study.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2016.07.002.

References

Aanesen, M., Armstrong, C.W., Hoof, L.V., 2012. The changing environment of fisheries policy in Europe. Mar. Policy 36, 1172–1177. http://dx.doi.org/10.1016/j.marpol.2012.02.002.

Arnason, R., 2012. Global warming: new challenges for the common fisheries policy? Ocean Coast. Manag. 70, 4–9. http://dx.doi.org/10.1016/j.ocecoaman.2012.04.003.

Baeta, F., Costa, M.J., Cabral, H., 2009. Changes in the trophic level of Portuguese landings and fish market price variation in the last decades. Fish. Res. 97, 216–222. http://dx.doi.org/10.1016/j.fishres.2009.02.006.

Borja, A., Elliott, M., Carstensen, J., Heiskanen, A.-S., van de Bund, W., 2010. Marine management- towards an integrated implementation of the European marine Strategy Framework and water Framework directives. Mar. Pollut. Bull. 60, 2175–2186. http://dx.doi.org/10.1016/j.marpolbul.2010.09.026.

Branch, T.A., Watson, R., Fulton, E.A., Jennings, S., McGilliard, C.R., Pablico, T., Ricard, D., Tracey, S.R., 2010. The trophic fingerprint of marine fishes. Nature 468, 431–435. http://dx.doi.org/10.1038/nature09528.

Brander, 2010. Impacts of climate change on fisheries. J. Mar. Syst. 79, 389–402. http://dx.doi.org/10.1016/j.jmarsys.2008.12.015.

Brodziak, J., Link, J., 2002. Ecosystem-based fishery management: what is it and how can we do it? Bull. Mar. Sci. 70, 589–611.

Browman, H.I., Stergiou, K.I. (Eds.), 2004. Perspectives on Ecosystem-based Approaches to the Management of Marine Resources. Marine Ecology Progress Series, 274, pp. 269–303.

Cardinale, M., Dörner, H., Abella, A., Andersen, J.L., Casey, J., Döring, R., Kirkegaard, E., Motova, A., Anderson, J., Simmonds, E.J., Stransky, C., 2013. Rebuilding EU fish stocks and fisheries, a process under way? Mar. Policy 39 (0), 43–52. http://dx.doi.org/10.1016/j.marpol.2012.10.002.

Christensen, V., Guénette, S., Heymans, J.J., Walters, C.J., Watson, R., Zeller, D., Pauly, D., 2003. Hundred-year decline of North Atlantic predatory fishes. Fish Fish. 4, 1–24.

EEA, 2010. European Environmental Agency. Marine Trophic Index of European Seas. SEBI, Copenhagen, Denmark, 012.

EEA, 2015. State of Europe's Seas. EEA Report No. 2/2015. ISSN 1977-8449. European Environmental Agency, p. 220.

Emeis, K.-C., Beusekom, J., van Callie, U., Ebinghaus, R., Kannen, A., Kraus, G., Kröncke, I., Lenhart, H., Lorkowsk, I., Matthias, V., Möllmann, C., Pätsch, J., Scharfe, M., Thomas, H., Weisse, R., Zorita, E., 2015. The North sea — a shelf sea in the anthropocene. J. Mar. Syst. 141, 18–33. http://dx.doi.org/10.1016/j.jmarsys.2014.03.012.

EU, Marine Strategy Framework Directive (2008/56/EC) of the European Parliament and the Council, 17th June 2008

EU, Commission Decision on Criteria and Methodological Standards on Good

Environmental Status of Marine Waters (2010/477/EU), 01st September 2010

EU, 2013. Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy. Amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and Repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC Official Journal of the European Union, Brussels.

Fey-Hofstede, F.E., Meesters, H.W.G., 2007. Indicators for the 'Convention on Biodiversity 2010' Exploration of the Usefulness of the Marine Trophic Index (MTI) as an Indicator for Sustainability of Marine Fisheries in the Dutch Part of the North Sea. Wekdocument 53.8, Wageningen.

Foden, J., Rogers, S.I., Jones, A.P., 2011. Human pressures on UK seabed habitats: a cumulative impact assessment. Mar. Ecol. Prog. Ser. 428, 33–47. http://dx.doi.org/10.3354/meps09064.

Foley, C.M.R., 2013. Management implications of fishing up, down, or through the marine food web. Mar. Policy 37, 176–182. http://dx.doi.org/10.1016/j.marpol.2012.04.016.

Froese, R., Pauly, D., 2014. FishBase. World Wide Web electronic publication version (08/2014). www.fishbase.org.

Froese, R., Proelß, A., 2010. Rebuilding fish stocks no later than 2015: will Europe meet the deadline? Fish Fish. 11, 194–202. http://dx.doi.org/10.1111/j.1467-2979.2009.00349.x.

Garcia, S.M., Zerbi, A., Aliaume, C., Do Chi, T., Lasserre, G., 2003. The Ecosystem Approach to Fisheries. Issues, Terminology, Principles, Institutional Foundations, Implementation and Outlook. FAO, Rome. FAO Fisheries Technical Paper. No. 443.

Gascuel, D., Bez, N., Forest, A., Guillotreau, P., Laloë, F., Lobry, J., Mahévas, S., Mesnil, B., Rivot, E., Rochette, S., Trenkel, V., 2011. A future for marine fisheries in Europe (manifesto of the association Françaised'Halieumétrie). Fish. Res. 109, 1–6. http://dx.doi.org/10.1016/j.fishres.2011.02.002.

Gascuel, D., Coll, M., Fox, C., Guénette, S., Guitton, J., Kenny, A., Knittweis, L., Nielsen, J.R., Piet, G., Raid, T., Travers-Trolet, M., Shephard, S., 2014. Fishing impact and environmental status in European seas: a diagnosis from stock assessments and ecosystem indicators. Fish Fish. 17, 31–55. http://dx.doi.org/10.1111/faf.120.90.

Guénette, S., Gascuel, 2012. Shifting baselines in European fisheries: the case of the celtic sea and Bay of Biscay. Ocean Coast. Manag. 70, 10–21. http://dx.doi.org/10.1016/j.ocecoaman.2012.06.010.

HELCOM, 2009. Eutrophication in the Baltic Sea – an integrated assessment of the effects of nutrient enrichment in the Baltic Sea region. Balt. Sea Environ. Proc. 115B.

Jayasinghe, R.P.P.K., Amarasinghe, U.S., Newton, A., 2015. Evaluation of marine subareas of Europe using life history parameters and trophic levels of selected fish populations. Mar. Environ. Res. 112, 81–90. http://dx.doi.org/10.1016/j.marenvres.2015.08.002.

Long, R., 2011. The Marine Strategy Framework Directive: a new European approach to the regulation of the marine environment, marine natural resources and marine ecological services. J. Energy Nat. Resour. Law 29 (1), 1–44. http://dx.doi.org/10.1080/02646811.2011.11435256.

Molfese, C., Beare, D., Hall-Spencer, J.M., 2014. Overfishing and the replacement of demersal finfish by shellfish: an Example from the English Channel. PLoS One 9 (7), e101506. http://dx.doi.org/10.1371/journal.pone.0101506.

Pastoors, M.A., 2014. Exponential growth in the number of words used for the European Common Fisheries Policy (CF P): does better management require more text? Mar. Policy 46, 101–104. http://dx.doi.org/10.1016/j.marpol.2014.01.008.

Pauly, D., Palomares, M.L., 2005. Fishing down marine food web: it is far more pervasive than we thought. Bull. Mar. Sci. 76 (2), 197–211.

Pauly, D., Watson, R., 2005. Background and interpretation of the 'marine trophic Index' as a measure of biodiversity. Phil. Trans. R. Soc. B Biol. Sci. 360, 415–423. http://dx.doi.org/10.1098/rstb.2004.1597.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., Torres Jr., F.C., 1998. Fishing down marine food webs. Science 279, 860–863. http://dx.doi.org/10.1126/science.279.5352.860.

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, 689–695. http://dx.doi.org/10.1038/n ature01017.

Piet, G.J., Albella, A.J., Aro, E., Farrugio, H., Lleonart, J., Lordan, C., Mesnil, B., Petrakis, G., Pusch, C., Radu, G., Ratz, H.J., 2010. Marine Strategy Framework Directive – Task Group 3 Report. Commercially Exploited Fish and Shellfish. EUR 24316 EN – Joint Research Centre. Office for Official Publications of the European Communities, Luxembourg, p. 82.

Pitcher, T.J., Hart, P.J.B., Pauly, D., 2001. Reinventing Fisheries Management. Kluwer Academic Publishers, Dordrecht/Boston/London.

Prellezo, R., Curtin, R., 2015. Confronting the implementation of marine ecosystem-based management within the Common Fisheries Policy reform. Ocean Coast. Manag. 117, 43–51. http://dx.doi.org/10.1016/j.ocecoaman.2015.03.005.

Probst, W.N., Oesterwind, D., 2014. How good are alternative indicators for spawning-stock biomass (SSB) and fishing mortality (F)? ICES J. Mar. Sci. http://dx.doi.org/10.1093/icesjms/fst207.

Rombouts, I., Beaugrand, G., Fizzala, X., Gaill, F., Greenstreet, S.P.R., Lamare, S., Le Loc'h, F., McQuatters-Gollop, A., Mialet, B., Niquil, N., Percelay, J., Renaud, F., Rossberg, A.G., Féral, J.P., 2013. Food web indicators under the marine Strategy Framework directive: from complexity to simplicity? Ecol. Indic. 29, 246–254. http://dx.doi.org/10.1016/j.ecolind.2012.12.021.

Rosenberg, A.A., 1995–1996. Precautionary Management Reference Points and Management Strategies. In Precautionary Approach to Fisheries. Part 2: Scientific Papers. Prepared for the Technical Consultation on the Precautionary Approach to Capture Fisheries (Including Species Introductions). Lysekil, Sweden, 6–13 June 1995. FAO Fisheries Technical Paper. No. 350, Part 2. FAO, Rome, p. 210. Available online: http://www.fao.org/docrep/003/w1238e/W1238E00.htm#TOC.

Sánchez, F., Olaso, I., 2004. Effects of fisheries on the Cantabrian Sea shelf ecosystem. Ecol. Model. 172, 151–174. http://dx.doi.org/10.1016/j.ecolmodel.2003.09.005.

Shannon, L., Coll, M., Bundy, A., Gascuel, D., Heymans, J.J., Kleisner, K., Lynam, C.P., Piroddi, C., Tam, J., Travers-Trolet, M., Shin, Y., 2014. Trophic level-based indicators to track fishing impacts across marine ecosystems. Mar. Ecol. Prog. Ser. 512, 115–140. http://dx.doi.org/10.3354/meps10821.

Valtysson, H., Pauly, D., 2003. Fishing down food web: an Icelandic case study. In Competitiveness within the global fisheries. In: Guomundsson, E., Villasante, S. (Eds.), Proceedings of a Conference Held in Akureyri, Iceland. April 6-7 2000. University of Akureyri, Akureyri, Iceland, pp. 12–24. Available online: http://www.seaaroundus.org/researcher/dpauly/PDF/2003/Books&Chapters/FishingDownTheFoodWebIcelandicCaseStudy.pdf.

Villasante, S., 2010. Global assessment of the European Union fishing fleet: an update. Mar. Policy 34 (3), 663–670. http://dx.doi.org/10.1016/j.marpol.2009.12.007.

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