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Short communication

Recent data suggest no further recovery in North Sea Large Fish Indicator

Tak Fung[1]*, Keith D. Farnsworth[1], David G. Reid[2], and Axel G. Rossberg[1]

[1]*School of Biological Sciences, Queen's University Belfast, 97 Lisburn Road, Belfast BT9 7BL, UK*
[2]*Fisheries Science Services, Marine Institute, Rinville, Oranmore, Co. Galway, Ireland*

**Corresponding Author. tel: +44 28 9097 2103; fax: +44 28 9097 5877; e-mail: tfung01@qub.ac.uk.*

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We detail the calculations of North Sea Large Fish Indicator values for 2009–2011, demonstrating an apparent stall in recovery. Therefore, recovery to the Marine Strategy Framework Directive's good environmental status of 0.3 by the 2020 deadline now looks less certain and may take longer than was expected using data from 2006 to 2008.

Keywords: community ecology, EAFM, LFI, MSFD, North Sea, OSPAR.

Introduction

The Large Fish Indicator (LFI) is a univariate metric characterizing the size spectrum of a fish community. It is defined as the biomass of fish above a length threshold ("large" fish) expressed as a proportion of the total fish biomass (Heslenfeld and Enserink, 2008; Greenstreet *et al.*, 2011; Shephard *et al.*, 2011). This means that the LFI captures decreases in large fish biomass caused by size-selective fishing (Pauly *et al.*, 1998; Shin *et al.*, 2005), as well as increases in small fish biomass caused by release from predation by large fish that have been fished (trophic cascades;, e.g. Frank *et al.*, 2005). Therefore, the LFI responds to both the direct and indirect effects of fishing (Greenstreet *et al.*, 2011; Shephard *et al.*, 2011).

The LFI has been adopted by OSPAR as an indicator for defining a fish community Ecological Quality Objective, under the Ecosystem Approach to Fisheries Management (Pikitch *et al.*, 2004; Heslenfeld and Enserink, 2008). It has also been listed as an indicator of "good environmental status" (GES) of foodwebs for the Marine Strategy Framework Directive (MSFD; Descriptor 4; European Commission, 2010). The MSFD requires member states to "take the necessary measures to achieve or maintain good environmental status in the marine environment by the year 2020 at the latest" (EU, 2008), so, if adopted, the recovery of the LFI to GES reference levels will become a statutory management goal.

Greenstreet *et al.* (2011) reviewed and summarized a decade of work by ICES that led to the selection and subsequent development of the LFI as a univariate metric for the state of demersal fish communities. Following the MSFD (EU, 2008), the LFI has been applied to several regions, including the North Sea (Greenstreet *et al.*, 2011), Celtic Sea (Shephard *et al.*, 2011), Baltic Sea (ICES, 2011b), and Grand Banks (ICES, 2011b). However, the operational development of this index is most advanced for the North Sea. Here, a large fish threshold of 40 cm was proposed for the demersal fish community, since it maximized the LFI sensitivity to fishing as opposed to environmentally driven recruitment variations (Greenstreet *et al.*, 2011). A reference level of 0.3 (using the 40-cm threshold) was proposed for the North Sea (Greenstreet *et al.*, 2011), where the LFI declined from 0.3 in 1983 to a low of 0.05 in 2001, followed by some recovery to 0.22 in 2008 (Greenstreet *et al.*, 2011). If this form of the LFI for the North Sea is adopted by MSFD member states with jurisdiction in the North Sea, fisheries management will have to ensure continued recovery to the GES reference level of 0.3 by 2020. Regular estimates of the North Sea LFI are therefore needed, but the last published was for 2008. Here, we report our calculations of the North Sea LFI for the years 2009–2011, displaying an apparent stall in recovery. We then present a discussion of the implications for fisheries management, including the consideration of the frequency with which it is useful to update the LFI.

Material and Methods

By definition (Greenstreet *et al.*, 2011), the North Sea LFI is based on data from the North Sea International Bottom Trawl Survey (IBTS) for the first quarter of each year. The IBTS covers the

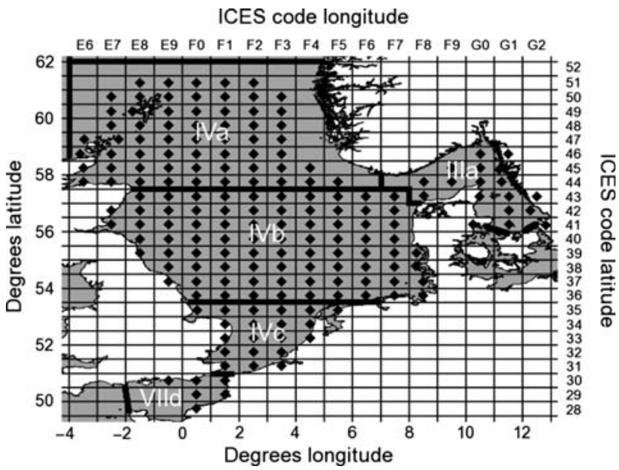

Figure 1. Map showing the area sampled by the IBTS during the first quarter of years 1986–2011. The bold lines delineate ICES Subareas, labelled as IIIa, IVa, IVb, IVc and VIId (ICES, 1977; http://www.fao.org/fishery/area/Area27/en). ICES rectangles marked with a diamond have at least one fish sampled by the IBTS during 1986–2011, according to DATRAS. This figure is based on ERSI shape files downloaded from ICES (http://geo.ices.dk/). Detailed maps of IBTS-sampled rectangles by year and species are available directly from ICES (http://ecosystemdata.ices.dk/Map/).

Greater North Sea region, specifically ICES Subareas IIIa, IV, and VIId (Figure 1). These data are publically available from the ICES Database of Trawl Surveys (DATRAS; http://datras.ices.dk/Home/Default.aspx). The data from DATRAS are for sampled organisms classified into taxonomic groups, mostly to the species level; each sampled organism is also classified by haul and length class. The cpue (catch per unit effort, i.e. the number of organisms caught per hour) is given for each combination of the taxonomic group, haul, and length class. Conversion of these data into LFI values involved several processing steps: removal of data for non-fish organisms and non-demersal fish; deletion of "dubious entries" (Daan, 2001); deletion of entries for Subarea VIId to ensure consistency with Greenstreet *et al.* (2011); conversion of numbers by the taxonomic group, haul, and length class into biomasses using appropriate length–weight regression parameters; and conversion of biomasses into biomass densities. A detailed protocol for these processing steps has not previously been published, and neither have some of the relevant parameters (e.g. length–weight regression parameters).

Below, we first detail the protocol followed in our calculations. It was developed using information available from Greenstreet *et al.* (2011), but in such a way that the LFI can be computed directly from IBTS data available by direct download from DATRAS. In contrast, Greenstreet *et al.* (2011) worked with raw IBTS data obtained directly by a formal request from ICES. To confirm that our approach gives LFI values closely matching those of Greenstreet *et al.* (2011), we then applied our protocol to the first quarter (Q1) IBTS data covering 1986–2008, from DATRAS, to derive a corresponding LFI time-series and compared this series with that of Greenstreet *et al.* (2011). DATRAS data for 1983–1985 were not used because these are not standardized for the same gear (GOV gear). Following the confirmation, we applied our protocol to Q1 IBTS data from 2009 to 2011 to calculate the most recent LFI trend. All DATRAS data were downloaded from the DATRAS website on 22 October 2011, in the format "cpue per length per haul", and 20 November 2011, in the formats "Exchange Data" and "SMALK". The data types used in each of these formats are given below, together with how they were used.

In detail, our protocol consists of the following steps. (i) Organisms were classified as fish or non-fish using the World Register of Marine Species (http://www.marinespecies.org/), enabling the removal of data for non-fish organisms. (ii) Fish were classified as demersal or non-demersal using the classifications of Greenstreet and Hall (1996) and Fraser *et al.* (2007) for the North Sea, supplemented by information from FishBase (Froese and Pauly, 2011), permitting the removal of data for non-demersal fish. (iii) "Dubious entries" were identified following Daan (2001) and either changed or deleted as appropriate. (iv) Entries sampled in ICES Subarea VIId were deleted to be consistent with Greenstreet *et al.* (2011). Note that although Greenstreet *et al.* (2011) stated that data from ICES Subarea IV were used, data from ICES Subarea IIIa were used as well (S. P. R. Greenstreet, in prep.). Subarea VIId entries only occur in 2007–2011 and their inclusion or exclusion has very little effect on the LFI (see Supplementary material for more detail). (v) For each remaining fish taxonomic group, length–weight regression parameter values were computed using DATRAS IBTS length–weight data (given in DATRAS data in the "SMALK" format) where possible. Failing this, North Sea parameter values from other sources were used where possible (Coull *et al.*, 1989; Robinson *et al.*, 2010) and parameter values for other locations were used otherwise (using references from FishBase; Froese and Pauly, 2011). (vi) Using the length–weight parameters, for each taxonomic group, length class, and haul, the number of organisms caught per hour (given in DATRAS data in the "cpue per length per haul" format) was converted into biomass caught per hour:

$$B_{ijkmn} = N_{ijkmn} a_i L_j^{b_i}, \tag{1}$$

where B_{ijkmn} and N_{ijkmn} are the biomass caught per hour ($g\,h^{-1}$) and the number of individuals caught per hour (h^{-1}), respectively, for taxonomic group i, length class j, and haul k by vessel m in year n; a_i and b_i the length–weight regression parameters for taxonomic group i, which convert length (cm) to biomass (g); and L_j the mid-point of length class j (cm).

(vii) The biomasses of organisms caught per hour were converted to biomass densities. For a particular taxonomic group, length class, and haul, the biomass density is equal to the biomass caught divided by the swept-area. The swept-area can be calculated as the fishing gear wingspread multiplied by the distance towed, which is the product of haul duration and vessel groundspeed. Since the biomass caught per hour is the biomass caught divided by the haul duration (in h), this gives the following formula for converting biomass caught per hour to biomass density:

$$\rho_{ijkmn} = \frac{b_{ijkmn}}{A_{kmn}} = \frac{b_{ijkmn}}{S_{kmn} d_{kmn}} = \frac{b_{ijkmn}}{S_{kmn} t_{kmn} v_{kmn}} = \frac{B_{ijkmn}}{S_{kmn} v_{kmn}}, \tag{2}$$

where ρ_{ijkmn} and b_{ijkmn} are the biomass density ($g\,m^{-2}$) and biomass (g), respectively, for taxonomic group i, length class j, and haul k by vessel m in year n; A_{kmn} the swept-area (m^2) of haul k by vessel m in year n; and S_{kmn}, d_{kmn}, t_{kmn}, and v_{kmn} the wingspread (m), towed distance (m), haul duration (h), and groundspeed (m h^{-1}) for haul k by vessel m in year n. S_{kmn} values were available (in DATRAS data in the "Exchange Data" format) for 17% of all hauls in 1986–2011, corresponding to 18% of all biomass density entries. For a further 69% of hauls (63% of biomass density entries), S_{kmn} was estimated as the average over the available S_{kmn} values for the same ICES rectangle; the rectangles were given in DATRAS data in the "cpue per length per haul" format. For the remaining 14% of hauls (19% of biomass density entries), S_{kmn} was estimated using the depth of the haul (m), D_{kmn}, and the regression line $S_{kmn} = 6.33(\log_{10} D_{kmn}) + 7.14$ ($n = 1716$, $r^2 = 0.44$, where r is the Pearson's product–moment correlation coefficient), derived using pairs of S_{kmn} and D_{kmn} values from DATRAS data in the "Exchange Data" format. D_{kmn} values were available in DATRAS data in the "cpue per haul per length" format for almost all the remaining hauls. For the <0.1% of hauls without D_{kmn}, this value was estimated as the average over available D_{kmn} values for the same ICES rectangle.

v_{kmn} values were available (in DATRAS data in the "Exchange Data" format) for 47% of all hauls in 1986–2011, corresponding to 51% of all biomass density entries. For a further 36% of hauls (33% of biomass density entries), v_{kmn} was calculated as d_{kmn}/t_{kmn} using d_{kmn} and t_{kmn} values given in DATRAS data in the "Exchange Data" format. For the remaining hauls, v_{kmn} was estimated depending on data availability. Considering one of these hauls, if there was at least one v_{kmn} value for another haul by the same vessel m in year n, then v_{kmn} was estimated as the average of v_{kmn} values for hauls by the same vessel in the same year; this was the case for 1% of hauls (1% of biomass density entries). If there were no v_{kmn} values for the same vessel and year, but there was at least one v_{kmn} value for another haul by the same vessel in a different year, then v_{kmn} was estimated as the average of v_{kmn} values for hauls by the same vessel m in different years; this was the case for 7% of hauls (6% of biomass density entries). If there were no v_{kmn} values for the same vessel in any year, then v_{kmn} was estimated as the average of v_{kmn} values for hauls by different vessels in all years; this was the case for 9% of hauls (9% of biomass density entries).

(viii) For each year considered, the LFI was then calculated by summing the biomass densities of all fish individuals with length >40 cm in the year considered and then dividing the result by the sum of the biomass densities of all fish individuals in the same year:

$$\mathrm{LFI}_n = \frac{\sum_i \sum_{j:L_j>40\mathrm{cm}} \sum_k \sum_m \rho_{ijkmn}}{\sum_i \sum_j \sum_k \sum_m \rho_{ijkmn}}, \tag{3}$$

where LFI_n is the LFI in year n.

To make our method transparent and our results reproducible, we provide, as Supplementary material, a list of all the taxonomic groups considered and their classification as demersal fish, non-demersal fish, or non-fish, together with details of which dubious entries were changed or deleted. Furthermore, we provide a list of synonymous demersal fish species names identified (only one name for each species retained) and a list of all length–weight regression parameters used. For the regression parameters, the corresponding sample sizes, length ranges of the samples, sampling locations, and references are also given, together with a discussion of the quality and relevance of the data used to derive the parameters.

Results

Figure 2 shows the complete LFI time-series we calculated for 1986–2011 and compares it with that calculated by Greenstreet *et al.* (2011) for 1983–2008. A strong correlation between the two time-series ($r^2 = 0.789$, $n = 23$) is evident during the period of overlap 1986–2008. The average absolute difference (over the 23 years) between the two time-series is 0.00984, which we take to be very small. Following the LFI increase in 2007/2008, the trend in the LFI found for 2009–2011 does not support a prediction of continued recovery, but rather shows an apparent stall in recovery, not inconsistent with an unsteady decline (Figure 2).

The years 2007 and 2008 show an anomalous deviation between our LFI values and those calculated by Greenstreet *et al.* (2011). This is explained by an unusually large increase in the proportion of large fish during 2007 and 2008 in the Kattegat and Skagerrak subarea (corresponding to ICES Subarea IIIa) within the data used by Greenstreet *et al.* (2011) (Figure 3). This large increase is not seen in the DATRAS data (Figure 3), which is continuously updated and corrected by an ICES Working Group (ICES, 2011a). If data from Kattegat and Skagerrak in 2007 and 2008 are excluded, then the two LFI time-series calculated using the protocol in this study and the protocol by Greenstreet *et al.* (2011) differ by <0.007 in 2007 and 2008 (S. P. R. Greenstreet, pers. comm.). The datasets differed for Kattegat and Skagerrak in 2007 and 2008 due to the inclusion of entries from ICES rectangle 40G2 in the data of Greenstreet *et al.* (2011) (S. P. R. Greenstreet, in prep.). This square had a high abundance of large cod in the anomalous years, considerably inflating the LFI calculated by Greenstreet *et al.* (2011) for 2007 and 2008 (S. P. R. Greenstreet, in prep.; Figures 2 and 3). However, this square lies outside ICES Subarea IIIa (Figure 1; ICES, 1977; http://www.fao.org/fishery/area/Area27/en) and should therefore be excluded as done in the IBTS data available from DATRAS. There is an excellent fit ($r^2 = 0.956$, $n = 21$) between the LFI series calculated using DATRAS data and that calculated by Greenstreet *et al.* (2011) over

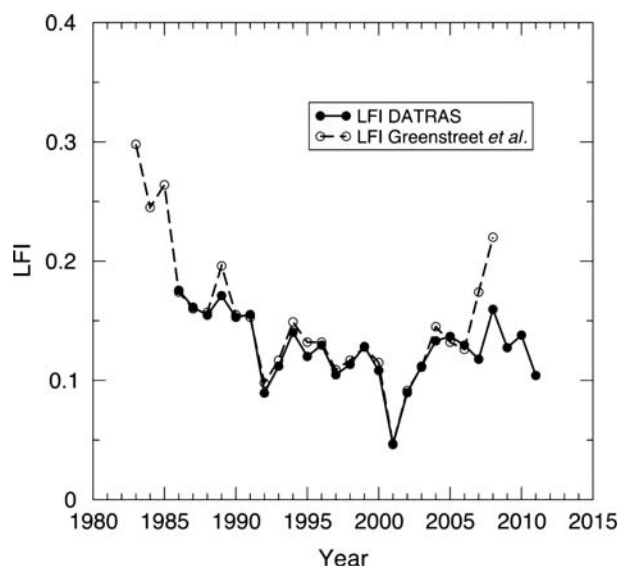

Figure 2. 1986–2011 time-series for the LFI calculated using Q1 IBTS data following the method detailed in this paper (solid line), together with the 1983–2008 time-series for the LFI calculated by Greenstreet *et al.* (2011) (dashed line).

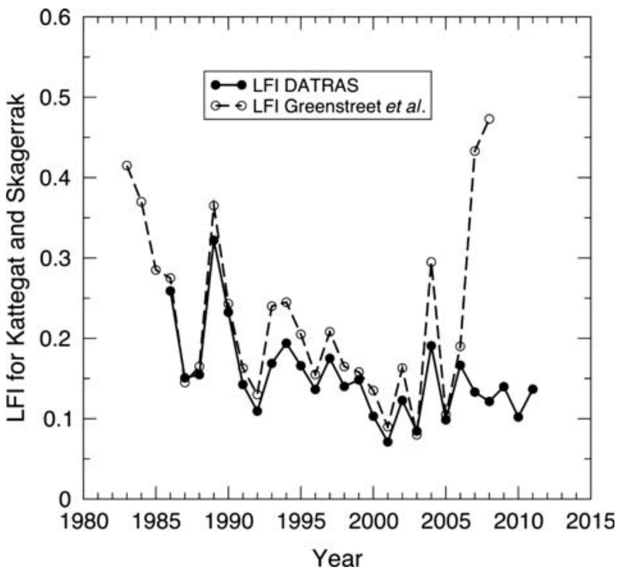

Figure 3. 1986–2011 time-series for the LFI in the Kattegat and Skagerrak subarea (corresponding to ICES Subarea IIIa) calculated using Q1 IBTS data following the method detailed in this paper (solid line); also shown is the corresponding 1983–2008 time-series for the LFI calculated by ICES (2010, Figure 5.5.3) using the data and protocol of Greenstreet *et al.* (2011) (dashed line).

the years 1986–2006, with an average absolute difference of 0.00522.

Discussion

An indicator with wide-ranging policy implications should be robust to minor variations in the protocol used to compute it. Notwithstanding data issues in 2007 and 2008, already discussed, our work confirms this property for the LFI. We worked with an IBTS dataset available by direct download from a public website, whereas Greenstreet *et al.* (2011) used a different, raw IBTS dataset that is not; as expected, this resulted in minor protocol variations. An indicator protocol that is based on free, public data and a simple, published algorithm for computation, as proposed in this paper, has the advantage of allowing all stakeholders to verify the results. The protocol we propose also invites research for further improvement, detailed studies of how management measures could affect the LFI, and updating of LFI values when new catch data become available.

Updating the North sea LFI from 2009 to 2011, together with a recalculation in 2007 and 2008 that includes only ICES rectangles in Subareas IIIa and IV, has shown no evidence of continued recovery in the index beyond 2008. This apparent stall in recovery suggests that meeting GES by 2020, corresponding to an LFI reference level of 0.3, now looks less certain and may take longer than would be expected given data calculated by Greenstreet *et al.* (2011) covering 2006–2008. This expectation was quantified by Greenstreet *et al.* (2011) using seven linear regression models, assuming that the LFI lagged the community-averaged fishing mortality by 12–18 years. The average of these models predicts an increasing LFI trend beyond 2008 so as to nearly reach the reference value by 2020 (Greenstreet *et al.*, 2011). Our update of the time-series for 2009–2011 shows that the 2020 target might be missed by a wider margin. Importantly, the new data (Figure 2) fail to support the prediction of LFI values based on a lagged correlation with the community-averaged fishing mortality—such an extrapolation would have suggested an increasing trend for the LFI in 2009–2011, corresponding to a decreasing trend in the fishing mortality in 1991–1999 (Greenstreet *et al.*, 2011). Recovery may be more complex a process than can be represented by an inverse linear time-lagged relationship between LFI and fishing mortality.

An adequate time interval for updating the LFI values is determined by a balance between the costs of updating and the benefits provided by the added information. Given that IBTS surveys are carried out yearly for other purposes and the data made available on DATRAS soon thereafter, the costs reduce to that of doing the calculations. The protocol described here can be fully automated, so that a yearly LFI update would come at minimal costs. Updating the LFI as often as every year gives rise to the benefit of reducing uncertainties faced by stakeholders planning on the basis of projected LFI trends. Such projections are subject to two kinds of uncertainty. First, the LFI time-series exhibit noticeable year-to-year fluctuations, resulting from a combination of statistical and ecological effects (future studies will need to disentangle and determine the relative strengths of these contributions). Any additional datapoint contributes to an averaging out of fluctuations at the end of the time-series, which can lead to better extrapolations for a given target year. Second, there remains considerable uncertainty regarding the processes driving the long-term dynamics of the LFI and associated response times. Large fish grow slowly relative to small fish, so it is expected that large fish biomass recovers slowly compared with small fish biomass (Hutchings, 2000). Therefore, it might be expected that the LFI also recovers slowly, perhaps approximately decades. However, Hutchings (2000) examined the recovery of 31 stocks of gadoids after 40–100% decreases in reproductive biomass and found that although most of them experienced little to no recovery after 5 years, eight of them recovered by over 20% of their original, pre-decline biomass and two made a full recovery (see Figure 2 in Hutchings, 2000). In addition, North Sea simulations using the FishSUMS model suggest that the LFI can exhibit large increases within 3 years if fishing pressure is low enough, $<$60% of 2006 levels (ICES, 2010, Figure 5.4.2.2.1). Currently, there is no generally accepted theory for the processes determining the time-scale of LFI recovery. Annual LFI updates can be useful for differentiating between models predicting different recovery rates, thus further reducing uncertainty for stakeholders using LFI projections. Therefore, we expect that the overall benefits of updating the LFI regularly, even as often as once a year, would outweigh the costs. However, we emphasize that an additional LFI value, arising from a regular update, should be interpreted in conjunction with all preceding LFI values to maximize the reliability of any derived trend—this is implied in our analysis above.

The LFI trend we found over 2009–2011 should be compared with those obtained using alternative protocols (e.g. that of Greenstreet *et al.*, 2011); if the same trend is found across protocols, then this strengthens support for this trend and the robustness of the LFI to protocol variations. Obviously, our updating by another 3 years does not necessarily predict a future trend, but it emphasizes the need for regular updates from now on. In addition, it provides an early indication suggesting that continued recovery of the North Sea demersal fish community to GES may require further (perhaps more sophisticated) management than the reduction in effort achieved so far.

Supplementary material

The following supplementary material is available at *ICESJMS* online: "Processing of ICES DATRAS 1986–2011 North Sea IBTS Data", which includes a list of the taxonomic groups considered and their classification as demersal fish, non-demersal fish, or non-fish; a list of synonymous demersal fish species names identified; details of which dubious entries were deleted or changed following Daan (2001); and a list of all the length–weight regression parameters used for demersal fish.

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