Anonymous Referee #1

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General Comments:

The manuscript presents a dataset of trawling effort in the North Sea, comprised of compiled as well as estimated data. The authors clearly explain why there is a need for such a dataset and ways in which it can be useful to future scientific studies. The manuscript is well written, and the language is clear and easy to understand.

The link for the dataset is functional, and metadata are included on the linked page. The map tab on the linked page shows the North Sea location. The map lacks the functionality of being able to display the trawl data, but this functionality is not critical.

Actually the map is able to display the trawl data; clicking on a location will display the data linked to it.

The data files (.csv and .shp) can be easily downloaded and opened. However, when viewing the shapefile in ArcCatalog, there are no metadata associated with the file. I recommend adding metadata to the file.

The shapefile was not generated by the authors. It is automatically generated from the csv file by the Data Hub's GEOSERVER. Unfortunately, there is no functionality currently that allows us to embed metadata on the shapefile. The metadata is displayed on the website with the download links, as noticed by the reviewer.

The inclusion of the estimated data is what makes this dataset unique, as it otherwise would only be a compilation of datasets already in existence.

We would like to point out that while the compiled datasets were indeed in existence, not all of them were published or readily accessible (e.g., downloadable from the internet), so even without the estimated data we believe the compilation itself could also prove useful.

It is therefore critical to have a measure of validity of these estimated data. While the authors acknowledge that there are errors associated with the estimated data, these are not quantified. The authors should consider if there are any methods which would be appropriate to validate their estimated data. For example, are there data outside of the study period (1985-2015) that could be used in order to conduct validation? If not, could data be removed and used as a testing dataset in order to statistically analyze how their methods perform? If the author thinks validation in this manner would not be appropriate or possible, they should consider whether there are any other methods by which they could quantify error.

We have now carried out an estimation of the errors of the estimated trawling hours. This was done for each individual country by reconstructing a period for which there was country data, so that the reconstruction could be compared by the real data and an error estimated as the median of the relative differences in all cells in the grid. In each case the period estimated and the method of estimation was kept as close as possible to the real estimation. See lines 24-33, page 5 and Table 2 in the revised manuscript.

The other point that needs to be addressed with the estimated data is in regards to the methods used to select the length of the time period utilized in calculating average spatial distribution. This will be explained in the following section.

See our response in the following section.

Specific Comments:

When performing the trawling effort reconstruction, the authors clearly state what data are being used to calculate the average spatial distribution of effort for each country. However, it is not explained why certain time periods are used and why different lengths of data are used for different countries. For example, for the 1985-1986 reconstruction, the Denmark spatial distribution is based on data from 1987-1989 (3 of the available 29 years for Denmark), whereas the French spatial distribution is based on data from 2000-2015 (16 of the available 16 years for France). Why was the number of years used not kept consistent when possible? How were decisions made about what length of time to use? This should either be kept consistent when possible (when the data are available to allow for it), or the authors should explain why using differing lengths of time is a more appropriate method.

In this revision we have recomputed the estimated trawling in a more systematic and consistent way and explained the rules we followed in the reconstruction (lines 4-17, page 5). As we say in the manuscript, we expect the spatial distribution of trawling effort to change slowly over time, and therefore have based the reconstruction of the spatial distribution of a country's trawling effort over a missing period as follows: For *n* missing years we have averaged the *n*/2 before and *n*/2 years after (or when this was impossible due to a lack of early data, on the *n* years after). See lines 6-11, page 5 in the revised manuscript.

If spatial distribution is assumed to change gradually over time as is stated in the assumptions, using a long time period when calculating average spatial distribution may result in loss of temporal specificity. Therefore, if a long time period is used for calculating average spatial distribution, it should be explained why this is appropriate.

We have now used the average spatial distribution of a period of the same duration as the period with missing data, and as close as possible in time to it (lines 6-11, page 5). There will indeed be a loss of temporal specificity when reconstructing a long time period, but this is inevitable. We also account for this when estimating errors, since the periods that were reconstructed for the estimation of the errors were, when data allowed, of the same duration as the periods with missing data.

Assumption 2 of the trawling effort estimates acknowledges that under particular circumstances, major changes may occur in spatial distribution. Were any major changes seen in the compiled trawling data? If so, how was this considered when estimating data?

We were referring to major social changes, such as those at the beginning of World War II which brought fishing in the North Sea to a near standstill. We are not aware of any such significant abrupt change taking place during our study period. We have clarified this in lines 31-33, page 4.

It is not made clear why there is no beam trawling data for Sweden. Is beam trawling not occurring, or is it occurring but there are no data?

Indeed, beam trawl effort by Swedish vessels in the North Sea has been absent or negligible (although otter trawl effort is fairly considerable). For example, in 2003, 2006, 2009 and 2012 respectively, there were reportedly 16574, 10535, 8116 and 5333 hours fishing by Swedish bottom otter trawlers in the North Sea, but 0 hours beam trawling in any of these years (according to the STECF database). Within 2003-2012 no Swedish beam trawl effort was officially reported to STECF. We now mention this on the manuscript in lines 3-4, page 3.

The listed countries are the most significant contributors to trawling in the North Sea, but are there other countries also trawling here? If so, approximately how much of the trawling effort can be attributed to the countries included in this study? Can an approximate quantification be given?

The listed countries comprise >99% of trawling effort in the North Sea. There are some further countries that sporadically exert trawling effort in the North Sea; these include Northern Ireland (on average, 0. 5% of total EU trawling effort over the period 2003-2012), Ireland (0.0005%) and Jersey (0.0002%). It is of note that prior to the introduction of Exclusive Economic Zones (EEZs) in 1977, countries not bordering the North Sea did in some years exert significant trawling pressure in the North Sea (e.g. Poland and the USSR in the 1960s and early 1970s; see Kerby et al., 2012), but this is well before the period under study here. We have added a clarification about this in line 5, page 3.

I found the description of the explanation for the discrepancy between the STECF data and the Scotland and England data (presented on page 9) to be not entirely clear. It is also unclear whether similar discrepancies would have been expected between STECF and other countries if data for other countries had been available. Did similar discrepancies exist for Denmark (the other country with a country-specific dataset)?

We agree that these discrepancies are somewhat puzzling, and as mentioned in the manuscript (lines 8-17, page 8), we are not able to explain these fully, though we suspect they stem from the conversion factor from days at sea to hours (24 is used by STECF in the case of England and Scotland, which does not acknowledge steaming time and other non-fishing hours). We find no such discrepancies for Denmark, where the national effort data almost perfectly matches that of STECF. We now mention this in lines 17-18, page 8.

Technical Corrections:

There is currently inconsistency in indenting paragraphs in the introduction section (some paragraphs are indented at the beginning and some are not).

This has now been corrected.

There is inconsistency in whether the word ‘data’ is used as singular or plural throughout the manuscript.

Thanks for pointing this out. We have gone over the manuscript checking the instances “data” appears to make sure it is always used in the singular.

In the abstract, the following sentence has potentially confusing wording: “The dataset was largely reconstructed using compiled effort data from 7 fishing effort time-series, each covering shorter time spans and some of the countries fishing the North Sea only.” This could be clarified in the following way: “The dataset was largely reconstructed using compiled effort data from 7 fishing effort time-series, each covering shorter time spans and only some of the countries fishing the North Sea.”

Thanks for this, sentence has been changed as suggested.

On Page 3 line 15, it states “For the 1977-1995 period...”. This is confusing, since the remainder of the paper states 1985 as the beginning of the period included.

We have replaced this with “For the earliest period until 1995” (line 14, page 3).

Typographical errors:

Page 8 line 15 - for the use of the data provided
Page 9 lines 15-16 - a factor of 2
Page 10 line 5 - rectangles
Page 11 line 13 - in relation to fishing pressure

All these have now been corrected.

Anonymous Referee #2

Received and published: 10 November 2019

First of all, I would like to recognize the huge work done by the authors and the potential relevance of this contribution. However, I think that the present version of this dataset

is characterized by some severe drawbacks. I identified three main problems in this paper:

1) the authors collated different blocks of data from different sources. Each of these datasets contains Nominal Effort (fishing effort in hours fishing) by area, for trawlers and beam trawlers. Unfortunately, it is largely acknowledged that all the impacts of these fishing gears are monotonically linked to the size / engine power of vessels. In the meantime, it is a fact that the structure of the EU fishing fleets changed a lot during the last decades. These two aspects, in combination, lead to the conclusion that the time series provided by the authors are not consistent. In other words, the values of effort at the beginning of the time series could not be compared with those at the end.
   A potential solution for this issues is represented by the combined usage of data about effort and data about fleet structure, assuming that the spatial distribution of fishing activities is the same for different fleet segments (a huge assumption, of course);

We fully agree that the structure of the fishing fleet and the fishing technologies have changed considerably over the 31 year period, and that therefore the potential impact on the seafloor of one hour of trawling effort in 1985 is likely to be very different than an hour in 2015. We already discuss this issue in lines 18-25, page 9. However, we have made it very clear throughout the manuscript that what we were compiling and reconstructing was **trawling effort**, quantified as hours of trawling by fishing vessels, and not "impact". This data is, by itself, relevant, and has a wide range of applications. For the particular application of analysing impact on benthic fauna it may be advisable to somehow "correct" this data to take into account technical developments (as we discuss in the manuscript in lines 22-25, page 9); for other applications it may not (i.e., a social study could just be interested in the number of hours themselves, possibly combined with other datasets regarding, for example, the numbers of people involved in the fishing industry, number of boats, etc). Data about the structure and evolving technology of the EU fishing fleet is unfortunately not readily available, certainly not at the spatio-temporal scale of this study. Some general estimations and approximations could be made, however we leave this as a subject for future work as it exceeds the aims of this manuscript.

2) Moreover, the efficiency of fishing gears changed (increased) during the last decades, as a consequence of the effort creep;

See our answer above for it also applies to this.

3) about the estimation of missing data: I think that the authors should at least crossvalidate the fitting methods applied. This is possible (and not very complicated) if some random years, for which data are not missing, are selected and used to evaluate the goodness of estimations. Cross-validation is a very common class of techniques that can be adapted to different case studies.

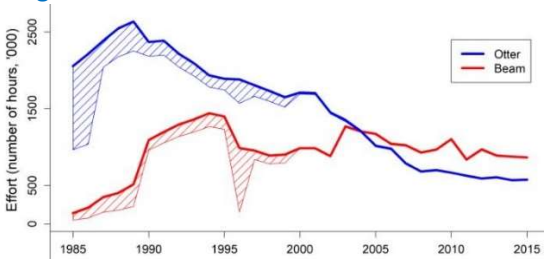
We fully agree that it is necessary to assess the reliability of the reconstructed missing data, and as the reviewer suggests we have done this by reconstructing non-missing data for each of the countries, and assessing how the reconstruction compares to the nominal data. However, instead of choosing random years we have attempted in each case to select periods that are as close as possible to the periods that had to be estimated due to missing data. See manuscript,

lines 24-33, page 5, together with Table 2. Additionally we have updated the dataset so that it now includes these errors.

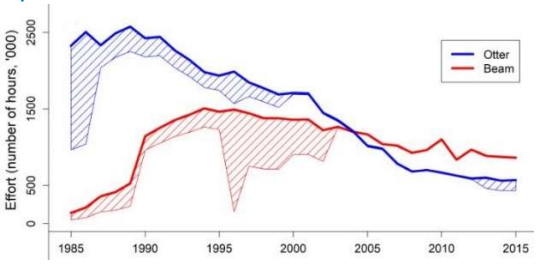
Note from the authors:

In addition to the changes suggested by the reviewers, it has also come to our attention that the data for the effort of the beam trawling German fleet in the 1997-2002 period in the MAFCONS dataset does not include shrimp trawls. These are, however, included in the STECF dataset and also, we believe, in the Jennings et al datasets, and represent a significant contribution to the total beam trawling pressure in the North Sea. Therefore for consistency we have decided not to use the MAFCONS beam trawling data for Germany and have instead estimated it in this period (see lines 27-31, page 3 in the revised manuscript). As a result of this, our reconstructed total pressure in the North Sea for this period now looks quite different as reflected in the revised Fig. 1 (see comparison below).

Original reconstruction:



Updated reconstruction:



Reconstructing three decades of total international trawling effort in the North Sea

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Abstract. Fishing – especially trawling – is one of the most ubiquitous anthropogenic pressures on marine ecosystems worldwide, yet very few long-term, spatially explicit datasets on trawling effort exist; this greatly hampers our understanding of the medium- to long-term impact of trawling. This important gap is addressed here for the North Sea, a highly productive shelf sea which is also subject to many anthropogenic pressures. For a 31-year time span (1985–2015), we provide a gridded dataset ofn the spatial distribution of total international otter and beam trawling effort, with a resolution of for all ICES rectangles (0.5° latitude by 1° longitude,) overf the North Sea. The dataset was largely reconstructed using compiled effort data from 7 fishing effort time-series, each covering shorter time spans and only some of the countries fishing the North Sea.The dataset was largely reconstructed using compiled effort data from 7 fishing effort time-series, each covering shorter time spans and some of the countries fishing the North Sea only. For the years where effort data for particular countries were was missing, the series was complemented using estimated (modelled) effort data. This new, long-term and large-scale trawling dataset may serve the wider scientific community, as well as those involved with policy and management, as a valuable information source on fishing pressure in a Large Marine Ecosystem which is heavily impacted, but which simultaneously provides a wealth of ecosystem services to society. The dataset is available on the Cefas Data Hub at: https://doi.org/10.14466/CefasDataHub.61 (Couce et al., 2019).

1 Introduction

Coastal and shelf seas are of great value to human societies and, being more productive than open oceans, provide some 80% of the world's wild-capture fisheries (Watson et al., 2016). Yet the process of fishing that is required to obtain these benefits and services, also exerts a major anthropogenic pressure on shelf seas worldwide – along with climate change, pollution, eutrophication and habitat loss (Hiddink et al., 2006; Jennings et al., 2016). Trawling, in particular, is considered one of the more invasive fishing methods, as it does not only impact the target fish populations (through removal of fish and size-selective harvesting) but also has wider-ranging ecosystem effects, including on benthic organisms and habitats, and other non-target fish species (Hiddink et al., 2017; Jennings et al. 2001; Schratzberger et al. 2002). Unfortunately, tThere is a lack

of available long-term, spatially explicit datasets on trawling effort, — and this has hampered our understanding of the direct and indirect effects of trawling pressure on the marine environment (Collie et al., 2017; Jennings et al., 2001).

The North Sea is one of the world's most important shelf seas in terms of fisheries production – and has been so for centuries, 'feeding' some of the world's most densely populated areas (e.g., Capuzzo et al., 2018). Yet it is also subject to extensive anthropogenic pressures due to its geographical location in central Europe surrounded by seven countries, with concerns about pollution, habitat degradation, major ecosystem changes, and overfishing (Emeis et al., 2015; Kenny et al., 2018). Trawling, in particular, is seen as one of the most significant impacts on not only fish but also marine benthos in the North Sea (Kenny et al., 2018).

Two trawl fishing methods predominate in the North Sea, and generally in shelf seas worldwide: beam trawlers (defined as any ~~trawlers~~ vessel~~le~~s towing nets supported by a rigid beam, usually one lowered from each side of the vessel) and otter trawlers (defined as any vessels towing bottom-fishing nets held open by trawl doors; Engelhard, 2008; Jennings et al., 2001). Both fishing methods impact the seabed and marine life, although in subtly different ways: with beam trawlers especially catching flatfish and the gear having particularly close and invasive contact with the seabed and benthos; and otter trawlers especially catching roundfish and the gear having less close contact with the ground but often over a much larger area, and fish being caught over a higher~~taller~~ 'vertical area' within the water column (Jennings et al., 2001).

The North Sea has been extensively studied in terms of ecology and oceanography, with historical datasets dating back to the late 19th or early 20th centuries (e.g., Engelhard et al., 2014; Morris et al., 2018; Rijnsdorp and Millner, 1996; Sguotti et al., 2016). This ~~gives rise to an opportunity to~~facilitates ~~study~~ studies of long-term change which ~~is~~ are rare~~ly~~ ~~available~~ in marine research. However, the availability of historical fishing effort data is very limited, because time spent fishing and location choices are often linked to commercial interests of the fishing industry. ~~This has generally led to a r~~Reluctance to share such data~~, and therefore~~has resulted in a scarcity of long-term spatially explicit temporal data on fishing pressure.

This paper aims at addressing this gap by presenting a 31-year long, spatially detailed dataset of total international trawling effort for the North Sea, distinguishing between otter and beam trawlers. There have been various previous attempts at putting together spatio-temporal datasets on trawling effort for the North Sea region, which have provided partial snapshots of the fishing in what is one of the most intensively exploited regions of the world (Callaway et al., 2002; Jennings et al., 1999). Unfortunately, while such evidence is available for distinct periods (e.g., see STECF, 2017 for the more recent period, and Jennings et al., 1999 for the early 1990s), it is not available for longer, multidecadal time-spans. Here we ~~seek to~~ compile ~~all such~~ existing datasets, and ~~additionally to attempt to~~ "fill in the gaps" by estimating likely country-level fishing effort in periods for which 'nominal' data ~~were~~ was lacking, in order to reconstruct as complete a picture as possible for the period from 1985 to 2015.

We envisage that the trawling effort data reconstructed here will be of great use for ~~future~~ researchers who seek to understand the impacts of commercial fisheries on marine organisms, making use of the plethora of other historical data~~-~~sets available in this region.

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2. Methods

For the 31-year period from 1985 to 2015, we collated or estimated data on total (demersal) otter and beam trawling effort per year for the North Sea, defined as ICES (International Council for the Exploration of the Sea) Sub-area IV. Specifically, the data ~~were~~ was spatially separated to the level of ICES statistical rectangles (1° latitude by 0.5° longitude). We did so for the demersal trawling effort by vessels landing in Belgium, Denmark, England, France, Germany, the Netherlands, Norway, Scotland and Sweden ~~(otter trawling only)~~(in the case of Sweden otter trawling only, since its contribution to beam trawling effort is absent or negligible; see STECF, 2017). These countries are the most significant contributors to trawling effort in the North Sea region, together comprising >99% of the total ~~pressure~~effort (García-Carreras et al., 2015; Greenstreet et al., 2007; STECF, 2017). The effort was quantified as number of hours fishing in a year per ICES rectangle, recorded separately for beam and otter trawling (Couce et al., 2019).

2.1 Compilation of existing datasets on trawling effort

Seven datasets on trawling effort were included, covering different intervals within our 1985–2015 study period (see Fig. 1a for an overview), with only one of these, trawling by vessels landing into England, covering the full time-span examined. Each of these datasets included either one or multiple countries, and in the latter case, two datasets ~~providing~~ provided only the aggregated total for multiple countries combined and not for each country separately (but disaggregated by rectangle). In the following ~~section~~paragraphs, we briefly describe all datasets used.

For the earliest period until 1995 ~~1977-1995 period~~, data ~~were~~ was collated from Jennings et al. (1999) who assembled two different trawling pressure datasets from the North Sea, differing in time-span covered and countries included. The first of these (here referred to as 'Jennings et al. dataset 1,' see Fig. 1a) compiled effort data for 1977-1995 ~~their entire study period~~ by English, German, Norwegian, Scottish and Welsh vessels. The second of these (here referred to as 'Jennings et al. dataset 2,' see Fig. 1a) covered a shorter time-span (1990-1995) but included effort by Danish and Dutch vessels in addition to those in the first dataset. For both of these datasets, only the data aggregated over all countries included was available, with no information on separate countries' contributions to the total (as had been agreed *a priori* by the different countries' institutions participating in the study). More details on the data and its sources can be found in Jennings et al. (1999).

The MAFCONS project ('Managing Fisheries to Conserve Groundfish and Benthic Invertebrate Species Diversity', www.mafcons.org) assembled data on demersal trawling and seining effort in the North Sea for the period 1997-2002 for Dutch, German, Norwegian, and UK vessels (Greenstreet et al., 2007). As in Jennings et al. (1999), data was aggregated as hours fishing by ICES rectangle. For Dutch and Scottish vessels this had to be estimated, since the data was provided as 'days absent from port' rather than number of hours fishing (for the method followed, see Greenstreet et al., 2007, 2009). Unlike for Jennings et al. (1999), total effort was broken down into individual country contributions. Data for the effort of ~~the~~ beam trawling for the German fleet in the MAFCONS dataset does not include shrimp trawls. This, however, is included in the other compiled datasets and represents a significant contribution to the total beam trawling pressure in the North Sea.

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Therefore, for consistency we did not to use the MAFCONS beam trawling data for Germany and instead estimated it for this period. Although the MAFCONS dataset also included seining effort, only data on demersal otter trawl and beam trawl effort ~~targeting the main demersal fish species were~~ was considered for the present study (referred to as 'MAFCONS dataset' in Fig. 1a).

From 2002 onwards, compilation of data on trawling effort by European Union countries in the North Sea and adjacent waters has been carried out by the Scientific, Technical and Economic Committee for Fisheries (STECF) of the European Commission. Member States are required to submit fishing effort data to STECF, in response to the Data Collection Framework (DCF) Fishing Effort Regimes Data Call in 2013 (Martinsohn, 2014). STECF spatial effort data is available as annual fishing hours per ICES rectangle, for different gear types and vessel size classes. For the present study, annual data for Belgian, Danish, Dutch, English, French, German, Scottish, and Swedish vessels over 15 meters, was downloaded on February 23rd, 2017 from https://stecf.jrc.ec.europa.eu/dd/effort/graphs-quarter. For two countries – Belgium and France – effort data was available from 2000 onwards, and for the other countries from 2002 onwards. The classification of gear types in STECF data follows definitions outlined in Annex I of Regulation 1342/2008 (Council of the European Union, 2008). For the present study, gears defined by STECF as 'BEAM', 'BT1' and 'BT2' were included in our 'Beam trawling' category, whereas 'OTTER', 'TR1', 'TR2', 'TR3' were included as 'Otter trawling' (in line with Engelhard et al., 2015; García-Carreras et al., 2015).

Three additional effort datasets were also collated to complement our study (see Fig. 1a). For the period 1985-2012, data on otter trawling effort by vessels landing into Scotland was obtained from the Fisheries Management Database of Marine Scotland. For the full study period 1985–2015, data on beam and otter trawling effort by vessels landing into England and Wales was obtained from the Fisheries Activity Database of the Department for Environment, Food & Rural Affairs (Defra, UK). For the period 1987–2015, data on beam and otter trawling effort by vessels landing in Denmark (held at the Ministry of Food, Agriculture and Fisheries, Denmark) was kindly provided by Ole Ritzau Eigaard (pers. comm.; National Institute of Aquatic Resources [DTU-Aqua], Denmark).

2.2 Estimating missing data

In the years for which trawling effort data was lacking for certain countries, estimates of trawling effort by rectangle were reconstructed, based on two assumptions: (1) that the relative contributions of each country to the total trawling effort ~~only~~ change slowly and gradually; and (2) that ~~moreover~~ the spatial distribution of trawling over time changes ~~only~~ slowly and gradually. Assumption (1) is tightly linked to the Common Fishery Policy's rule of 'relative stability,' whereby the quotas of all commercial fish stocks in the North Sea are allocated between countries according to a fixed allocation key, so that the distribution of fishing effort between countries will also be fairly constant; this is illustrated in Fig. 2 for a subset of all data included here (i.e., the STECF data). Assumption (2) partly relates to fishing vessels being based at particular ports, having traditional fishing grounds and fishing preferences, and having quotas associated with particular areas; these constraints imply that spatial distribution of fishing aggregated at fleet level will only change gradually from year to year (for examples

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of gradual change only in spatial distribution of fishing, see Engelhard, 2005; Greenstreet et al., 2007; Jennings et al., 1999). We ~~—~~acknowledg~~eing~~ that over longer time-spans or under particular circumstances, major changes may occur~~:. such as what happened at t~~The outbreak of World War II in 1939, for example, brought ~~when~~ fishing in the North Sea ~~came~~ to a near standstill (Engelhard 2008). However, we are not aware of any such abrupt change taking place over our study period. Thus, in cases where a country was lacking effort data for a particular year, effort was estimated based on the same country's average spatial distribution of effort over ~~the~~ a close~~st~~ time period with available data, normalised so that the relative contribution of effort by the country compared to other ~~the~~ countries ~~where effort in a given year was known,~~ was maintained.

The precise procedure followed to estimate the trawling effort for a period of *n* consecutive years ("the missing period") for which a country ("the target country") lacks data was:

1) Estimating the spatial distribution of effort:
   a) ~~a~~Average of the spatial distribution of trawling effort for the target country in the 0.5*n* years before and 0.5*n* years after the missing period.
   b) ~~I~~When 1.a is not possible, use *n* adjacent years (of if less than *n* years are available, use them all).
2) Scaling the contribution:
   a) Using the longest time interval for which data is available for the target country, compute the average ratio between trawling by the target country and the aggregated trawling by as many other countries as possible with compiled data in the missing period, and normalise so that this ratio is maintained.
   b) When the missing period is covered by an aggregated dataset it ~~may happen~~is possible that no interval exists with data for both the target and all the countries in the aggregated dataset; in that case, ~~we~~ use an interval with data for the target country and the majority of the other countries in the dataset, and estimate the contribution of the countries lacking data in that interval, following the procedure in step 2.a.

Table 1 summarises the missing periods that had to be estimated for all countries, and details how the estimation was carried out in each case (i.e., the periods and source data used when following steps 1 and 2 listed above). One exception to this procedure was the reconstruction of otter trawling ~~pressure~~effort for Scotland for 2013-2015. This data is~~In the following paragraphs, the 31-year study period is broken down to indicate what portion of data was available for different time intervals, what data (if any) had to be estimated, and how this was done.~~

~~2.2.1 Years 1985–1986~~

~~For this period, available trawling effort data were comprised by the aggregated totals of beam and otter trawling by rectangle, for England, Scotland, Germany, Wales and Norway combined, from 'Jennings et al. dataset 1' (Fig. 1; and see Jennings et al., 1999). As individual countries' contributions were unknown in this dataset, we were unable to use country-specific effort data for England and Scotland for this period even though these were available to us. We reconstructed beam~~

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and otter trawling effort by rectangle for the remaining countries, i.e. Belgium, Denmark, France, the Netherlands, and (otter trawling only) Sweden, based on the average spatial distributions of effort for these countries in other periods with available data. For Denmark, this was based on the average effort distribution in 1987–1989 (using the 'Danish effort' dataset); for the Netherlands, this was based on the average distribution in 1997–2002 (using the MAFCONS dataset); for Belgium and France, on the average distribution in 2000–2015 (using the STECF dataset); and for Sweden, on that in 2003–2015 (also using the STECF data). For each country, these average spatial distributions of effort by rectangle were then scaled up or down such that the ratio of the country's total effort when compared to the combined effort for England, Scotland, Germany and Norway remained constant, and moreover was equal to this ratio when averaged over the years 2003–2012. This was used as reference period because of data being available for all countries with the exception of Norway. Here it was assumed that Norway's contribution to total effort in 2003–2015 amounted to 3% of the total effort for England, Scotland and Germany combined (based on the analysis of the MAFCONS dataset).

2.2.2 Years 1987–1989

We used the same, aggregated trawling effort data for the countries of England, Scotland, Germany, Norway and Wales combined, i.e. 'Jennings et al. dataset 1'; and in addition, country data for Denmark. Trawling effort by the Netherlands, Belgium, France, and (otter trawling only) Sweden was reconstructed in a similar way as the previous time period, using the same spatial distribution and normalising based on the average effort ratio of each of these countries versus the aggregated total for the countries of England, Scotland, Germany, Norway and Denmark combined.

2.2.3 Years 1990–1995

Datasets covering this period included 'Jennings et al. dataset 2,' which contained the aggregated effort for England, Scotland, Wales, Germany, Norway, Denmark and the Netherlands combined, in addition to country-specific data for England, Scotland (otter trawling only), and Denmark. By comparing 'Jennings et al dataset 1' with 'dataset 2' for this period we were able to calculate the contribution of Denmark and the Netherlands combined (as these countries were absent from the former dataset but included in the latter). However we concluded that Denmark's otter trawling data were highly unlikely to have been included in 'Jennings et al. dataset 2', on grounds that the total otter trawling effort obtained thus for the two countries was substantially less than that for Denmark alone, if calculated based on the Denmark country dataset. Therefore we proceeded on the assumption that Danish otter trawl effort was missing from 'Jennings et al. dataset 2', and complemented this with the Danish otter trawling effort data provided by the Denmark country dataset. Trawling effort by Belgium, France, and (otter trawling only) Sweden was reconstructed following the same approach as applied for both preceding periods, again normalising using the average ratio versus the aggregated total for all countries with available data for 1990–1995.

2.2.4 Year 1996

~~Very little data was available for this particular year. We used the country datasets for England, Scotland (otter trawling only) and Denmark, and estimated approximate effort for all remaining countries in the study: Germany, Norway, Sweden (otter trawling only), the Netherlands, Belgium, France and Scotland (beam trawling). Effort for Belgium, France, and Sweden (otter trawling) was reconstructed as above, using STECF data and normalised to maintain their relative percentages versus the combined effort of England, Denmark and Scotland (otter trawling) during 2003–2012. For Germany, Norway, the Netherlands and Scotland (beam trawling) we looked at the MAFCONS database for 1997–2002 to estimate the average spatial distribution of effort by each of these countries, and normalised by computing the average effort in these years in relation to the combined totals for England, Scotland (otter trawling), and Denmark.~~

~~2.2.5 Years 1997–1999~~

~~This period is covered by the MAFCONS dataset, which includes effort data for England, Scotland, Germany, the Netherlands, and Norway (distinguished by country). In addition, country-specific effort data were available for England, Denmark, and Scotland (otter trawling only), which was used instead of the MAFCONS data for those countries. We reconstructed effort by Belgium, France and Sweden (otter trawling), following the same procedure as described above for the period 1990–1995.~~

~~2.2.6 Years 2000–2002~~

~~This period is still covered by the MAFCONS dataset and the country data for England, Denmark and Scotland (otter trawling), and in addition to this there is also STECF data for two EU member states, i.e. Belgium and France. Therefore it was only necessary to estimate Swedish otter trawling effort, following the same procedure as described above for preceding periods.~~

~~2.2.7 Years 2003–2012~~

~~For this period, the STECF dataset includes North Sea effort data for all EU member states fishing in the North Sea. Country-specific datasets for England, Denmark, and Scotland (otter trawling) were used instead of the corresponding STECF data for these countries. Fishing effort by Norway during this period was estimated based on this country's data for the period covered by the MAFCONS dataset (i.e. 1997–2002).~~

~~2.2.8 Years 2013–2015~~

~~The same procedures were applied as for 2003–2012. Unlike for the preceding period, there was no longer country-specific data on otter trawling for Scotland. This was~~ actually~~however~~ included in the STECF dataset, but ~~since~~ there was a significant ~~difference between~~ mismatch between our Scotland dataset~~.~~ and that ~~included~~ in STECF~~.~~, Therefore, for 2013-2015 we normalised Scotland otter trawling effort in STECF by a correction factor which was the average of the annual total number of hours reported for Scotland in STECF versus our country dataset in 2003–2012.

In order to quantify the errors of the estimation of trawling pressure data in cases of missing vealues, for each country we calculated estimates of trawling effort by rectangle, using the same approach as applied in cases of missing entriesoutlined above, but now– for estimated additional periods for which there was compiled data for that country wereas actually available. , so thatIn that way, the differences between our estimationsces and the compiled data could be analysquantified. In each case, and when data allowed, the period that was estimated was chosen to be close in time and similar in duration to the 'real' missing periods. Additionally, the estimation rules listed above were adjustrelaxed so that, whenever possible, the procedure matched the one that had been followed for the estimation of the real missing periods. A median relative error between estimated and compiled data among all ICES rectangles and over the entire period was then computed, and applied to the estimated national trawling pressure data to produce a measurement of total absolute error of our estimations. Details on the periods that were estimated for each country and the data used in the estimation, together with the relevant median relative errors are listed in Table 2.

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3. Results

We were able to estimate the total international beam trawl effort by rectangle in the North Sea for all years from 1985-20–2015 (Fig. 3) and, likewise, the total international otter trawling effort for the same period (Fig. 4). For the majority of years, but especially after 2000/2002, the reconstructed trawling effort by rectangle could be directly sourced from compiled data on 'nominal' trawling effort (see white sections of pie charts in Fig. 3 and 4) as opposed to estimated (black sections of pie charts). For some of the earlier years, there was less availability of compiled data and hence larger proportions of the reconstructed effort data had to be estimated. For beam trawl effort, >50% of reconstructed effort data were was estimated in case of the years 1985–1989 and 1996, and for 1997–2002 the proportion to less was also close to 50%. For otter trawl effort, >50% of reconstructed effort data were was estimated in case of the years 1985 and 1996 1986 only. The greater scarcity of beam trawl effort data in the 1980s was related to a lack of nominal effort data for the Netherlands, which is the country that generally predominates beam trawling in the North Sea. Since the proportion of estimated data is not dominating the reconstructed total for most years, the relative errors (Fig. 5 and 6) remain at very low levels for the majority of the North Sea during the study period. Exceptions to this are the earliest period until 1989 together with 1996 for beam trawling, and 1985-1986 for otter trawling, where a significant part of the study region reachinged relative error values around 0.5.

The spatial distribution of beam trawl effort in the North Sea (Fig. 3), based on our reconstructions, has generally remained fairly constant during 1985–2015, with a clear northwest–southeast gradient. Absolute levels of beam trawling were highest in the 1990s; since 2000, total beam trawl effort has declined and gradually become more concentrated in the shallower, eastern and south-eastern parts of the North Sea. Whereas Whilst our results indicate that in the 1980s–1990s there were

appreciable levels of beam trawling off eastern and north-eastern Scotland, beam trawling in these areas has very much declined since then.

No clear spatial gradient was evident for the distribution of otter trawl effort in the North Sea, which over the years 1985–2015 was generally spread more evenly throughout the region (Fig. 4). The overall levels of otter trawling have declined, especially since 2000. Within the North Sea, some localised areas stood out as undergoing greater otter trawl effort. These include areas off eastern Scotland (Moray Firth Ground, Wee Bankie); off north-east England (Farn Deeps, western Dogger Bank); west of Denmark (Little Fisher Bank, Jutland Bank); and the southernmost rectangles within the North Sea (between the Thames estuary and Belgium). In many years, otter trawl effort was also high along the western slopes of the Norwegian Trench. The deeper parts of the Norwegian Trench received low otter trawl effort (Fig. 4). The shallower parts of the Southern Bight and German Bight, especially in recent years, received very little otter trawl effort (but highest levels of beam trawl effort; compare Fig. 3 and 4).

Although there have been changes in the total levels of otter trawling in the North Sea, there was evidence of fairly persistent spatial patterns; however, the relative contribution of trawling in the western North Sea off north-eastern England and Scotland was higher in the 1980s–1990s than in more recent years (Fig. 4).

4. Data availability

Reconstructed, nominal and estimated trawling effort data ~~are~~ is available from the Cefas Data Hub (Couce et al.: Reconstruction of North Sea trawling effort 1985-2015, DOI: 10.14466/CefasDataHub.61, 2019).

The contents of the Cefas Data Hub website are provided as part of the Cefas role as a Defra agency under the Defra Open Data Strategy.

Cefas requires users to make their own decisions regarding the accuracy, reliability, and applicability of information provided. The data provided by the Cefas Data Hub are believed by Cefas to be reliable for their original purposes and are accompanied by discovery metadata that provide a copy of the information available to Cefas scientists, describing the original purposes of data collection. It is the responsibility of the data user to take this information into account when reusing data. Regardless of any quality control processes, Cefas does not accept any liability for the use of the data provided; use is at the users' own risk. Cefas does not give any warranty as to the quality or accuracy of the information or the medium on which it is provided or its suitability for any use. All implied conditions relating to the quality or suitability of the information and the medium and all liabilities arising from the supply of the information (including any liability arising from negligence) are excluded to the fullest extent permitted by law.

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restrictions on the use of data such as for commercial purposes, and that data may only be redistributed, i.e. made available in other data collections or data portals, with the prior written consent of Cefas.

5. Discussion

This study represents the first reconstruction of total international trawling effort in the North Sea, spatially detailed by ICES rectangle, over a multi-decadal time span. The reconstructions were, as much as possible, based on compiled (nominal) effort data. ~~but w~~Where such data ~~were~~ was not available, efforts were made to 'fill in' any gaps by modelling effort estimations, and so provide a holistic picture of the total trawling pressure in the North Sea over the past 31 years. Earlier studies that have attempted to compile international trawling effort in the North Sea have covered considerably shorter time spans (e.g. Jennings et al. 1999: period 1990–1995; Callaway et al., 2002: year 1998; Greenstreet et al. 2007: period 1997–2004; STECF 2017: 2002–2015; Engelhard et al. 2015: periods 1990–1995 and 2003–2012). Those studies moreover did not attempt to reconstruct data ~~gaps~~ in cases where country-specific effort data ~~were~~ was lacking for certain years (with the exception of Greenstreet et al. 2007).

Reconstruction of missing data may in some cases have led to erroneous estimations. In all cases, for the spatial distribution of the effort we attempted to use the most relevant country-specific data available, from a period close in time ~~and for the same rectangle~~. Moreover, we have been transparent in keeping ~~separate~~ the compiled (nominal) and modelled (estimated) data separate, and when displaying totals we have indicated the proportion of the data that was estimated (e.g., see black and white pie charts in Fig. 3 and 4). Likewise, Greenstreet et al. (2007) who attempted to reconstruct total international trawling in the North Sea for the 1997–2004 period, also had to model effort for some countries, which in their case was lacking for Belgium, Sweden, France and Denmark. They used a different approach to tackle this problem, based on a combination of landing, catch-per-unit-effort, and fleet size data. Encouragingly, in spite of the different approaches, their reconstructions of total international otter and beam trawl effort by rectangle are in broad agreement with those presented here (compare our Fig. 3 and 4 with pages 118–119 in Greenstreet et al. 2007).

We acknowledge discrepancies between our otter trawl effort data for England and Scotland (based on the national databases of England and Scotland) and the data collated by STECF since 2002 for these two countries. ~~They~~ Effort data differ by roughly a factor of 2 in each case (our otter trawling effort data for Scotland is half that of STECF, and twice as much in the case of England). Although we cannot fully explain this discrepancy, we believe it relates to the conversion factor 24 assumed in the STECF compilation to convert from days-at-sea to number of hours fishing; but a considerable portion of time that fishing vessels are away from port~~,~~ is spent ~~in~~ either steaming or spent handling the catch, with a variable portion spent in the actual fishing operations (see discussion, and supplementary materials, in Engelhard et al., 2015). This might, to ~~an~~ some extent, have ~~impacted~~ affected our estimations on spatial distribution of trawling. Given that Scotland has extensive otter trawl fisheries especially in its near waters, our maps might underestimate otter trawling effort in areas near Scottish

coastlines (see Greenstreet et al., 1999 for a review and spatio-temporal patterns of Scottish trawl fisheries). No significant discrepancy was found between the Danish national dataset and the STECF-collated data over the period they overlap.

When the present study's effort distribution maps for specific years are compared~~, side by side,~~ with earlier studies, some ~~discrepancies~~ differences may be noted. For example, for the period 1990–1995 our trawling reconstructions, compared to Jennings et al. (1999), indicate higher levels of otter trawl effort in the area north-west of Denmark. This difference relates to the inclusion of Danish otter trawling in our study, which was likely omitted in Jennings et al. (1999), and suggests that the benthic environment in this particular area was subjected to greater anthropogenic pressure than previously assumed. For the year 1998, however, a very close spatial match of our trawling reconstruction was noted, compared with that collated by Callaway et al. (2002) ~~to~~ assessing links between trawling distribution and the diversity and community structure of epibenthic invertebrates and fish in the North Sea.

The broad-scale, long-term patterns in trawling distribution ~~laid bare by this study~~presented here confirmed spatial patterns described by shorter-term studies on trawling effort – such as the spatial gradient in beam trawl effort (Fig. 3), closely matching the depth gradient in the North Sea and the associated distributions of the key target species, sole *Solea solea* and plaice *Pleuronectes platessa* (e.g. Engelhard et al., 2011; van Keeken et al., 2007; Rijnsdorp et al., 1998). It is worth noting that, if analysed at a much finer spatial scale than ICES rectangles, the spatial distribution of beam trawling is much more patchy and localised, again reflecting local distributions of flatfish, and competitive interactions between fishing vessels (Rijnsdorp et al., 1998, 2000). Likewise, the distribution of otter trawling across the North Sea, when analysed at the scale of ICES rectangles (Fig. 4), appears smooth and broad~~, , but i~~It is found to be much more patchy when analysed at finer spatial scales, as has been made possible by the introduction of VMS (Vessel Monitoring System) on EU fishing vessels in the early 2000s (e.g. Lee et al., 2010). While VMS data provides a powerful tool for monitoring, analysing and describing fishing effort distribution, no such data ~~are~~ is available prior to the start of the twenty-first century. By contrast, the logbook-based dataset presented here – albeit less spatially detailed than VMS data – does go back to the 1980s, allowing systematic, long-term comparisons of trawling impacts on fish, benthic invertebrates, and other organisms living on or near the seabed of the North Sea (Collie et al., 2017; Hiddink et al., 2006).

The long-term reduction in both beam and otter trawling fishing hours in the North Sea, which is evident from our reconstructed time-series, is closely associated with the European Union fleet reduction scheme, adopted since the turn of the Millennium (Villasante, 2010). This scheme, in which decommissioning of fishing vessels was paramount, was instigated specifically to address overcapacity in the European fishing fleet, and significant concerns of overfishing of key commercial fish stocks including sole, plaice, cod ~~*Gadus morhua*~~ and sandeel ~~*Ammodytes marinus*~~ (Bannister, 2004; Villasante, 2010). Since then, with the reduction in total trawling effort, strict quota regulations and the introduction on long-term management plans, several North Sea fish stocks have indeed recovered, most notably North Sea plaice (ICES, 2017). There is also evidence of recovery in the Large Fish Indicator (LFI), an OSPAR indicator of good environmental status in marine foodwebs, in response to reduced trawling pressure (Engelhard et al., 2015).

With these positive signs, it is worth noting that trawling remains one of the most pervasive anthropogenic pressures in the North Sea (Kenny et al., 2018), and it will continue to be important to monitor and assess its impacts on marine fauna and habitats. Moreover, it is very likely that the observed reduction of hours of otter trawl fishing since the 1990s would be partially –or even fully– offset in many cases by increases in vessel size, engine power, gear size and other technological developments that have taken place ~~in~~ over these decades (e.g., see Eigaard et al., 2014). Consequently, fishing pressure and impacts on e.g. target stocks, seabed habitats or bycatch species is unlikely to have declined to the same extent that fishing hours have been reduced. Kilowatt hours of fishing may be a more useful metric to study trawling impact~~,~~. ~~however~~ However, the relevant data is not available for all countries over the time period of the study. Attempts have been made to model the impact of these technological developments on fisheries (e.g., see Eigaard et al., 2011), and could be considered for some applications of the trawling hours dataset produced in the present study.

We have previously argued that a lack of multidecadal, spatially detailed data on trawling effort has hampered ~~our~~ attempts to study the long-term environmental footprint of trawling. The present dataset – mostly based on compiled (nominal) effort data, and for a smaller part on estimated (modelled) data – may help overcome this ~~gap~~. For the North Sea, long-term datasets on a range of biotic and abiotic variables already exist. These include time-series of sea surface and sea bottom temperature (e.g., MacKenzie and Schiedek, 2007; Morris et al., 2018); on phytoplankton abundance and primary production (Capuzzo et al., 2018; Reid et al., 2003); on water turbidity (Capuzzo et al., 2015) and on hydrodynamics (van Leeuwen et al., 2015). Long-term data on the North Sea fish fauna, collected on International Bottom Trawl Surveys (IBTS) and Beam Trawl Surveys (BTS), ~~are~~ is held in the 'Datras database' of ICES (e.g. Hofstede and Daan, 2008; http://www.ices.dk/marine-data/data-portals/Pages/DATRAS.aspx), and ICES also holds data on international fisheries landings dating back to the year 1903 (https://www.ices.dk/marine-data/dataset-collections/Pages/Fish-catch-and-stock-assessment.aspx). The Continuous Plankton Recorder (CPR) data provides an excellent source on zooplankton, phytoplankton, and ichthyoplankton data (Lynam et al., 2013; McQuatters-Gollop et al., 2017). ~~With the current contribution these~~ These sources are now complemented by ~~a~~ our long-term, trawling effort dataset.

Two papers, based on the present data in combination with ecological data, have already been submitted – one on 'threshold' impacts of trawling pressure on North Sea benthos (Couce et al., accepted ~~n.d.~~)~~(Couce et al., submitted)~~ and one on feeding guilds within the fish community of the North Sea, in relation to fishing pressure, climate change and other drivers (Thompson et al., submitted). We encourage the use of the spatio-temporal dataset on trawling ~~pressure~~ effort provided here~~,~~ to all those working in the fields of marine science, management and policy, who have ecosystem conservation and sustainability of marine living resources at heart, both of which are aided by a better understanding of the long-term impact from this major, widespread anthropogenic pressure.

6. Author contribution

E.C. conceived the research idea, E.C. and G.E. compiled the effort data and designed the methodology to reconstruct missing data and E.C. carried out the reconstruction. All authors participated in the interpretation of results and the writing of the manuscript and gave final approval for publication.

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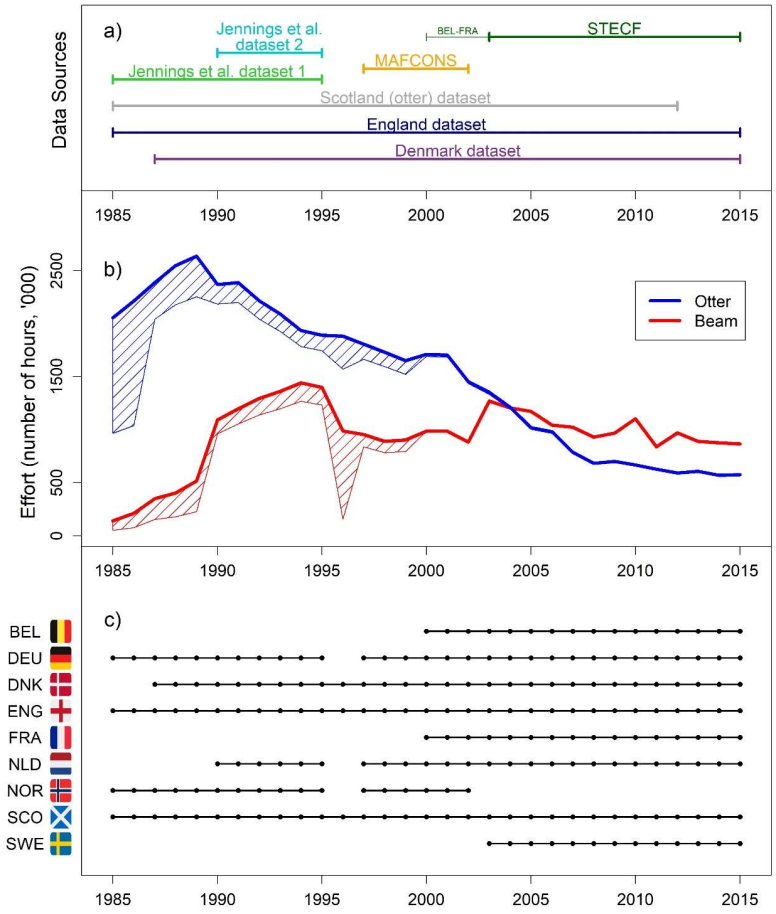
Figures


a)
Data Sources
Jennings et al. dataset 2
Jennings et al. dataset 1
BEL-FRA
STECF
MAFCONS
Scotland (otter) dataset
England dataset
Denmark dataset
1985
1990
1995
2000
2005
2010
2015
b)
Effort (number of hours, '000)
0
500
1500
2500
Otter
Beam
c)
BEL
DEU
DNK
ENG
FRA
NLD
NOR
SCO
SWE

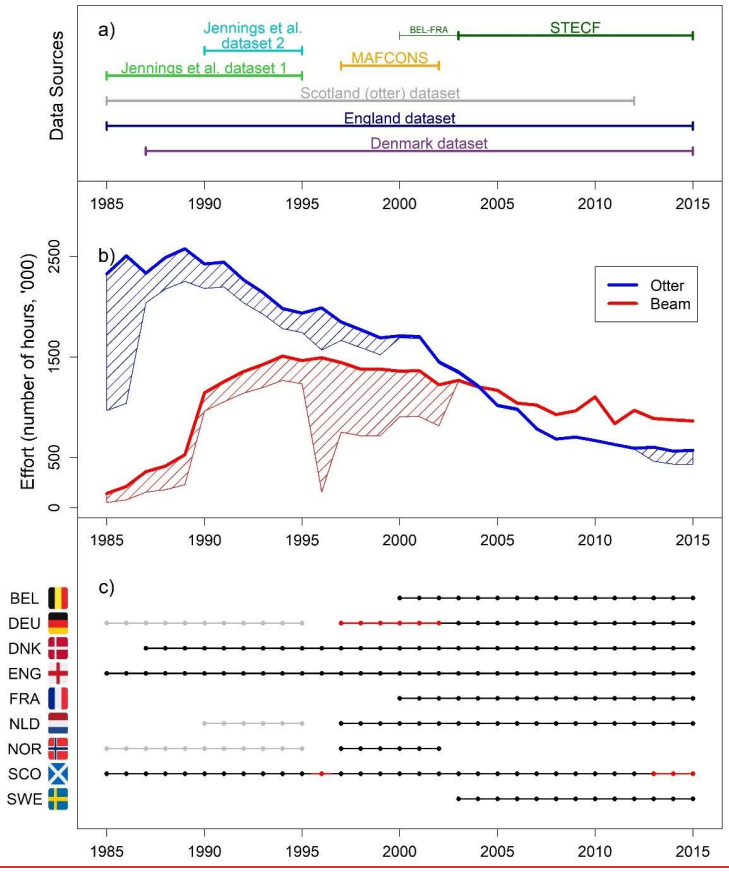
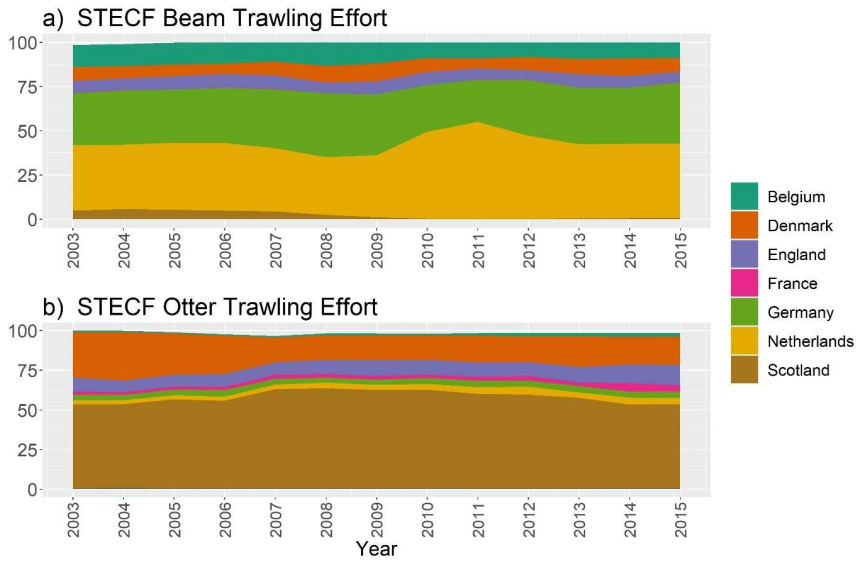


Figure 1: (a) The timelines for seven sources of compiled (nominal) fishing effort data, included in the present study; see methods section for full detail of each dataset. (b) Reconstructed total fishing hours in the North Sea by beam (red) and otter trawlers (blue), from 1985 to 2015. White-shaded areas show the proportions of the reconstructed total based on compiled (nominal) fishing effort data, and dashed areas show the proportions based on estimated (modelled) data. (c) The timelines, by country, for which nominal effort data were available, and compiled for this study. The periods shown in grey indicate years for which country data was available but only as part of a compiled set, and the individual country contribution to the total was unknown (this is data which therefore cut not be used to estimate missing periods). The periods shown in red indicate years for which only part of the data was available, or there was an issue with the compiled data.


a) STECF Beam Trawling Effort
100
75
50
25
0
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
b) STECF Otter Trawling Effort
Year
Belgium
Denmark
England
France
Germany
Netherlands
Scotland

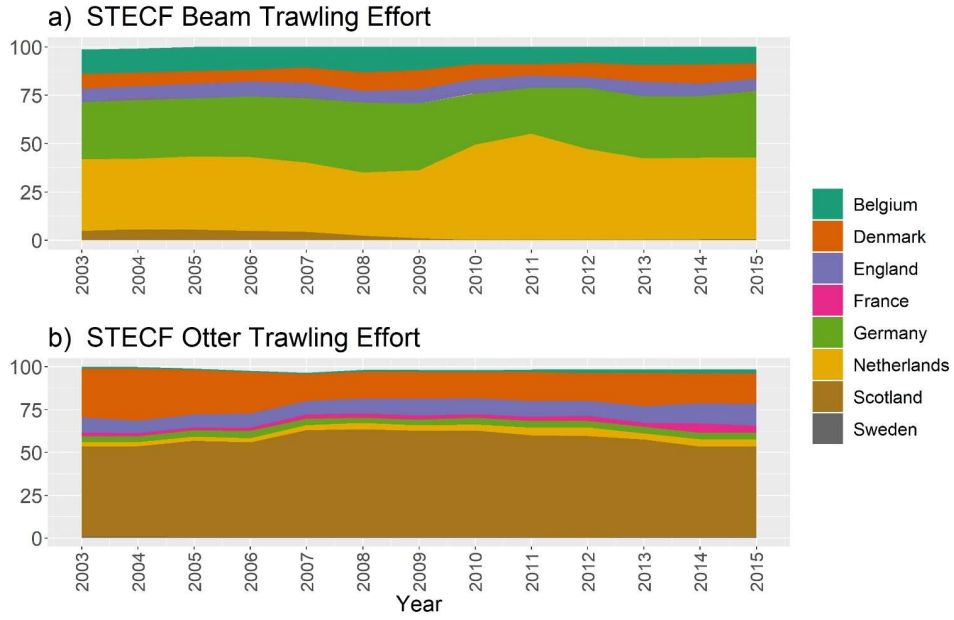


Figure 2: Percentage contribution of individual countries over time to (a) total beam trawl effort and (b) total otter trawl effort in the North Sea, based on the STECF dataset.

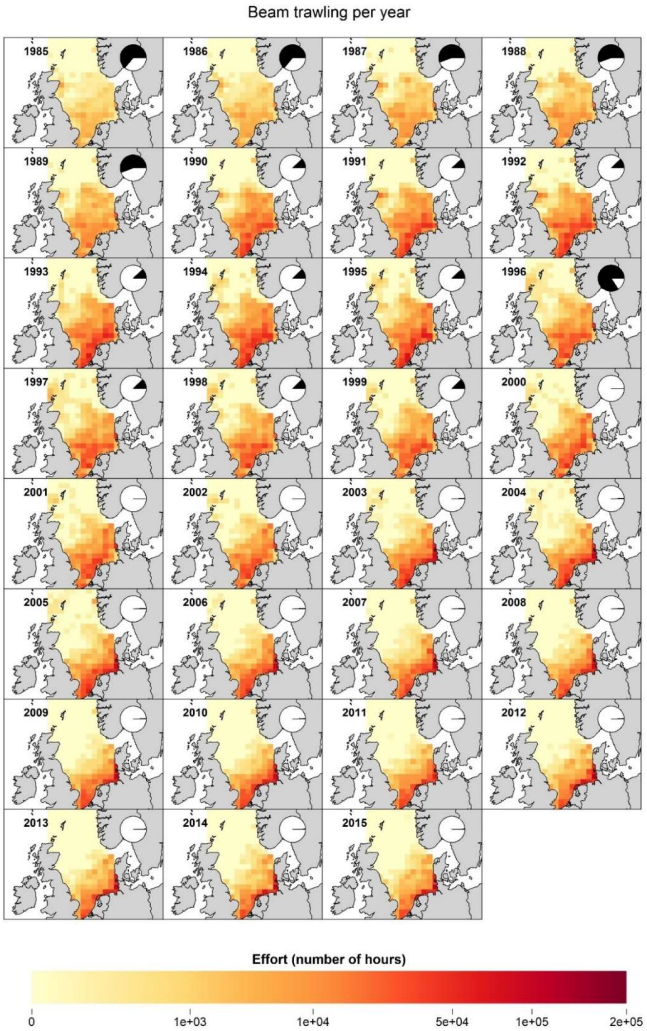


Figure 3: Spatial distribution of beam trawling effort (number of hours trawling per ICES rectangle) in the North Sea in 1985–2015. Pie charts in the top right corners of each plot show the proportions of reconstructed trawling effort sourced from compiled (nominal) data (white) and estimated (black).

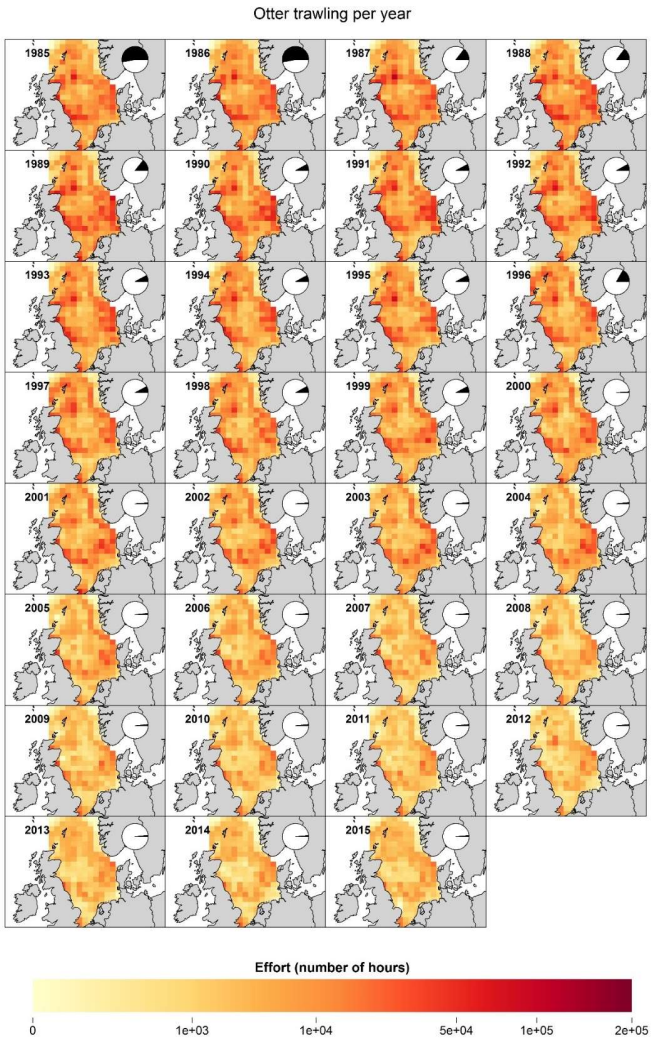


Figure 4: Spatial distribution of otter trawling effort (number of hours trawling per ICES rectangle) in the North Sea in 1985–2015. Pie charts in the top right corners of each plot show the proportions of reconstructed trawling effort sourced from compiled (nominal) data (white) and estimated (black).

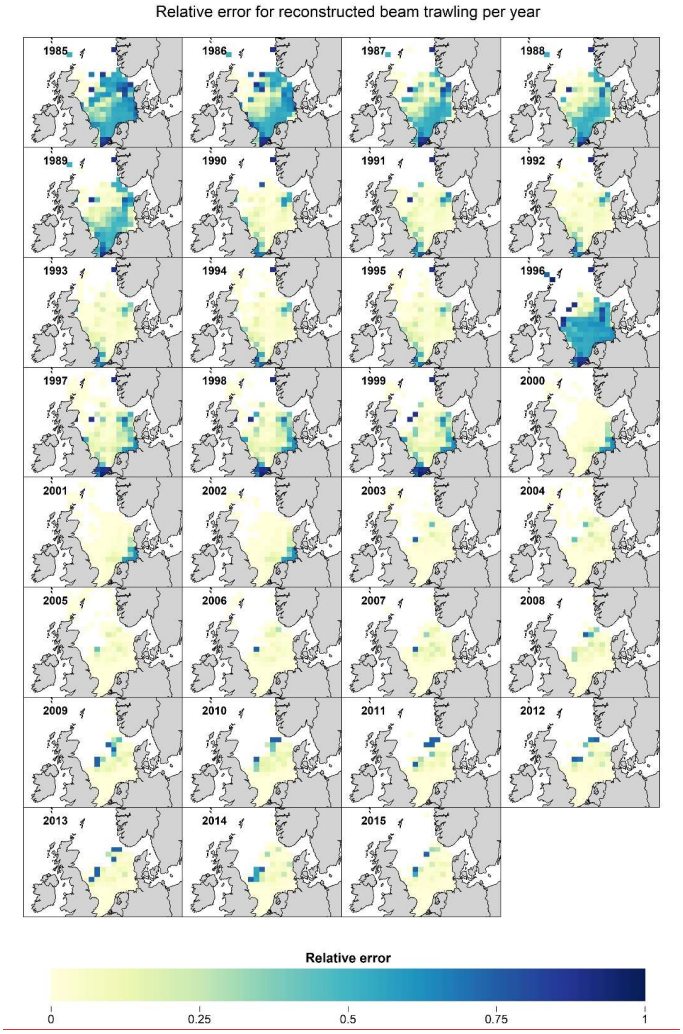


Figure 5: Spatial distribution of relative error of the reconstructed beam trawling effort (~~e.g.~~i.e. the ratio between the error of the estimated ~~error~~effort and the total effort compiled + estimated) per ICES rectangle in the North Sea in 1985–2015.

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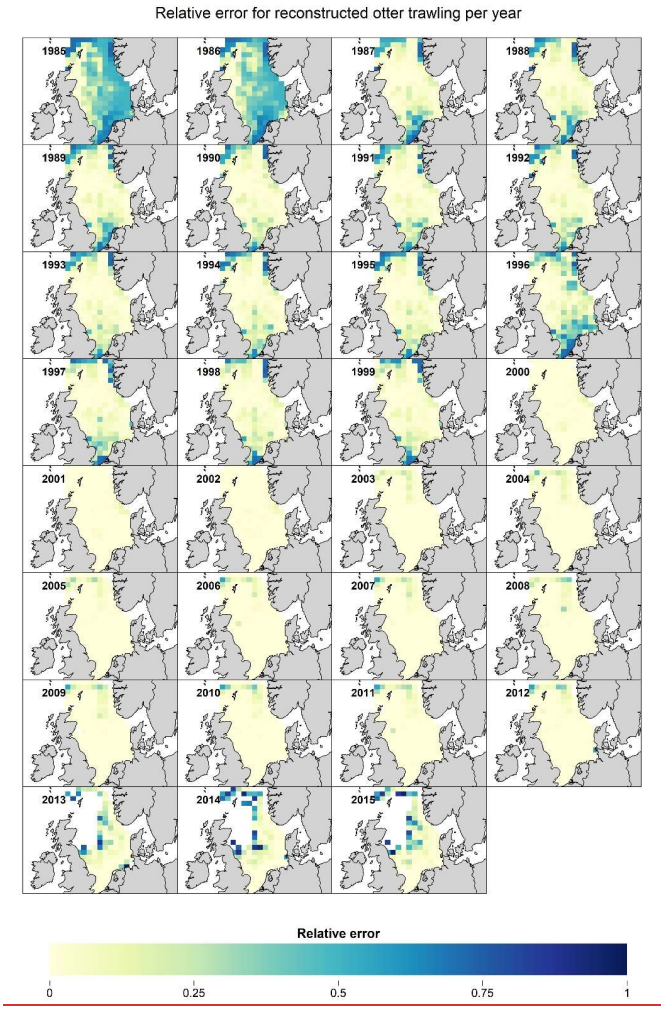

Figure 6: Spatial distribution of relative error of the reconstructed otter trawling effort (i.e. the ratio between the error of the estimated effort and the total effort compiled + estimated) per ICES rectangle in the North Sea in 1985–2015.

Tables

Table 1: Data used in the estimation of periods of missing data for each of the countries. An average spatial distribution of effort is calculated from the data in the "Source data for spatial distribution" column, and scaled to maintain the ratio of trawling by the target country with respect to the countries listed in the "Method for estimating total trawling" column.

Country	Missing period	Gear	Source data for spatial distribution	Method for estimating total trawling
Germany	1996	Otter	1997 MAFCONS data	• Comparing with DNK + ENG + SCO in 1997-2012.
Germany	1996-2002	Beam	2003-2009 STECF data	• For 1996 comparing with DNK + ENG in 2003-2015. • For 1997-1999 comparing with DNK + ENG + NLD + SCO in 2003-2015. • For 2000-2002 comparing with DNK + ENG + NLD + SCO + BEL + FRA in 2003-2015.
Belgium & France	1985-1999	Beam, Otter	2000-2014 STECF data	• For 1985-1986 comparing with ENG + SCO + DEU + NOR in 2000-2002. • For 1987-1989 comparing with ENG + SCO + DEU + NOR + DNK in 2000-2002. • For 1990-1995 beam trawling comparing with ENG + SCO + DEU + NOR + NLD + DNK, and for otter trawling comparing with ENG + SCO + DEU + NOR + NLD, in 2000-2002. • For 1996 beam trawling comparing with ENG + DNK in 2000-2015, and for otter trawling comparing with ENG + DNK + SCO in 2000-2012. • For 1997-1999 comparing with ENG + SCO + DNK + DEU + NLD + NOR in 2000-2002.
Denmark	1985-1986	Beam, Otter	1987-1988 DNK data	Comparing with ENG + SCO + DEU + NOR in 1997-2002.
Scotland	1996	Beam	1997 MAFCONS data	Comparing with ENG + DNK in 1997:2015.
Scotland	2013-2015	Otter	2013-2015 STECF data	STECF SCO otter data scaled by the average ratio between Scotland (otter) dataset and STECF otter data in 2003-2012.
Norway	1996	Beam, Otter	1997 MAFCONS data	For beam trawling comparing with ENG + DNK and for otter trawling with ENG + DNK + SCO in 1997-2002.
Norway	2003-2015	Beam, Otter	1997-2002 MAFCONS data	For beam trawling comparing with ENG + DNK+ SCO + NLD and for otter trawling with ENG + DNK + SCO + NLD + DEU in 1997-2002.
Sweden	1985-2002	Otter	2003-2015 STECF data	• For 1985-1986 comparing with ENG + SCO + DEU + NOR in 2003-2012 (using estimated NOR data). • For 1987-1989 comparing with ENG + SCO + DEU + NOR + DNK in 2003-2012 (using estimated NOR data). • For 1990-1995 comparing with ENG + SCO + DEU + NOR + NLD in

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				2003:2012 (using estimated NOR data). • For 1996 comparing with ENG + DNK + SCO in 2003-2012. • For 1997-1999 comparing with ENG + SCO + DNK + DEU + NLD in 2003-2012. • For 2000-2002 comparing with ENG + SCO + DNK + DEU + NLD + BEL + FRA in 2003-2012.
Netherlands	1985-1989	Beam, Otter	1997-2001 MAFCONS data	• For 1985-1986 comparing with ENG + SCO + DEU + NOR in 2003-2015 (for beam trawling, using reconstructed NOR data), and in 1997:2002 (for otter trawling). • For 1987-1989 comparing with ENG + SCO + DEU + NOR + DNK in 2003-2015 (for beam trawling, using reconstructed NOR data), and in 1997:2002 (for otter trawling).
Netherlands	1996	Beam, Otter	1997 MAFCONS data	For beam trawling comparing with ENG + DNK in 1997-2015, and for otter trawling with ENG + DNK + SCO in 1997-2012.

~~Table 1: Data used in the estimation of periods of missing data for each of the countries. An average spatial distribution of effort is calculated from the data in the "Source data for spatial distribution" column, and scaled to maintain the ratio of trawling by the target country with respect to the countries listed in the "Method for estimating total trawling" column.~~

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Table 2: Periods for which trawling effort was estimated for the quantification of errors for each of the countries, and the data used for each of the estimations. The last column shows the median error, where errors were calculated as of the absolute values of the relative differences between estimated and compiled data for all ICES rectangles and all years~~The last column shows the median of the absolute values of the relative errors between estimated and compiled data for all ICES rectangles and all years in the estimated period~~.

Country	Estimated period	Gear	Source data for spatial distribution	Method for estimating total trawling	Median error: estimated – compiled estimated ~~of abs. relative errors~~
Germany	1997	Otter	1998 MAFCONS data	Comparing with DNK + ENG + SCO in 2000-2012	0.71
Germany	2003-2008	Beam	2009-2014 STECF data	Comparing with DNK + ENG + NLD + SCO in 2009-2015.	0.62
Belgium & France	2000-2007	Beam, Otter	2008-2015 STECF data	Comparing with DNK + ENG + NLD + BEL/FRA (BEL when estimating data from France, and vice versa) in 2008:2015.	BEL Beam: 0.89 BEL Otter: 0.75 FRA Beam: 1.82 FRA Otter: 0.70
Denmark	1987-1988	Beam, Otter	1989-1990 DNK data	Comparing with ENG + SCO + DEU + NOR in 1997-2002.	Beam: 0.68 Otter: 0.49
Scotland	1997	Beam	1998 MAFCONS data	Comparing with ENG + DNK in 1998-2015.	1.05
Scotland	2013-2015	Otter	2013-2015 STECF data	Error was estimated looking at the relative differences between STECF otter data for Scotland and the Scotland (otter) dataset in 2003-2012.	2.86
Norway	1997-1999	Beam, Otter	2000-2002 MAFCONS data	For beam trawling comparing with ENG + DNK+ SCO + NLD and for otter trawling with ENG + DNK + SCO + NLD + DEU in 2000-2002.	Beam: 0.74 Otter: 0.56
Sweden	2003-2008	Otter	2009-2015 STECF data	Comparing with ENG + SCO + DNK + DEU + NLD + BEL + FRA in 2009-2015.	0.67
Netherlands	1997-2002	Beam, Otter	1997-2001 STECF data	For beam trawling comparing with ENG + DNK+ SCO in 2003-2015 and for otter trawling with ENG + DNK + SCO + NLD + DEU in 2003-2012.	Beam: 0.52 Otter: 0.70

~~**Table 2: Periods that were estimated for the quantification of errors for each of the countries, and the data used for each of the estimations. The last column shows the median of the absolute values of the relative errors between estimated and compiled data for all ICES rectangles and all years in the estimated period.**~~

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