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Cefas contract report C3140

Marine Ecosystem Integrity: Development of a Marine Trophic Index for UK waters and recommendations for further indicator development

for

Natural Environment Group, Science Division, Defra (CRO 382)

Marine Ecosystem Integrity: Development of a Marine Trophic Index for UK waters and recommendations for further indicator development.

Final report for Natural Environment Group, Science Division, Defra Bristol, UK (CRO 382)

by

John Cotter
Stuart Rogers
Jim Ellis
Steve Mackinson
Nick Dulvy
John Pinnegar
Simon Jennings
Simon Greenstreet*

Centre for Environment, Fisheries and Aquaculture Science (Cefas)
Lowestoft
United Kingdom, NR33 0HT

email: john.cotter@cefas.co.uk

**Fisheries Research Services, Aberdeen, Scotland, AB11 9DB*

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Contents

Executive Summary

The marine trophic index (MTI) is an indicator which is used to summarise feeding relationships in marine ecosystems. The so-called "trophic pyramid" consists of top predators at the apex, predators and grazers in the centre, and plants and bacteria at the wide base. The MTI was developed by Pauly and co-workers to demonstrate that marine ecology on a global scale is being fundamentally altered by the tendency of commercial fishing to selectively remove many top predators and other large fish from the sea because of their financial value and, frequently also, their vulnerability to fishing. The MTI raised much public interest, including that of the Convention on Biological Diversity (CBD), but it has also been subject to criticism because factors other than fishing can reduce the MTI for a region, and because management responses to a changing MTI are not necessarily obvious. Cefas were commissioned (CRO 382) to investigate and develop an MTI for UK marine waters, and to identify the development requirements of additional indicators of marine ecosystem integrity, either alternative or complementary to the MTI.

Project work on the MTI included a brief literature review, and computation of an MTI using (1) international fishery landing statistics for waters around the UK, and (2) Cefas groundfish surveys. Trophic level (TL) estimates were obtained from stomach contents analysis of numerous species of fish together with modelling using Ecopath, and from N-isotope analyses. The first method of estimating trophic level provides a snapshot of trophic relationships depending on what has just been eaten; the second integrates trophic relationships over months by estimating the degree to which predators concentrate the heavier isotope of nitrogen. The correlation between the two methods for different fish species was investigated and found to be poor. The MTI for landings showed a gradual decrease from the 1970s, the more so for the N-isotope TLs, but then so too did the time series of total landings by weight. The English otter trawl survey of the North Sea showed a weakly declining MTI, but with only one of the methods of estimating trophic level. A major step downwards of the MTI in 1992-1994 coincided with, and might have been explained by, a change of survey trawl to one that catches more pelagic (mid-water) species having a somewhat lower TL than the roundfish usually caught by otter trawls. Two beam trawl surveys showed scarcely any trend in MTI. The disappointing results with the three surveys underline the importance of the trawl gear in use and the range of trophic levels caught. MTIs were also calculated with an allowance made for change of TL as individual fish grow in size and alter their prey species. The refinement offered little benefit, possibly because TL versus size relationships were only available for 15 common species and made no allowance for possible geographic variations. Calculating the MTI for the UK could involve costly extension and updates of estimated TLs depending on what refinements are thought necessary. Consultations with scientists outside Cefas revealed a lack of consensus about the effort needed for, and the scientific validity of, the MTI.

A number of length-based derived indicators (LBIs) were also assessed for their ability to measure the loss of large fish from ecosystems. Large individuals of a species serve to buffer a fishery against poor recruitment years as well as providing a reservoir of breeding individuals. Large species are important for maintaining the balance of species down the food chain, thereby preventing subsidiary trophic levels from becoming over- or under-abundant, so-called trophic cascades. Two multi-species LBIs were examined, one the 'proportion of large fish' based on an OSPAR Ecological Quality Objective (EcoQO) prepared by ICES, the other based on the idea of measuring all fish in proportion to their maximum observed length so allowing amalgamation of length histograms across species and generalisation of results using life history theory. Both indicators showed downward trends with survey data, but not in all circumstances. They have the important advantages of being relatively well understood, and of being widely applicable without new expense because lengths are already routinely measured for most species of fish caught commercially or on surveys. They can be compared with length-at-maturity as a reference level. Consultation of scientists outside Cefas did not reveal opposition to the use of LBIs though it was pointed out that objectives must be set carefully.

A third type of index was considered and known as a 'threat' index. This index (recently published) measures the threat of extinction for rare species of fish. A feasible short-term objective for the threat index would be to aim for a trend of reducing threat. The index was re-formulated to operate with presence/absence of a number of species at different fishing stations on surveys. Occupancy data were considered more stable than abundances for the assessment of rare species. The proportion of stations occupied, after statistical smoothing, was found to exhibit clear trends for some species, signalling expansion or contraction of geographic ranges. This is relevant to the CBD since it allows threatened species to be identified and trends in status to be observed. The locations of remaining occupancy could help decide management actions that might ameliorate species identified to be declining. These might include fishery restrictions such as closed areas, restrictions on gear types, etc. Consultations with non-Cefas scientists at a project workshop raised interest in occupancy indices, preferably combined with other geographic studies and the selection of suitable species.

The use of non-fish based indicators was not considered within this report, but a short discussion is given on the possibilities for monitoring other marine species for CBD reporting purposes. The need for consistent, standardised methods of monitoring is stressed, as is the relevance of the indicator and its potential to indicate what management action is needed. It is likely that new sources of funding would be required to generate consistent, regular time series. National groundfish surveys operated by England, Scotland, and Northern Ireland present good opportunities for monitoring epibenthos and marine mammals, because they cover most of the UK marine area and the cost of the ships is already paid. There are few other current, non-fish time series that span UK marine waters consistently over time, though the continuous plankton recorder is one that might be used to provide indicators of ecological integrity. One other feature of this report is a short review of statistical methods for assessing trends and combining indicators.

<u>If an MTI is to be calculated for UK waters</u>, it is concluded that;

1. Landing statistics are used in preference to fish survey data.

2. Landed quantities are taken from the ICES international statistics. They include the fisheries of all nations. Geographically, they relate to ICES divisions which include and overlap UK national waters.
3. These landing statistics are likely to be secure for the foreseeable future but they are updated only to two years behind the present year.
4. ICES landings statistics for UK waters cover a wide range of fish trophic levels but the range is more restricted in some regions within UK waters depending on the types of fisheries present. This impairs application of the MTI regionally.
5. Available data on trophic levels of marine species (including fish) are poorly representative of UK waters because of the limitations of stomach sampling and N-isotope analyses to date. The data should be extended to more species and regional seas involving English, Scottish, and Northern Irish surveys as an initial one-off exercise, with reviews possible in future. Estimates should be made of the standard errors of estimates of trophic level. This project would involve significant costs.
6. Calculating the MTI after removal of lower trophic level fish species is not recommended.
7. Attempting to estimate changing trophic level with size would require more extensive fish sampling and analysis. Initial results found here do not indicate that the extra expense would be worthwhile.
8. There are no agreed thresholds for the MTI to distinguish healthy from unhealthy marine ecosystems. The MTI is currently low due to heavy fishing, so the best guidance on what is a "healthy" signal is that the MTI should gradually rise from today's levels.

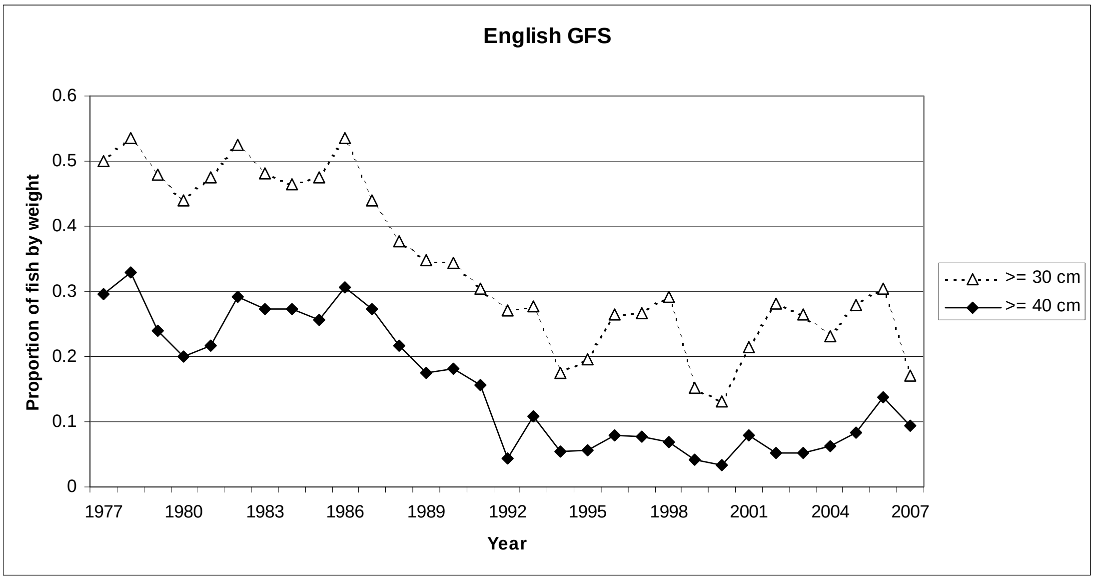
<u>However, from a scientific perspective an MTI is not recommended</u> for routine monitoring by the UK because:

1. Landing statistics are too prone to errors for commercial, legal, and technical reasons. The MTI would be vulnerable to the same criticisms as have been levelled at fish stock assessments that also depend on landings data.
2. Desirable improvements to available trophic level data would be costly to obtain. See (5) above.
3. Trends in a UK-wide MTI may or may not be related to changes in the ecosystem and will not necessarily be interpretable without controversy.
4. The MTI fails as an indicator of UK regional ecological integrity because we share regional seas (from which the data are collected) with other Member States.
5. There are no agreed thresholds for the MTI to distinguish healthy from unhealthy marine ecosystems.

On assessment of indicators within this report LBIs were **recommended** for monitoring ecological integrity of UK waters as:

1. Length is related to reproduction, predation, trophic level, and migrations, and thus clearly to ecological integrity.
2. LBIs display long-term trends that can be interpreted with care. Allowance must be made for variable recruitments that can affect LBIs.

3. Length-at-maturity is one promising possibility for defining thresholds for LBIs.
4. LBIs can be designed for multi- and single-species monitoring and for various aspects of species' biology.
5. The OSPAR EcoQO / ICES 'proportion of large fish' and the 'proportionate length' indicators tested in this study would provide complementary monitoring (between and within species) of the tendency for large fish to be removed by commercial fishing.
6. These LBIs require several years to respond to changed environmental conditions depending partly on the time required for growth, and partly on the low numbers of large fish available in UK waters for measurement. The requirement for a long period before changes are detectable is the same for many types of indicator.
7. Length information for all fish species is available already from UK fish surveys. The only additional costs would be for new data processing. These surveys are securely funded under the EC Data Collection Regulations.
8. UK otter trawl surveys would provide good representative sampling of all offshore UK waters for LBIs except in the Channel. UK beam trawl surveys could be used in the Irish Sea and Channel but LBIs from beam trawl surveys appear less responsive than from otter trawl surveys. LBIs found from different types of trawl survey should not be compared because of different length selectivities.
9. Preserving more large fish in the sea through use of LBIs would stabilise fisheries against fluctuations of recruitment and thereby contribute to ecosystem integrity.



Graphical representation of the ICES (2007) lenth-based indicator describing the OSPAR fish community EcoQO (proportion by weight of individual fish of all species exceeding stated cut-off lengths) calculated for the English groundfish survey (GFS) of the North Sea, ICES subarea IV for two threshold lengths (30 and 40cm).

Conclusions drawn from the assessment of the use of threat and occupancy indicators for marine waters were:

1. Threat and occupancy indices based on fish surveys are recommended for monitoring ecological integrity of UK waters. A threat index serves to communicate the number of species in danger of local extinction; occupancies reveal declining geographic spread of individual species which may be indicative of unfavourable conditions for them.
2. Loss of species is of obvious relevance for biodiversity, the CBD, and to ecosystem integrity.
3. Occupancy indices provide responsive, long term, interpretable trends because they are based on simple presence/absence data. Composite threat indices are harder to measure because of statistical problems associated with estimating catch rates for rare species.
4. Concerning thresholds, threat indices are themselves based on IUCN criteria for extinction risk. A feasible objective for the threat index in the short term would be to aim for a trend of reducing threat. Occupancies are less directly related to extinction risk. Discussions have not yet started on thresholds for occupancies.
5. Threat and occupancy indices can be computed easily from existing survey data. However, increasing threat or declining occupancies would often prompt special ecological studies to find the causes; these would probably incur significant new costs.
6. Suitable survey data are available and secure for calculating threat and occupancy indices for UK waters, or regionally within them, but more care is needed to ensure consistent identification of non-commercial and rare species. This would involve additional, regular, taxonomic training for survey staff.
7. UK otter trawl surveys would provide good representative sampling of all offshore UK waters for threat and occupancy indices. UK beam trawl surveys could be used in the Irish Sea and Channel but a different range of species is caught, making the two types of survey non-comparable.

Conclusions drawn from considering the use of groups other than fish were based on literature work and experience of fish surveys and are outlined below[1].:

1. The plankton data collected with the continuous plankton recorder and held by SAHFOS at Plymouth should be examined with a view to defining planktonic indicators of biodiversity, ecological state, and environmental or climatic effects on plankton. This might be a 6-month project for one scientist. Thereafter there would be a need to ensure security of data collection, and to make the requisite calculations.
2. Sampling of epibenthos using the proven technique of towing a standard, 2-metre lightweight beam trawl at the beginning and end of each day during UK fish surveys should be funded. Indicators should be developed to monitor biodiversity, fishing, and, if possible, climatic effects. Development of suitable indicators with existing data held by FRS and Cefas might be a 6-

[1] . Estimated research times for special projects are for approximate guidance only. Also note non-fish data were not analysed as part of this project

month project for one scientist. Thereafter, 3 months of a scientist's time would be needed for each fish survey used for epibenthic sampling. Five otter trawl surveys, two by Cefas (North Sea and SW), two by FRS (E and W of Scotland), and one by Northern Ireland (Irish Sea and North Channel) would be good candidates for this work. A sixth, a Cefas beam trawl survey, would cover the Channel. More than 6 staff would be needed due to overlapping timing of some surveys.

3. A monitoring survey for seabirds, seals, and cetaceans should be designed and implemented for UK. Seabirds have been successfully monitored from UK groundfish surveys but monitoring of breeding colonies on land may be a better proposition, as it may for seals. Training of regular fish survey staff to observe whales and dolphins at sea may also be practicable.
4. A statistical project to review and further develop methods for combining indicators, together with applications to case studies with existing data, should be funded. This might be collaborative with the previous three suggestions. A statistical scientist for one year would be needed.
5. There is probably also a strong case for monitoring fish and benthic biodiversity inshore, beyond the reach of groundfish surveys. Some surveys already exist that might benefit from expansion and improved long term security of data collection.

In conclusion, the MTI is not recommended for use by UK due to its cost, difficulties in interpreting it, and that more suitable indicators are available to provide reporting on marine ecosystem integrity. Length-based, threat, and occupancy indices are recommended and the use of non-fish based indicators are supported in principle, but the lack of comprehensive data will mean further work to develop these for plankton, epibenthos, cetaceans, seabirds, seals, and perhaps inshore fauna.

It was recommended that a statistical project is developed to assist in ascertaining the most suitable method for combining the results of multiple indicator series.

Lastly, it was also recommended that a short project is established to prepare the recommended indicator (LBI) for reporting. This will require the necessary data and input from Scotland, England, and Northern Ireland.

Tabular summary of candidate indicators against proposed criteria – Marine Trophic Index

	MTI computed with landings statistics	**MTI computed with groundfish surveys**
Data security:	High, but ICES stats 2 years behind present; [National stats are more up-to-date but cover fewer fisheries/trophic levels.] Landings stats often said to be biased. .	High. Main UK surveys are funded under the EC Data Collection Regulation. Survey gear is constant and must remain so to provide an effective indicator.
Represents UK waters:	Yes, but ICES and national stats cover, but not mappable to national boundaries. Trophic levels (TL) in landings may not represent UK ecosystem well. TLs for species available for limited localities in UK waters at present. MTI is poor for regions within UK waters.	Otter trawl surveys are best because they catch target and non-target species at most trophic levels. They cover all marine regions around UK except for the Channel. However, trophic levels (TL) for fish species are only available for limited localities in UK waters at present.
Long-term, interpretable trends?	Not necessarily. MTI is affected by commercial, regulatory, practical fishing, regional, and ecological factors making interpretations potentially controversial.	Possibly. A survey-based MTI is not immediately affected by factors affecting commercial fishing, but trends tend to be weak because of low density of fishing stations and restricted range of TLs caught. Including size effects on TL might help but would add considerably to costs.
Relevant to marine ecosystem integrity?	Yes. Trophic structure is central to ecological integrity but other factors, e.g. fishery closures, low TACs, could cause irrelevant changes in MTI. .	Yes. Trophic structure is central to ecological integrity but other factors, e.g. fishery closures, low TACs, could cause irrelevant changes in MTI.
Threshold values exist?	No. There is little guidance on desirable values for an MTI for UK seas. However, a simple trend upwards is currently needed for conservation purposes.	No. There is little guidance on desirable values for an MTI for UK seas. However, a trend upwards is currently needed for conservation purposes.
Statistical power to detect change and trends:	> 10 years for meaningful change using a major trawl survey (Nicholson and Jennings 2004). Quicker changes can occur in a landings-based MTI but for fishery-related, not ecological reasons.	> 10 years for meaningful change using a major trawl survey (Nicholson and Jennings 2004).
Modifications Refinements	Establish TLs for more catchable species. Sample them from more localities around UK. Choose best TL method and quality control (QC) procedures. Ideally, investigate factors affecting MTI series and food web structure.	Establish TLs for more catchable species. Sample them from more localities around UK. Choose best TL method and quality control (QC) procedures. Ideally, investigate factors affecting MTI series and food web structure.
Scientific cost implications (approx):	Calculations, meetings, investigating causes: 3 person months (p.m.) annually Extending TL information, quality control (QC): 12 p.m. + analytic costs Updating TLs annually, QC: 6 p.m. + analytic costs	Calculations, meetings, investigating causes: 3 person months (p.m.) annually; Scotland: add 3 p.m. Northern Ireland: add 3 p.m. Extending TL information, QC: 12 p.m. + analytic costs Updating TLs annually + QC: 6 p.m. + analytic costs

Tabular Summary of candidate indicators

	Length-based indicators (LBI) computed with groundfish surveys	Threat and occupancy indicators computed with groundfish surveys
Data security:	High. Surveys are supported by EC Data Collection Regulation and Defra. All fish are already measured routinely. Survey gear is constant and must remain so to provide an effective indicator.	High. Surveys are supported by EC Data Collection Regulation. Survey gear is constant and must remain so to provide an effective indicator.
Represents UK waters:	Coverage good but not comprehensive for any one gear. Suitable UK otter trawl surveys exist for North Sea, west of Scotland, Irish Sea, and (recently) south west of England, but not the Channel. Beam trawl surveys exist for southern North Sea, Channel, and the Irish Sea.	Coverage good but not comprehensive for any one gear type. Suitable UK otter trawl surveys exist all around UK except for the Channel. Beam trawl surveys exist for southern North Sea, Channel, and the Irish Sea.
Long-term, interpretable trends?	Factors affecting fish lengths are well understood. Change can often be tied to fishing effects. Variable recruitments are the major interfering factor.	Yes. More 'threatened' species, and declining geographic occupancies both suggest less biodiversity, but occupancies are not necessarily linked to abundances.
Relevant to marine ecosystem integrity?	Yes. Length is linked to breeding, and predation. Length tends to correlate with trophic level.	Yes. Declining biodiversity implies an impacted ecosystem.
Threshold values exist?	The most promising candidate reference level is provided by length of 50% maturity, approximately 0.6 to 0.7 of maximum length for many species. Mean size and 'Large fish' EcoQO thresholds in preparation in OSPAR.	No. The start of a survey series, or historical records, may allow reference values to be derived. Reversal of downward trends would usually be good for conservation, and sufficient for medium term goals.
Statistical power to detect change and trends:	> 10 years for meaningful change (Nicholson and Jennings 2004). The time required for fish to grow limits the speed of response of the ecosystem to management measures, e.g larger mesh sizes.	Threat status assessed from abundances is likely to be unstable for rare species giving low power (Dulvy *et al.* 2006; Blanchard *et al.* 2007). Smoothed occupancies offer a good chance of revealing ecosystem changes within 5 to 10 years.
Modifications Refinements	Meet with other users of LBIs, ICES, EurOceans etc, to choose the most easily interpretable and standardisable measures, plus reference levels. Investigate factors affecting existing LBI series.	Meet with IUCN, ICES etc, to choose the most easily interpretable measures of threat or occupancy. Investigate historical occupancies as reference levels. Consider standardisation across surveys.
Scientific cost implications (approx):	Calculations, meetings, investigating causes: 2 person months (p.m.) annually for England & Wales. Add Scotland: 2 p.m. Add Northern Ireland: 2 p.m. Investigate reference values & trends: 6 p.m.	Calculations, meetings, investigating causes: 2 person months (p.m.) annually for England & Wales. Add Scotland: 2 p.m. Add Northern Ireland: 2 p.m. Investigate reference values & trends: 6 p.m.

Tabular summary of non-fish candidate indicators

	Cetacean observations from groundfish surveys	**Continuous Plankton Recorder (SAHFOS)**	**Epibenthic (seafloor) sampling from groundfish surveys**
Data security:	Funding of groundfish surveys is secure but cetacean observers are not currently funded.	Mostly good, though more secure funding may be needed. However, depends on ships of opportunity.	Funding of groundfish surveys is secure but epibenthic sampling from them is not currently funded.
Represents UK waters:	Otter trawl surveys traverse all UK waters except the Channel where a beam trawl survey could be used.	Several CPR tows traverse UK waters.	Otter trawl surveys traverse all UK waters except for the Channel where a beam trawl survey could be used
Long-term, interpretable trends?	Yes. Cetaceans also affected by fishing but links are not clear.	Yes. Plankton are affected by predation by fish, and climatic effects.	Yes. Epibenthic communities are affected by heavy fishing gear, and climatic effects.
Relevant to marine ecosystem integrity?	Yes. Cetaceans are obvious and attractive components of marine biodiversity. They are important top predators.	Yes. Biodiversity is important for planktonic communities. Plankton form the base of the marine food chain.	Yes. Seafloor animals provide food and shelter for fish. They also process particulate detritus.
Threshold values exist?	Not known.	No, but there has been little research into reference values or directions.	No. Biodiversity research was started but discontinued. Needs revisiting to find threshold values or trends.
Statistical power to detect change and trends:	Depends on density and frequency of observer coverage.	Unknown - possibly high because of the continutity of each plankton tow, meaning less local sampling variance. Missing tows could be a problem.	Depends on density and frequency of sampling. Some changes would, however, be obvious.
Modifications Refinements	Design indicators of biodiversity, ecological state, and environmental or climatic effects using existing data. Ensure security of future data by funding observers or providing training for regular survey officers on the bridge.	Design indicators of biodiversity, ecological state, and environmental or climatic effects using existing CPR data. Ensure security of future data.	Design indicators of biodiversity, ecological state, and environmental or climatic effects using existing epibenthic data. Ensure security of future data by funding observers.
Scientific cost implications (approx):	Develop cetacean indicator: 3 person months (p.m.). For observer option: Bird+mammal observers x 2 + calculations annually, for English surveys (NS, Ch, IS, SW): 16 p.m + seagoing costs; Add Scotland (east, west): 8 p.m. + seagoing costs; Add Northern Ireland (IS): 4 p.m. + seagoing costs (detailed costing proposals to be developed - HBDSEG)	Develop indicators: 12 person months (p.m.) Calculate annually: 3 p.m.	Develop indicators: 6 person months (p.m.) Epibenthic sampler, calculations annually, for English surveys (NS, Ch, IS, SW): 8 p.m. + seagoing costs Add Scotland (east, west): 4 p.m. + seagoing costs Add Northern Ireland (IS): 3 p.m. + seagoing costs (More detailed costing proposals will be developed through HBDSEG)

1. Introduction

1.1 Project Background

The Convention on Biological Diversity (CBD), Rio de Janeiro, 1992, has as its objectives "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilisation of genetic resources"[2]. These objectives were endorsed at the Johannesburg World Summit on Sustainable Development, 2002[3]. Wide ranging scientific discussion of the issues surrounding monitoring of biodiversity in relation to the CBD with emphasis on terrestrial species can be found in the symposium proceedings edited by Balmford *et al*. (2005).

Measuring success of objectives is normally undertaken using a set of indicators. One such is the Living Planet Index (LPI) which summarises rates of change in populations of vertebrate species. It includes a marine component with 267 species, mostly fish, sea birds, and marine mammals from four oceans. The marine LPI fell by about 25% between 1970 and 2000 (Loh *et al.* 2005). Much of the concern about loss of species and biodiversity in the sea is directed at commercial fishing because so many fisheries are in a depressed state around the world (Beddington and Kirkwood 2005; FAO 2006) as well as in European waters (Commission 2001) implying that high mortalities have been suffered by commercial species and their associated by-catch species.

An *ad hoc* technical group under the CBD recommended using a small number of composite indices for providing information on changes in species and biogeographic populations[4] in the marine environment. One such composite indicator was the Marine Trophic Index (MTI) which Pauly *et al.* (1998a) had put forward for measuring a phenomenon they called “fishing down marine foodwebs”.

The UK Government has also outlined a vision for the marine environment as one of ‘clean, healthy, safe, productive and biologically diverse oceans and seas’. *Safeguarding Sea Life: the joint UK response to the Review of marine Nature Conservation* set out the overarching policies for marine nature conservation shared between the four administrations within the UK, and includes the establishment of Ecosystem Objectives. The publication by the European Commission of a proposal for a Marine Strategy Directive also has at its core Good Environmental Status (GES), which will require an objective-led process to enable reporting on the state and overall health of the marine environment.

The Marine Trophic Index (MTI) is listed for development in the EU/CBD focal area ‘ecosystem integrity and ecosystem goods and services’. The UK Biodiversity Partnership Standing Committee has also agreed a draft set of 18 UK biodiversity candidate headline indicators, of which is the ‘Marine Trophic Index’ (MTI). The two main drivers for this reporting are:

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[2] http://www.un.org/millennium/law/xxvii-24.htm
[3] http://daccessdds.un.org/doc/UNDOC/GEN/N02/636/93/PDF/N0263693.pdf?OpenElement
[4] http://www.cbd.int/doc/meetings/sbstta/sbstta-10/information/sbstta-10-inf-07-en.pdf

- In 2001, the Council of the European Union agreed to a binding target *that biodiversity decline should be halted with the aim of reaching this objective by 2010;* and

- In 2002, signatories to the World Summit on Sustainable Development in Johannesburg agreed to '*achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on earth*'.

In order to fulfil the UK commitment to reporting on the MTI, Cefas were commissioned (CRO 382) to undertake a critical assessment of the MTI approach and its application to the UK and to identify and test modifications/refinements that could improve the power and reliability of the MTI. The development of the indices also needed to fit into the current Marine Objective framework being developed by Government and the UK Marine Monitoring and Assessment Strategy (UKMMAS).

1.2 Project Aims and Objectives

The project objectives as set out in the tender specification were:

1. To identify and develop a range of options for the production of a UK Marine Trophic Index (MTI). The options should address the following:
    - selection of data source (considering both commercial fish catches and fisheries-independent data);
    - identification of geographic coverage of data;
    - calculation method (to cover, amongst others, the use of a cut-MTI to remove lower-ranking species; differential allocation of trophic status depending on fish size).
2. To critically assess the MTI options against criteria which includes:
    - availability and future security of data;
    - suitability and relevance to trophic status of the marine environment;
    - representativity of UK waters;
    - capacity to provide interpretable trends;
    - validity to set thresholds and report on trends.
3. To consult and engage with the wider scientific and conservation community on the suitability of the indicator;
4. To identify a single MTI that provides the most secure, suitable, representative and capable option and to set out clearly the mechanism for and cost of updating the indicator annually;
5. To provide a critical assessment on the ability of the favoured MTI option to provide an assessment of marine ecosystem integrity in UK waters and the ability of the indicator to detect change and trends (i.e. consideration of the power to detect change);
6. To recommend likely thresholds, considering any regional differences; and
7. To identify, in consultation with the wider scientific and conservation community, further indicators that should be developed to provide a comprehensive picture of marine ecosystem integrity (at present we envisage a maximum of three additional indicators).

After discussions at contract start up, the Project Steering Group identified three main stages:

1. To develop options for a refined Marine Trophic Index (MTI) which provided a long-term, robust and accepted indicator of marine ecosystem integrity in UK waters;
2. To develop options for an alternative to the MTI or to supplement; and
3. To evaluate the options using a critical set of evaluation criteria and systematic consultation with relevant experts in the scientific community.

It was also agreed that additional indicators would be considered with the aim of selecting an indicator for marine ecosystem integrity, whether based on MTI or an alternative formulation.

Final recommendations within this report were to be based on the above assessment, with corresponding data and methods included.

1.3 Scope

In order to produce a UK index, the geographical scope of this work extended to UK Waters (England, Scotland and Northern Ireland territorial waters and UK offshore waters). Where possible the ability to use the data to provide a national picture was highlighted.

The report focussed on fisheries data for the assessment of the MTI and in consideration of alternative/supplementary indicators, although it is recognised that indices for other marine ecosystem components (i.e birds; mammals etc) could be developed.

Reasons for this focus of effort were that the MTI was originally drawn up with FAO commercial fisheries landings data; fisheries are widely considered to be the dominant anthropogenic influence on the sea; and fisheries data are readily available in the UK whereas other types of data are less so.

Nevertheless, the approach adopted here was not intended to be an argument against the use of other types of data for meeting our biodiversity obligations. Section 6 discusses opportunities for pursuing additional, non-fish approaches.

1.4 Report Structure

Section 2 of this report outlines the data and methods used to develop MTI using fisheries data and two other selected classes of diversity indicator, one based on fish sizes (lengths), the other considering the threat of local extinction of rare species. In sections 3 to 5, each class of indicator is presented with a short literature review, estimation of time series using fisheries landings or survey data, and an assessment of the suitability of the method against the selected criteria given in section 1.2, as well as any other relevant considerations. The assessments benefited considerably from a workshop held at Defra, London (3 Mar 2008) and attended voluntarily by invited scientists and government workers. Full minutes can be found at Annex 1 of this report. A list of conclusions and recommendations taken from throughout the report can be found at the end of the Executive Summary, section 0, along with tabular summaries of how each indicator fares against the standard criteria in the objectives.

Section 6 briefly considers indicators for marine animal groups other than fish. Section 7.1 reviews the statistical assessment of trends, drawing attention to the variety of methods available. Other annexes tabulate trophic level and other data used in this project, describe responses to a written consulation (Annex 7), and provide operating details for the database that was developed to hold all data. Lastly, conclusions from the project and recommendations for further work to provide the UK with national time series of indicators of marine ecological integrity are recommended in the Evaluation and Conclusions, section 8.

2. Data and Methods

This section describes data and methods common to all of the indicators tested.

2.1 Sources of fisheries data, geographical coverage and computations

Two types of fisheries data qualify for use for estimation of indicators of ecological integrity:

- Data summarising the landings of commercial fishing vessels. Landings do not include small fish discarded at sea. They are also subject to commercial factors affecting the market value of species and the fishing effort applied, and to regulatory factors such as quota and technical measures that may control when and where species are caught; and
- Fish survey data. These are obtained by research vessels fishing with an otter or beam trawl in a standardised way at a fixed set of stations every year in order to estimate abundance indices for each species. The assumption is that numbers caught per hour of trawling are proportional to local abundance of the species.

Two readily available sources of landings data were:

- Defra landings statistics covering quantities landed to England and Wales by vessels of any nationality, and to ports overseas by English and Welsh registered vessels; and
- ICES landing statistics covering quantities landed anywhere of more than 200 species from ICES divisions (marine regions) around the UK by vessels registered in any of 20 member countries including all provinces of the UK.

The ICES landings data were preferred as they provide data from all international fleets exploiting the fish populations around the UK, not just those fleets from England and Wales. The quantities landed are therefore likely to be larger and steadier over time, and, for the MTI indicator, a wider range of trophic levels is included.

Landings data submitted by ICES member countries were taken from http://www.ices.dk/fish/statlant.asp on 15 November 2007. The data are for tonnes of fish as live weight. Parameters of the retrieval using the Statlant system were:

- Years = 1973 to 2005, i.e. all available
- Nationalities = All
- Species = All. Seaweeds were omitted because of the large and sporadic tonnages, mostly landed by France.
- ICES regions = IV (all divisions), VIa, VII (unspecified divisions + a, d, e, f, g, h, f-k, g-k). These regions include all UK coastal waters but omit divisions distant from Britain to the North (IIa, Vb), and to the west of Ireland (VIb, VIIb, c, j, k excepting those in the joint groupings f-k and g-k). A map of the ICES sub areas and divisions around the British Isles is shown in figure 2.1.

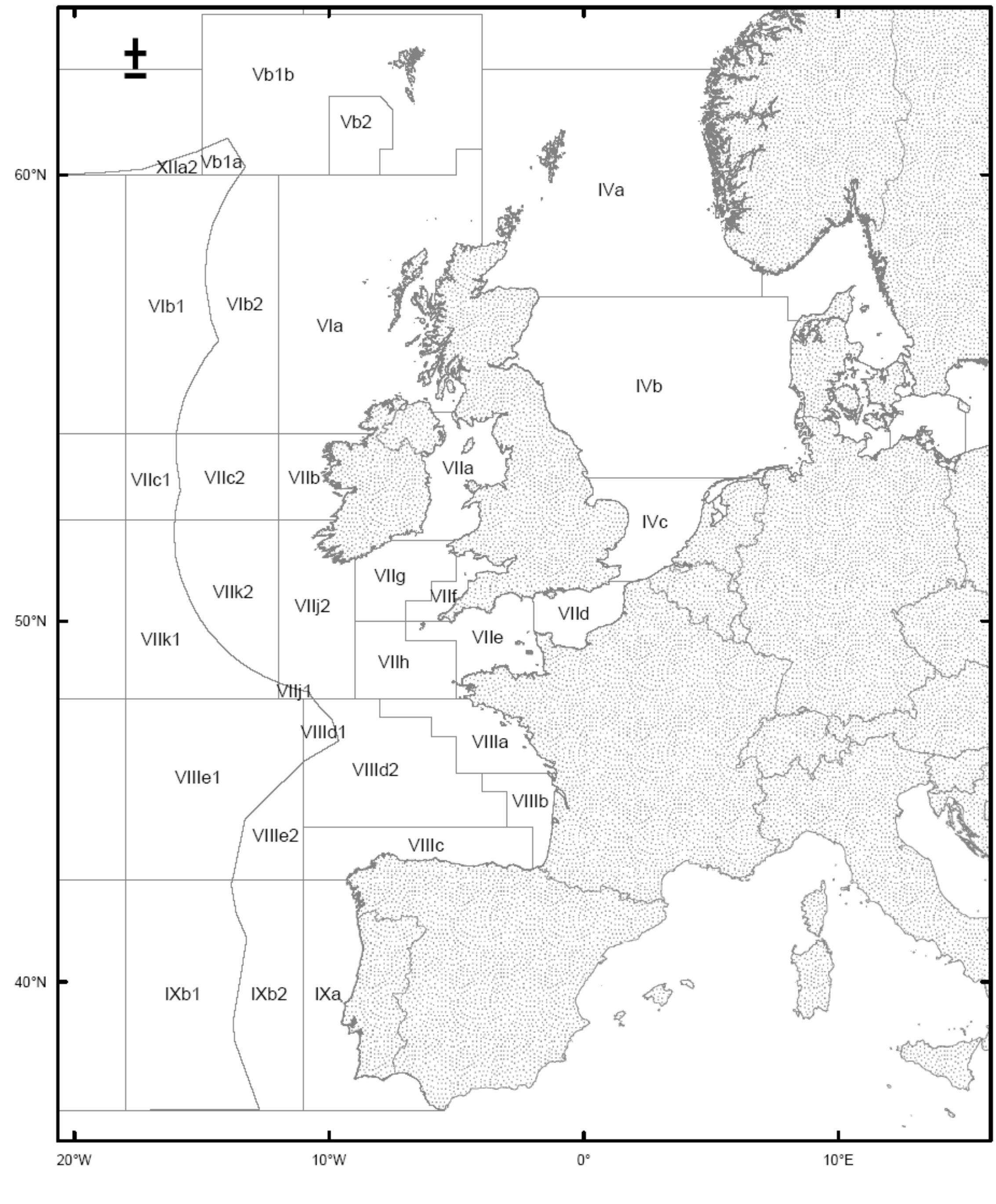


Figure 2.1. Map of ICES divisions around the British Isles**.**

Time series of research vessel survey data available to Cefas included:

- Catch per unit effort (CPUE) data obtained with the Grand Ouverture Verticale (GOV) otter trawl for the entire North Sea from the Thames to Norway and Shetland. This is known as the English groundfish survey (EGFS);

- CPUE data obtained from 4-metre beam trawl surveys (BTS) in the Irish Sea and Bristol Channel, the “Irish Sea BTS”, and in the eastern Channel and southern North Sea, the “Channel BTS”.

Both types of data are directly measured as Kg of fish caught per hour of trawling using motion-compensated electronic balances on the deck of the survey vessel. All fish species are also measured and recorded as numbers-at-length. Cefas carries out other localised surveys but their small scale and focus on single species (e.g. bass, Blackwater herring, various shellfish) imply that they would be difficult to use for national indicators. One Cefas survey, the SW beam trawl survey, was omitted from this study because of inconsistent sampling of non-target species (due to the small numbers of staff on this survey). One other Cefas survey recently terminated (the SW otter trawl survey) and was not therefore considered for use, but a replacement, the Western otter trawl survey recently began and might be considered in future.

Additionally, otter trawl surveys to the east and west of Scotland are conducted by Fisheries Research Services at Aberdeen, and in the Irish Sea by the Department of Agriculture, Northern Ireland. These agencies were not funded to provide data to Cefas. For this reason, work on this project was carried out without their data[5].

All data assembled for this project were compiled into a Microsoft Access database, thereby permitting relatively easy merging of files of data from different sources, as well as the development of standard queries that could be repeatedly operated with different input parameters. A summary of the computations is given in the sections on each indicator. Operating details for the database are given in Annex 5.

2.2 Standardised criteria for assessing the suitability of the MTI and alternatives for UK marine waters

Standardised criteria for assessment of the suitability of the MTI and alternative indicators for UK marine waters were used,and fall under the following subheadings:

1. Availability and future security of data;
2. Representativeness for UK waters;
3. Capacity to provide long term, interpretable trends;
4. Relevance to marine ecosystem integrity, and validity of thresholds;
5. Power of the indicator to detect change or trends;

Other relevant scientific criteria are considered under ‘Discussion and further conclusions’ for each indicator. Practical matters, including approximate costs, associated with further development and use of the various indicators taken together are given in section 8.

[5] Survey data were obtained from FRS, Scotland via the ICES Datras database on 28 Feb. 2008 but too late to include analyses of them in this report.

2.3 Assessment using scientific expertise

A workshop of invited scientists and government officials was held in London on 3 March 2008 to discuss the MTI and other candidate indicators for UK. Minutes of the wide-ranging discussions can be found in Annex 1 of this report.

Consultation with scientists outside Cefas was an important part of the project. A consultation paper detailing MTI option proposals was circulated to a body of scientists and policy makers for comment (see Annex 7 for the consultation list, responses and associated paper). The paper set out potential data sets to use, and indicators to test. The outcomes of the research were also presented verbally to the Healthy and Biodiverse Seas Evidence Group (HBDSEG) in Edinburgh, and to scientists at Fisheries Research Services, Aberdeen during February 2008.

A one-day scientific workshop with participants from the research community and governemt bodies was undertaken as part of the project during March 2008. The purpose of the workshop was to widen the discussion on the MTI and its options for development; alternative indicators to the MTI; and other candidate indicators which might be appropriate for marine ecosystem integrity reporting. Comments and input received as part of the workshop were incorporated into the assessment (Annex 7).

3. The marine trophic index (MTI)

3.1 Introduction and review

The concept behind the MTI is that a healthy ecosystem consists of a trophic pyramid with large numbers of primary producers (plants and bacteria, level=1) at the base, moderate numbers of grazers and predators of grazers (levels=2, 3) in the middle, and small numbers of top predators (levels=4, 5) at the apex. Nowadays, trophic levels are considered to be fractional for each species, depending on the balance of trophic levels found in its prey and, in fact, 'food web' is probably a better term than 'trophic pyramid' since trophic relationships can be very complicated. Numerically, the MTI is the average product of the weight of different species in the landings and their trophic level. The latter can be estimated using stomach contents analysis and modelling (Christensen and Pauly 1992; Pauly *et al.* 1998a; Chassot *et al.* 2008), biological knowledge, or the relative concentrations of the naturally occuring isotopes of nitrogen, the heavier of which (N^{15}) tends to become concentrated in the tissues of predators depending on dietary preferences (Pinnegar & Polunin 2000).

Fishing often targets the highest predators, allowing individuals at the next trophic level to expand in numbers, leading to excessive grazing on the level below, reduced predation on the level below that, and so on, alternately, down to the base of the food chain. These 'trophic cascades' can, in extreme circumstances, be disastrous for marine ecosystems (Daskalov *et al.* 2007; Daskalov and Mamedov 2007). Concerns such as these, and the well-known loss of biodiversity worldwide (Loh *et al.* 2005), motivated Pauly et al. (1998a) to create the MTI from the combination of FAO international fish landings statistics and trophic levels estimated for 220 species or taxonomic groups of fish. It was published as a means of demonstrating fundamental, global-scale changes in marine ecosystems. They found that the MTI had declined measurably since the 1950s, and that recent landings contained fewer large piscivorous, and more planktivorous fishes and invertebrates. They stated "This may imply major changes in the structure of marine food webs."

The methods and conclusions of Pauly *et al.* (1998a) have been widely debated. A number of scientists (Caddy *et al.* 1998) have highlighted issues on the potential weakness of the MTI which have included:

1. Mean trophic level of international fisheries could decline by the small amounts reported for several reasons other than "the fishing down of foodwebs", for example due to:
   - development of new technology for processing large amounts of pelagic fish leading to new fisheries targeted at lower-trophic-level species, e.g. for Peruvian anchovy;
   - growth of aquaculture for low-trophic-level species such as shellfish which are included in the FAO stats;
   - coastal nutrient enrichment leading to greater availability of low-trophic-level grazing species; and
   - closure of a high-trophic-level fishery.

2. The limited attention paid to changing trophic level as individuals grow and select different prey, as well as over-reliance on FAO landing statistics which are

affected by many inaccuracies and which reflect significant regulatory and economic forces acting on the fishing fleets;
3. The methods for determining trophic level were too simple; and
4. The MTI has no absolute values available for use as targets for environmental management.

Robust replies to these criticisms were given by Pauly *et al.* (1998b) and Pauly and Watson (2005). The assumption by Pauly and Watson (2005) that landings will reflect the relative abundance of species at different trophic levels in the ecosystem can be reasonably defended when using international, global fisheries data because of the diversity of fisheries represented. They appear less defensible at smaller scales, for example for national marine waters that do not support fisheries operating at a wide range of trophic levels. Also, at these small scales, fisheries landings can be changed radically by market and political forces, fishing regulations and discarding, the chance successes from year to year of year classes of commercial species, and even by the weather.

Fishery-independent data, i.e. obtained by research vessel trawl surveys, may be more sensitive to changes in the underlying ecosystem (Jennings *et al.* 2002a), particularly if individual body size is taken into account, since many species grow by orders of magnitude from birth to old age and must adjust their trophic levels accordingly (Caddy *et al.* 1998; Jennings *et al.* 2002b). There are, however, draw-backs to using survey data to calculate MTIs. Surveys catch fewer fish than commercial fisheries with the result that sampling variability can be much higher. The fishing gear used for the survey is also critical. Otter trawl surveys target demersal roundfish and catch varying proportions of pelagic species depending on the headline height of the trawl, and generally low proportions of flatfish depending on the groundgear fitted. Beam trawl surveys target flatfish and generally catch very low proportions of pelagic and roundfish. Both types will only occasionally catch shellfish, and benthic species – which are also relevant to an MTI – will only be caught systematically if special efforts are made to monitor the catches for non-fish species. A single survey can therefore only be relied upon to provide a partial and unbalanced sample of the different trophic levels of fish species. These considerations warn that MTI series prepared with landings or fish surveys are likely to produce different signals.

A questionable assumption behind the MTI is that the dietary preferences of species, and thus their trophic levels, do not change appreciably over time. Studies of the N-isotope composition of individual animals in museums (Wainright *et al.* 1993; Thompson *et al.* 1995) indicate otherwise, though the time periods studied were long. More recently, Chassot et al. (2008) confirmed that some predatory commercial fish species in the Celtic Sea feed oportunistically and change their diet with region, season, and body size or age. There is therefore a case for re-estimating trophic levels for all species regularly whilst an MTI is being monitored. Trophic-level indicators have already been estimated in a research context using research vessel (RV) survey data from the North Sea (Jennings *et al.* 2002a), and RV and commercial landings data from the Celtic Sea (Pinnegar *et al.* 2002) and Mediterranean (Pinnegar *et al.* 2003). Additionally, relationships between body weight and trophic level have been estimated for 15 common species found in the northern North Sea (Jennings *et al.* 2007). These relationships would also have to be re-estimated and extended to other species and localities if an MTI is intended to take into account changing trophic levels with growth of individuals. The task of estimating trophic levels, either by stomach contents analysis or by N-isotopes, requires significant scientific effort, especially if relationships with size are considered important. In practical terms, an additional scientist would be needed on a 30-day survey in each region of UK seas to collect the samples, say 5 surveys in a year, and several hundred samples would have to be analysed at a cost of approximately £15 each for N-isotopes, and about the same again in laboratory time for stomach contents analysis.

The following subsections outline the sources of trophic level data used (3.2), computational procedures (3.3) for calculating the MTI, then estimate UK MTIs for ICES landings data (3.4), for three Cefas surveys, the EGFS, the Channel BTS, and the Irish Sea BTS (3.5), and again for the surveys but using linear relationships describing changing trophic level with fish size for 15 species (3.6). An assessment of the suitability of the MTI for UK waters using the standardised criteria listed in section 2.2 and other scientific reasoning is given in section 3.7. Sources of landings and survey data were described in section 2.1.

3.2 Sources of trophic level data for UK marine fish

Two sources of trophic level data for UK marine fish were readily available to Cefas from recent research (Pinnegar *et al.* 2002; Pinnegar *et al.* 2003; Jennings *et al.* 2007; Lees and Mackinson 2007):

- Those assembled by Mackinson and Daskalov (2007), Lees and Mackinson (2007), Araujo et al. (2005), and Stanford and Pitcher (2004) were based on stomach contents analysis together with modelling using the Ecopath model (Christensen and Pauly 1992; Christensen and Walters 2004; Christensen *et al.* 2005). The Ecopath model estimates trophic levels for trophic functional groups (i.e. groups thought to display common feeding habits) using data for stomach contents as observed on fish surveys. These data provide a snap-shot of a species' eating habits and may overlook easily digestible materials such as gelatinous plankton, micro organisms, and detritus.
- Those assembled by Pinnegar et al. (2002; 2003) and Jennings et al. (2007) come from N-isotope analysis. This method uses the fact that the concentration of ^{15}N is on average 3.4 parts per thousand (ppt) greater in the tissues of a predator than in its prey. Knowing the N-isotope balance at the base of the food chain, trophic level 1, the trophic level higher up the food chain can be estimated (Jennings *et al.* 2002a). N-isotope analysis is thought to integrate eating habits over a year or more but is reliant on the factor of 3.4 ppt at each trophic step (Pinnegar *et al.* 2003).

Note that the two methods may scale the trophic levels slightly differently, depending on the method of standardisation. Consequently MTI time series may be situated at slightly different overall levels.

Both sources of trophic level data were used for this study, and the results compared. The table of Ecopath trophic levels used was assembled and supplied by S. Mackinson (Annex 2). The table of N-isotope trophic levels was assembled and supplied by J. Pinnegar (Annex 3). Neither of these tables uses exactly the same species or group names as the ICES Statlant tables of landed quantities, or as the Cefas survey data. A mapping between them was therefore necessary. The one used is shown at Annex 4. The tables show variations in trophic levels for each species depending on the source regions. Since the regional values are patchy in availability and not very different from each other, a single median of all available values in each row was used to estimate the UK MTI, rather than attempting to regionalise the calculations. The median was chosen, rather than the mean, because it is less sensitive to extreme values. Figure 3.2.1 shows the rather weak relationship between trophic levels determined for species of fish by stomach contents analysis (Ecopath) and by N-isotope analysis. The R^2 value shown implies that only 14% of the variation is due to a linear relationship between the two methods.

Size-based trophic level data based on N-isotope analysis were available for only 15 common fish species. Users of a size-based MTI computed from them must therefore assume that other species would provide a negligible contribution to the results. Two parameters, *a* and *b*, were estimated from regression modelling of trophic level (TL) as a function of body weight, *W*, in grammes:

$$TL = a + b\log_{10} W$$

(Jennings *et al.* 2007). The species, the estimates of their parameters, and the numbers of individuals upon which they are based are shown in table 3.2.1.

Since *a* and *b* relate to weights of individual fish and weights are not available for individual fish caught on a survey, CPUE in terms of numbers-at-length (in one- or half-centimetre length classes) must be converted to weights using a length-weight relationship. The usual allometric growth formula was used:

$$W = cL^d$$

where *L* is fish length in centimetres. This formula is appropriate when the shape of the fish does not change as it grows. The values used for *c* and *d* were taken from Coull *et al.* (1989) and are also shown in table 3.2.1.

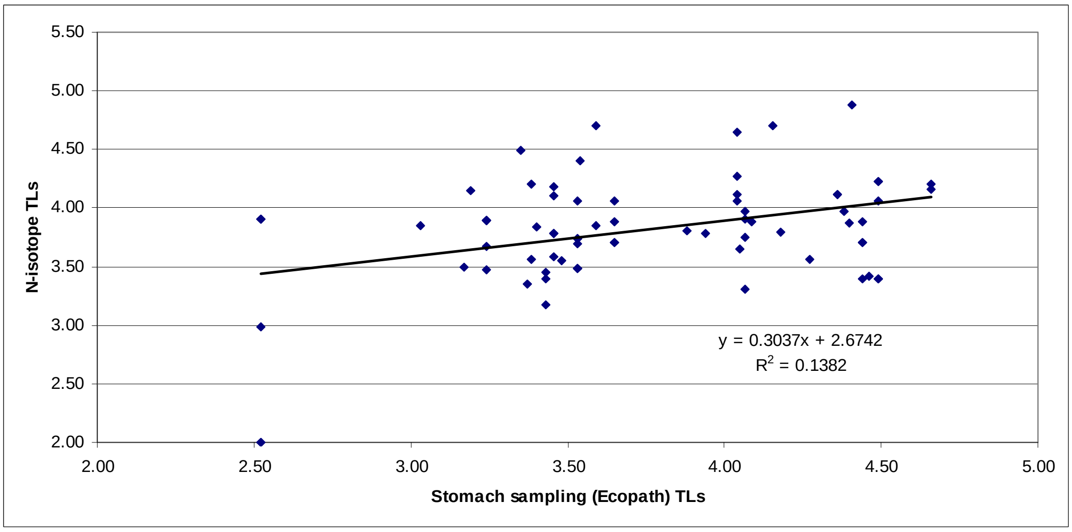


Figure 3.2.1. Relationship between the trophic level determined for a species or trophic group by stomach contents analysis followed by Ecopath modelling, and N-isotope analysis. Data supplied by S. Mackinson and J. Pinnegar, Cefas Lowestoft.

Table 3.2.1 Size-based trophic level (*TL*) parameters for 15 species of fish. *a* and *b* are coefficients in the regression model, $TL = a + b\log_{10} W$, fitted to pooled results for N-isotope TLs and body weights, *W*, collected by the North Sea EGFS, 2002-2005 by Jennings *et al.* (2007). *c* and *d* are parameters for estimating weight from length allometrically (Coull *et al.* 1989). *n* is the number of individuals included. n.a.=not available.

Common name	**Latin name**	***n***	***a* ± 95% CI**	***b* ± 95% CI**	**c**	**D**
Norway pout	*Trisopterus esmarki*	145	4.17 ± 0.22	-0.06 ± 0.15	0.0092	3.027
Long rough dab	*Hippoglossus platessoides*	107	3.61 ± 0.28	0.39 ± 0.18	0.0044	3.209
Dab	*Limanda limanda*	122	3.24 ± 0.21	0.62 ± 0.12	0.0074	3.113
Grey gurnard	*Eutrigla gurnardus*	121	5.22 ± 0.33	-0.29 ± 0.15	0.0062	3.100
Whiting	*Merlangius merlangus*	157	4.00 ± 0.12	0.39 ± 0.05	0.0093	2.946
Lemon sole	*Microstomus kitt*	107	2.73 ± 0.43	0.77 ± 0.19	0.0255	2.764
Plaice	*Pleuronectes platessa*	58	5.17 ± 3.53	-0.27 ± 1.41	0.0215	2.790
Starry ray	*Amblyraja radiata*	121	3.49 ± 0.19	0.32 ± 0.09	0.0409	2.897
Haddock	*Melanogrammus aeglefinus*	127	4.00 ± 0.21	0.17 ± 0.09	0.0157	2.827
Saithe	*Pollachius virens*	114	3.67 ± 0.28	0.31 ± 0.09	0.0238	2.737
Anglerfish	*Lophius piscatorius*	92	3.38 ± 0.36	0.47 ± 0.12	0.0136	2.984
Cod	*Gadus morhua*	121	4.39 ± 0.17	0.19 ± 0.06	0.0175	2.857
Herring	*Clupea harengus*	97	6.85 ± n.a.	-1.24 ± n.a.	0.007	3.000
Horse-mackerel	*Trachurus trachurus*	66	4.84 ± n.a.	-0.24 ± n.a.	0.0034	3.294
Mackerel	*Scomber scombrus*	78	5.12 ± n.a.	-0.39 ± n.a.	0.003	3.290

3.3 Computation of the MTI

All landings and trophic level data were archived in tables in a Microsoft Access database. Computational details for landings-based MTIs are given in Annex 5.1. The mapping used to link the different group and species names in the landings and trophic level tables was drawn up with the judgements of marine biologists and is shown in Annex 4. Calculations with the landings data involved:

- summing annual tonnages landed over all nationalities of vessel for each year, species, trophic functional group, and ICES region;

- multiplying these by median trophic levels (stomach-contents or N-isotope method) for each species or functional group;
- summing the products over all species and ICES regions in the set of regions selected to represent seas around the UK, and finally,
- dividing the summed products by total tonnages landed to give an MTI for each year in which the trophic level for each species was weighted by the tonnage landed.

Computational details for the survey-based MTIs are given in Annex 5.2. The mapping used to link the species names used in the Cefas surveys with the codes or names of species and trophic functional groups in the trophic levels tables is shown in Annex 6. Note that trophic level estimates were not available for all of the less common species found in survey catches. This is not thought important because their contributions to catch weights were small. Calculations were carried out separately for each survey and involved:

- Summing the total Kg caught per hour over all size categories by species at each station in each year of the cruise;
- Summing these weights per hour over all stations to give total weights per hour by species for each annual survey;
- Multiplying these by median trophic levels (Ecopath and N-isotope) for each species or functional group;
- Summing the products over all species for each annual survey;
- Dividing the summed products by total kg per hour caught for all species to give an MTI for each annual survey in which the trophic level for each species was weighted by the kg per hour caught. Note that this method of estimating an MTI statistically weights the results at each station according to the physical weight of fish caught per hour.

Computational details for the size-based MTIs are given in Annex 5.3. Estimated values for *a*, *b*, *c*, and *d* (see equations in section 3.2) available for 15 common species, as shown in table 3.2.1., were added to the mapping table in the database Calculations were carried out separately for each survey. They involved:

- Merging numbers-at-length by species with values for *a*, *b*, *c*, and *d*;
- For each species, calculating the weight (W) of each fish, the total weight caught in each length class, the estimated trophic level (TL) of each length class, and the product, $W.TL$, of each length class;
- Summing the weights caught, and the $W.TL$ products over all length classes, and over all species;
- Calculating the size-based MTI as $\sum W.TL \big/ \sum W$, i.e. an average weighted by the Kgs-at-lengths observed for each species.

3.4 MTI results using UK landings data

<u>UK results</u>: Figure 3.4.1 shows annual total landings for the selected ICES regions and species in tonnes. A gradual decline is evident from the 1970s, possibly steepening in the 2000s. Figure 3.4.2a shows the two MTIs for UK waters, one

computed with trophic levels derived from stomach sampling and Ecopath, the other from N-isotope analyses. The latter displays a clearer downward trend.

Pauly and Watson (2005) proposed that the MTI be calculated with trophic levels < 3.25 excluded so that the overall index is not influenced by pelagic fisheries that remove very large amounts of such species. In the North Sea (which dominates UK landings, see below), pelagic and industrial fisheries both remove large quantities of species, several of which would be at low trophic levels. Figure 3.4.2b-c show the two UK MTI series with different cut-off levels to remove lower trophic levels. Removing all but the highest trophic levels (>=4.5) renders the MTI series almost flat. Cut-offs at lower levels affect the series variably, especially in recent years when signals may go up or down depending on the cut-off and the method for analysing trophic level. The relationship between the results of the two methods for different species was shown in figure 3.2.1.

<u>Regional results</u>: Figure 3.4.3a-d show the tonnages landed for regions around the UK, namely the North Sea, west of Scotland, the Irish Sea and southwestern approaches, and the Channel. It can be seen (from the scaling of the vertical axes) that the landings from UK waters (fig. 3.4.1) were dominated by those taken from the North Sea.   The irregularities in the regional landings series are probably explained at least partly by changing fishing patterns.   Figure 3.4.4a-d shows the corresponding regional MTIs. The two for the North Sea (fig. 3.4.4a) closely resemble those for the UK (fig. 3.4.2) except that there is a slightly clearer trend downwards for the Ecopath MTI. For other regions (fig. 3.4.4b-d), both types of MTI become more erratic, as is typically found when fishery data are disaggregated and sample sizes become smaller.

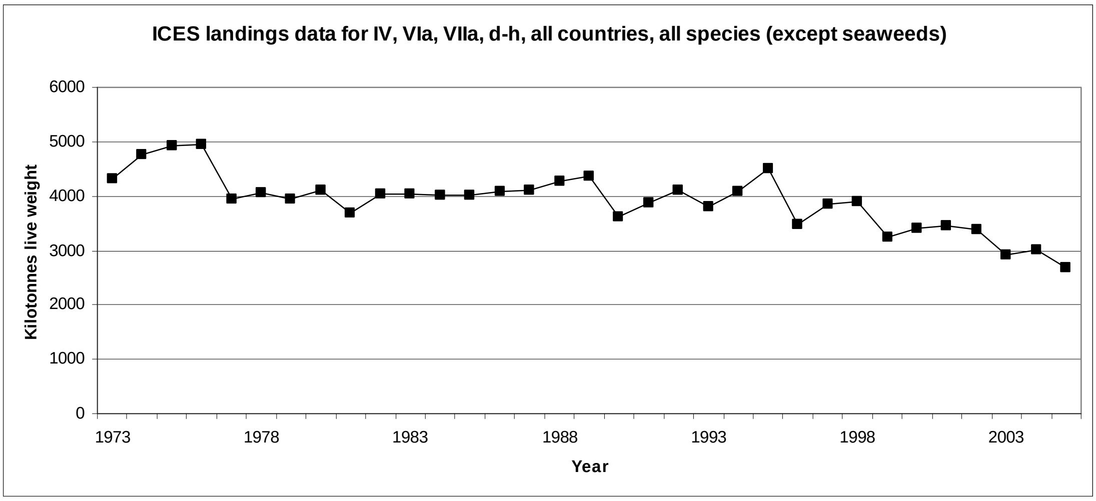
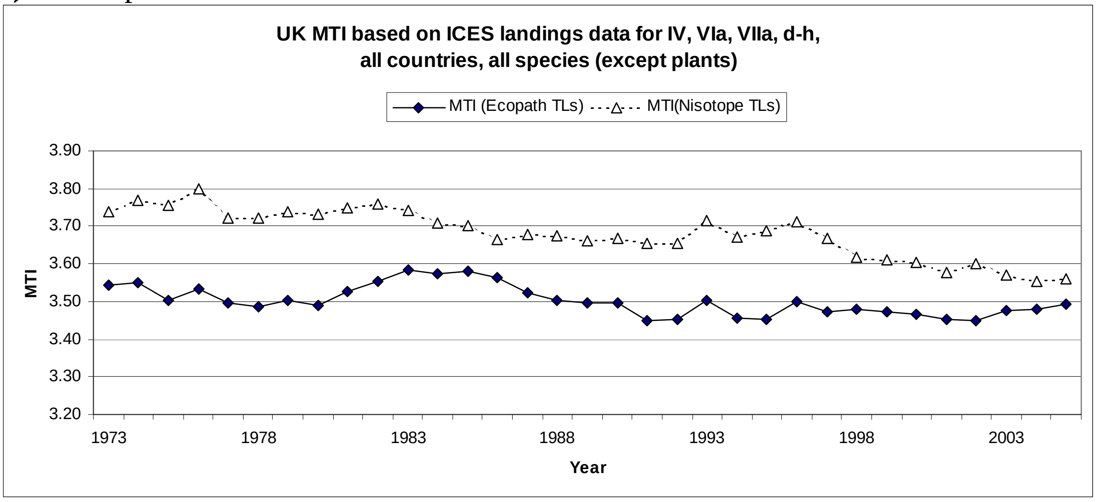


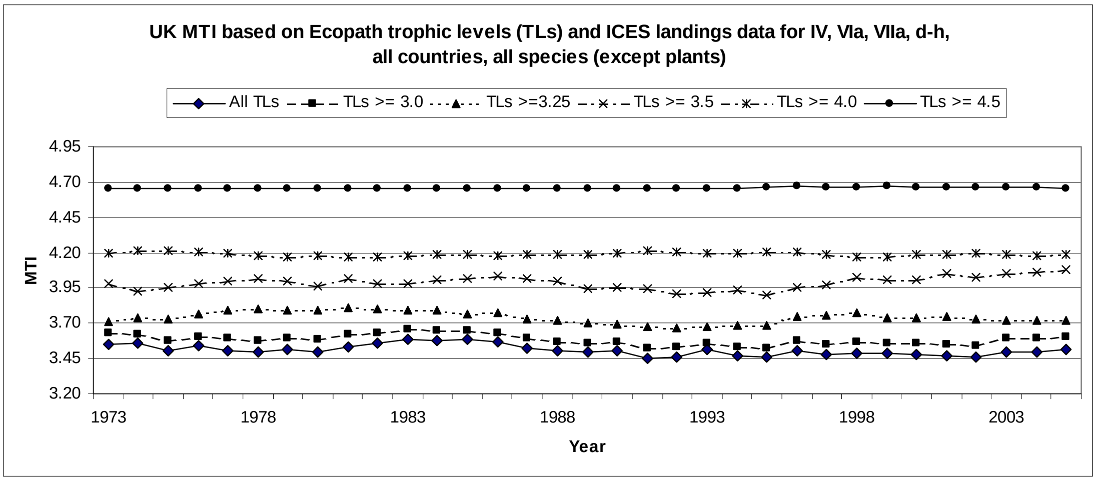
Figure 3.4.1 ICES regions IV, VIa, VIIa, d,e,f,g,h: Total landings (tonnes liveweight) for all species except seaweeds.

Figure 3.4.2. ICES regions IV, VIa, VIIa, d,e,f,g,h: MTI estimated with trophic levels from two methods (a), and with different cut-offs (b, c) applied to see effects of removing lower trophic levels from the index.

a) All trophic levels



b) Stomach sampling and Ecopath method; trophic levels cut-off as shown



c) N-isotope method; trophic levels cut-off as shown

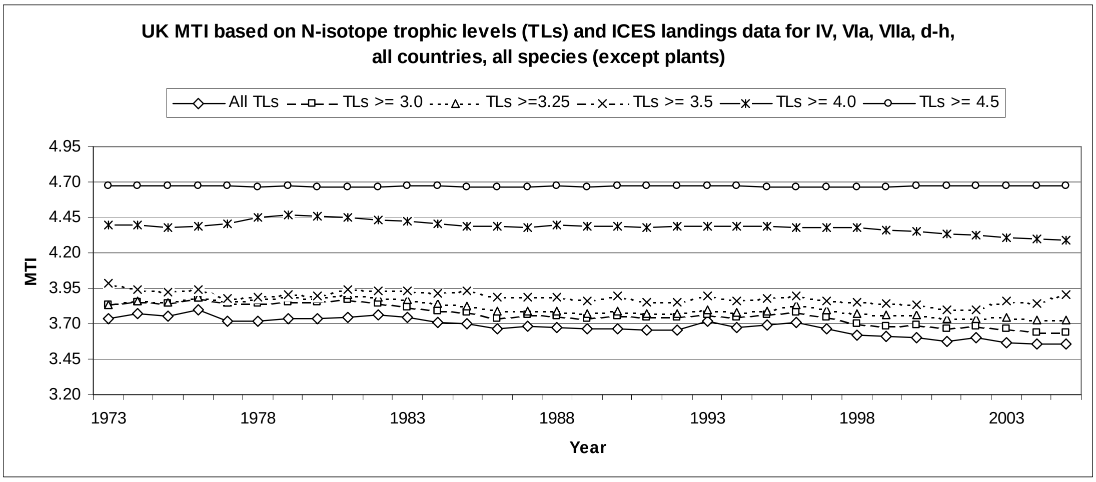
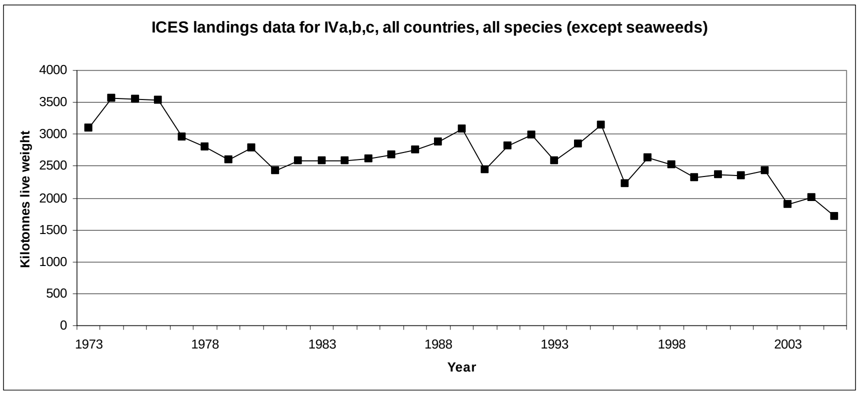
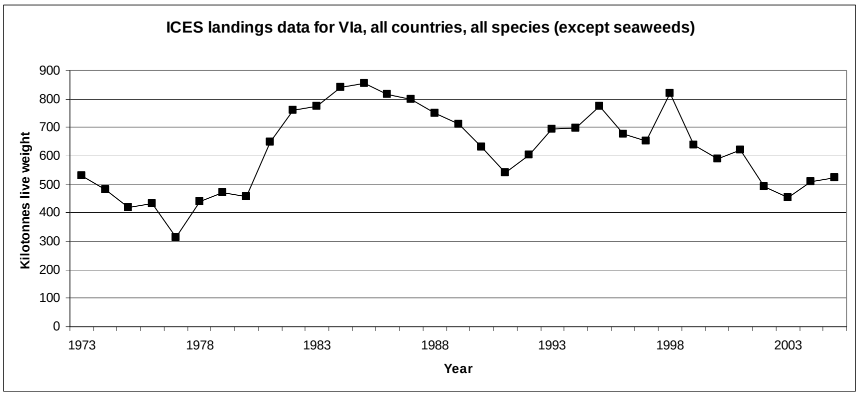


Figure 3.4.3 ICES total landings (tonnes liveweight) from regional waters around UK by region for all species except seaweeds.

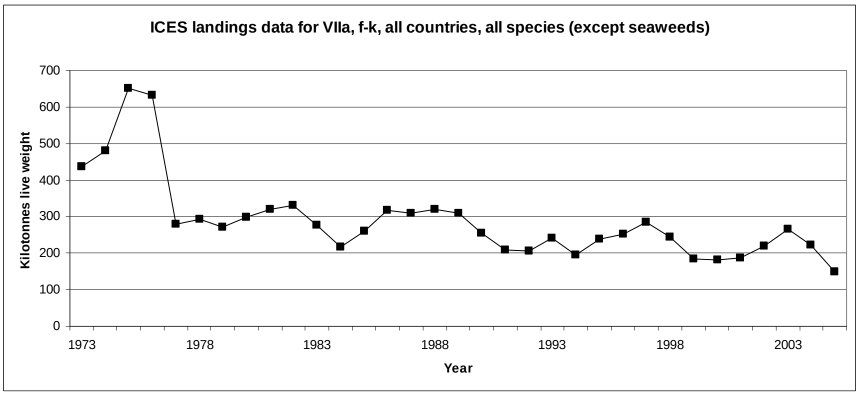
a) North Sea, sub area IV



b) West of Scotland, division VIa



c) West and south western seas, divisions VIIa, f-k



d) Channel, divisions VIId,e

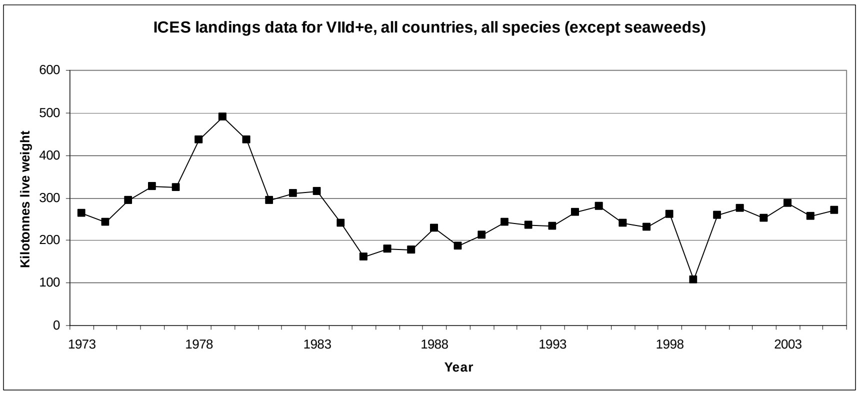
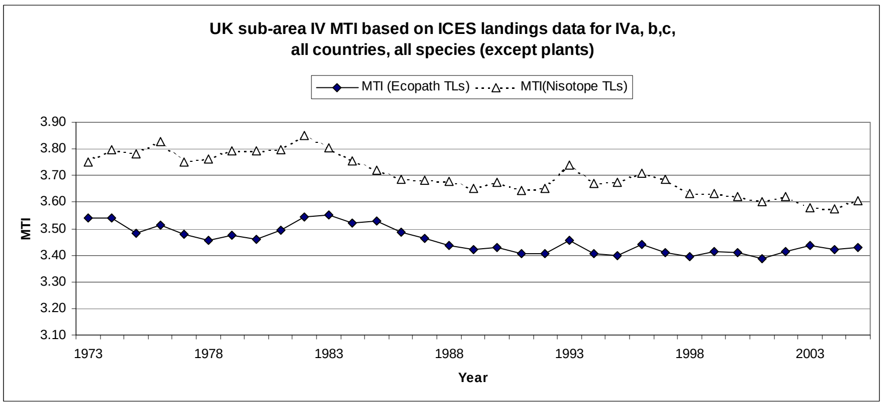
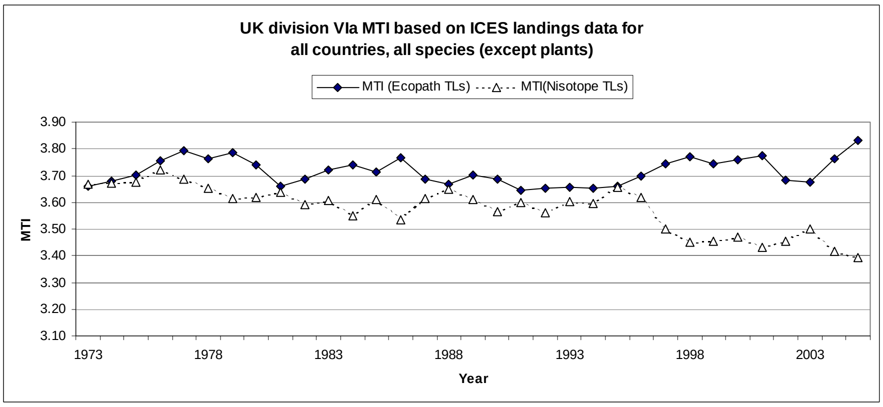


Figure 3.4.4. UK regional MTIs estimated with trophic levels from two sources.

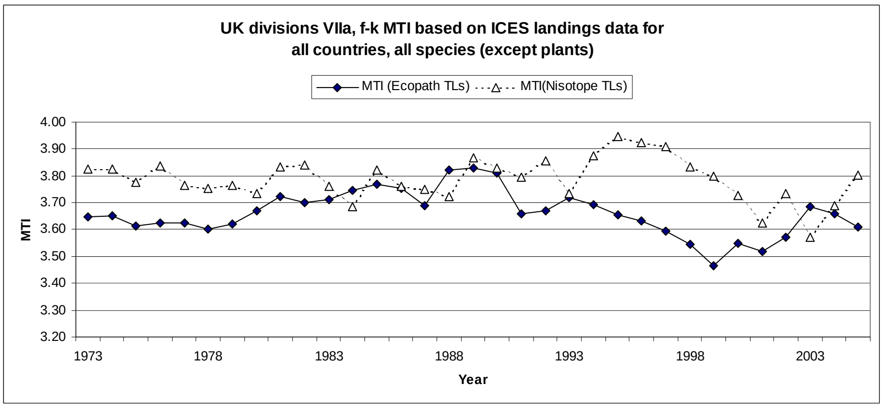
a) North Sea, sub area IV



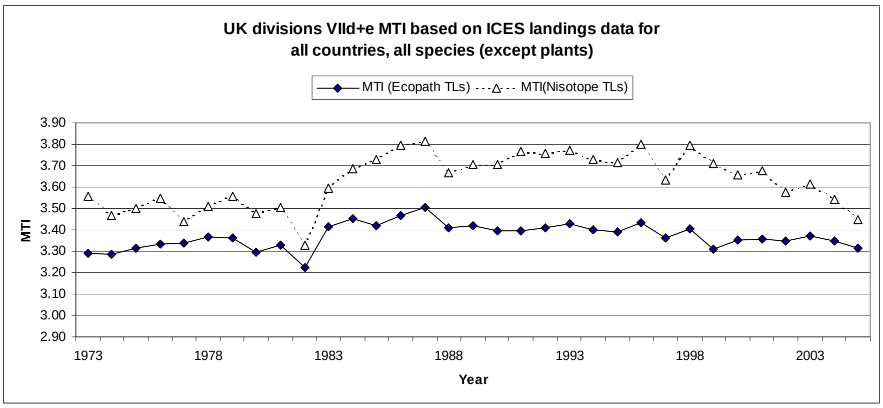
b) West of Scotland, division VIa



c) West and south western seas, divisions VIIa, f-k



d) Channel, divisions VIId,e



3.5 MTI results using UK surveys

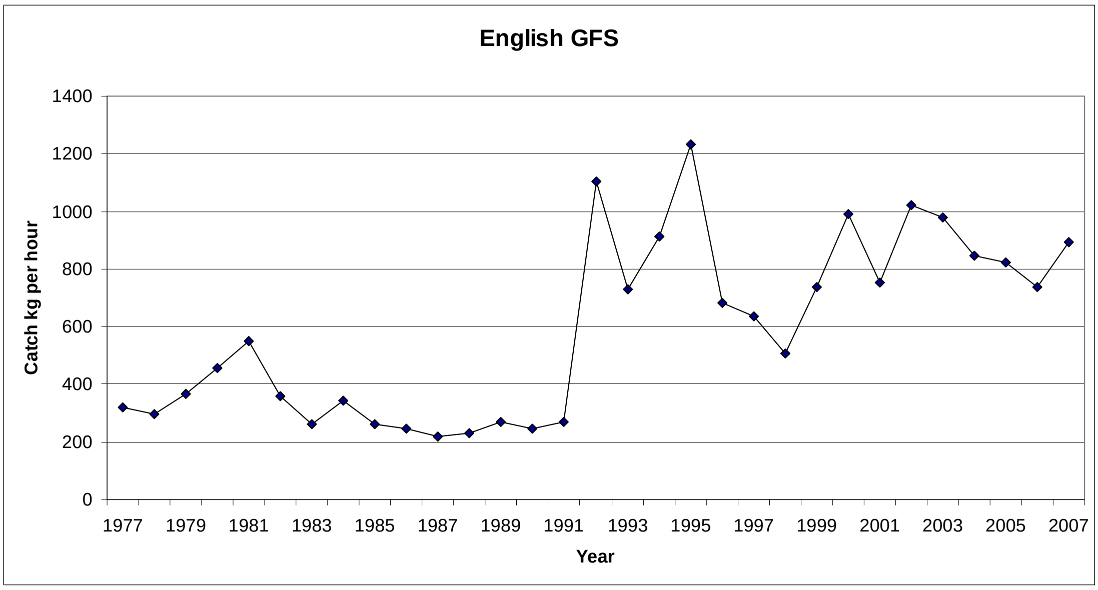
EGFS (North Sea) results: Figure 3.5.1a shows the total catch weight per hour of trawling for all fish species caught on the EGFS. The series steps upwards in 1992, the year that the survey trawl was changed from a Granton to a GOV design. The latter has a higher headline height and tends to catch more pelagic fish. Figure 3.5.1b shows the Ecopath and N-isotope MTI indices. Both show a gradual decline. There is a dip in the N-isotope series in 1992 that is not so marked in the Ecopath series. The most likely explanation is that larger catches with the GOV of relatively low trophic level pelagic species resulted in lower MTIs. If this were the case, the N-isotope MTI picks up the effect more clearly than the Ecopath MTI. The N-isotope points are always above the Ecopath points due to relative scaling of the two methods.

Channel beam trawl survey: Figure 3.5.2a shows the total catch weight per hour for all fish species caught on the Channel BTS. There is a suggestion of a gradual increase since the early 1990s but with two notable spikes, one in 1996, the other in 2006. Figure 3.5.2b shows the Ecopath and N-isotope MTI indices. The series are level from the 1990s except for some single-year spikes, and most of the N-isotope points are slightly higher than the Ecopath points for reasons of scaling.

Irish Sea beam trawl survey: Figure 3.5.3a shows the total catch weight per hour for all species caught on the Irish Sea BTS. There is a suggestion of a gradually increasing trend since the mid 1990s. Figure 3.5.3b shows the Ecopath and N-isotope MTI indices. The series are both steady and level except for a step down in 2000 for unknown reasons. The N-isotope points are always above the Ecopath points due to scaling.

Figure 3.5.1 English groundfish survey (EGFS) of the North Sea, ICES subarea IV. a) Total weight per hour of all species caught; b) MTI calculated using two types of method for estimating trophic level by species.

a)



b)

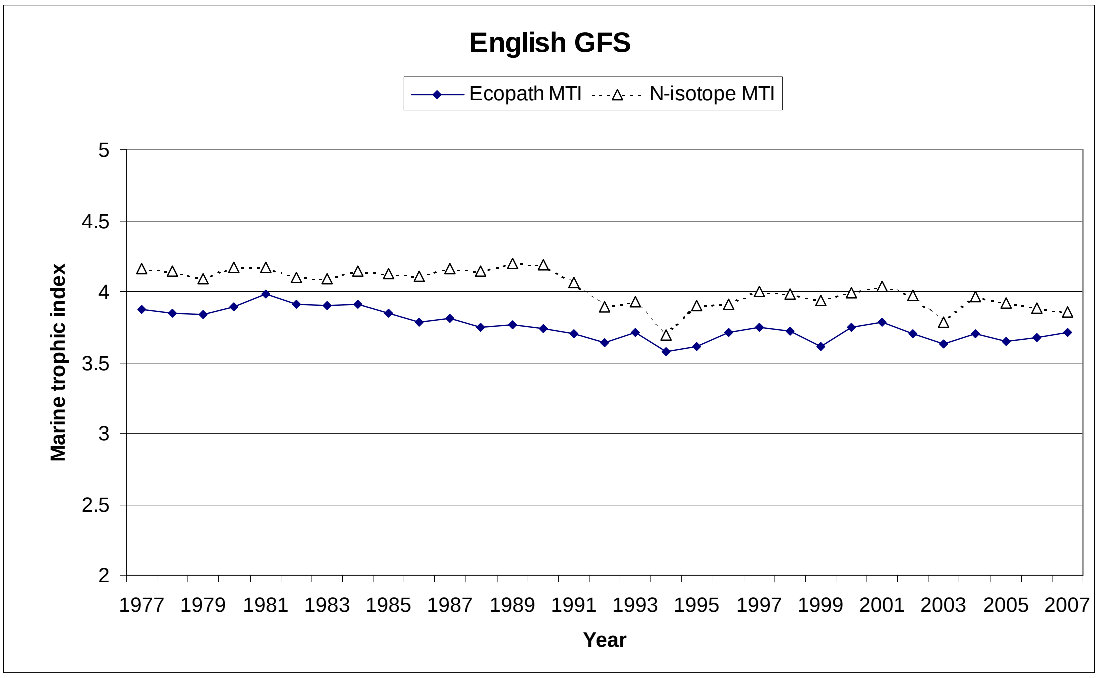
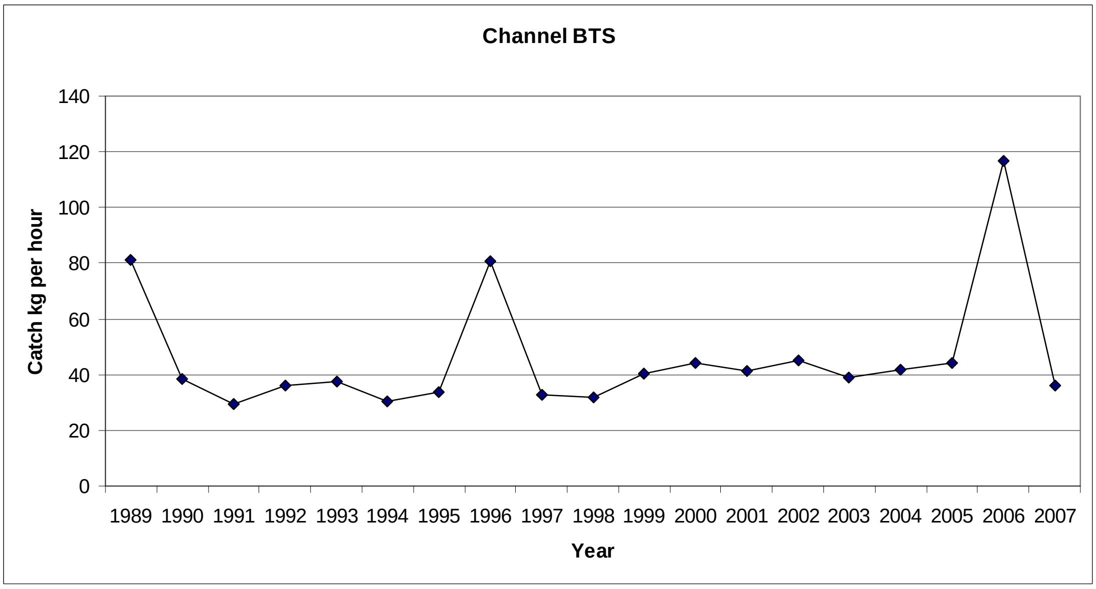


Figure 3.5.2 Channel beam trawl survey, ICES divisions IVc, VIId.
a) Total weight per hour of all species caught; b) MTI calculated using two types of method for estimating trophic level by species.

a)



b)

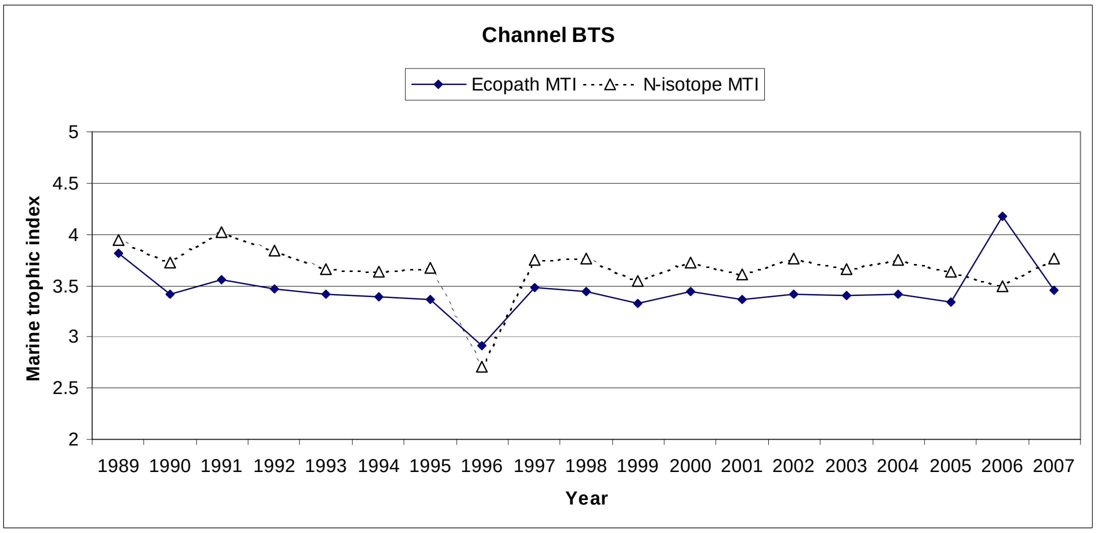
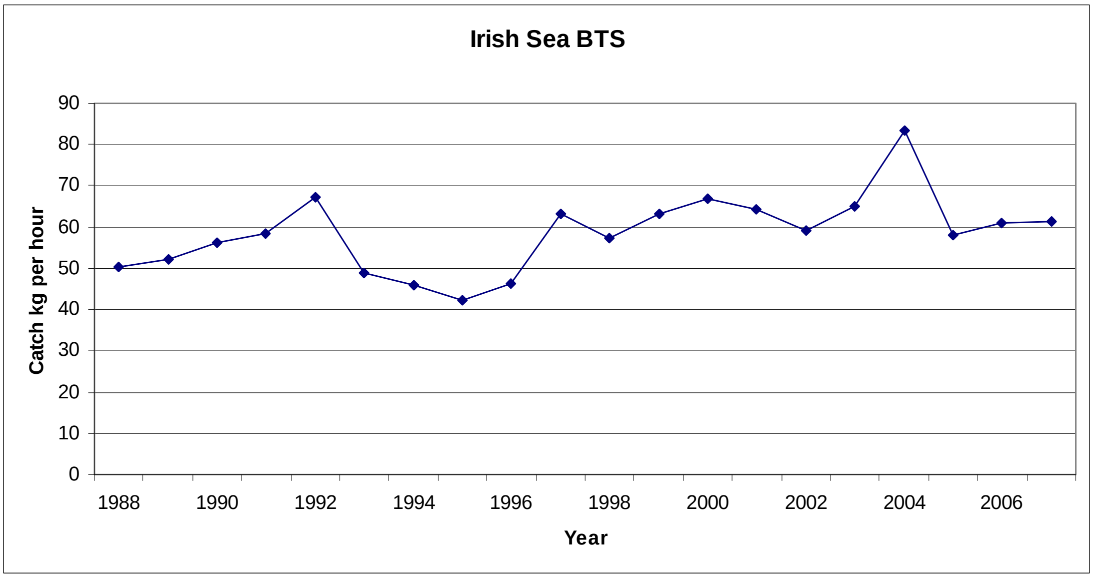
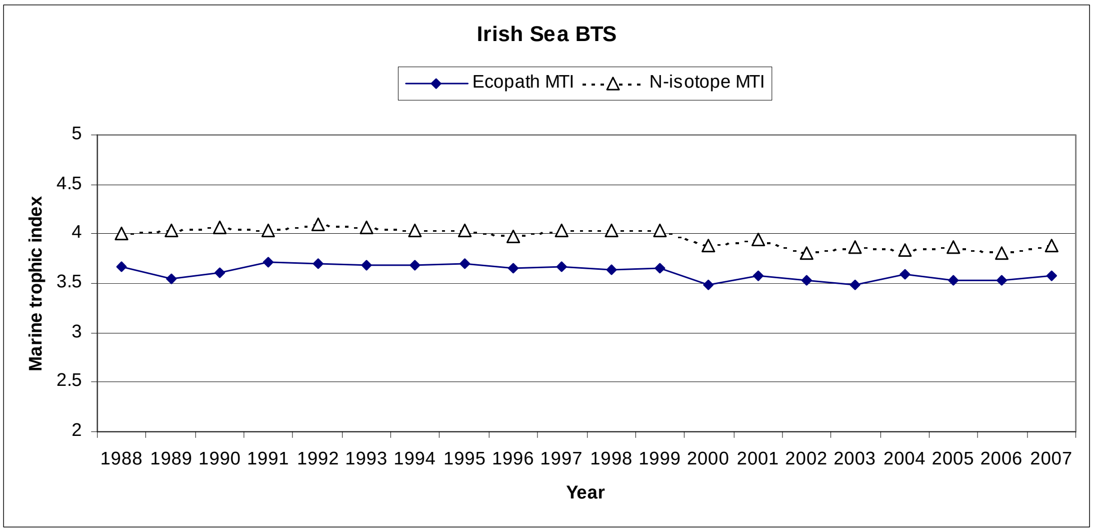


Figure 3.5.3 Irish Sea beam trawl survey, ICES divisions VIIa, f, g, e.
a) Total weight per hour of trawling of all species caught; b) MTI calculated using two types of method for estimating trophic level by species.

a)



b)



3.6 MTI results using size-based trophic levels and UK surveys

EGFS: Figure 3.6.1 shows the N-isotope, size-based MTI calculated for the North Sea. The level appears quite stable at around 3.5 until 1991, then increases somewhat and becomes more variable. The timing of the change in behaviour coincides with the change of trawl from the Granton to the GOV in 1992.

Channel BTS: Figure 3.6.2 shows the size-based MTI for the Channel. Levels are between 3.8 and 4.5, mostly somewhat higher than for the EGFS, and no overall trend is obvious from the time series.

Irish Sea BTS: Figure 3.6.3 shows the size-based MTI for the Irish Sea. After an initial drop in the late 1980s, levels are quite stable between 3.2 and 3.5, i.e. mostly lower than for the Channel, and for the EGFS results from 1992. The early part of the series shows a trend downward followed by a levelling off.

Figure 3.6.1 English groundfish survey (EGFS) of the North Sea, ICES subarea IV: size-based MTI calculated with 15 common fish species; trophic levels based on N-isotope method.

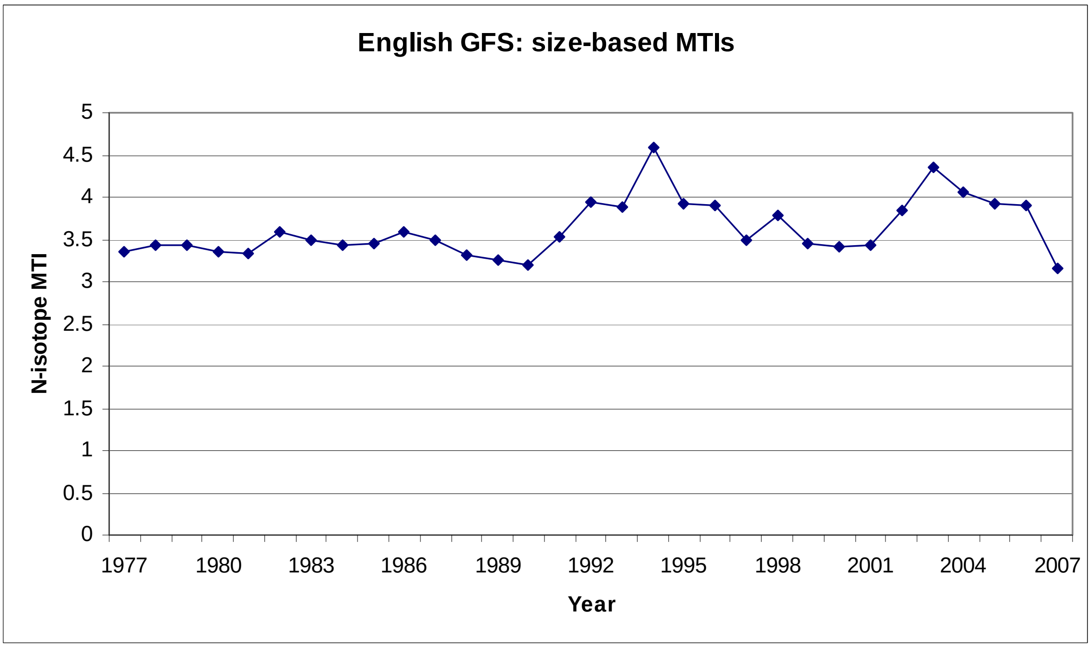


Figure 3.6.2 Channel beam trawl survey, ICES divisions IVc, VIId: size-based MTI calculated with 15 common fish species; trophic levels based on N-isotope method..

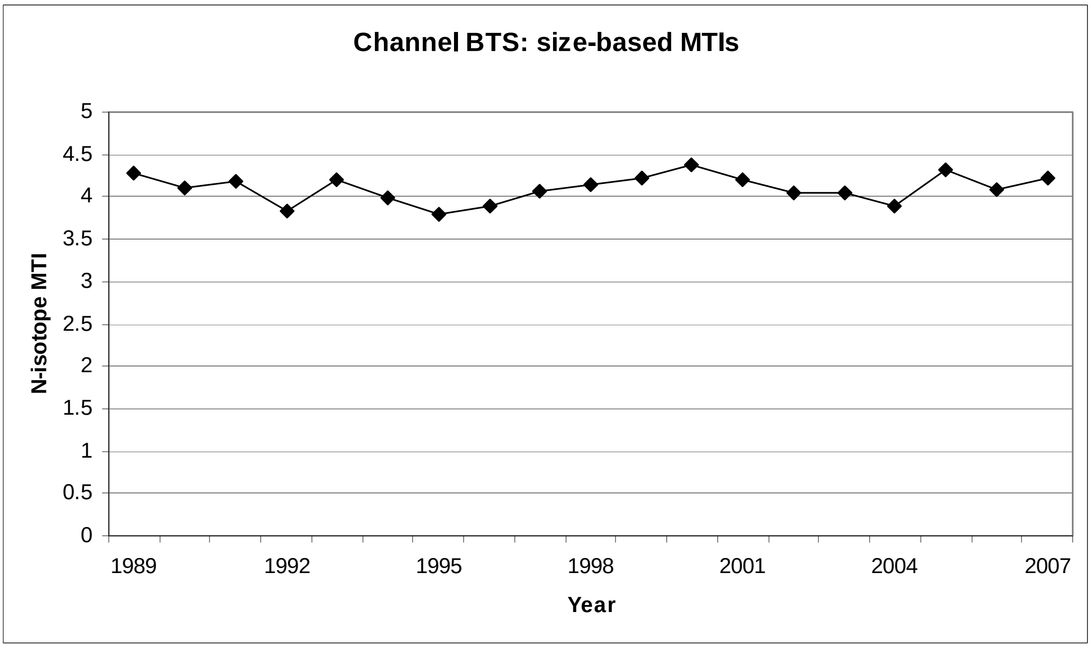
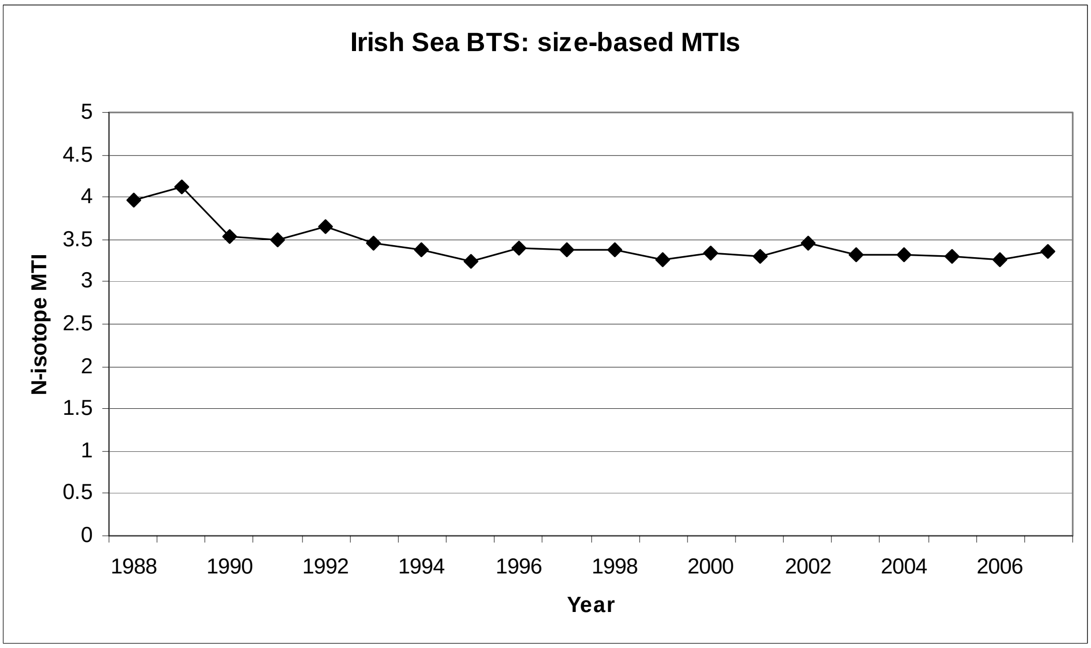


Figure 3.6.3 Irish Sea beam trawl survey, ICES divisions VIIa, f, g, e.:
size-based MTI calculated with 15 common fish species; trophic levels based on N-isotope method..



3.7 Assessment of the MTI options for UK marine waters

The subsections below draw together the findings of the project to assess the MTI options against the chosen criteria. The assessment has included the views of those involved in the consultation exercise. Note that, because of the timing of this report, the minutes of the workshop (Annex 7) had not been seen or confirmed by participants.

3.7.1 Availability and future security of data

Continued monitoring of UK and international landings is expected under the EC Data Collection Regulation for the foreseeable future, and collation of the data by ICES (and FAO) can also be expected for the purposes of stock assessment and research. Continuing support for UK surveys is also expected under the EC Data Collection Regulation for the foreseeable future. However, surveys tested in this study did not provide clear trends in MTI and appear to be of secondary value for that purpose, as discussed further below.

Opinions of those consulted were divided on the Cefas proposals A and B of the consultation exercise to use commercial landings data as a basis for a UK MTI (Annex 7). Serious doubts were voiced about the original use made of landings statistics by Pauly and co-workers, and the dangers of repeating their short-comings. Concerns were expressed about bias, e.g. if the species landed change over time. Calls were made for other data to be used as well, and for supplementary modelling studies. Most respondents agreed that, if commercial landings data are to be used, obtaining them from the international compilations by ICES is satisfactory, as put in proposal C.

Extensive sets of trophic level data based on stomach contents and N-isotope analyses are available at Cefas, as shown in Annexes 2 and 3, and could be used for continuing monitoring of the UK MTI. However, the data are neither complete for species, nor do they represent more than a few restricted regions, mostly in the North Sea. Furthermore, the agreement between the results of the two methods of analysing trophic level is poor (Figure 3.2.1), casting a shadow on the value of both sets for monitoring trophic levels. Relationships between size and trophic level are only available for 15 species from a few locations in the North Sea. If the MTI is to become a national indicator, extension and completion of the existing set of trophic level data, and clarification of the reasons for methodological variance would be important for credibility. Estimates of the analytical standard errors would also be needed.

Opinions were also divided amongst consultees about which type of trophic level data to use, proposal D (Annex 7). Use of stomach sampling and the Ecopath trophic model, as used by Pauly and co-workers, was thought unreliable by some respondents. Others agreed with the Cefas proposal to try out both types of data. Suggestions were made for more elaborate research into marine trophic guilds. Controversy was also stirred by the proposal (E) not to use trophic level-versus-weight relationships in computing a landings-based MTI. Some accepted the practical issues, while others felt that this would compromise the science behind the index too much because many fish are known to change trophic level significantly through their life history.

Views expressed at the scientific workshop (Annex 1) differed on whether trophic levels should be measured repeatedly, or whether values estimated in the late 1990s could serve for many future years. Repeated measurements would assist with determining a useful standard error for an MTI series, and would allow for changing trophic levels of opportunistic feeders as species assemblages changed in response to fishing, but would form a costly overhead. Trophic levels should also be measured for different marine regions, and for different sizes or ages of fish because many species move to higher trophic levels as they grow. Others felt that this level of scientific refinement and cost would not be merited. A compromise would be to re-measure trophic levels every decade or so, though this might lead to step changes in the index. Ignoring the size effect on trophic level means that the MTI is conservative because fishing tends to remove large individuals first, causing a decline of mean trophic level within species that is not registered by the indicator.

Concerning the choice of trophic level data to use to calculate the MTI for surveys, proposal G, opinions in the consultation were either unavailable or more or less similar to those expressed for use with landings data, proposal D. We proposed not to use trophic-level-versus-weight relationships for computing MTIs with survey data, proposal H, and most accepted this position. One respondent disagreed, pointing out the importance of juvenile fish and nursery areas in relation to management advice.

A single project to improve UK trophic level data would require a scientist to take part in several national groundfish surveys, each of about 1 months duration, plus analytical and laboratory costs of the order of tens of thousands of pounds. Considering the mixed views at the workshop, concensus could be found for upgrading the existing set of trophic levels to more species and regions in UK waters as a one-off exercise, with reviews possible in future.

Conclusions: Landings and survey data are secure, though the former offer the best MTI. Computing an MTI would require that existing UK trophic level data should be extended to more species and regional seas involving English, Scottish, and Northern Irish surveys as an initial one-off exercise, with reviews possible in future. Estimates should be made of the standard errors of analyses of trophic level.

3.7.2 Representativeness for UK waters

ICES landings data cover ICES divisions around UK but cannot be mapped exactly onto UK territorial waters. They include all nationalities of vessel fishing there. National landings data on the other hand cover the national fleet wherever it may be fishing, but only those foreign vessels landing to English ports. They would exclude several major fisheries, e.g. Danish and Norwegian industrial fisheries removing very large tonnages of low trophic level species; also large pelagic fisheries landing to Holland and Norway. There are many questions over whether landings data adequately represent the underlying food web of the marine ecosystem. Fishers tend to prosecute a wide range of trophic levels over large sea areas since each level offers a financial reward, but specialisation is more often the norm regionally because of lack of opportunities to prosecute all types of fishery. As discussed at the scientific workshop, landings data are known to be subject to mis- or incomplete declarations, and never include the many small and non-target fish that are discarded at sea.

If an MTI is calculated from UK survey data otter trawl surveys should be used as this gear type finds the largest range of trophic levels. At present, there are otter trawl surveys in the North Sea by England and Scotland, another west of Scotland, a Northern Irish survey in the Irish Sea, and a new English survey to the west and south west of England. There is no otter trawl survey in the Channel. That they are all otter trawl surveys is probably sufficient for combining the results into a UK survey-based MTI, if we can ignore the Channel.

Proposal F in the consultation dealt with the computation of an MTI for four of the major fish surveys carried out annually by Cefas around England and Wales. Most agreed with this, accepting our concerns about biased representation geographically and by fishing gear. One felt that biases should not be an obstacle and that new ways of using all available data should be found. The analysis ultimately used only three surveys. The SW beam trawl survey was rejected because catches were not consistently weighed during cruises on the small commercial vessel used.

The representativeness of UK trophic level data is discussed with security in section 3.7.1 above. Currently available data are poorly representative and should be supplemented by one-off national survey with opportunities for review in future.

Conclusions: ICES landings data extend beyond UK territorial lines but can reasonably be considered to refer geographically to seas around UK. Data may not be representative of all trophic levels in UK waters, especially regionally. Available data on trophic levels are poorly representative of UK waters and should be extended to more species and regional seas as already noted (3.7.1).

3.7.3 Capacity to provide long term, interpretable trends

Views expressed on the interpretability of the MTI at the scientific workshop (Annex 1) were that the MTI has the advantages of being simple, comparable across areas, readily communicable, and well established. The disadvantages stated were that it is linked to fisheries landings which are affected by commercial and regulatory factors, e.g. the growth of industrial fisheries for low trophic level species; and the setting of TACs. Landings data were also noted to be subject to mis- or incomplete declarations, and never include the many small and non-target fish that are discarded at sea.

The UK MTI based on <u>landings</u> data provided differently sloping trends, depending on the type of trophic level data used, and on whether lower trophic levels were excluded (See figure 3.4.2). Establishing which is the "correct" trend would require detailed debate about the methods of analysing trophic levels and thus the correct trophic levels for many species. This aspect would be greatly assisted by the one-off trophic level estimation exercise proposed in section 3.7.1. Establishing the correct trend would also require detailed analysis of trends in landings of the type shown in figure 3.7.1 for the North Sea. Given that industrial species (e.g. sandeel, sprat) generally have low trophic levels, pelagic species (e.g. herring, mackerel) mid levels, and demersal species have high trophic levels, comparisons with the trends in the North Sea MTI (figure 3.4.4a) could be attempted. The UK MTI based on survey data provide less clear signals than the landings and suffer from the same analytical uncertainties. Additionally, trends in the MTI could arise for various reasons aside from "fishing down foodwebs". In Europe, closure of a substantial fishery, or just tightening of TACs would affect the MTI, as would trends in fishing methods or discarding. Climatic effects, and changing primary production due to nutrient enrichment are other possible factors (Caddy *et al.* 1998). These competing explanations for a change in the MTI could easily create controversy about what is actually happening in the UK ecosystem.

Conclusion: Trends in a UK MTI may or may not be related to changes in the ecosystem, and will not necessarily be interpretable without controversy.

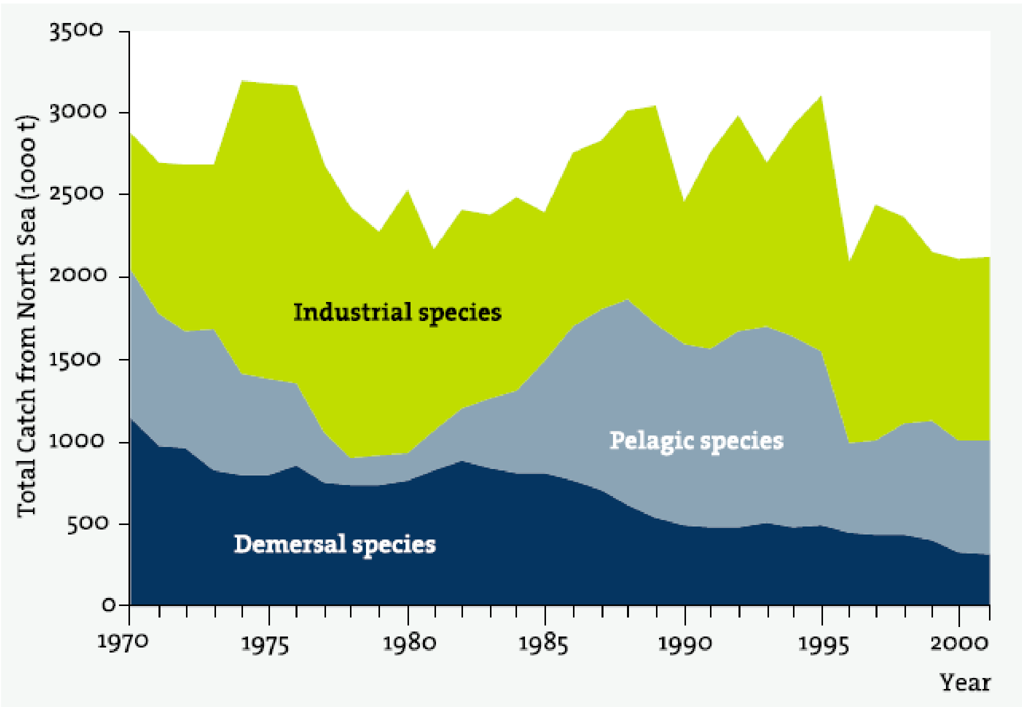


Figure 3.7.1. Breakdown of total catch of North Sea. Taken from (ICES 2003).

3.7.4 Relevance to marine ecosystem integrity, and validity of thresholds

Views expressed at the scientific workshop (Annex 1) about the relevance of the MTI to ecosystem integrity were that it is linked with the food web and so has an obvious ecological relevance. Against this, its reliance on commercial landings statistics, already mentioned under interpretability in section 3.7.3, mean that changes in the MTI can reflect changes in the commercial fishery rather than in the ecosystem. The Fishing in Balance indicator (FIB) might help to separate the effects of changing food webs on the MTI from those of changing fisheries. Thresholds for the MTI signifying healthy or unhealthy ecosystems, or ecosystems under threat, are not available or agreed

Creating thresholds for the MTI during this project was not considered feasible. Even small amounts of fishing alter the trophic structure of marine fish communities appreciably (Jennings 2007) and there are no opportunities to look at marine ecosystems "like" those around UK that have not been impacted in some way by fishing. Consequently, even if the course of action in response to a changing MTI is decided, the time when to take it is not clear. An easier management strategy in the medium term may be to assume that the MTI is currently low as a result of a long history of heavy fishing, and to try for a sustained increase in the level by reducing fishing pressures on the ecosystem (Jennings 2005). Research on threshold values might be carried out during that period to try to find suitable thresholds for management actions. Comments in section 3.7.3 concerning interpretability of the MTI also pertain to 'relevance to marine ecosystem integrity'.

Conclusion: There are no agreed thresholds for the MTI to distinguish healthy and unhealthy marine ecosystems. Assuming that levels are too low now due to heavy fishing and seeking a rise could, however, be acceptable as a medium-term strategy for conservation of biodiversity.

3.7.5 Power of the indicator to detect change or trends

The scientific workshop (Annex 1) agreed there was a need for statistical confidence to be known for indicator series. However, in the case of the MTI computed from landings, standard error bars could be misleadingly small because they would summarise only the variability from the estimated trophic levels, whilst excluding any bias in the landings data which are a complete census, not based on statistical sampling. Error bars would also not include biases revealed by the differently sloping trends found by Cefas using the two methods for estimating trophic level. Other statistical methods exist for deciding when a trend has changed (see section 7.1), and modelling methods exist for estimating a probability of misclassification as pass/fail, etc. These methods would be less affected by bias if it could be assumed constant, a condition that some at the workshop felt might not be tenable. It was pointed out that, if the MTI were calculated using survey data in preference to landings data, the coverage geographically and seasonally would be lower and variance would be higher.

Examination of figure 3.4.2 strongly indicates that the MTI is unlikely to respond quickly to changed ecological integrity, or fisheries management regime. In support of this, Nicholson and Jennings (2004) estimated that at least 16 years would be necessary before there would be 90% statistical power for finding the maximum predicted rate of change of mean trophic level for the International Bottom Trawl Survey of the North Sea, an otter trawl survey in which between 300 and 400 stations are fished annually (Heessen 1997). [Compare this with the EGFS which fishes about 80 stations.] There are several statistical methods for assessing changes of trends (see section 7.1), some of which may offer slightly quicker responses than obtained by Nicholson and Jennings (2004). It is necessary to assume that biases in the landings data are constant over time since an undetected change of bias would look like a change in the level of the MTI. Standard error bars could be added to MTI series, given good estimates of analytical variance, but they would not indicate variable bias in the equally important landings component of the MTI, nor the fact that the MTI is the product of two variables thus adding considerably to uncertainty. Quantities landed are estimated by a census procedure not involving a sampling or statistical process. Error bars are not therefore available for this component of the MTI.

Conclusion: The MTI is a long-term monitoring device. Many years would be required before an apparent change could be confirmed with confidence by statisticians.

3.7.6 Discussion and further conclusions

At the UK level, neither landings-based MTI index is adding much to the message of depleting fisheries from 1973 to 2005 provided by the total landings data alone, as seen by comparing figures 3.4.1 and 3.4.2.

The signals provided by the landings-based MTIs (figure 3.4.2) might be more clearly downwards if sizes of fish had been allowed for. This is because most species occupy lower trophic levels when young and small than when adult, and trawling tends to reduce the average size and age of fish in the stocks. The ICES landings data do not provide information about the sizes of fish landed so, if it is thought necessary to include size in the analysis, it would be necessary to source landings data from national (UK) archives. However, national landings stats are less well balanced across different types of fisheries and trophic levels than ICES stats; for example, UK stats omit the large tonnages of low-trophic level fish landed by Danish and Norwegian industrial fisheries. For these reasons, use of ICES international landings statistics is **recommended**.

Disaggregating the landings data by region revealed the dominant influence of North Sea landings, as well as the variable nature of fisheries when viewed on regional scales. The regional MTI results gave a clear signal (downwards) for the North Sea but, elsewhere, the signal wandered, sometimes in different directions with the two different methods of calculating the MTI. Some of this disagreement may arise from the poor relationship between the stomach sampling and N-isotope methods (figure 3.2.1) but it also appears that regional data suffer from the effects of smaller sample sizes, both on the quantities landed and the species compositions, and from inadequate ranges of trophic levels being landed. As a consequence, they do not appear to be providing ecosystem indices that are likely to be useful for communicative or managerial purposes. **In conclusion**, the MTI fails as an indicator of regional ecological integrity within the UK marine area.

Survey CPUE are regional and based on few fishing stations relative to commercial fishing. Relatively high variability in Kg CPUE seen in all (a) panels of figures 3.5.1 to 3.5.3 is therefore not surprising. None of the survey-based MTIs reveal marked declines, no doubt partly for the same reasons as the landings-based regional MTIs give unreliable signals. The signal from the EGFS appears clearer than from the two beam trawl surveys but this was enhanced artificially as a result of the change in trawl gear implemented in 1992. The GOV trawl generally catches demersal roundfish effectively, and will also catch large numbers of pelagic species with somewhat lower trophic levels, such as herring, sprat, horse mackerel, and mackerel, but only if a shoal is encountered near the sea floor. Flatfish tend not to be caught effectively. The

GOV trawl is therefore unlikely to reveal large changes in MTI because its sampling of different trophic levels is restricted. The beam trawl is presumably even worse in this respect because it is only good at catching bottom-dwelling flatfish. **In conclusion**, survey-based MTIs are less likely to reveal a clear signal than the MTI calculated from all international landings in UK waters.

The size-based MTIs calculated with survey data do not reveal clearer trends than the non-size based MTIs described in section 3.5. For example, comparing figure 3.5.1b with figure 3.6.1, there is more variability in the series from 1992 when size is taken into account than when it is not. A likely explanation is that the number of species for which trophic level versus size relationships were available, namely 15, was too small. The size-based MTIs could be calculated so as to include more species by assuming that those species for which no trophic-level-versus-size relationship is available can instead be assigned the fitted relationship of another comparable species, i.e. of similar trophic level and with similar changes of trophic level with growth. However, it is questionable whether we know enough about the biology of the unmodelled species to allow this, and such assumptions could be controversial. The solution would be to sample fish of more species and different sizes so that more trophic level versus size relationships could be estimated. This would increase the number of trophic level analyses required by several times, not forgetting that relationships are required regionally as well since they are likely to differ. Omitting sized-based relationships tends to make the MTI conservative in estimating the effects of fishing (Pauly *et al.* 1998b) and, given the high analytical costs of doing the job properly, it is **recommended** that changing trophic level with size be ignored when calculating a UK MTI.

4. Length-based indicators (LBI)

4.1 Introduction and review

Commercial trawling tends to reduce the average size of fish in trawl-vulnerable stocks (Bianchi *et al.* 2000) partly because large fish are more catchable than small fish and partly because they will have been exposed to fishing gear more often. Since most predators have to be larger than their prey, there are concerns that commercial fishing is fundamentally altering the trophic functioning of ecosystems, as has already been discussed in connection with the MTI. In addition, stages in the life history of fish tend to be associated with certain body lengths, e.g. for sexual maturation, changes of diet, and migrations, implying that body length has fundamental biological relevance. Add to this that length is routinely measured on research vessel surveys and at markets, and length becomes an obvious candidate for forming biological indicators for fish. Length-based indicators (LBI) can monitor the well-being of stocks of individual species, or they can provide composite measures of the changing size structure of a fish community. Furthermore, models of whole ecosystems can be based on size structure alone (Shin and Cury 2004). LBIs therefore appear well-suited both practically and theoretically as indicators of ecosystem integrity. Greenstreet and Rogers (2006), Blanchard *et al.* (2005), and Shin *et al.* (2005) provide examples of the successful application of length-based indicators to deduce effects of fishing but all these writers caution that interpretation of trends needs care, depending on such factors as recruitment, competition for food, density dependent growth, competitive release of small fish, climate, and environmental factors. Like the MTI, few LBIs have widely agreed reference points that unambiguously signal a ‘healthy’ environment, though the maintenance of a reasonable proportion of individuals in the population above the length of 50% maturity has often been suggested. A good proportion of large fish in a stock also protects the yield of a fishery from a sequence of poor recruitment years, a benefit that could be of interest to the fishing industry.

One composite, length-based indicator was favoured and considered by the ICES Fish Ecology working group (ICES WGFE) (ICES 2006; 2007b) in response to a request from OSPAR for “further development of the ecological quality objective (EcoQO) on changes in the proportions of large fish and hence the average weight and average maximum length of the fish community”. Subsequently, the Advisory Committee on Ecosystems (ICES 2007a) recommended that “The proportion (by weight) of fish greater than 40 cm in length should be greater than 0.3” (using the ICES quarter 1 International Bottom Trawl Survey series). The ICES WGFE used a 30-cm cut-off but this was found to be susceptible to the effects of a large year class of haddock. There is clearly scope for testing it and similar indicators on a wider range of surveys and with different cut-offs.

Another, probably better-known, composite length-based indicator is the size spectrum. Catches are divided into a sequence of length bins, usually arranged in constant logarithmic intervals, e.g. 2, 4, 8, 16 cm, etc., and the numbers of individuals caught per hour (CPUE) in each is averaged across species. It is found that the log average CPUE tends to decline with increasing size, and with a greater steepness for communities that are more heavily fished (Bianchi *et al.* 2000). The decline is usually modelled with a straight-line function but curvature can also occur, either as a result of special factors affecting young fish or because of selection or sampling bias. Shin *et al.* (2005) point out that use of size spectra as indicators for management purposes presupposes that a reliable model for the decline is available which, given doubt about sampling bias and curvature, may not be the case. Rochet and Trenkel (2003) express concern about the lack of response to fishing found in some studies and the uncertainties imparted by the size selectivity of fishing gear. Size spectra therefore seem less robust than LBIs estimated directly from catches without using models. They also have the disadvantage of being esoteric for communication to the public, compared to indicators such as 'mean length' and 'maximum length'.

Studies of size spectra of fish from waters close to the UK have already been undertaken using survey data (Rice and Gislason 1996). In general, they confirm that fishing is accompanied by an increase in the numbers of small species, and a decrease in the numbers of large (Jennings and Dulvy 2005). Daan *et al.* (2005) report that fish assemblages in the North Sea take more than 6 years to respond to changes in exploitation rates. Blanchard *et al.* (2005) found that fishing had a greater effect on size structure than temperature or climate in the Celtic Sea. These results all add to the general understanding of LBIs.

Here we calculate the ICES index (ICES, 2007) with 30- and 40-cm maximum length cut-offs, for three Cefas surveys. We also try out another possible indicator called a 'Proportionate length indicator'. The two indicators are complementary because the first measures the proportions of large fish of any species, while the second measures the proportions of large fish within each species. Time series for 3 other size-based indicators, namely the mean individual body mass, the slope of the size spectrum, and the mean maximum body mass are given by Jennings and Dulvy (2005).

4.2 Computations

Trial estimates of length-based indicators were made with the EGFS, the Channel BTS, and the Irish Sea BTS. Numbers-at-length caught per trawling hour were utilised for each species. All fish species caught were measured on these three surveys. Weights were estimated from numbers-at-length using the allometric length to weight conversion formula with constants for each species as provided by Coull *et al.* (1989).

4.2.1 OSPAR EcoQO / ICES (2007) length indicator

Computations followed those described by ICES 2007 as closely as possible. For each survey, measured fish (i.e. all species caught) were categorised as being less than 30 cm in length, or greater than or equal to 30 cm, and the total numbers in each category summed over all species and stations for each year of the survey. The same task was also carried out using the 40-cm cut-off. The proportions greater than or equal to 30 (or 40) cm were then estimated by weight for each survey. Operational details of Access queries used for this are described in Annex 5.4. The two constants for each species needed for the allometric length-to-weight conversion are given in Annex 4.

4.2.2 Proportionate length indicator

This indicator is based on fish lengths transformed to proportions of the maximum length for the species. For example, an individual 20 cm long of a species whose maximum observed length is 50 cm would be described as 0.4Lmax. Recreational fishers have used this system for many years (Willis *et al.* 1993). Measured lengths are then scaled to be comparable across species, allowing creation of a multi-species, composite length indicator that benefits statistically from relatively large numbers of fish and species caught.

First, Lmax for every species found in the survey was taken from Ellis *et al.* (2008). They were generally very large values reflecting the largest sized individual thought to have existed ever. [Alternative published sources include Fishbase, http://www.fishbase.org/, and Pauly (1980), or Lmax could be estimated from previous survey results with, say, 15% added to prevent bunching in the largest length class.] Multi-species retrievals were then made for species having an Lmax > 30, 40, or 50 cm. This range of cut-offs was chosen in case small species had increased in number following the removal of large predatory species by commercial trawling (Pope 1991). For other retrievals, species were restricted to selected, commercially targeted species. The lengths of all measured fish of the accepted species were then transformed into 20 bins: 0 to ≤0.05 Lmax, 0.05 Lmax to ≤ 0.10 Lmax, etc.. The upper boundaries of these bins are referred to here as 'proportionate lengths', i.e. 0.05, 0.1, etc. The composite histogram may then be calculated in two ways: (a) by summing numbers in each bin across species and finding proportions of the total in each bin; or (b) finding proportions in each bin for each species separately, then averaging the proportions. (a) forms a histogram weighted towards those of the most numerous species, not necessarily the same each year, while (b) weights the histogram of each species equally. (b) was preferred because it has a fixed relationship to species present and it appears better suited for damping down sporadic, major fluctuations in abundance of individual species brought about by large year classes or other events since different species are unlikely all to show good recruitments in the same year.

The proportions of fish by estimated weight that were observed in each proportionate length bin on each annual survey were retrieved from the project database using MS Access queries described in Annex 5.5. A length quantile was then chosen as the cut-off point above which fish were "large". Ideally, this is a high quantile, e.g. 0.9, so that the indicator measures truly large fish and is not affected by varying abundances of recruiting ages. In practice, the high quantiles yielded very small numbers of large fish on the three surveys and, consequently, very unsteady proportions by weight exceeding the cut-off lengths from year to year. It was therefore necessary to use the 0.65 proportionate length as the cut-off for all species, and either the 0.5 or the 0.35 proportionate length for selected target species. The proportion by weight greater than the selected quantile was estimated by summing the proportions in the 0.05 length quantile bins exceeding the selected length quantile. The proportions were plotted over years.

4.3 LBI results using UK survey data

4.3.1 English groundfish survey

Application of the ICES (2007) length-based indicator to all species caught on the English groundfish survey (EGFS) of the North Sea is shown in Figure 4.3.1a. A gentle trend downwards followed by a levelling off from around 1992 can be seen with both the 30- and 40-cm cut-offs, though the 30-cm cut-off series shows more variability from 1992. 1992 was the year in which the GOV trawl was fished for the first time on the EGFS so the levelled proportions of large fish could have something to do with the change of survey trawl type. Nevertheless, the decline over the previous years occurred when the Granton trawl was fished consistently.

The proportions of fish by weight > 0.65 of Lmax for species of different Lmax are shown in figure 4.3.1.b. For Lmax > 0 cm, i.e. all fish species caught by the EGFS, a gentle decline from 1977 to the present can be seen moving through the year-to-year variance. Removing small species by gradually increasing the Lmax cut-off to 50 cm reveals steeper overall declines, as would be expected if commercial trawling is the cause. There is also more variability because fewer species are represented. An effect of the change of survey trawl in 1992 is not evident in any of the series.

One might expect that declining proportionate length would be most evident in the three principal roundfish target species of the otter trawling fleet in the North Sea, namely cod, haddock, and whiting. Figure 4.3.1c confirms that the proportions by weight of "large" fish (> 0.5 of adj.Lmax) did reduce for these species in the 1980s, with a levelling-off in the 1990s, and, for whiting, an increase from 2000. The average series – with all three species given equal weighting – smooths the three one-species series quite well.

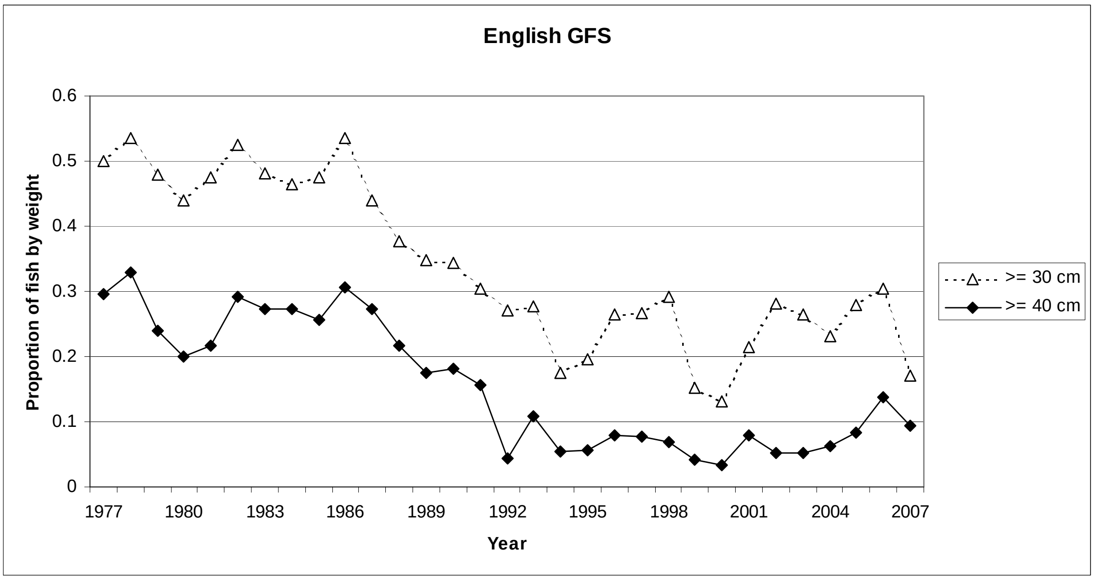
4.3.2 Channel beam trawl survey

Neither the ICES (2007) measure nor the proportionate length indicator show clear trends for the Channel beam trawl survey in the southern North Sea and Channel. See figure 4.3.2a and b. However, the two principal target species of commercial beam trawlers, namely plaice and sole, show fairly distinct downward trends in the proportions of fish greater than 0.35 of Lmax (figure 4.3.2c). There appear to be more large sole than plaice in relation to total numbers.

4.3.3 Irish Sea beam trawl survey

As for the Channel BTS, neither the ICES (2007) measure nor the proportionate length indicator show clear trends for the Irish Sea beam trawl survey (figure 4.3.3a and b). The series of proportionate length indicator for sole, figure 4.3.3c shows a possible trend upwards with much year-to-year variability. The same series for plaice, also figure 4.3.3c, shows continuing low proportions of large fish.

Figure 4.3.1 a) The ICES (2007) indicator describing the OSPAR fish community EcoQO (proportion by weight of individual fish of all species exceeding stated cut-off lengths) calculated for the English groundfish survey (GFS) of the North Sea, ICES subarea IV.



b) Proportion of fish of all species having Lmax > stated lengths that exceed 0.65 of Lmax.

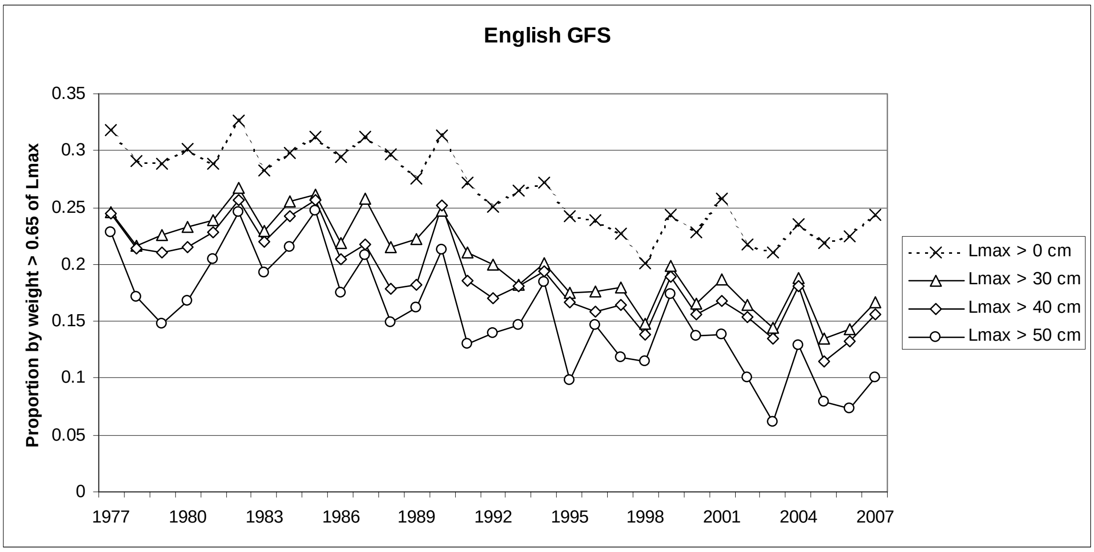


Figure 4.3.1 continued
c) proportion of cod, haddock, and whiting, as individual species and as an average of the three, that exceed 0.5 of Lmax.

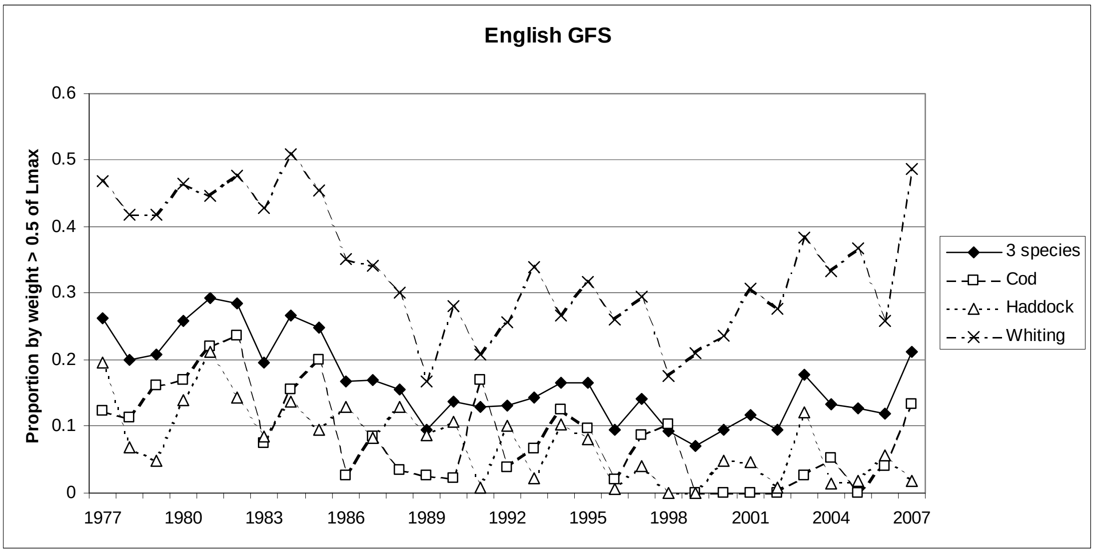


Figure 4.3.2 Channel beam trawl survey (BTS) of the southern North Sea and Channel, ICES divisions IVc and VIId.
a) ICES (2007) indicator: proportion by number of individual fish of all species exceeding stated lengths.

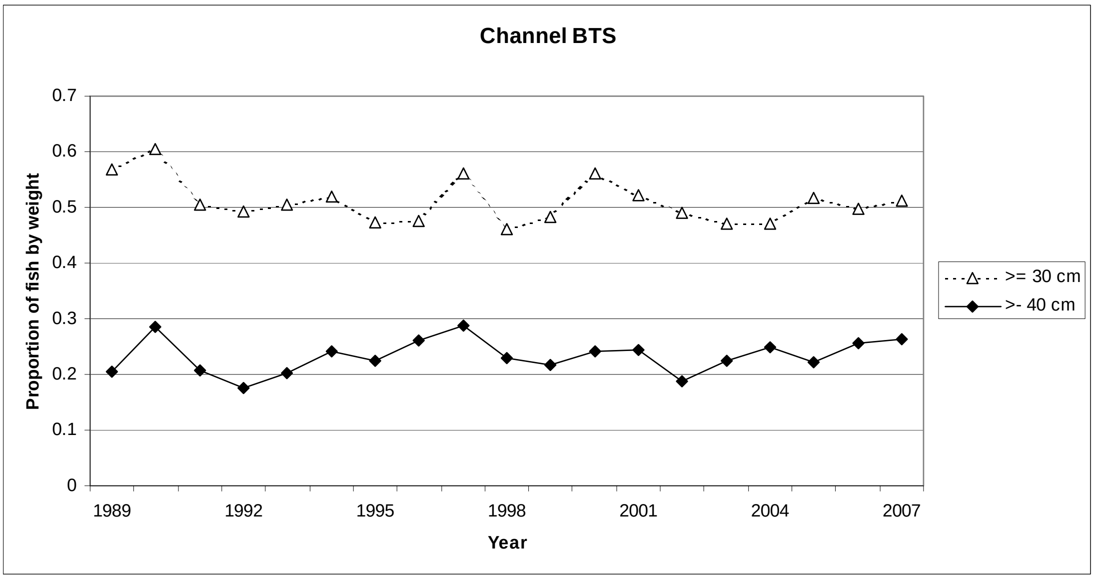
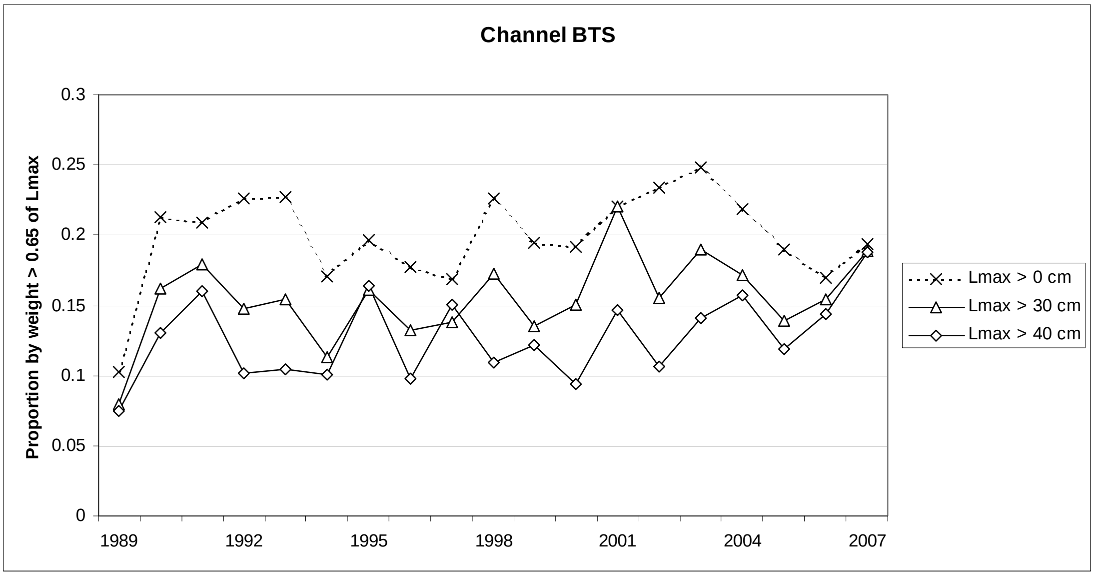


Figure 4.3.2 Channel beam trawl survey, continued.
b) Proportion of fish of all species having Lmax > stated lengths that exceed 0.65 of Lmax.



c) proportion of plaice and sole that exceed 0.35 of Lmax .

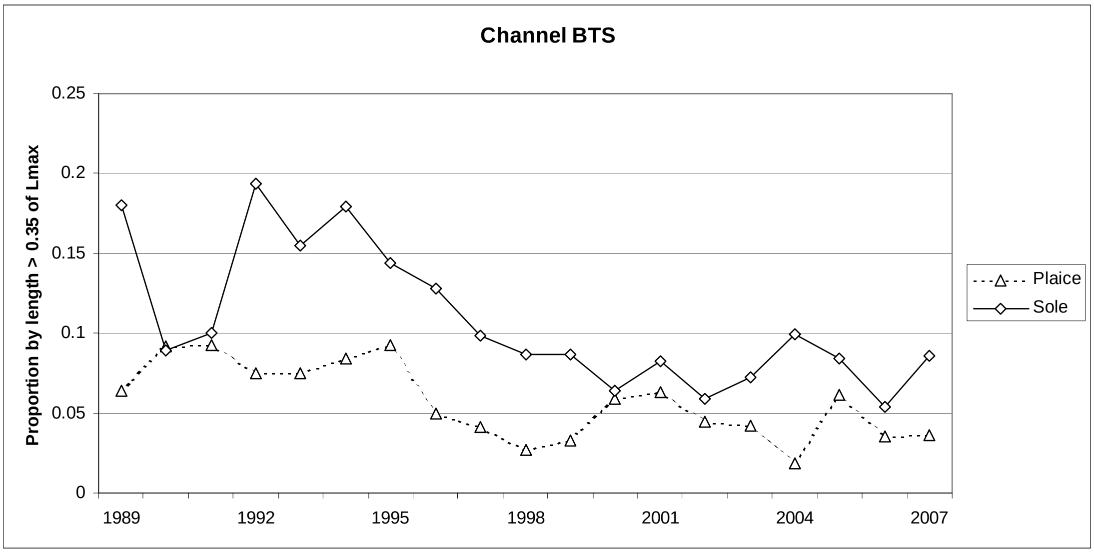
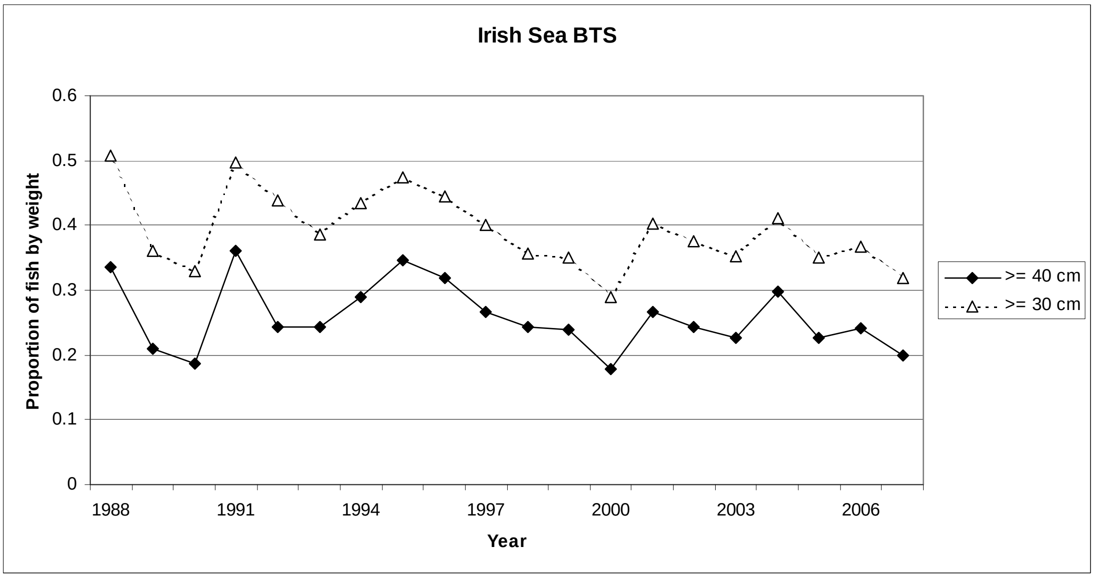


Figure 4.3.3 Irish Sea beam trawl survey (BTS) in ICES subarea VII.
a) ICES (2007) indicator: proportion by number of individual fish of all species exceeding stated lengths.



b) Proportion of fish of all species having Lmax > stated lengths that exceed 0.65 of Lmax.

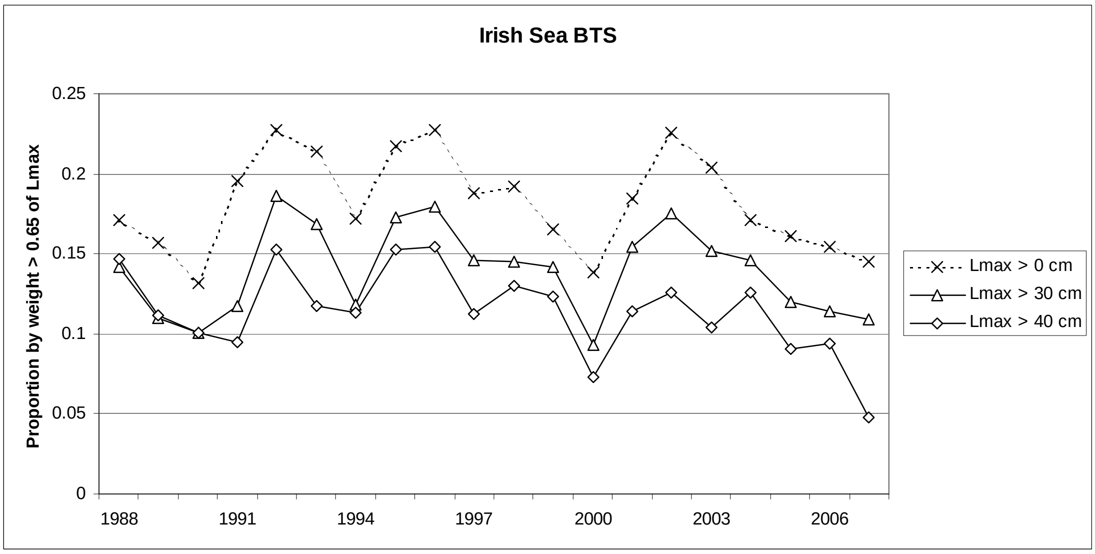
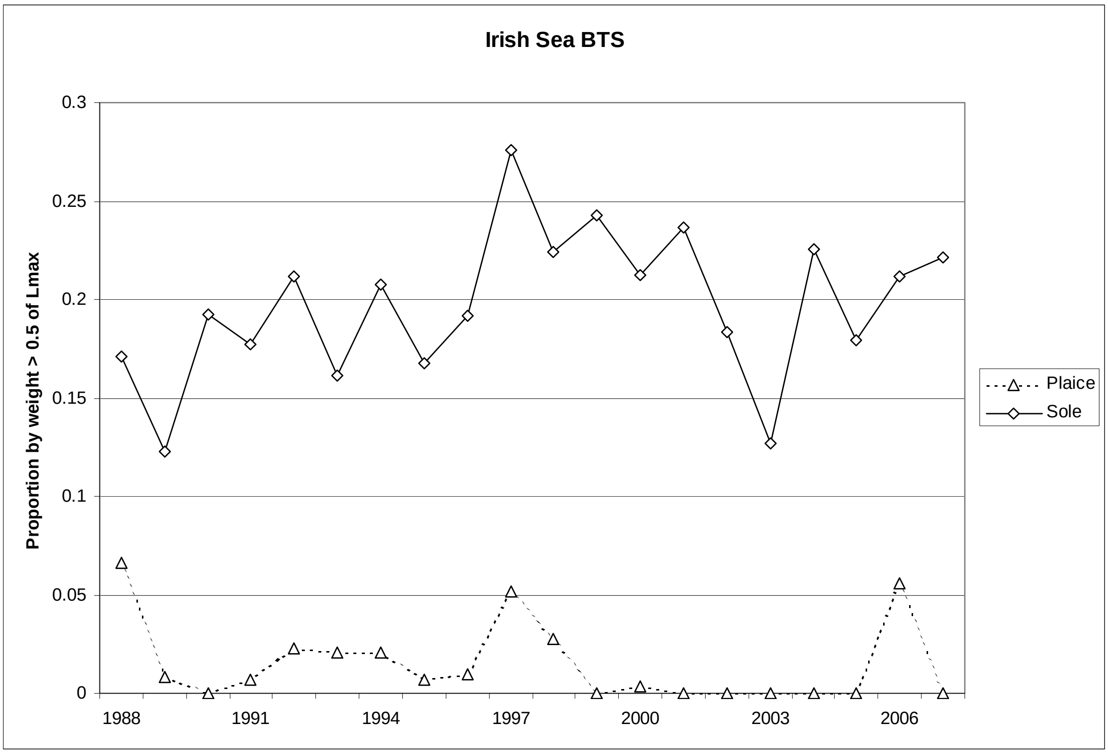


Figure 4.3.3 Irish Sea beam trawl survey continued.
c) proportion of plaice and sole that exceed 0.5 of Lmax.



4.3.4 Scottish otter trawl survey

Scottish colleagues have used survey data for Scottish waters (Scottish August groundfish survey (SAGFS) and the quarter 1 International Bottom Trawl Survey (IBTS)) to calculate the 'proportion of large fish indicator' at the ICES Advisory Committee on Ecosystems (ICES 2007a). Efforts focussed on determining which cut-off length to use, whether 30 or 40 cm, and whether to calculate proportion in terms of numbers or biomass (=weight). Results of these analyses (Figure 4.3.4) show that trends in SAGFS (Scottish waters) and IBTS (UK waters) data show consistent declines from 1970 regardless of method applied. The committee concluded that the 40-cm threshold was preferable because it was much less affected by large recruitments for individual species in each year, and that computation of the indicator using biomass (computed allometrically from lengths) gave a clearer trend over time for the indicator. Readers are referred to their report for more details of their analysis and recommendations.

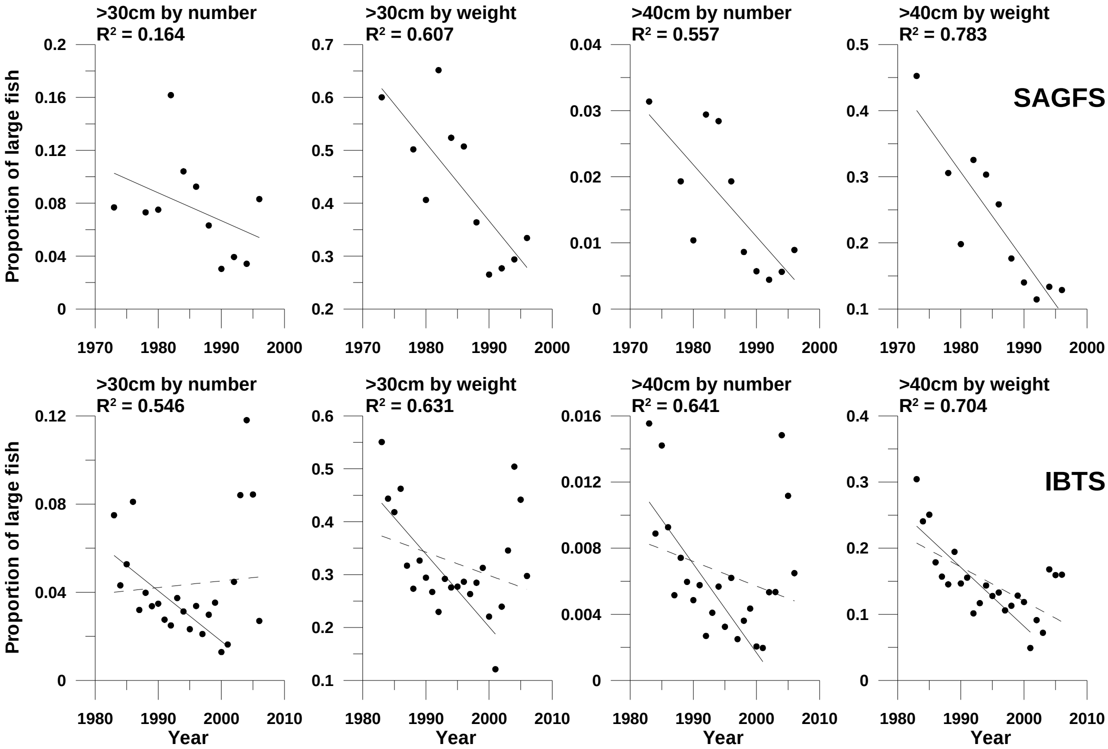


Figure 4.3.4 Temporal trends in the North Sea "Proportion of Large Fish" indicator calculated from both the Scottish SAGFS and the IBTS data sets, where the threshold defining large fish is either >30 cm or >40 cm, and where the proportion has been calculated on the basis of numbers or biomass. The solid line in the IBTS plots shows the linear fit to the time period 1983 to 2001, excluding the strong 1999 haddock cohort recruitment event. The correlation coefficients shown refer to this fit. The dashed lines show the linear fit to the entire IBTS time series. Copy of figure 5 from ICES ACE report (ICES 2007a).

4.4 Assessment of length-based indicators (LBIs) for UK marine waters

The subsections below draw together the findings of the project in order to identify options for monitoring length-based indicators (LBIs), assuming that they are adopted for use by the UK. Consistently with objective 3 of the project, they also quote relevant parts of the minutes of the scientific workshop of invited scientists held on 3 March 2008, shown in full at Annex 1. This is to include views of those other than the authors of this report. Note that, because of the timing of this report, the minutes cited had not been seen or confirmed by participants. Little discussion was given to LBIs at the workshop (compared to the MTI) even though a presentation on LBI results was made. The utility of LBIs was not disputed.

4.4.1 Availability and future security of data

All species of fish caught are traditionally measured on groundfish surveys around UK, and the main surveys are funded under the EC Data Collection Regulation for the foreseeable future. Collecting together Scottish and Northern Irish survey data would require some resources to supply and make them compatible in one database. This is not seen as a major issue because Scottish data have already been given to Cefas. Alternatively, in future, computations could be made separately by Scotland, Northern Ireland, and England and the results combined in an agreeable way to make a UK index.

Conclusion: Length-based survey data are available and secure for UK.

4.4.2 Representativeness of UK waters

At present, there are otter trawl surveys in the North Sea by England and Scotland, another west of Scotland, a Northern Irish survey in the Irish Sea, and a new English survey to the west and south west of England. There is no otter trawl survey in the Channel. Beam trawl surveys exist in the Channel, southern North Sea, and the Irish Sea. These could all be used for length based indicators within each survey domain. Combining them into UK indicators would require discussions among the UK fisheries laboratories concerning the combination of different surveys and geographic domains, and the most agreeable formulations for the indicators to be put forward.

Conclusion: UK otter trawl surveys would provide good representative sampling of all offshore UK waters for LBIs except in the Channel. UK beam trawl surveys could be used in the Irish Sea and Channel but their LBIs appear less responsive than with otter trawl surveys probably because different species are caught by the different gears. For the same reason, the two types of survey would not be comparable for LBIs. National discussions are needed to decide how data from the different surveys can be combined most agreeably into UK LBI(s).

4.4.3 Capacity to provide long term, interpretable trends

Composite (multi-species) length-based indicators are among the best understood of ecological indicators for fish. Nevertheless, interpretation requires care and possibly some special research. Length data are collected by fish surveys and are not subject to the problems of varying bias that can arise when commercial fisheries are used to collect data for indicators.

Conclusion: LBIs can provide long term trends. Interpretation is feasible with care.

4.4.4 Relevance to marine ecosystem integrity

Size is known to be responsive to fishing as each generation grows and becomes vulnerable to trawls, fixed nets, and hooks. Size can serve as a substitute for measurements of trophic level since many top predators are large. Size within a species is clearly related to sexual maturity, predation strategy, and to migrations, all important biological processes relevant to ecosystem integrity.

A point made at the scientific workshop (Annex 1) was that length indicators should be carefully designed to prevent management towards undesirable ends, e.g. many individuals of one or a few large species, possibly of low importance for ecological integrity. Abundance Biomass curves and size spectra were other options suggested for informative, multispecies, size-based indicators but they were not considered in this study.

Conclusion: LBIs are relevant to ecosystem integrity. There are various design options for them which should be carefully considered to prevent management towards undesirable goals.

4.4.5 Validity to set thresholds

The most obvious size-based threshold to set is the length at which 50% of individuals are mature. Using proportionate length, as defined here, all species could be dealt with at once by assuming as an approximation based on life-history theory (see below) that the length at 50% maturity = 0.65 maximum length. Agreement on the proportion of a population to be allowed to reach this length then has to be obtained, e.g. by negotiation with the fishing industry. Many large fish in a population help to stabilise fisheries against poor recruitment years.

Conclusion: LBIs can be judged against biologically meaningful thresholds and, in due course, would be of benefit to fishers.

4.4.6 Power of the indicator to detect trends.

Figure 4.3.1a and b indicate that many years of results would be needed before changes in ecosystem structure could be confidently acknowledged. Partly, the delay arises because most species of fish take several years to grow to near to their maximum length. Much of the variability in the current series arises because large individuals of many species are currently rare, thus giving high sampling variance. If and when they become more common, year-to-year variability in the series should reduce and LBIs can be expected to show smoother trends and be more responsive to any subsequent changes in conditions.

Conclusion: LBIs require several years to respond to changed environmental conditions.

4.4.7 Discussion and further conclusions

The two length indicators calculated for this project are complementary in that the ICES (2007) length indicator measures large fish of any species, while the proportionate length indicator specifically measures large individuals of each species. A difference between the two indicators is that the ICES (2007) indicator, as described (ICES 2007a) requires addition of the weights of individuals across all species rather than averaging of results for species individually. It is therefore weighted towards the species forming the bulk of the survey catches. Proportionate length indicators, on the other hand, as calculated here, give equal weighting to each species included. For this reason, year-to-year variability due to recruitment events for individual species should be less, unless many species recruit strongly in the same year.

Variability in LBI time series also comes about because of the typically small numbers of fishing stations yielding large fish. A station that is consistently favoured by large individuals may produce zero, or many large fish in any one year, depending on the exact circumstances of the survey tow there, weather, previous tows, etc.. If there is only a handful of such stations among the 75 fished by the EGFS each year, substantial variability can be expected just as a result of chance events.

Neither the ICES (2007) nor the proportionate length indicator found clearly declining abundances of large fish from the two beam trawl surveys. See figures 4.3.2a, b, and 4.3.3a, b. The Channel BTS series started in 1989, and the Irish Sea series in 1988 by which times much of the declines in proportions of large target species in the North Sea had already occurred (figure 4.3.1c), so one likely explanation is that the beam trawl series started too recently to reveal major effects of fishing.

An advantage of using proportionate length for multispecies size-based indicators is that life history parameters are sometimes expressible in terms of proportions of the maximum length (Charnov 1993; Jensen 1997; Dulvy *et al.* 2004). For example, length at maturity is approximately 0.66 for teleosts and 0.73 for elasmobranchs of asymptotic length or Linfinity, roughly the same for practical purposes as the Lmax values used in this project. Choice of 0.65 of Lmax as the cut-off for the all-species proportionate length indicators thus coincides well with the expected maturation point of most species and indicates the proportion of biomass capable of breeding, obviously an important point for conservation of biodiversity. Size-based reference points suitable as targets or limits for managing fisheries are difficult to define agreeably (Jennings and Dulvy 2005); use of proportionate lengths rather than centimetres for measuring fish could open more possibilities.

5. Threat and occupancy indicators

5.1 Introduction and review

Dulvy et al (2006) proposed a "threat" index based on fish found to be rarely caught on groundfish surveys. It was intended as a readily communicable, composite measure of marine biodiversity as well as being consistent with one of the criteria for assessing the threat of extinction used by the World Conservation Union (IUCN) Red List for birds, mammals and amphibians. Most of the various protocols used by the IUCN are difficult to apply to marine fish (Dulvy *et al.* 2004) but one, the A1 decline criterion (Butchart *et al.* 2005), can be applied, with care. For this, species are classified as "critically endangered", "endangered", and "vulnerable" if declines in abundance of ≥90%, ≥70%, and ≥50%, respectively, have been observed.

Dulvy *et al.* estimated the threat index for the North Sea using the English groundfish survey (Figure 5.1.1). Standardised trawling has taken place in the 3rd quarter of each year since 1977 over a survey grid of 75 to 80 stations, the aim being to estimate abundance indices for commercial roundfish (principally cod, haddock, and whiting) and other trawl-catchable species in the North Sea as catch per hour. Dulvy *et al.* restricted their analyses to 23 selected species of trawl-vulnerable fish species whose maximum adult size exceeded 40 cm, the second restriction being imposed because small fish were generally increasing in abundance, possibly as a consequence of the depletion of large predators. Having estimated percentage declines in the abundances of these 23 species compared to abundances at the beginning of the survey series (or at the beginning of a moving window on the series), the composite threat index was calculated annually as the sum of the threat scores for each species, where 1=vulnerable, 2=endangered, and 3=critically endangered. Species that recovered in abundance were not scored further when mean catch rates exceeded that averaged over the first three years of the series. The index was seen to decline fairly steadily from 1992 to 2002, implying a gradual increased in threat to the large fish fauna in the North Sea.

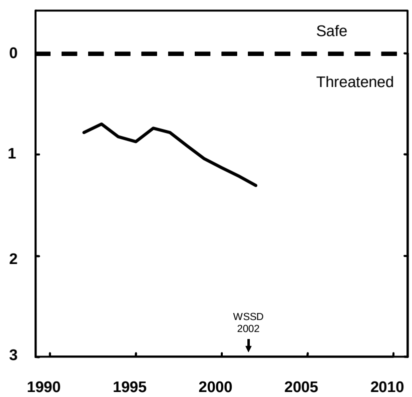


Figure 5.1.1. An indicator of threat for a suite of 23 selected trawl-vulnerable species of North Sea demersal fishes (modified from Dulvy *et al.*, 2006), measured as extent of decline. Averaged over these species, a score of 1 = all species are Vulnerable, 2 = all species are Endangered, 3 = all species are Critically Endangered.

This threat index could clearly alert managers to increasing rarity of trawl-vulnerable species and thus, presumably, to the ecological effects of commercial trawling. It does, however, present some awkward aspects largely because of the difficulties of working with relatively short time series of trawl survey abundance data. A consequence is that classifications of species as threatened or not could be unsteady. The problems seen are:

- The decline and recovery criteria are dependent on the starting year of the survey and may repeatedly incorporate any bias in the initial estimates of abundance.
- Abundance indices (CPUE figures) for rare species are not accurately estimated by groundfish surveys (Maxwell and Jennings 2005). This is partly because fish species tend to contract towards favoured habitats at low population densities (Blanchard *et al.* 2007).
- The least squares, linear modelling method used for assessing decline is not well tailored for noisy, serially correlated time series for which there is no prior expectation of linearity.
- Log transformation is usually used for modelling abundance data but the choice of constant applied to zero values occurring for rare species may cause bias, particularly if the number of zeros is high.

In spite of these reservations, which will be present for all indicators of this type, the major advantage of the threat indicator is the ability to set a clear and unequivocal threshold value as a target for managers. The use of the IUCN decline criteria as the basis for this indicator suggests that the target threat value for the North Sea should be zero, i.e. the point at which, on average, no species are under threat or in decline (Figure 5.1.1).

Other modelling approaches are summarised by Dulvy *et al.*(2004) but, as the authors say, most require assumptions about the species being in equilibrium which will almost certainly not be the case as it declines in abundance towards extinction. An alternative to modelling would be to estimate the trend using nonparametric methods, e.g. the Thiel’s or Sen’s slope estimator (Cotter 2007b). This would reduce (but not remove) the statistical assumptions being made but it does not get around the problems of estimating low abundances.

Whichever statistical method of assessing percentage decline is chosen, an additional procedure has to be designed to allow for species that recover in abundance and which should then be taken off the vulnerable list. It could be argued that any rare species that shows clear signs of increasing abundance has become self-sustainable and thus is no longer threatened. This implies that a clear reversal in the trend of abundance from negative to positive is a sufficient signal, even though absolute numbers are low. On the other hand, others may consider, as Dulvy *et al.* (2006) did, that absolute numbers should exceed a certain threshold before de-classification. The problem then is to decide what absolute numbers are acceptable. Linking the safety level to abundances observed at the beginning of the survey series seems arbitrary and unsafe for rare species. Whether using a trend or a level, demonstrating that de-classification is appropriate using noisy survey data is likely to require several years of survey data, probably decades (Maxwell and Jennings 2005), to obtain any statistical confidence.

Since a threat index for UK waters has already been published for 23 UK species by Dulvy *et al.* (2006), values have not been re-calculated here. Instead, a different formulation has been tried based on the statistically more robust presence-absence data obtainable from surveys. These occupancies, as they are called, can be combined into an overall occupancy indicator if required, but they are probably of more use for tracking the well-being of species individually in a way that would be complementary to the threat index.

5.2 Method

Dulvy *et al.* (2004) advocated a two-tiered approach for assessing extinction risk: (a) simple methods for rapid assessments of large numbers of populations and species to identify those that are potentially vulnerable, and (b) more detailed and rigorous population analyses for the species of most concern. In this section, a screening method fitting under category (a) is put forward and trialed.

Presence/absence data were preferred to abundance or CPUE data because many marine fish tend to occur in clusters, e.g. as shoals or as aggregations around suitable food or habitat. Trawls tend to catch parts of these clusters depending on the position of the trawl path relative to that of the cluster. Consequently, numbers caught per hour tend to be highly variable from haul to haul, particularly for the less common species. Presence/absence data measure the proportion of stations at which a species occurs within the survey domain, whether as a cluster or as an isolated individual, so much less variability can be expected. This will be referred to as the percentage occupancy, or just 'occupancy'. Percentage occupancies provide a measure of ubiquity which is not quite the same as abundance for assessing the threat status of a species but, given that sampling variance is much lower, that all contributing fished stations represent independent observations within the survey, and that some species of fish are known to contract their range into favoured habitats when abundance is low (Myers and Stokes 1989; Hutchings 1996; Harley *et al.* 2001), may prove preferable for fish species. The inverse of proportion of stations occupied can provide an index of 'threat' close to the sense of that word as used by Dulvy *et al.* (2006). A formulation is given below.

The species to include or exclude from a threat index is another important consideration:

- Most marine regions have species that were present historically but that have not been caught on trawl surveys even though they are known to be catchable. Such species are referred to as locally extinct. Dulvy *et al.* (2006) list seven formerly common, trawl-vulnerable, locally extinct species in the North Sea. A threat index purporting to summarise the extent to which species are rare or endangered might reasonably include such species if a list of them were available. On the other hand, if they don't occur and are very unlikely to do so, their inclusion merely adds a constant value to the index which functions to mask current changes in its value. The following formulations of threat indices therefore exclude all species until they have been caught at least once during the first few years of a survey.
- The list of all species found by a survey will tend to lengthen gradually with almost every new survey cruise. This implies, firstly, that a threat index should be formulated so as not to depend on the number of species contributing to its value. Secondly, and more subtly, the additional species found as the survey

series gets longer are likely to be rarer than those found earlier because of the delay before finding them. They may be rare in the survey area, they may be new immigrants, or most likely, they may only be marginally catchable by the survey trawl. Such species might not be encountered a second time for years, a non-event that could be mistaken for local extinction in a casual analysis. Dulvy *et al.* (2006) selected 23 species for measurement of their threat index. The species were known to be well sampled by the survey trawl, to have once occupied a large part of the survey area, and to have a maximum body length greater than 40 cm, the size group most likely to be directly affected by commercial trawling. An initial sifting of species in this way requires significant previous biological knowledge and could be influenced by personal views. Another approach, preferred here, is to use the survey itself to select the species to include. We arbitrarily used the first 4 years of results; species found afterwards were excluded. The list of species included restricts the generality of the resulting index but is otherwise not critical because it is still possible later to revise the cut-off year , or to sift species by maximum length or some other criterion, provided that trends in threat are only assessed with a constant number of species in the time series.

In this project, trial estimates of occupancies were made using presence/absence data by fishing station and by year for the English GFS, the Irish Sea BTS, and the Channel BTS. Information about these surveys can be found in section 3.2.1. Occupancies could be combined in various ways to indicate overall reducing biodiversity. One option is discussed below.

5.3 Theory

The proposed formulation for assessing the threat to biodiversity is centred on the occupancies for individual species, defined as the proportion of stations fished during each annual survey at which at least one individual of species *s* occurs. The number of stations fished by the survey should, of course, be constant from year to year. Let the proportion be

$$P_{y,s} = o_{y,s} / n_y$$

in year *y* where *o* is the number of stations at which it occurs, and *n* is the number fished. The occupancy, $P_{y,s}$, can be thought of as estimating the probability of finding species *s* at a randomly selected station. The subscripts can be dropped for generalisations, so let the number of stations where the species was absent in year *y* be $a = n - o$. Using Bayesian statistical ideas, *P* is a random variable having the beta distribution where

$$beta(P|o,a) = \frac{(o+a-1)!}{(o-1)!(a-1)!} P^{o-1}(1-P)^{a-1} \quad \text{for} \begin{cases} 0 \le \mathrm{P} \le 1 \\ 0 \le \mathrm{o} \le \mathrm{n} \end{cases}$$

The expectation (mean) of *P* is $\frac{o}{n}$, and the variance is $\frac{oa}{n^2(n+1)}$. The beta distribution may be used to describe our belief concerning what the distribution of *P* will look like next year. This is called a ‘prior’ distribution. The prior distribution then becomes a 'posterior' distribution after next year's results have been analysed using the Bayesian equation. In this case, a beta prior with parameters o_y and a_y gives rise to a beta posterior with parameters $(o_y + o_{y+1})$ and $(a_y + a_{y+1})$ having expectation $\frac{(o_y + o_{y+1})}{(n_y + n_{y+1})}$ (Schmitt 1969). In other words, the number of stations at which *s* occured and the number fished can simply be added over a fixed number of previous years to find the posterior distribution of *P* in the current year. A period of 4 years was selected [to match that used to select which species were catchable by the survey], i.e.

$$P_{y,s} = \frac{\sum_{x=y-3}^{y} o_{x,s}}{\sum_{x=y-3}^{y} n_x}.$$

Using a short summation interval gives freedom for *P* to vary over time, while a longer interval provides more damping of year-to-year fluctuations. Long periods of absence after an initial occurrence result in declining estimates of *P*, whereas re-occurrences every few years result in fairly constant estimates. Standard errors, if required, are available using the variance. An index, referred to here as the Bayesian occupancy index (BOI), for year *y* and for all *S* included species could then be formulated as

$$BOI = 1 - \sum_s P_{y,s} \big/ S .$$

This increases from 0 to 1 as species are found at fewer and fewer stations, i.e. the BOI moves in the opposite direction to the occupancy, $P_{y,s}$, as threat increases. [Alternatively, a coefficient of ubiquity ranging between 0 and 1 could be defined as $\sum_s P_{y,s} \big/ S$. It would move in the same direction as the individual species' occupancies.] The BOI is most altered by species that are widely found at the beginning of a series and only at a few stations at the end, or vice versa. Sporadic rarities, by contrast, have low $P_{y,s}$ and so have relatively little influence. The BOI might be adopted as a descriptive summary of threat as indicated by a survey but, whether it is increasing or decreasing, it is also instructive to look at time series of $P_{y,s}$ to see whether any individual species are presenting conservation problems.

5.4 Results

5.4.1 English GFS

Figure 5.4.1a shows the BOI for 74 fish species that were caught by the English GFS in the North Sea. All of the species included were caught in the first four years of the survey, between 1977 and 1980. Species found for the first time subsequently were excluded. Also shown is the index for the subset of 52 species having maximum length (Lmax) greater than 40 cm. Neither index showed much signal, though a wave downwards was maintained from 1990 to 1995, starting 2 years before the survey trawl changed from a Granton to a GOV. The curves for all species, and those just for large-bodied species, are nearly coincident, probably because the large species exerted most influence on the overall index.

Figure 5.4.1b is the left-hand side of histograms of estimated occupancies for a range of selected years, 1990, 2000, and 2007. Low values imply rarity but not necessarily a threatened status. There was little difference between the proportions of species in the lowest occupancy categories in the three years. In 2007, the species with occupancies < 0.005 were conger eel (*Conger conger*), viviparous blenny (*Zoarces viviparous*), great silver smelt (*Argentina silus*), lesser silver smelt (*Argentina sphyraena*), 'pipe fishes and seahorses' (*Syngnathidae*), Ray's bream (*Brama brama*), pearlfish (*Echiodon drummondi*), Norway haddock (*Sebastes marinus*), sandy ray (*Raja circularis*), common skate (*Raja batis*), scorpion fish (*Taurulus bubalis*), three-bearded rockling (*Gaidropsarus vulgaris*), and velvet belly (*Etmopterus spinax*). Since all of these species were found previously on the survey, their rarity in 2007 may be significant.

Figure 5.4.1c shows estimated occupancies for an illustrative selection of North Sea species. Interestingly, several heavily fished commercial species maintained their geographic domains throughout the time series, namely cod, lemon sole, and haddock. Herring, strikingly, increased its occupancy, suggesting that recovery of a species after heavy fishing can be detected. The increases began before 1992 and so cannot be ascribed to the change of survey trawl. Spurdog, catfish, and common skate all declined in occupancy. The fit of the smoothed estimates of occupancy to the observed proportions of stations occupied is shown for herring and common skate in figure 5.4.1.d and e. They indicate that the smoothing method, including adoption of a 4-year interval for the Bayesian estimate, worked reasonably well. For the herring, there is a slight lag before the fitted line catches up with the rise of observed values in the 1980s. In the case of the skate, several observations fall above the line but these are balanced by the many less prominent observations on the axis, i.e. zero occurrences.

Results here with occupancies may be compared with those obtained with the original threat index based on declines in abundance as applied to 23 large North Sea species by Dulvy *et al.* (2006, their figure 3), also using the EGFS. They found different results according to the three methods of assessing decline, and the impressions of threat given often contrast markedly with those given by the BTI. So, for example,

- The cod, moved from vulnerable to endangered in 2001 with the 10-year moving window (10yW), was unclassified (i.e. not threatened) in all years from 1992 to 2002 with the 15-year moving window (15yW), and moved from vulnerable to endangered in 2002 with the extent-of-decline method (EoD). The estimated occupancies (figure 5.4.1c) on the other hand, found that the cod was gradually reducing its geographic coverage from 1977 to 2005.
- The spurdog moved from critically endangered to endangered in 2001 with the 10yW, from endangered to unthreatened in 1999 with the 15yW, and was critically endangered continuously from 1994 to 2002 with the EoD. The estimated occupancies decreased steadily from 43 to less than 5% in 2007. Many would accept that this implies a species under threat.
- The wolf fish (= catfish in figure 5.4.1c) moved from unclassified to endangered in 1998 with the 10yW, or in 2000 with the EoD. It was totally unclassified with the 15yW. The estimated occupancies found decreasing presence from 35% of

stations in 1981 to 5 or 7% from 1999. Conservation status appears to be as endangered as the spurdog.

5.4.2 Channel BTS

The BOI for the Channel shown in figure 5.4.2a showed scarcely any signal after an initial stabilisation period. Values remained just above 0.85, slightly above the level found for the North Sea, figure 5.4.1a. This is mentioned to caution about comparing absolute values across surveys when other issues are likely to be relevant, for example the relative geographic areas and different gears of the two surveys.

Figure 5.4.2b shows the left hand side of the histograms of occupancies for a range of selected years, 1993, 2000, and 2007. There is a suggestion that more species are in the very rarest category (< 0.005 occupancy) in 2007 than previously. The species in this category included the spurdog (*Squalus acanthias*), the electric ray (*Torpedo nobiliana*) and the marbled electric ray (*Torpedo marmorata*), the lesser forkbeard (*Raniceps raninus*), the common ling (*Molva molva*), the lumpsucker (*Cyclopterus lumpus*), the painted goby (*Pomatoschistus pictus*) and the sand goby (*Pomatoschistus minutus*), the Tompot blenny (*Parablennius gattorugine*), and the three-spined stickleback (*Gasterosteus aculeatus*).

Figure 5.4.2c shows estimated probabilities of occurrence for an illustrative selection of Channel species. As for the North Sea, commercial species appear to be maintaining their geographic ranges, e.g. the brill, the lemon sole, the plaice, and the sole. The whiting is generally not caught in numbers by the 4-metre beam traul used for the Channel survey but, recently, has been caught at more stations. The sand goby is notable for being found in many fewer places than in 1989.

5.4.3 Irish Sea BTS

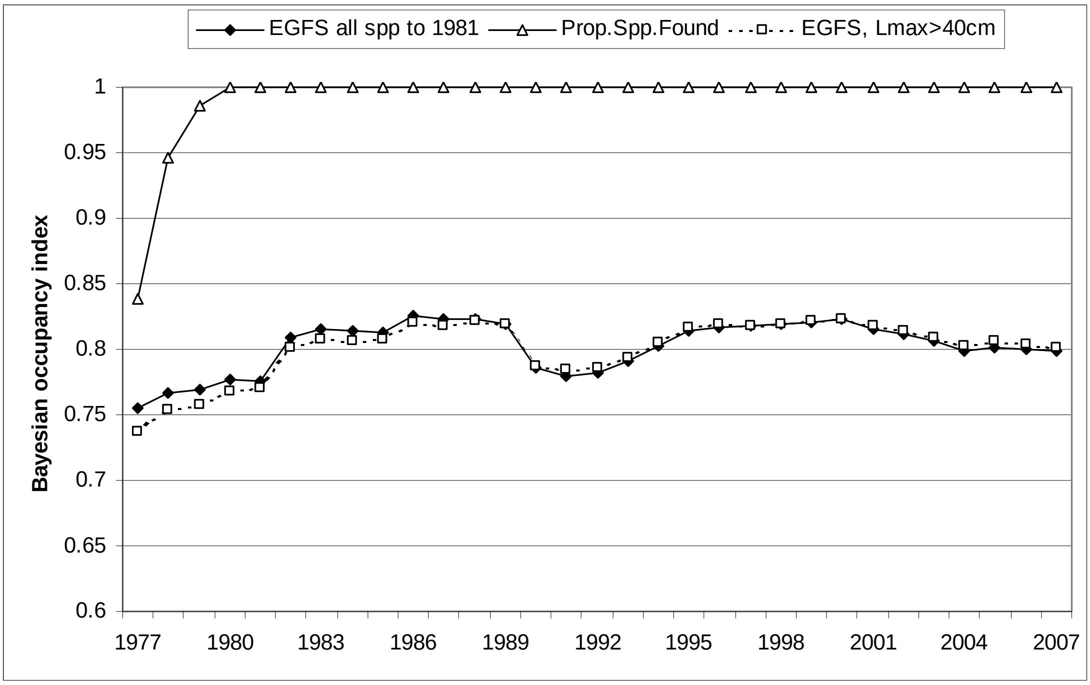
The BOI for the Irish Sea shown in figure 5.4.3a showed little signal following the initial period when the survey was finding all species to be included.

Figure 5.4.3b shows the left hand side of the histograms of occupancies for a range of selected years, 1992, 2000, and 2007. The largest number of species in the rarest category (< 0.005 occupancy) occurred in 2000. The species in this category in 2007 included the clingfishes (*Gobiesocidae*), the spurdog (*Squalus acanthias*), the tope (*Galeorhinus galeus*), Nillson's pipefish (*Syngnathus rostellatus*), the red bandfish (*Cepola rubescens*), and the small-mouthed wrasse (*Centrolabrus exoletus*).

Figure 5.4.3c shows estimated occupancies for an illustrative selection of Irish Sea species. As for the other surveys, some commercial species appear to be maintaining or increasing their geographic ranges. The lemon sole in particular increased its occupancy rate from 0.1 to 0.4 in the period before 1996. The whiting also increased its occupancy rate from 0.56 to 0.75, even though it is not caught in numbers by the 4-metre beam traul used on this and the Channel survey. The bib is an example of a fish that appears to have fared less well.

Figure 5.4.1 English groundfish survey (EGFS) of the North Sea, ICES subarea IV. a) Bayesian occupancy index (BOI) for 74 species occurring in the survey from 1977 to 1980, and for 52 species with Lmax > 40 cm. Also shown is the proportion of species found and included in the index. b) LHS of histograms of occupancies for the 74 species in 3 selected years of an 18-year period. c) Estimated probabilities of occurrence for selected contrasting species. d, e) As for (c) but also showing observed proportions of stations at which herring and common skate were found

a)



b)

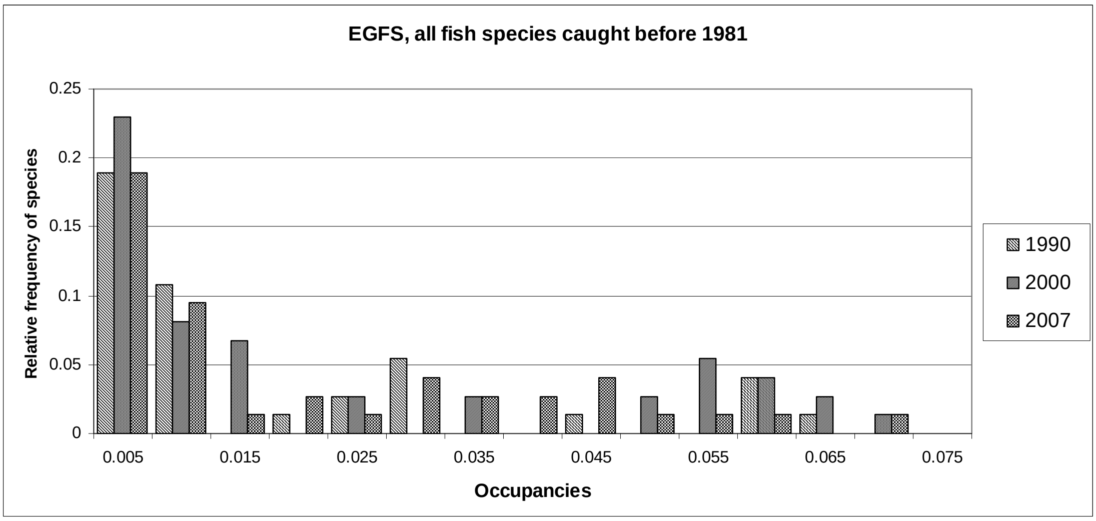
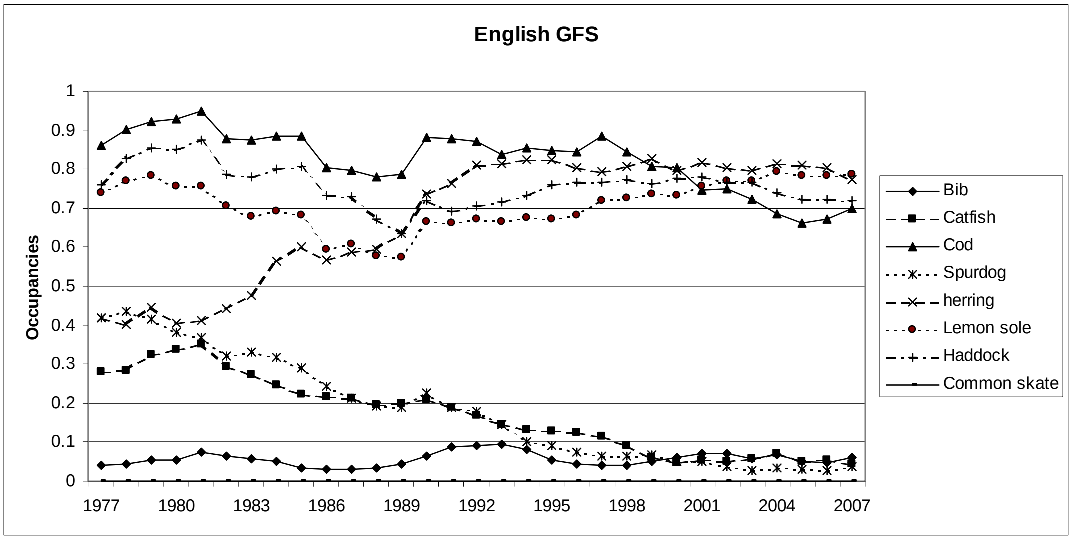
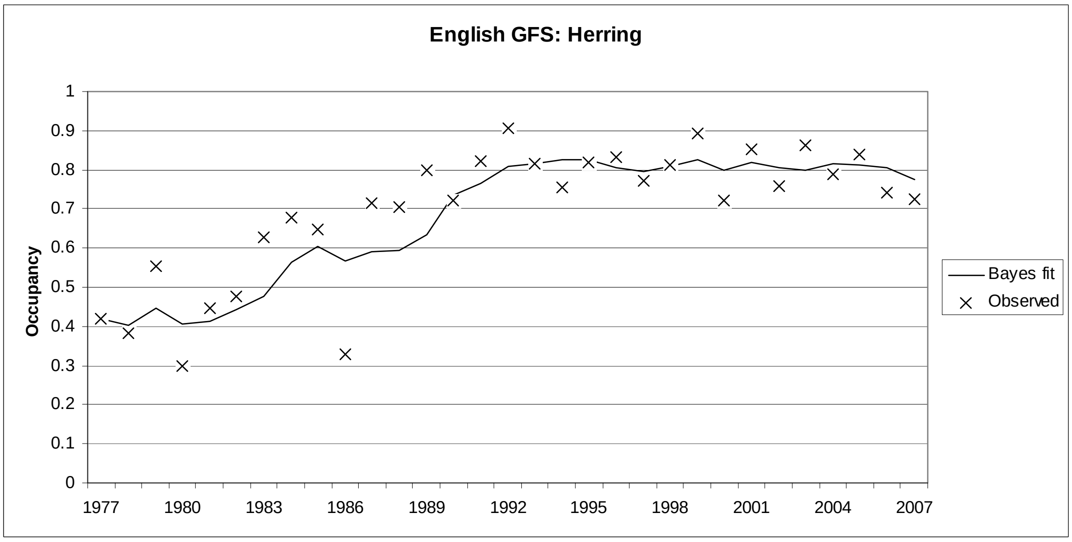


Figure 5.4.1 continued

c)



d)



e)

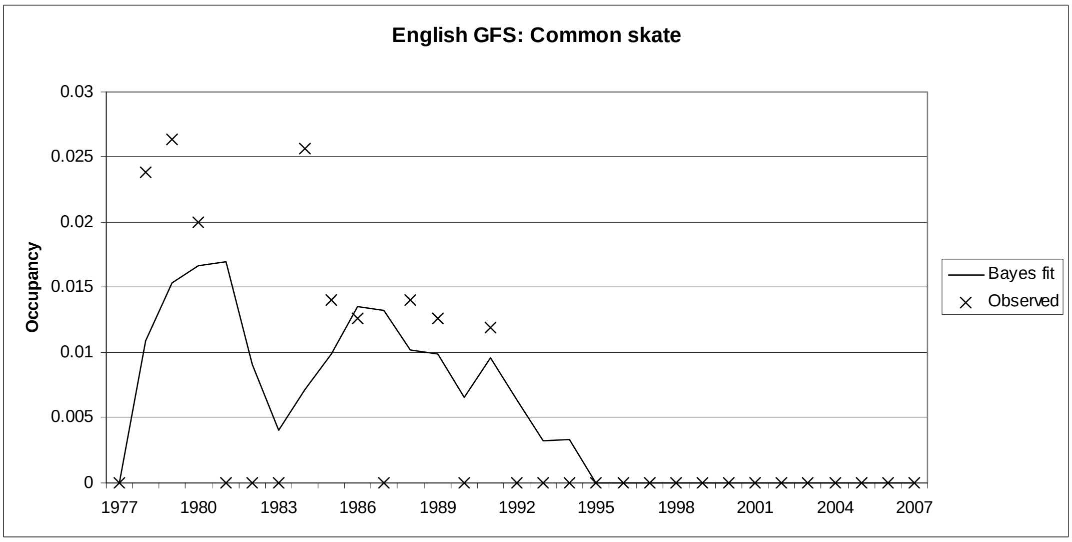
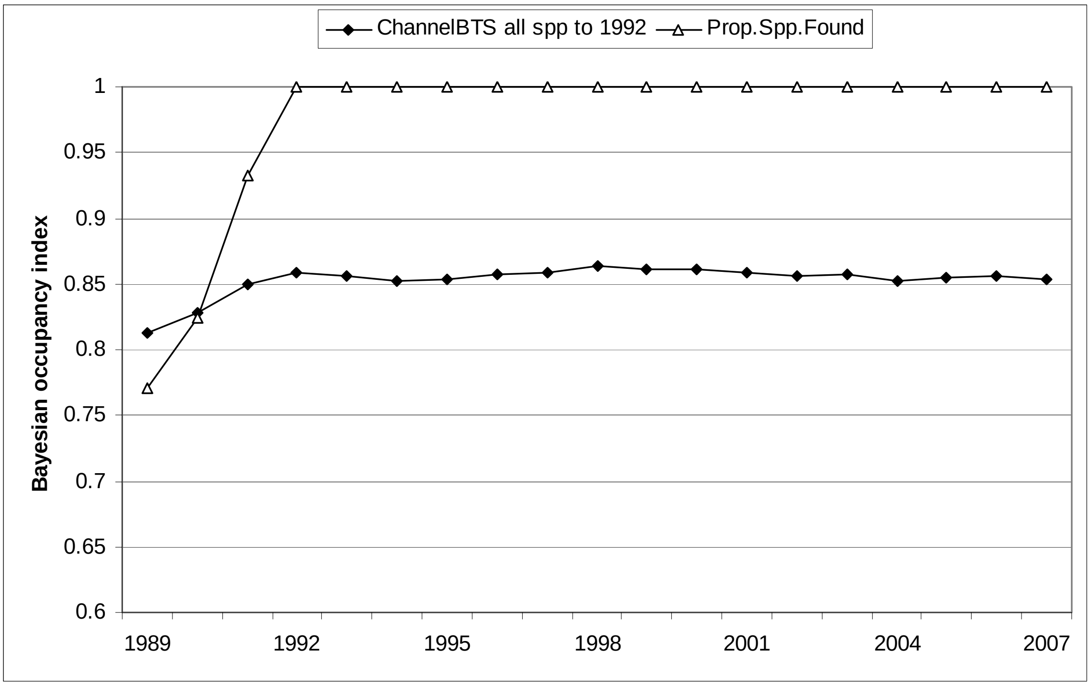


Figure 5.4.2 Channel beam trawl survey, ICES divisions IVc, VIId. a) Bayesian occupancy (BOI) index for 74 species occurring in the survey from 1989 to 1992. Also shown is the proportion of species found. b) Lower part of histograms of occupancies for the 74 species in 3 selected years of a 15-year period. c) Estimated occupancies for selected, contrasting species.

a)



b)

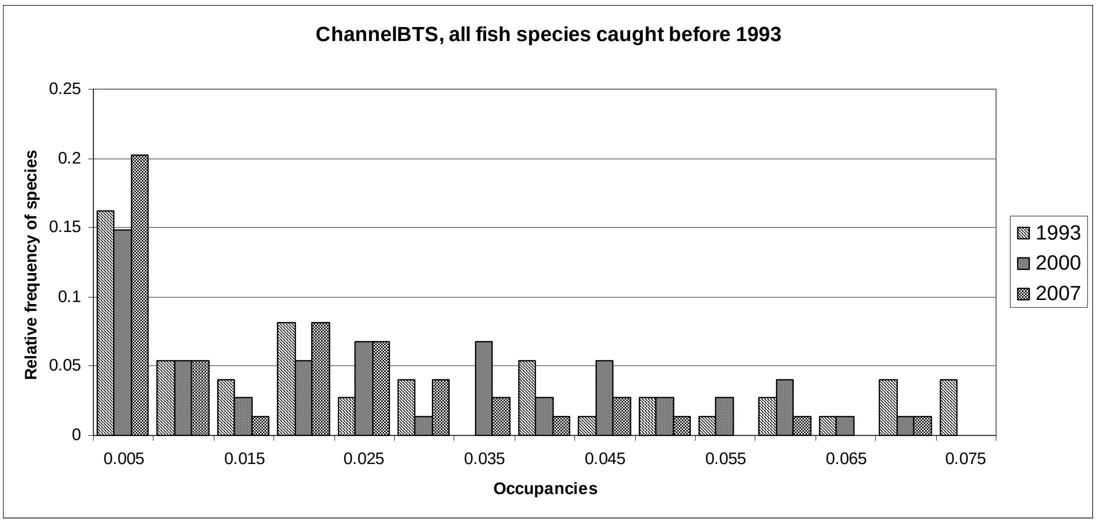


Figure 5.4.2 continued

c)

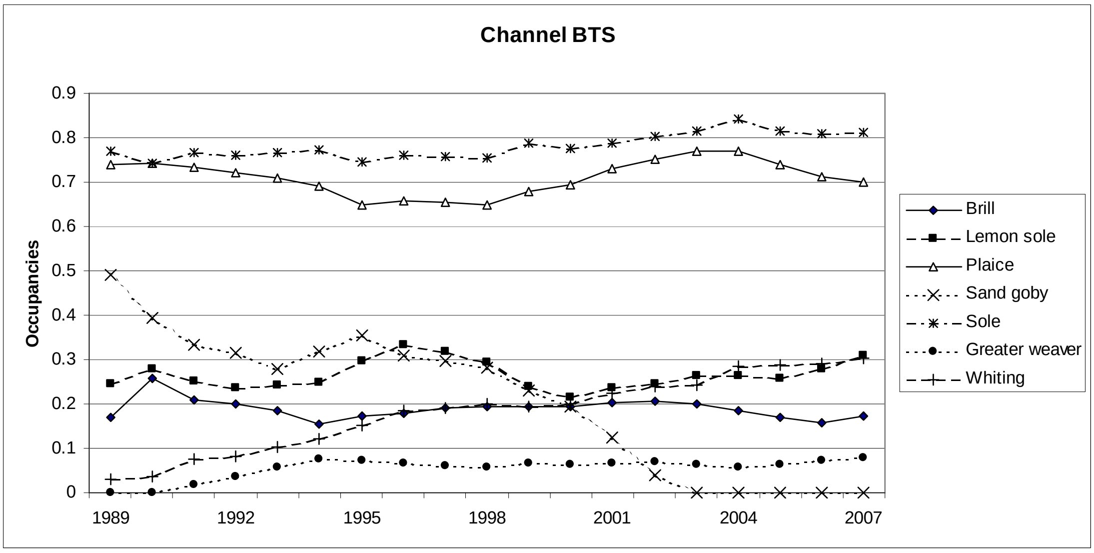
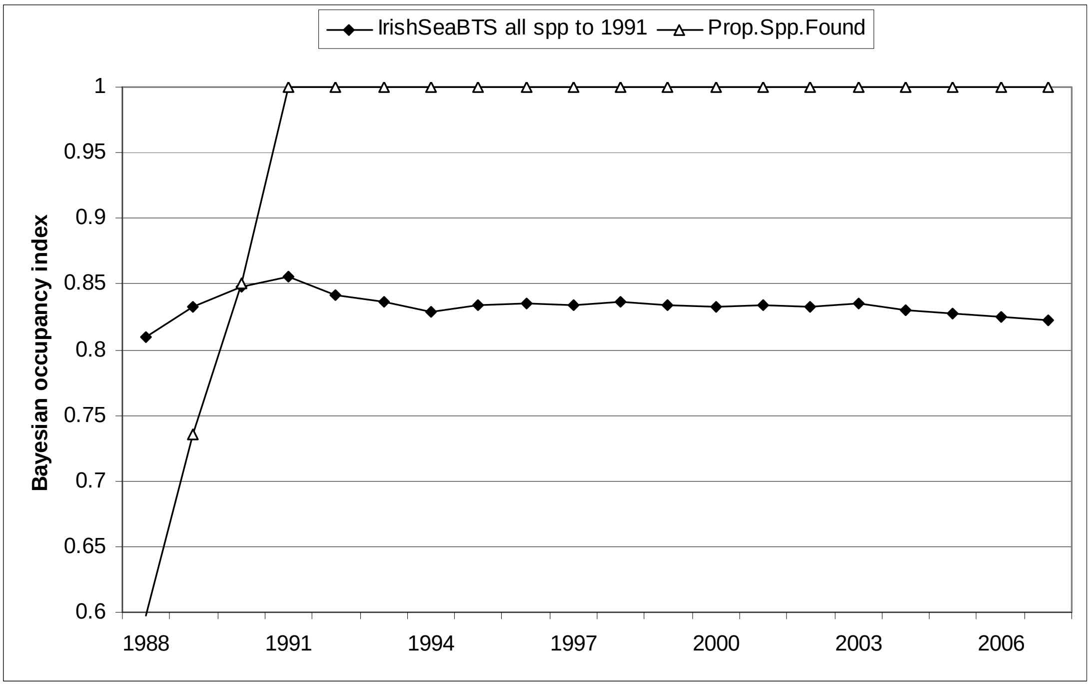


Figure 5.4.3 Irish Sea beam trawl survey, ICES divisions VIIa, f, g, e. a) Bayesian occupancy index (BOI) for all 87 species occurring in the survey from 1989 to 1991. Also shown is the proportion of species found. b) Lower part of histograms of occupancies of 74 species in 3 selected years of a 16-year period. c) Estimated occupancies for selected contrasting species.

a)



b)

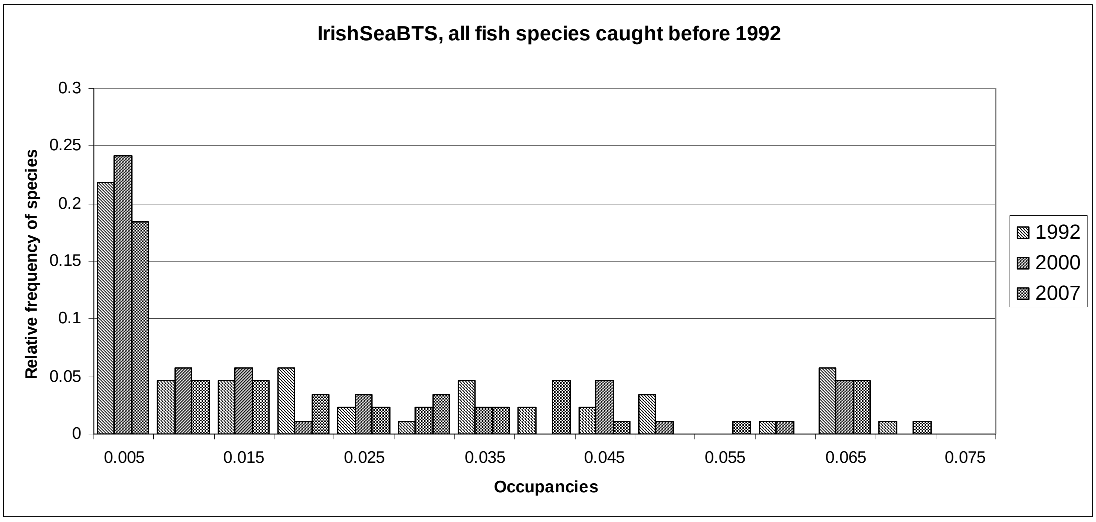
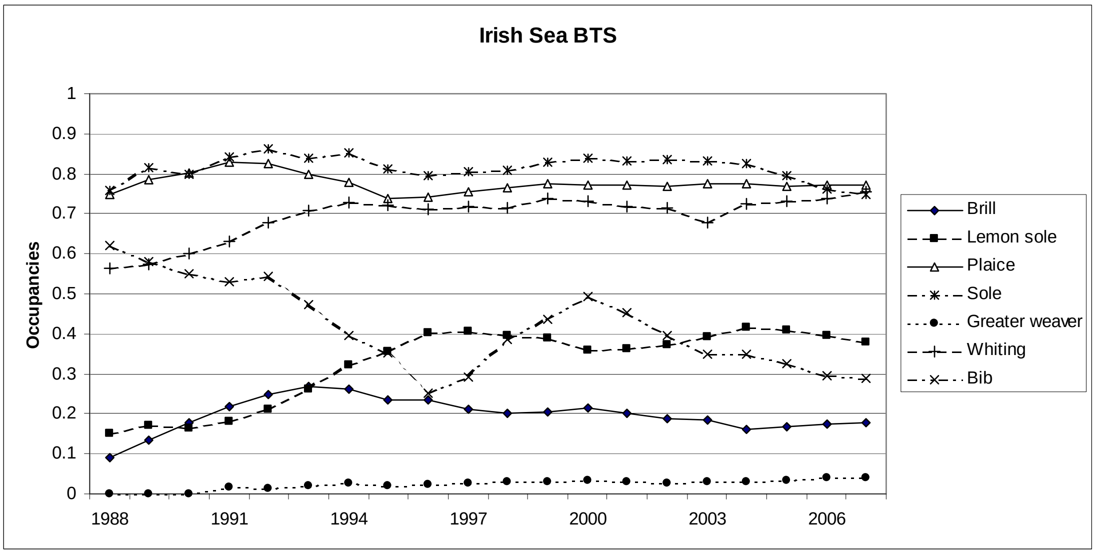


Figure 5.4.3 continued
c)



5.5 Assessment of threat and occupancy indicators for UK marine waters

5.5.1 Availability and future security of data

Security and availability of the requisite survey data are as remarked upon in relation to length-based indicators in section 4.4.1. However, in addition, careful attention needs to be given to the identification of rare species, involving additional training and testing of survey staff. Poor identifications of non-target species have been identified as a problem in international survey series (Daan 2001).

Conclusion: Survey data are available and secure for UK but careful attention must be paid to the identification of rare species.

5.5.2 Representativeness of UK waters

At present, there are otter trawl surveys in the North Sea by England and Scotland, another west of Scotland, a Northern Irish survey in the Irish Sea, and a new English survey to the west and south west of England. There is no otter trawl survey in the Channel. Beam trawl surveys exist in the Channel, southern North Sea, and the Irish Sea. These could all be used for threat or occupancy indicators within each survey domain. Combining them into UK indicators would require discussions among the UK fisheries laboratories concerning the combination of different surveys and geographic domains, and the most agreeable formulation for the indicators to be put forward.

Conclusion: UK otter trawl surveys would provide good representative sampling of all offshore UK waters for length-based indicators except in the Channel. UK beam trawl surveys could be used in the Irish Sea and Channel but a different range of species is caught, making the two types of survey non-comparable.

National discussions are needed to decide how data from the different surveys can be combined most agreeably into UK threat and/or occupancy indicators.

5.5.3 Capacity to provide long term, interpretable trends

Occupancy indices for individual species provide long term trends that are interpretable in relation to geographic spread which, for many species, is linked to abundance. Composite occupancy and threat indices are less valuable for management purposes because results for species that are becoming extremely rare can be masked by those for others that are becoming less rare. In practice, assessment of the occupancies of species individually appears more relevant for biodiversity management and conservation.

Conclusion: Occupancy indices can provide long term interpretable trends. Composite threat and occupancy indices could mask serious reductions of individual species.

5.5.4 Relevance to marine ecosystem integrity

Localised extinction of a species from an area, and geographical expansions and contractions of species, are both relevant to ecosystem integrity although the reasons for, and the consequences of these events are likely to need special investigations in each case.

Conclusion: Occupancy indices are relevant to marine ecosystem integrity. An increasing index of threat should prompt an assessment of the needs for conservation of individual species. Occupancy indices could be used for this.

5.5.5 Validity to set thresholds

IUCN thresholds based on changes in abundance are available, although they are somewhat arbitrary for survey-caught species, and they leave recovery from a threatened status poorly defined. Significant problems with them in a fisheries context are that the start of the survey fixes the start of the abundance measure arbitrarily – usually well after the onset of commercial fishing pressures – and fish surveys are very poor at measuring the abundance of rare species. Nevertheless, a feasible objective for the threat index in the short term would be to aim for a trend of reducing threat. Later, when fewer species are threatened, hard decisions on just how far to take this conservation process could be addressed. Occupancies are useful also because they complement the threat index and are easy to measure but they would require new discussions.

Conclusion: A feasible short term objective for the threat index would be to reduce threat. Thresholds might be agreeable for occupancies but discussions have not yet started.

5.5.6 Power of occupancies to detect change and trend.

The relative smoothness of the trends shown in figures 5.4.1c, 5.4.2c, 5.4.3c imply that occupancies, after a straightforward statistical smoothing procedure, are among the more stable of ecological indicators. The figures suggest that changes become apparent within 5 or so years.

Conclusion: Occupancy indices offer promise as a relatively responsive indicator of ecological integrity.

5.5.7 Discussion and further conclusions

The proportions of stations occupied, as formulated and applied here, yielded some interesting results. Occupancies declined noticeably for several minor species over the last two or three decades, e.g. the spurdog, catfish, and common skate in the North Sea, the sand goby in the Channel, and the bib in the Irish Sea. Declines in the less common, uncharismatic species such as the sand goby in the Channel, figure 5.4.2c, could easily be missed without examination of systematic plots of the type presented here. A decline in geographic occupancy implies that the survey can catch the species if it is present and, therefore, that a conservation issue exists. However, two more prosaic explanations are that species are not being identified or coded in the same way as they were, quite a possibility for non-target species (Daan 2001), or that the survey design and execution were not maintained adequately consistent over the years of the series. This proved to be the case for the EGFS because replicate tows were made at each station in the first five years of the survey, while, in later years, although the total number of stations fished remained the same, more localities were fished but without replicates. This caused an apparent but spurious increase in occupancies for some species after the first five years (corrected in this version of the report).

The surveys also found many other species that have been rare throughout the survey series. That result could be a consequence of poor catchability, e.g. if they don't usually occur at the stations fished, or if they are not vulnerable to the survey trawl. This does not by itself signal a conservation issue even if one exists. Zühlke (2000) found that a 2-metre beam trawl towed near the main survey stations where a GOV high headline otter trawl was fished on the North Sea groundfish survey caught many fish species not taken in the GOV trawl, and that different spatial patterns of species richness and diversity for the fish fauna resulted from using the two markedly different trawling methods. Her results emphasise the point that survey results are gear-specific. Another possible explanation for rarity throughout a survey series is that it suffered its main decline prior to the start. This only signals a conservation issue if the species is known to be easily catchable with the survey trawl, as is the case for the common skate, for example.

The time series of geographic occupancies presented here are generally much steadier than those for the abundance of a species, as can be seen by comparing with abundance series presented by Maxwell and Jennings (2005, their appendix 1) for example. Some of the problems of abundance estimation for non-randomly distributed fish populations are discussed by those authors and by Blanchard *et al.* (2007). Composite occupancy and threat indicators are less informative than results by species if increasing and reducing abundances cancel in the overall index.

Geographic occupancy is therefore **recommended** as a measure for tracking the status of rare species using a fish survey. The Bayesian estimation method assisted the signal from the occupancies by smoothing out sampling variation. The choice of smoothing interval, here 4 years, is arbitrary but appears to have worked well except for the species showing very marked changes of occupancy, e.g. the herring in the North Sea in the 1980s, figure 5.4.1d, when a lag in response occurred in the smoothed line.

Expecting a composite threat or occupancy index, however formulated, to convey the historic loss of well-known species such as the tuna fish and the sturgeon from UK waters when the index is based on groundfish surveys would be wrong. Those species may or may not still exist in our waters as a few isolated individuals but the chances of a Cefas survey with only around 80 to 100 trawl tows finding them is remote. Even if they are found repeatedly in small numbers, estimates of abundance, and even estimates of geographic occupancy have high sampling error because of well-known statistical theory that very large sample sizes are needed to achieve reasonable levels of precision for rarities. A composite index might be applied to commercial landing statistics so as to benefit from the much larger number of trawl tows made by commercial fishing fleets but this might only yield data about the charismatic and trophy species because of identification difficulties for all the others. Furthermore, commercial fishing is influenced by many variable commercial, legal, and practical factors that would greatly complicate interpretation of a threat index based on landings. It is **concluded** that assessing threat or biodiversity using commercial fisheries is not advisable.

There appear to be other possibilities for occupancies. If the probability of finding a species at a randomly chosen station is taken as $P_{y,s}$, the probability of finding no individuals of that species on the next entire survey is

$$\hat{P}\{0\}_{y+1,s} = \binom{n_{y+1}}{0} P_{y,s}{}^{0} \left(1 - P_{y,s}\right)^{n_{y+1}}$$
$$= \left(1 - P_{y,s}\right)^{n_{y+1}} .$$

The probability of finding the species at at least one station is then

$$1 - \left(1 - P_{y,s}\right)^{n_{y+1}} ,$$

and the probability of finding it at at least one station during a sequence of surveys treated as independent is

$$1 - \left(1 - P_{y,s}\right)^{\sum_{k=y+1}^{end} n_k}$$

This expression might serve as the probability of local extinction from the survey area given that species *s* is not found anywhere during the last sequence of surveys. Take, for example, the common skate which has not been seen by the EGFS since 1991 when $P_{1991,c.skate}$ was approximately 0.012 (figure 5.4.1e). Assume an average of 75 stations on each annual survey. The probability of early extirpation from the EGFS area given that it was not found in 1992 is $1-\left(1-0.012\right)^{75} = 0.5956$, and the probability of local extinction in 2007 after 16 consecutive surveys failed to find an individual is $1-\left(1-0.012\right)^{75*16} = 0.999999$. Other statistical models for assessing extinction, mostly based on abundance indices, are reviewed by Dulvy *et al.* (2004).

6. Non-fish based Indicators for assessing marine ecosystem integrity

The CBD is concerned with all species of plants and animals. If equivalent indicators are to be published for non-fish components of the ecosystem, it will be essential that they be monitored in a consistent and standardised way every year. Otherwise, published indicator values could say as much about methodological inconsistencies as about the marine environment and would quickly fall into disrepute. A few examples of extensive and reliable monitoring of other components of ecosystems exist, such as for plankton in the northeast Atlantic (SAHFOS, Plymouth, UK) (Vezzulli and Reid 2003), and the comprehensive but intermittent surveys for small cetacea (SCANS II[6]) and sea birds (Seabird 2000[7]). These could form the basis for further investigations to develop informative indicators but a likely finding is that the extent and regularity of routine, wide-scale monitoring of groups other than fish in UK marine waters needs to be improved. Dedicated surveys would provide the necessary data but at relatively high cost. In the case of seabirds and seals, adequate surveys of breeding colonies can often be done from land. Plankton, benthos, and cetaceans, on the other hand, have to be surveyed at sea, adding considerably to expense unless the surveys can be add-ons to national fisheries surveys already conducted by England, Scotland, and Northern Ireland. At various times in the past, observers on board have satisfactorily carried out surveys of sea birds, marine mammals, plankton, and benthic invertebrates living on or under the sea floor. Unfortunately, these surveys have been intermittently funded, and may also have been poorly standardised because of short term, localised objectives. Designing biodiversity monitoring programmes to add on to groundfish surveys would be relatively easy if secure funding were in prospect, and would add value to an existing, costly task.

A second consideration for non-fish indicators if they are to be presented publicly is that they hold some popular meaning and implication. Most ideas for indicators suffer from a lack of obvious reference values to distinguish "healthy" from "unhealthy", and from a lack of clear links to anthropogenic influences. Some time series might, however, hold interest just because of current trends. For example, many people are likely to be interested in knowing that abundance or geographic spread of marine mammal species is decreasing or increasing because these species hold biodiversity interest in themselves. In contrast, changes in, say, the trophic relationships of plankton communities would be more difficult to understand and explain to the public even if just as important ecologically. The challenge, therefore, is to find meaningful and informative indices for these different groups. Benthic species, particularly those living on the sea floor, can be expected to be affected by commercial fishing, either by being damaged by nets and ground gear, or by benefiting from discarded offal from fishing boats. Suitable indices relating to such effects could probably be found quite easily based on extensive previous work (Callaway *et al.* 2002; Callaway *et al.* 2007), assuming that a consistent annual survey were to be funded. Indicators for sea birds could also benefit from previous efforts (Tasker *et al.* 1984; Frederiksen *et al.* 2007), and relationships with industrial fishing

[6] http://iwcoffice.org/_documents/sci_com/2006progreports/SC-58-ProgRepUK.pdf

[7] http://www.jncc.gov.uk/pdf/Complete_seabird_pops_exec_summary.pdf

for prey species such as sandeels (Furness and Tasker 2000) and discarding (Garthe *et al.* 1996) are two aspects likely to arouse public interest. None of these possible avenues has been explored in the present study.

A further important consideration when monitoring several different components of a marine ecosystem is how to combine the results meaningfully. The various contributing indicators will, almost certainly, be correlated amongst each other, either because the different methods of measurement have common features, e.g. sampling from the same ship in the same weather, or because environmental variables cause related variability in the different indicators. The consequence is that different indicators tend to convey similar messages and may, consequently, be raising too much confidence and/or wasting monitoring resources. Multivariate statistics are required to take account of the correlations. An interesting example of an attempt to combine many ecological indicators into a single 'combined standardised index' using multivariate methods is given by Boyd and Murray (2001). Their method used the statisticians' device of standardising the many types of variable measured by, in each case, subtracting the mean of the time series and dividing by the standard deviation. Another example is the living planet index (LPI) which combines abundance indices as log ratios (or using a linear model) within different biomes, then averages the results from each (Loh *et al.* 2005). Other multivariate methods, including a method which takes into account autocorrelation along multiple time series, can be found in an ICES manual of methods for indicators (Cotter 2007a). A problem with most multivariate methods is that they are necessarily based on higher mathematics making understanding and communication of the results much harder. It also increases the risk of sampling variation or missing values generating signals that are not recognised as being spurious. The combination of indicators is, by itself, probably a subject worthy of further research with the objective of improving reliability and transparency of conclusions from multiple time series. Buckland *et al.* (2005) offer a good starting point. On the other hand, Trenkel *et al.* (2007) describe a simple and intuitive way of combining indicators which avoids some of the mathematical issues.

7. Other aspects

7.1 Statistical assessment of trends

Indicators of the ecological integrity of marine ecosystems tend to be more or less variable from year to year and seldom trace out a smooth and unambiguous trend. A clear statistical method is required to separate sampling variability from true environmental signal. There are several possibilities but first, some necessary jargon:

Reference level (or point): An agreed value, ideally one based on scientific reasoning, that an indicator should not exceed (or fall under, as appropriate) when the ecosystem is in an agreeable condition.

Reference direction: Jennings and Dulvy (2005) point out that reference levels (or points) are often difficult to define for ecosystem indicators, and that a reference direction, up or down, is preferable.

Type 1 error: Thinking you have an infringement of a reference level, or a change in trend direction, when you do not.

Type 2 error: Thinking you do not have an infringement of a reference level, or a change in trend, when you do.

Linear trend: A straight trend up or down.

Smooth function: a smoothly bending line fitted to a time series of observations.

Power of a test: The probability of finding an infringement or a trend when it does exist.

7.1.1 Smoothing method

Indicator series can be statistically smoothed and an estimate of variance around the smoothed trend calculated (Fryer and Nicholson 1993; 1999; Nicholson and Fryer 2002). Nicholson and Jennings (2004) simplified the mathematics to considering a time series of observations y_t for $t = 1, \ldots, T$. The model is

$$y_t = \mu_t + \varepsilon_t$$

where $\varepsilon_t \sim N(0, \sigma^2)$ i.e. errors are normally distributed around zero with variance σ^2, and $\mu_t = g(t)$ for a pre-trend period, where $g(t)$ is the smooth function, and $\mu_t = \alpha + \beta t$ thereafter, i.e. a linear trend (up or down) over time. The variance term, σ^2, is used to test whether the trend is significantly different from zero, or not. Nicholson and Jennings (2004) used this method to estimate the power of the North Sea International Bottom Trawl Survey (IBTS) to detect trends in indicators of fish ecosystem integrity based on trophic level, length, and weight. They found that the survey was poor at detecting new trends, requiring decades or longer for reasonable statistical confidence that a change in trend had truly occurred.

A possible explanation for this result is that power was low because the indicators tested were all based on observed abundances-at-length. They tend to be highly variable on trawl surveys and are mutually correlated among lengths because survey trawls catch clusters of fish, not random samples (Cotter *et al.* 2004). As a result, there is much less information in the data than there appears to be from a count of the fish measured (Pennington and Vølstad 1994). These properties of the data serve to diminish the power of a survey to detect changing trends. The method itself also has weaknesses. The degree of smoothing used has to be chosen by judgement (Fryer and Nicholson 1999) and the choice can be much harder for some series than others, yet the result fixes the estimate of σ^2 and hence the power of the method. Fitting a straight line or a simple curve amounts to assuming a model for the trend which may be an overly simple idea for its shape over time, as does the selection of a starting point unless there is a good prior reason for choosing one year over another. As Nicholson and Jennings (2004) point out, an observed trend may not have been caused by fishing alone and there are grounds to question whether the null hypothesis of "no trend" would ever be tenable except as an approximate model.

7.1.2 Estimating 2nd derivatives

This method also uses smoothing and is due to Fewster *et al.* (2000). It has been adapted for fisheries indicators by Trenkel (section 5.3 in Cotter *et al.* 2007) in a way which emphasises the salient features of the series in order to give most emphasis to the direction of the current trend – always the one of most interest. Trenkel's description of the method is the source of the following summary:

- Fit a GAM smooth to the time series;
- Calculate 1st and 2nd derivatives for all years using 1st and 2nd differences between consecutive data points;
- Test whether 1st and 2nd derivatives are significantly different from zero for a given year using a parametric bootstrap to create resampled data series;
- The values of the derivatives are calculated for each bootstrap and ordered into a histogram to provide confidence limits.

Trenkel proposes decision rules based on the results for deciding the direction of change in the most recent years of an indicator series. If the maximum is not found within the last three years and the annual slopes (first derivative) are predominantly negative and annual second derivatives are negative or zero in the last five years (no change point appears with sign of second derivative passing from –1 to +1), the direction of change is declared as recently decreasing. The second derivative is used to establish whether an improvement has already taken place most recently. Similarly for a recently increasing series, the minimum should not be within the last three years, the average of the annual slopes should be positive (apart from one year) and no change for a decreasing trend (sign of second derivatives positive) should have occured during the last five years. For all other cases there is no indication for a change. Trenkel states that these decision rules are based on empirical tests, and are not prescriptive. The important point is the principle, i.e. the combination of different measures of the dynamics of a time series, minimum, slope and change points. In particular the time spans considered, which is five years for the first and second derivatives and three years for the location of the maximum and minimum, are easily adapted for a particular study.

7.1.3 Nonparametric methods

A variety of nonparametric statistical methods have been used for assessing trends, including binomial, rank-based, and Mann-Kendall correlation methods. They have been briefly reviewed with a discussion of statistical inference and example calculations with fishery data by Cotter (section 5.3.4 in Cotter *et al.* 2007). The advantages of nonparametric methods are that dependence on hypothetical models for the trend and the statistical distribution of residuals can be avoided, thereby helping to make the tests less dependent on decisions by the statistical analyst. The null hypothesis can be different too. Instead of assuming no trend until a positive or negative trend is demonstrated, a trend can be assumed to exist from the outset on the grounds that no two measurements in the natural environment are ever exactly the same. Then, a nonparametric test is used to decide whether the trend is positive or negative (less than or equal to zero), and smoothing or estimation methods may be used to estimate its trajectory. In this circumstance, the concept of statistical power is only applicable to the ability of a test to distinguish positive from negative slopes.

Nonparametric methods have been widely used for the monitoring of water pollution where the sporadic and chaotic nature of variation combined with frequent gaps in the time-series has stimulated development of nonparametric methods because of their minimal assumptions. Fisheries scientists typically prefer modelling, i.e. parametric methods, for assessing trends in fish stocks and have exploited nonparametric methods relatively lightly. Frequently however, well established, structural models are not available for the behaviour of ecological indicators.

7.1.4 Quality control methods

Manufacturing industry has long used statistical methods to assess whether items are within the required specifications or not. The consequences of type 1 and 2 errors can be very expensive. Exactly the same problems arise in environmental quality control when threshold values can be set to signal good or bad environmental situations, except that the marine environment is much slower to respond to changes than a factory assembly line and, for many indicators, can only be measured imprecisely. Much depends on society's attitude to environmental risk, i.e. the allowable probabilities of type 1 and 2 errors. For a review of statistical quality control methods as applied to marine fishery indicators, see Mesnil and Petitgas (2007).

8. Recommendations and conclusions

The following recommendations are based on the analyses of data, literature review, and considering views expressed during written consultations and at the scientific workshop (refer to Annex 1).

8.1 MTI

The MTI is not recommended for UK waters as:

- It will be costly to apply given that there is a clear case for extending and refining existing data on trophic levels (section 3.7.1). These costs would diminish resources available for other, more ecologically informative marine environmental monitoring.
- Despite the cost, the MTI says very little that can be clearly distinguished from the effects of changing fishing practices, or that is additional to the information about the availability of different types of fish that can be inferred from quantities landed commercially.
- The MTI does not give clear signals for regions within UK waters, and those for the UK as a whole give different trends depending on the method of analysing trophic levels. The agreement between the different methods of describing trophic levels (stomach contents and Ecopath method and the N-isotope method) is poor.
- Trends in a UK MTI may or may not be related to changes in the ecosystem, and may change for environmental reasons other than 'fishing down the food web' so that, even without complications due to changing fishing practices, changing levels of MTI are likely to arouse controversy.
- Threshold values distinguishing 'good' from 'bad' ecosystems do not exist and seem unlikely to be agreeable in the next few years.
- The MTI can be made independent of commercial landings data by basing it on survey data but the number of stations fished by UK surveys is too small, and the range of trophic levels caught too narrow to provide a responsive index.

If, nevertheless, a MTI is chosen the following should be taken into account:

- ICES landings statistics should be used at the UK level to account for the wide range of fisheries and trophic levels covered. The costs of gathering and processing these data from the internet are minor if the 2-year delay inherent in these data is acceptable. Otherwise, a special effort would be needed to gather more timely landings statistics from each nation fishing in ICES divisions around UK. National landings stats are less well balanced across different types of fisheries and trophic levels than ICES statistics. For example, UK stats omit the large tonnages of low-trophic level fish landed by Danish and Norwegian industrial fisheries. For these reasons, use of ICES international landings statistics is recommended.
- This may be feasible under the data sharing provisions of the EC Data Collection Regulation (EC 1639/2001, Article 11) or otherwise through ICES.

- We have also recommended that a one-off exercise be undertaken to improve and extend the national inventory of trophic level information for different species and regions. Computing an MTI would require that existing UK trophic level data are extended to more species and regional seas involving English, Scottish, and Northern Irish surveys as an initial one-off exercise, with reviews possible in future. Estimates should be made of the standard errors of analyses of trophic level.
- Assuming that a scientist is present on surveys to sample fish for this purpose, approximately 2 person months (p.m.) would be needed to take part in each of the
    - English groundfish survey (g.f.s.) of the North Sea
    - Scottish g.f.s. of the North Sea
    - Scottish g.f.s. west of Scotland
    - Northern Irish g.f.s. in the Irish Sea
    - Western groundfish survey west and south west of England, and
    - Channel beam trawl survey.

The total effort is 12 p.m. distributed around UK. At least 1000 to 2000 trophic level analyses would be needed, creating costs in the order of £30,000 for the N-isotope method. These numbers could be much higher if care is taken to collect separate samples from different regions within each survey area.

Concerning the method for estimating trophic levels if an MTI is adopted, the N-isotope method has the advantages over stomach contents analysis in that it provides an integrated assessment of trophic level for each fish implying that the measure is more repeatable, and that it is more amenable to standard methods of chemical quality control (QC). High standards would obviously be essential for a national programme. It would be necessary to take several samples of each fish, preferably from different trawl tows within each locality, and analyse them independently to allow a reliable estimate of the variability of trophic levels. Ideally, there would also be laboratory resources to analyse stomach contents on the same fish that are collected for N-isotope analyses. The aim would be to try to improve the correspondence (figure 3.2.1) between the two methods. Collating and archiving all these data would be an additional significant task which, together with management of a database and preparation of data reports, could need approximately an additional 12 person months.

8.2 Length-based Indicators

Length-based indicators (LBIs) for fish are recommended for use by the UK as:

- LBIs relate to normal biological processes of fish with obvious ecological relevance, for example: reproduction, growth, predation, and migrations. Length can be used as a proxy for trophic level.
- Changing lengths of fish in the sea are quite well understood in relation to processes such as recruitment, loss of predators, and food supply.
- The required survey data are already available and securely and routinely collected. UK otter trawl surveys would provide good representative sampling of all offshore UK waters for LBIs except in the Channel. UK beam trawl surveys could be used in the Irish Sea and Channel but their

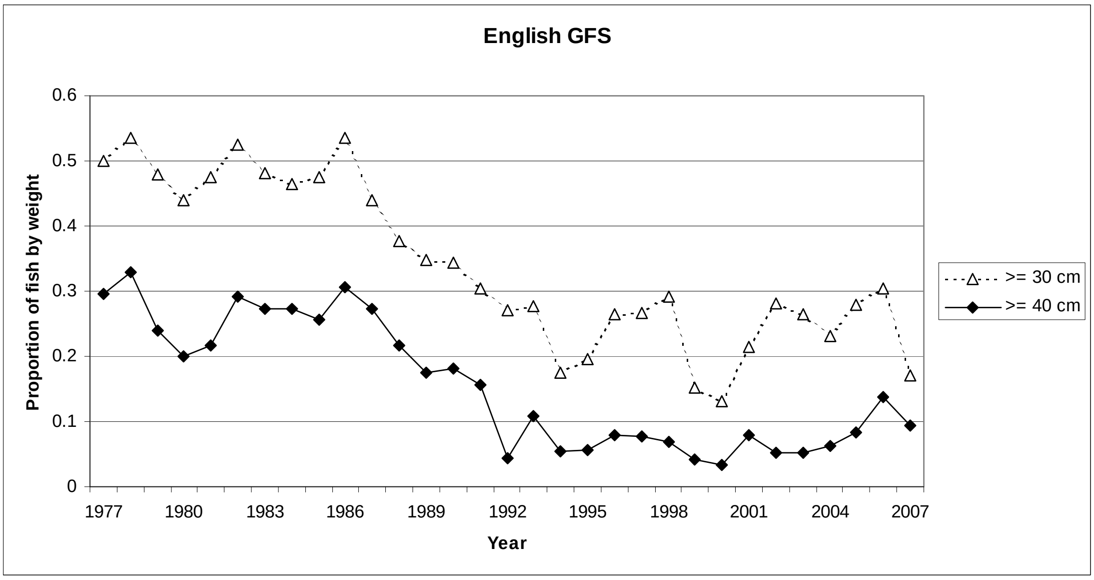
LBIs appear less responsive than with otter trawl surveys probably because different species are caught by the different gears. For the same reason, the two types of survey would not be comparable for LBIs. National discussions are needed to decide how data from the different surveys can be combined most agreeably into UK LBI(s)LBIs could therefore be presented by UK for the small costs of annual computations plus liaison with ICES, OSPAR, or other groups with an interest e.g. EurOceans EAF indicators working group[8].

- Numerous designs of LBIs have been described in addition to those investigated here, e.g. mean length, length quantiles, length spectra, abundance-biomass curves (Jouffre and Inejih 2005; Yemane *et al.* 2005). These allow different facets of a species' or group of species' ecology to be investigated separately.
- LBIs can provide long term trends, and interpretation is feasible with care. They require several years to respond to changed environmental conditions.

LBIs can be estimated for single or multiple species. In practice, the choice of one or more of these indicators is not final because all come from the same secure source of data, namely fish surveys funded jointly by the European Union and Defra. For Scottish, English and other international waters of the North Sea (and using the English contribution to the International Bottom Trawl Survey (IBTS)), the OSPAR/ICES indicator will take the form illustrated in Figure 4.3.1a) and reproduced below;

[8] http://www.eur-oceans.eu/research_themes/wp6/index.php?to_url=ws/eafindic/index.php&mode=fromEuroceans

Figure 4.3.1.
Graphical representation of the ICES (2007) lenth-based indicator describing the OSPAR fish community EcoQO (proportion by weight of individual fish of all species exceeding stated cut-off lengths) calculated for the English groundfish survey (GFS) of the North Sea, ICES subarea IV.



The indicator calculated for the same region using Scottish Ground Fish Survey data and the entire IBTS dataset, and using the same length thresholds, shows comparable trends (Figure 4.3.4).

There was insufficient time to reproduce these indicators for all survey datasets held in Northern Ireland and Scotland, although results in Figures 4.3.2a) and 4.3.3a) for other UK regions suggest that the process is straight-forward.

The recommended way forward for application of LBIs by the UK is for a short, national enabling project to be funded. The following set of actions describes what is required to compile the final indicator, and includes the decisions, agreements and data compilation necessary:

1. A small, nominated group of experts/contractors representing country agencies and fisheries laboratories, with advice and guidance from government, should decide whether the ICES/OSPAR EcoQO (section 4.2.1) is the most suitable LBI. The recommendations in this report can contribute to this decision.
2. This group will need to agree on which survey data sets should be used (from the waters of Scotland, Northern Ireland, England and Wales) to best represent UK waters, but avoiding duplication. To complete this stage effectively it will be necessary to ensure that at least groundfish survey staff from Cefas, FRS and DARD (NI) are involved. Key considerations will be spatial extent, gear type and future data security. Once agreed, compilation of datasets will be straightforward.
3. Once the indicator and datasets have been agreed, the group should confirm the technical methods to be used and agree the analytical code to be applied to the data. Both these already exist so will not involve any further new work. Nominated individuals with responsibility for national fisheries datasets should

then be assigned to compile the datasets and calculate the indicators using the following specification.

4. Agreeement will be required on maximum size (length) thresholds or reference directions for these LBIs that are relevant to the region for which the indicator is developed (N.B. the 40cm threshold identified by ICES refers only to the North Sea). These can be developed by selecting a proportion of total observed lengths (e.g. 0.9) at which the absolute length threshold can be determined for each survey.
5. Agreement will be required on whether English, Scottish, and Northern Irish length data are processed locally or centrally. We recommend the former, and if so, procedures will also need to be agreed to describe how data will be transferred to a central point for combination, and in what format the final indicator will be published.
6. For the North Sea survey, measured fish (i.e. all species caught) should be categorised by length less than 40 cm, or greater than or equal to 40 cm, and the total numbers in each category summed over all species and stations for each year of the survey. The proportions greater than or equal to 40 cm should then be estimated by weight for each survey. Operational details of Access queries that can be used for this analysis are provided in Annex 5.4, with constants needed for the allometric length-to-weight conversion given in Annex 4. The same method will need to be repeated in other regions using the survey-specific length cut-offs selected in 5.
7. Once calculated, national data will need to be compiled in a suitable format to generate UK results. At present this is still to be determined, but could be undertaken regionally by gear type, and/or regionally and by combining data from each gear. This latter analysis will require a small amount of statistical investigation as part of the programme.
8. It will be sensible to notify OSPAR of the work undertaken by the UK so that results can be incorporated as a case study in the OSPAR QSR.
9. Once regional and national indicators are generated, the final decision will be to provide estimates of the cost of routine annual updates.

It is estimated that this should be approximately a 6-month-duration project with a month of scientific time allocated to each of the three fisheries laboratories, plus resources to allow national meetings. This task could be combined with others recommended in connection with other indicators below.

8.3 Threat and/or occupancy indicators

In addition, threat and/or occupancy indicators are recommended for the UK as:

- They relate directly to biodiversity in accordance with the CBD.
- Threat indices relate to IUCN criteria.
- Threat indices provide threshold values as targets for managers, based on internationally agreed targets to halt biodiversity decline.
- Occupancies, suitably smoothed, are among the most stable of ecological indicators; they allow many species caught on a survey to be checked for conservation risk.
- The requisite survey data for fish are already available and securely and routinely collected. Threat and/or occupancy indices could therefore be

presented by UK for the small costs of annual computations plus liaison with ICES, OSPAR, or other groups with an interest e.g. EurOceans EAF indicators working group[9].

- Careful attention must be paid to the identification of rare species. UK otter trawl surveys would provide good representative sampling of all offshore UK waters for length-based indicators except in the Channel. UK beam trawl surveys could be used in the Irish Sea and Channel but a different range of species is caught, making the two types of survey non-comparable. National discussions are needed to decide how data from the different surveys can be combined most agreeably into UK threat and/or occupancy indicators.
- Occupancy indices can provide long term interpretable trends and are relevant to marine ecosystem integrity. Composite threat and occupancy indices could mask serious reductions in abundance of individual species. An increasing index of threat should prompt an assessment of the needs for conservation of individual species.
- A feasible short term objective for a thhreat index would be to reduce threat.
- Commercial fishing is influenced by many variable commercial, legal, and practical factors that would greatly complicate interpretation of a threat index based on landings. It is concluded that assessing threat or biodiversity using commercial fisheries is not advisable.

For the North Sea, a threat indicator for fish species would take the form illustrated in Figure 5.1.1 (below) as calculated by Dulvy *et al.*, 2006.

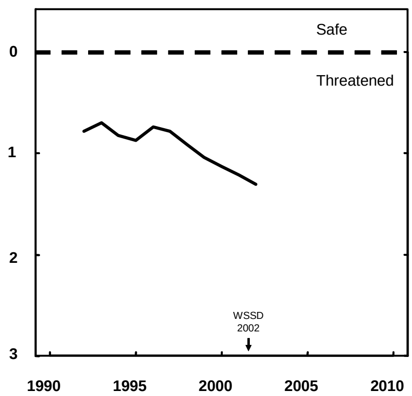


Figure 5.1.1 An indicator of threat for a suite of 23 selected trawl-vulnerable species of North Sea demersal fishes (modified from Dulvy *et al.*, 2006), measured as extent of decline. Averaged over these species, a score of 1 = all species are Vulnerable, 2 = all species are Endangered, 3 = all species are Critically Endangered.

In practice, the choice of one or more threat or occupancy indicators for fish populations is not final because all come from the same secure source of data, namely fish surveys funded jointly by the European Union and Defra. A feasible objective for the threat index in the short term would be to aim for a trend of reducing threat.

[9] http://www.eur-oceans.eu/research_themes/wp6/index.php?to_url=ws/eafindic/index.php&mode=fromEuroceans

Later, when fewer species are threatened, hard decisions on just how far to take this conservation process could be addressed.

The occupancy indices complement the threat index and identify when non-target, uncharismatic species are being driven towards local extinction from a survey area by fishing, or perhaps other causes. Initially, the only resources needed are for annual calculations and liaison with ICES, OSPAR, or other interested groups. However, simple occupancy statistics or threat indices are unlikely to satisfy those concerned by loss of biodiversity. A species whose geographic range is diminishing clearly calls for a special investigation of the problems. The changing spatial state of its apparent distribution will be of obvious interest and may require additional, more closely spaced fishing stations than are carried out on the main survey, with a consequent rise in costs. Newly available spatial indices that can characterise geographic distributions could be very useful for such studies (Woillez *et al.* 2007). Occupancy indices might also be valuable for epibenthic studies of the type already carried out from fish surveys (Callaway *et al.* 2002).

The recommended way forward for application of threat and/or occupancy indices is similar to that described for LBIs above. The objectives of a short, national enabling project in relation to threat and/or occupancies could be:

1. A group will need to be established to agree whether, and how to, calculate threat and/or occupancy indices, either based on those published by Dulvy *et al*, or in this report. T|his group could be the same experts / contractors that develop the LBI (described above).
2. The group will need to agree on which survey data sets should be used (from the waters of Scotland, Northern Ireland, England and Wales) to best represent UK waters and those regions supporting threatened species. To complete this stage effectively it will be necessary to ensure that at least groundfish survey staff from Cefas, FRS and DARD (NI) are involved. Key considerations will be spatial extent, gear type and future data security. Once agreed, compilation of datasets will be straightforward.
3. Once the threat / occupancy indicator has been selected, the group should confirm the technical methods to be used and agree the analytical code to be applied to the data. These components of the work will need some refinement but relatively limited new work. Nominated individuals with responsibility for national fisheries datasets should then be assigned to compile the datasets and calculate the indicators using the agreed specification.
4. Agreeement will be required on thresholds for threat indicators. It is suggested that these refer to the need for improvement in trend, rather than a target point.
5. Agreement will be required on whether English, Scottish, and Northern Irish length data are processed locally or centrally. We recommend the former, and if so, procedures will also need to be agreed to describe how data will be transferred to a central point for combination, and in what format the final indicator will be published.
6. Once calculated, national threat and/or occupancy indicators will need to be compiled in a suitable format to generate UK results. At present this is still to be determined, but could be undertaken regionally by gear type, and/or regionally and by combining data from each gear. This latter analysis will require a small amount of statistical investigation as part of the programme.

7. Once regional and national indicators are generated, the final decision will be to provide estimates of the cost of routine annual updates, including the cost of any new training necessary for accurate identification of the non-target fish species that are caught on national groundfish surveys.

If necessary the proposals for developing LBI and threat and / or occupancy indicators could be combined.

8.4 Non-fish indicators

Although this study has not examined non-fish indicators, the following suggestions are offered for developing them, based partly on experiences of successful monitoring efforts on Cefas groundfish surveys (estimated staff times are approximate):

- The resources of plankton data held by SAHFOS at Plymouth should be examined with a view to defining indicators of biodiversity, ecological state, and environmental or climatic effects on plankton. This might be a 3-6 month project for one scientist. Thereafter there would be a need to ensure security of data collection, and make the requisite calculations.
- Sampling of epibenthos using the proven technique of towing a standard, 2-metre lightweight beam trawl at the beginning and end of each day during UK fish surveys should funded. Indicators should be developed to monitor biodiversity, fishing, and, if possible, climatic effects. Development of suitable indicators with existing data held by FRS and Cefas could be a 6-month project for one scientist. Thereafter, 3 months of scientist time would be needed for each fish survey used for epibenthic sampling. Five otter trawl surveys, two by Cefas (North Sea and SW), two by FRS (E and W of Scotland), and one by Northern Ireland (Irish Sea and North Channel) would be good candidates for this work. A sixth, a Cefas beam trawl survey, would cover the Channel. More than 6 staff could be needed due to overlapping timing of some surveys.
- A monitoring survey for cetaceans should be designed for UK groundfish surveys and trained observers deployed on the research vessels. Possibly, this need only involve regular merchant navy officers present on the bridge and appropriately trained and briefed. Alternatively, special scientific observers could be used at higher cost. Such observer programmes in summer usually require 2 observers per vessel to cover the whole day. The appropriate cetacean specialists should be funded to design such a programme, if necessary with attendance on a survey to assist design of practical arrangements. Using observers, better value for money (and the job made more interesting) if seabirds were also monitored at the same time, even though this may be achieved more effectively by monitoring of breeding colonies on shore.
- There are probably also strong cases for monitoring seabirds, and marine life inshore, beyond the reach of groundfish surveys. Readers are referred to other advisers for this.
- Monitoring of infaunal benthic species using grabs, and of fish stomach contents are other activities which many would consider should be part of a national ecological monitoring programme. However, in both cases,

sample analysis is very labour intensive, involving much laboratory work after each survey has finished. For this reason, they should be given lower priority.

It is envisaged that the plankton, cetacean, seabird, and inshore proposals would be separate projects carried out by appropriate scientific groups.

The proposal for an epibenthic monitoring programme using groundfish surveys would sensibly involve national fisheries laboratories because they already have much experience in carrying out epibenthic surveys. An enabling project, possibly linked with those proposed for LBIs and threat/occupancy indicators, would be needed with the following objectives:

- To agree the most communicable, ecologically relevant, and achievable indicators of epibenthic ecological integrity to be monitored from national groundfish surveys.
- To agree and standardise the gear and fishing methods to be used so as to achieve consistent, scientifically credible sampling of epibenthic species all around the UK.
- To agree what training is necessary for accurate identification of the epibenthic species that are likely to be caught by the chosen sampling method.
- To decide whether English, Scottish, and Northern Irish epibenthic data should be processed locally or centrally and, if the latter, how data will be communicated and published, in what formats, for what annual deadlines, and who will perform the computations.
- To decide how regional results should be configured to create UK results, e.g. geographically, seasonally, etc.
- To decide whether international links should be maintained in connection with epibenthic sampling and, if so, why and how, e.g. with ICES, OSPAR.
- Since epibenthic distributions are linked to trawling, to agree how to obtain the best international measures of trawling effort by geographic region, and the statistical methods for relating these to epibenthic monitoring results.
- To estimate costs of future annual updates.

8.5 Presenting multiple indicators

A monitoring programme for ecological indicators is almost certainly going to involve more than one indicator. The long-standing question of how to combine the results from multiple indicators into a single communication, or how to decide on related management measures to correct perceived conservation problems, is discussed in section 6. One further project is recommended, a statistical project with the following objectives:

- To review and further develop methods for statistically combining indicators into one or more communicable composite indices that are likely to be relevant for management of overall biodiversity and the causes of change.

- To assess the effects of missing values, bias, and sampling variance on these composite indices.
- To apply the preferred methods to national data sets in order to demonstrate their robustness, informativeness, and the value they add compared with the indicator series presented separately.

The project should be collaborative with the other proposed national projects since liaison with other laboratories would be necessary to obtain the data required. A 1-year project is thought to be necessary to assemble the data and complete the objectives.

9. Glossary of terms

allometric growth	Growth without change of shape. Allows weight of an organism to be modelled as a cubic (or nearly so) function of length.
beam trawl	Trawl net held open by a heavy overhead beam supported on large sliders at either side. Beam trawls are often fitted with tickler chains stretched across the mouth to disturb fish partly buried in the sea floor. Beam trawls tend to be best for catching flatfish such as sole and plaice.
benthos	species living on or under the sea floor; e.g. lugworm
bias	Deviation of an observed statistic from the true value
Biodiversity	the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. Taken from CBD.
BTS	Beam trawl survey
by-catch	Unmarketed species caught by commercial fishing vessels and usually discarded.
catch	fish of any type or size taken by a fishing vessel
CBD	Convention on Biological Diversity. See http://www.cbd.int/
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CPUE	Catch per unit of effort; e.g. numbers of fish per hour of trawling
Defra	Department of environment, food and rural affairs, UK government.
demersal	species living in the water column typically near the sea floor; e.g. cod
discards	subset of catch that is not marketed but thrown away at sea
EC	European Commission
Ecopath	An ecosystem model based on trophic relationships (Christensen and Pauly 1992). Used with stomach sampling on fish surveys to estimate current trophic levels.
EGFS	English groundfish survey – an otter trawl survey in the North Sea
epibenthos	benthic species living on the sea floor; e.g. crab
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
Fishery-independent data	Data obtained independently of commercial fisheries. See ‘surveys’.
flatfish	Flattened fish that typically live close to the sea floor. Most are vulnerable to beam trawls; e.g. sole, plaice, lemon sole, megrim.
FRS	Fisheries Research Services, Aberdeen
GOV trawl	Grande overture verticale. Otter trawl with high headline and light groundgear. Catches mainly round and pelagic fish.
Granton trawl	Otter trawl with rather low headline height and heavy groundgear. Catches mainly round and flatfish.
HBDSEG	Healthy and Biologically Diverse Seas Evidence Group of the UKMMAS
ICES	International Council for the Exploration of the Sea. See www.ices.dk
indicator (for ecosystems)	A measurable environmental variable whose value is thought to signal the state, well-being or integrity of significant components of the ecosystem; e.g. the MTI.
IUCN	International Union for Conservation of Nature

landings	Subset of catch brought home to market. Frequently much less than the total catch.
LPI	Living Planet Index; summarises rates of change in populations of vertebrate species (Loh *et al.* 2005)
MTI	Marine trophic index; usually the mean trophic level calculated from landings of fish and trophic levels estimated for each species.
N-isotope analysis	Analysis of the relative balance of the two stable isotopes of nitrogen, ^{14}N and ^{15}N. Useful for estimating the long-term average trophic level of a species because the heavier isotope is concentrated in muscle tissue by approximately 3.4 parts per thousand on average at each predatory step.
otter trawl	Trawl net held open by a door on each side dragging over the sea floor and angled so that water flow pushes them outwards. Otter trawls tend to be best for catching demersal round fish such as cod, haddock, and whiting.
pelagic	species typically living in the water column without association with the sea floor; e.g. herring
roundfish	Fish characterised by a round cross section. Most are demersal and vulnerable to otter trawls; e.g. cod, haddock, whiting, saithe, ling
SAHFOS	Sir Alister Hardy Foundation for Ocean Science, Plymouth
sampling error	random variation of an observed statistic resulting from which members of the population were chosen for observation, and from the measurement errors that happened in each case.
survey	In this report, survey refers to fish surveys made with research vessels. A standard set of stations is fished in the same way every year primarily to generate indices of relative abundance of commercial species of fish.
threshold (for indicator)	Value dividing 'good' and 'bad' ecosystem states. For most indicators, these are very hard to define.
trophic level	Position of a species in the food chain, where level 1 represents primary producers such as algae and bacteria, 2 represents grazers on them, 3 represents predators of grazers, and subsequent levels represent predators on predators. Fractional trophic levels result from mixed diets.
UK	The United Kingdom of Great Britain and Northern Ireland
UKMMAS	UK Marine Monitoring and Assessment Strategy
variance	a measure of the variability of sampling error; consistent bias is not included.
WSSD	World Summit on Sustainable Development. See http://www.un.org/events/wssd/

10. References

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Annex 1: Minutes of workshop, London 3 March 2008

(Unconfirmed and subject to revision)

Marine Trophic Index: Workshop with invited participants, 3 March 2008
Defra, Whitehall Place, London

Present
Dan Laffoley, Natural England
Chris Pirrie, Natural England
Lucy Oliver, Countryside Council for Wales
William Cheung, University of British Columbia, Fisheries Centre
Phil Kunzlik, FRS Aberdeen
Matt Service, Fisheries & Aquatic Ecosystems Branch, AFESD
David Connor, JNCC
Ian Boyd, Sea Mammal Research Unit, St Andrews
Henrik Sparholt, ICES, Copenhagen
Paul Somerfield, Plymouth Marine Laboratory
Jo Myers, Marine biodiversity adviser, Defra, NESD
Mark Stevenson, Defra, NESD
Stuart Rogers, Cefas, chair
John Pinnegar, Cefas
John Cotter, Cefas

Minutes
Background
J. Myers, Defra customer, outlined the origins of the Marine Trophic Index (MTI) project from the Convention on Biological Diversity (CBD) and, subsequently, the UK Government's declared vision for the marine environment as one of 'clean, healthy, safe, productive and biologically diverse oceans and seas'. The purpose of the present workshop was to obtain the input of experts other than the Cefas contractors on the MTI and other candidate indicators. The criteria by which each indicator would be assessed were:

- security of data (now and in future)
- representative of UK waters
- capable of providing long term, interpretable trends
- relevant to marine ecosystem integrity
- valid for setting thresholds, and should have
- statistical power to detect change and trends.

It was acknowledged that there may be other criteria and workshop delegates were encouraged to provide a rigorous scientific assessment of the proposals. '
Indicators were intended to communicate the ecological state of the marine environment and, if possible, to prompt management responses when necessary. The MTI was listed for development, together with 17 other possible headline indicators. Indicators of marine ecological integrity other than the MTI could be considered and may prove more acceptable, or complementary. Other governmental initiatives to monitor and protect the marine environment included the UK Marine Monitoring and Assessment Strategy being carried out for the OSPAR commission, and the EU's Marine Strategy Directive. Ecological indicators were also being considered in these two fora.

The MTI
A draft report[10] of the work undertaken by Cefas for Defra was circulated prior to the meeting. A summary of the findings for the MTI was presented to the meeting by J. Cotter. An MTI calculated with ICES landings stats showed a downward trend from 1973 but the slope depended on whether the trophic levels were estimated with stomach contents analysis and Ecopath, or with nitrogen-isotope analysis, the latter being the steeper. Disaggregating the UK MTI regionally revealed much more variability in the time series, apparently masking any environmental signals. MTIs were also calculated with three Cefas surveys: one otter trawl survey in the North Sea, a beam trawl survey in the Channel, and another in the Irish Sea. The series were mostly flat and devoid of signal, except for that with the otter trawl survey and trophic levels determined by stomach contents analysis. It showed a weak downward trend. An effect of changing from a Granton to a GOV otter trawl in 1992 could be seen in the N-isotope MTI series, underlining the importance of gear type to results. The lack of clear signal from the surveys suggested that their ranges of catchable trophic levels were too restricted.

In a lively discussion, advantages of the MTI were said to be that it is simple, comparable across areas, readily communicable, well established, and linked with the food web so that it has an obvious ecological relevance. Disadvantages raised were that it is linked to commercial fisheries landings data which are affected by commercial and regulatory factors, e.g. the growth of industrial fisheries for low trophic level species; and the setting of TACs. Landings data are also known to be subject to mis- or incomplete declarations, and never include the many small and non-target fish that are discarded at sea. UK fisheries span most trophic levels but the different types of fishery are strongly regionalised. The MTI is thus affected by both ecological and fishery-related factors creating a problem for interpretation of trends.

The importance of being able to “drill down” from an indicator into the contributing data in order to be able to learn the likely causes of change was emphasised. The desirability of subsetting the MTI for different groups of species was discussed, e.g. demersal, pelagic, industrial, shellfish. This might aid interpretation. On the other hand, the value of the MTI as an indicator for complete ecosystems would be reduced and the concept of “fishing down the foodweb” lost. There was a need for statistical confidence to be known for indicator series. In the case of the MTI computed from landings, standard error bars could be misleadingly small because they would summarise only the variability from the estimated trophic levels, whilst excluding any bias in the landings data which are a complete census, not based on statistical sampling. Error bars would also not include biases revealed by the differently sloping trends found by Cefas using the two methods for estimating trophic level. Other statistical methods exist for deciding when a trend has changed (see section 7.1 of the Cefas report), and modelling methods exist for estimating a probability of misclassification as pass/fail, etc. These methods would be less affected by bias if it could be assumed constant, a condition that some felt might not be tenable. It was pointed out that, if the MTI were calculated using survey data in preference to

[10] Marine ecosystem integrity: development of a Marine Trophic Index for UK waters and recommendations for futher indicator development by Cotter, Rogers, Ellis, Mackinson, Dulvy, Pinnegar, and Jennings, dated 26 Feb 2008.

landings data, the coverage geographically and seasonally would be lower and variance would be higher.

Interpretation of the MTI can be assisted with the Fishing in Balance indicator (FIB). This can show whether a decline in MTI was caused by "fishing down the foodweb" or simply by expansion of commercial fisheries. The FIB may stay level in the first case; or, it could go down if the ecosystem were damaged such that fishing down the foodweb did not yield the expected larger tonnages of low trophic level species. It could also go up if expansion of the fishery led to additional catch. Some of the richest UK fisheries take low-trophic level species, e.g. pelagic and shellfisheries. The meeting agreed that the MTI currently has no clear reference level to assist interpretation. Comparison with past results were considered but it was pointed out that, even if these are known for UK waters, they are likely already to have been affected historically by fishing which can cause significant changes in MTI even at low levels of effort.

Views of the meeting differed on whether trophic levels should be measured repeatedly, or whether values estimated in the late 1990s could serve for many future years. Repeated measurements would assist with determining a useful standard error for an MTI series, and would allow for changing trophic levels of opportunistic feeders as species assemblages changed in response to fishing, but would form a costly overhead. Trophic levels should also be measured for different marine regions, and for different sizes or ages of fish because many species move to higher trophic levels as they grow. Others felt that this level of scientific refinement and cost would not be merited. A compromise would be to re-measure trophic levels every decade or so, though this might lead to step changes in the index. Ignoring the size effect on trophic level means that the MTI is conservative because fishing tends to remove large individuals first, causing a decline of mean trophic level within species that is not registered by the indicator.

The way in which trophic level is estimated is important for the MTI. Both N-isotopes and stomach contents analyses (on which Ecopath models are usually built) have their advantages and disadvantages (and the best results are obtained when comparative exercises are carried out). Stomach contents tend to offer only a snap-shot of preferences, the method ignores soft items, and it tends to aggregate items such as 'polychaetes' when such prey items may actually include several trophic levels. N-isotope analysis, by contrast, tends to pick out more different trophic levels, but the method usually assumes a standard 'per trophic level' fractionation value of 3.4 which may have large standard errors for some species. N-isotope analysis appears to be more amenable to objective quality control than stomach contents analysis. All agreed that, whichever method is chosen, it should be maintained and applied consistently from year to year.

The chair asked the meeting to summarise their individual views on the MTI following the discussions. As bullet points, they were:

- Too high level, difficult to interpret;
- Too insensitive; changes will be slight;
- Both trophic level methods could be used with ICES supporting extra sampling;
- Lack of reference level, biased landings data, and uncertain links between MTI and biodiversity are worrying;

- MTI well understood and accepted; calculate with landings data;
- Nervous about assuming that trophic levels are constant when they vary, and lack of error bars;
- MTI must have error bars;
- MTI nicely links with ecosystem but must distinguish different trophic levels accurately;
- As previous bullet; MTI is valid because people understand it;
- Unreliable landings data are a problem;
- MTI confounds fishery and ecosystem; simpler, better indicators are available;
- Concerned by lack of reference level and lack of responsiveness;
- MTI needs to be broken down; concerned about commercial factors and lack of error bars.

A vulnerability indicator
W. Cheung briefly summarised his published work on a vulnerability indicator for fish. Each species is categorised with degrees of vulnerability (0 to 100) depending on life history characteristics that render it vulnerable to fishing, e.g. late maturation, slow growth, large size, etc. This serves to prioritise species for special protection measures. Species vulnerabilities can also be weighted by tonnages landed (as trophic levels are for the MTI) to create a vulnerability index (VI). In most situations, decline in the VI matches a decline in catch per unit effort (CPUE), strongly implying that the decline in the CPUE was caused by commercial fishing. Vulnerabilities were found to be correlated with trophic levels because of a correlation with body size and other life history characteristics. Vulnerabilities have been calculated for most European species of fish and are available on the Fishbase web site. Cefas indicated that they would attempt to include VIs in the final report of the project if time permitted[11]. W. Cheung also spoke about the FIB indicator; those comments are summarised with issues surrounding the MTI, above.

Status of fish stocks
H. Sparholt presented two slides showing the number of fish stocks assessed around Europe, and the proportion of these that were considered to be over-exploited, i.e. outside “safe biological limits”. This can serve as a useful indicator of marine ecological integrity or, possibly, fishing pressure. It is already published by the European Environment Agency, and is being considered by the UK as a useful indicator. The meeting noted that assessments are only conducted on commercial species (more in northern Europe than in the south). Hence the indicator is not a substitute for indicators that look at all species.

Length-based indicators
J. Cotter presented results for two multi-species, length-based indicators calculated with the Cefas North Sea otter trawl survey. One was that chosen by the OsloParis (OSPAR) Commission and considered by ICES, namely the proportion of large fish, where ‘large’ is defined as > 30 cm or > 40cm. Much variability was observed, particularly with the lower cut-off limit, probably as a result of sporadic, numerically abundant year classes. Less variability is expected if the indicator is calculated as the

[11] VIs were calculated after the meeting using ICES landings data and EGFS data for the North Sea. Vulnerabilities were taken from Cheung et al. (2007) Marine Ecology Progress Series 333: 1-12. No trend was apparent from either the landings or the survey data. The reasons for this were unclear and the indicator was therefore not included in this report.

proportion of large fish by weight (not by number) as recommended by ICES. Nevertheless, clear declines in the indicator were seen in the late 1980s, suggesting an effect of fishing but not conclusively without further detailed analyses. A second length-based index was calculated by transforming all fish lengths from cms to proportions of maximum length for the species, finding the numeric proportions in each length category, then averaging these proportions across species. This indicator also showed substantial variability from year to year but with a clear overall decline from the early 1990s. Possibly, this was associated in some way with the change of trawl to the GOV in 1992. Length-based indicators have the advantages of being based on extensive data that are already available, of having relatively well-understood responses to fishing in different circumstances, and of being easily understood. Length can be linked with size at maturity so that the indicator can tie in with the proportion of fish able to breed, giving ecological meaning. Length is also relevant to predation and trophic level.

In discussion, it was noted that length indicators should be carefully designed to prevent management towards undesirable ends, e.g. many individuals of one or a few large species, possibly of low importance for ecological integrity. Abundance Biomass curves and size spectra were other options for informative, multispecies, size-based indicators.

Threat and occupancy indices
Cefas also presented results for their project studies of threat and occupancy indices. As originally formulated by Dulvy et al., species are classified as vulnerable, endangered, or critically endangered depending on the percentage declines that have been observed for their populations. This accords with ideas in use by IUCN for assessing the threat status of terrestrial species. Since percentage declines for fish depend rather arbitrarily on the starting year for a survey, and abundances are very poorly measured by fish surveys for rare species, Cefas had examined a simplification during this project. Each survey uses a constant number of fishing stations in the same locations each year (depending on weather, etc.). Fish were classified as present or absent, and the proportion of stations occupied estimated for each year. Several species, including heavily fished commercial species, were found to be increasing their occupancies[12]. The method also successfully identified those that were decreasing, suggesting a conservation issue worthy of further study. An overall threat index could be based on occupancies, e.g. the number of species declining, and would have direct relevance to the Convention on Biological Diversity (CBD).

In discussion, several noted that occupancies were worth examining for individual species. The relationship between occupancy and abundance was a fundamental ecological question needing more research though, trivially, it can occur as a result of species being poorly catchable by a survey. Others felt that changing spatial distributions of species would be more revealing of ecological or climatic factors than simple occupancies.

[12] Following the meeting, a re-examination of the EGFS data for North Sea revealed that, for the first 5 years, the survey fished approximately 50 stations with replicate tows instead of the later 80 stations without replicates. Re-calculating the occupancies with the smaller number of locations indicated that the increases in occupancies observed for several heavily fished species were probably erroneous. See section 5.4 of this report.

Other biodiversity measures not using fisheries data

The CBD was concerned with much more than fish species. The chair therefore asked for suggestions of other data sets and indicators of marine ecological integrity not solely based on fish. The following suggestions were made:

- CCAMLR use a "combined standardised index" for the Antarctic that includes seals, penguins, sea birds, whales, etc. Apart from combining a large variety of data types, it is also robust to missing data.
- Time series of CPUEs for shark species are available for UK waters. This might be useful as an indicator for a group of top predators.
- UK has much data on sea birds but surveys have been patchy. Counts of seabird colonies have been more consistent.
- The EC Data Collection Regulation is being revised to require member states to monitor several new variables for management of marine ecology in addition to the previous sole purpose of managing commercial fish species.
- The Continuous Plankton Recorder (CPR) towed by ships of opportunity through UK seas for many years could provide an index to monitor the ecological integrity of plankton communities. The meeting did not know of any indices currently in use for this purpose. CPR data were also useful for assessing climatic effects.
- The EC Water Framework Directive requires the sampling of benthic marine invertebrates within 1 mile of the coast but not further offshore. Annex 3 of the Directive lists critical issues such as physical disturbance, habitat loss, and noise pollution. Ideally, headline marine indicators would relate to these.
- The National Marine Monitoring Programme (NMP) had been monitoring benthic invertebrates at fixed stations offshore for many years. The sites were mostly representative of zones of siltation. Epifauna and Nephrops burrows were also being monitored using underwater video.
- Groundfish surveys carried out by Scotland, England, and Northern Ireland present several opportunities for systematic surveys of seabirds, marine mammals, and epibenthic species. Such surveys have already been completed successfully and can be carried out at low cost because ship time is already paid for.
- Commercial fishing effort should be known better, especially with regard to locality since this could be related to habitat and species loss.
- Fish stomach contents have twice been sampled extensively, at approximately decadal intervals under ICES programmes. One view is that they can offer a useful measure of biodiversity. New monitoring would also tie in with estimation of trophic levels for the MTI.

Close

J. Myers thanked all for attending the meeting and contributing to interesting discussions. The meeting had been very helpful for widening the scientific input to the project, and for learning what kinds of problems need to be ironed out before the MTI could be used by UK. Concerning other indicators, there was a need to prioritise. Cefas were required to present a report to her, modified in the light of the discussions, by 10 March. The Defra initiative was welcomed by the meeting as a step in the right direction.

John Cotter and John Pinnegar,
Minutes, 5 March 2008

Annex 2: Table of trophic levels by functional group as obtained from stomach contents analysis and Ecopath modelling.

Function group	FunGroup #	North Sea	Irish Sea	English channel	Western channel	MedianTL	MeanTL
Baleen whales	1	4.45	3.87			4.16	4.16
Toothed whales	2	4.78	4.42	4.45	4.36	4.435	4.50
Seals	3	5	4.31	4.71	4.63	4.67	4.66
Seabirds	4	3.5	3.81	3.66	3.51	3.585	3.62
Juvenile sharks	5	4.29				4.29	4.29
Spurdog	6	4.77			3.36	4.065	4.07
Large piscivorous sharks	7	4.93	4.29	4.45	4.36	4.405	4.51
Small sharks	8	4.34	4.05			4.195	4.20
Juvenile rays	9	4.23				4.23	4.23
Starry ray + others	10	4.49				4.49	4.49
Thornback & Spotted ray	11	4.49	3.65		3.4	3.65	3.85
Skate + cuckoo ray	12	4.44				4.44	4.44
Juvenile Cod(0-2, 0-40cm)	13	4.43	3.37	3.35	3.45	3.41	3.65
Cod (adult)	14	4.83	4.16	3.83	3.92	4.04	4.19
Juvenile Whiting (0-1, 0-20cm)	15	4.27		3.78	3.29	3.78	3.78
Whiting (adult)	16	4.4	4.26	3.97	4.05	4.155	4.17
Juvenile Haddock (0-1, 0-20cm)	17	4.06	3.24			3.65	3.65
Haddock (adult)	18	4.28	3.89			4.085	4.09
Juvenile Saithe (0-3, 0-40cm)	19	4.03				4.03	4.03
Saithe (adult)	20	4.36				4.36	4.36
Hake	21	4.91		4.13	4.4	4.4	4.48
Blue whiting	22	4.1				4.1	4.10

Annex 2 continued:

Function group	FunGroup #	North Sea	Irish Sea	English channel	Western channel	MedianTL	MeanTL
Norway pout	23	3.59				3.59	3.59
Other gadoids (large)	24	4.53	4.32			4.425	4.43
Other gadoids (small)	25	3.83	3.41	3.35	3.36	3.385	3.49
Monkfish	26	4.85	4.66		4.16	4.66	4.55
Gurnards	27	4.52	3.57	3.21	3.34	3.455	3.66
Herring (juvenile 0, 1)	28	3.42				3.42	3.42
Herring (adult)	29	3.44	3.72	3.3	3.1	3.37	3.39
Sprat	30	2.96		3.03	3.13	3.03	3.04
Mackerel	31	3.9	3.56	3.07	3.4	3.48	3.48
Horse mackerel	32	4.33		3.22	3.54	3.54	3.70
Sandeels	33	3.35	2.96	3.43	3.13	3.24	3.22
Plaice	34	3.99	3.67	3.13	3	3.4	3.45
Dab	35	4.01		3.09	3.19	3.19	3.43
Long-rough dab	36	4.18				4.18	4.18
Flounder	37	4.38				4.38	4.38
Sole	38	4	3.65	3.05	3.01	3.35	3.43
Lemon sole	39	3.94				3.94	3.94
Witch	40	4.05				4.05	4.05
Turbot and brill	41	4.62				4.62	4.62
Megrim	42	4.46				4.46	4.46
Halibut	43	4.85				4.85	4.85
Dragonets	44	3.98	3.78			3.88	3.88
Catfish	45	4.27				4.27	4.27
Large	46	4.21	3.68	4.13	3.95	4.04	3.99
Small	47	4.21	3.57	3.03	3.09	3.33	3.48
Miscellane	48	3.43				3.43	3.43
Cephalopo	49	3.86	3.31	3.63	3.43	3.53	3.56
Carnivoro	50	3.23	3.01	3.03	3.16	3.095	3.11
Herbivoro	51	2.06	2.02	2.03	2.16	2.045	2.07
Gelatinous	52	3.58	2.69			3.135	3.14
Large	53	3.71	2.59	2.45	2.44	2.52	2.80
Nephrops	54	3.51	2.83			3.17	3.17
Epifaunal	55	3.31	3.15	2.24	2.23	2.695	2.73
Infaunal	56	2.88	2.82	2		2.82	2.57
Shrimp	57	3.05	2.14	2.4	2.43	2.415	2.51

Annex 2 continued:

Function group	FunGroup #	North Sea	Irish Sea	English channel	Western channel	MedianTL	MeanTL
Small	58	2.91	3.11			3.01	3.01
Small	59	2.95	2	2		2	2.32
Sessile	60	2.8	2.46	2.56	2.61	2.585	2.61
Meiofauna	61	3.03	2.11			2.57	2.57
Benthic	62	2.24				2.24	2.24
Planktonic	63	2.14	1		2.06	2.06	1.73

Annex 3: Table of trophic levels by species as obtained from N-isotope analysis for nitrogen.

LatinName	CommonName	Code	TL_Celtic	TL_Northsj	TL_sj2001	TL_NSdas	TL_sjAequ	TL_median
Aphrodita aculeata	Sea-mouse	AAC				-	-	4.10
Haliotis lamellosa	Abalone	ABX				-	1.7	1.74
Halocynthia papillosa		AIP				-	2.7	2.65
Atelecyclus rotundatus	Circular crab	ALR						3.10
Engraulis encrasicolus	anchovy	ANE	4.2	-	-	3.4		3.40
Anomurid decapods (mixed)	Hermit crabs & squat lobsters (mixed)	ANZ					2.8	2.77
Astropecten irregularis		API				-	-	2.50
Asterina gibbosa		ATG				-	-	3.90
Beryx splendens	beryx	BER	3.1	-	-	-		3.06
Bivalve molluscs (mixed)	Bivalves (mixed)	BIA				-	2.3	2.25
Trisopterus luscus	bib	BIB			4.8	4.6		4.70
Sponyliosoma canthurus	black sea bream	BKS	4.4	-	-	-		3.91
Capros aper	boarfish	BOF	2.9	-	3.4	-		3.15
Boops boops	bogue	BOG	-	-	-	-		2.96
Notacanthus bonaparte	Shortfin spiny eel	BPS	-	-	-	-		4.06
Myxocephalus scorpius	bull-rout	BRT	-	-	4.7	-		4.71
Anarhichas lupus	wolf-fish	CAA	-	3.5	3.6	-		3.56
Corystes cassevelinus	Masked crab	CCV						3.70
Callionymus lyra	dragonet	CDT	3.6	4.3	3.6	4.0		3.81
Crangon allmani		CGA						3.40
Cerastoderma edule		COC				-	2.5	2.49
Gadus morhua	cod	COD	4.4	4.7	4.7	4.6		4.65
Conger conger	conger eel (deep)	COE	-	-	-	-		4.27
Palaemon serratus	Common prawn	CPR				3.3	3.3	3.29
Cephalopods (mixed)		CPZ				-	3.6	3.55
Cancer pagurus	Edible crab	CRE						3.90
Carcinus maenas	Shore crab	CRG				3.6	-	3.56
Crangon crangon	Brown shrimp	CRH				4.1	-	4.09
Palinurid decapods (mixed)	Lobsters (mixed)	CRW					3.6	3.59
Sepia officinalis	Cuttlefish	CTC				3.7	3.8	3.74
Leucoraja naevus	cuckoo Ray	CUR	3.9	3.9	3.6	-		3.88
Limanda limanda	dab	DAB	4.2	4.1	4.4	3.9		4.15

Annex 3 continued:

LatinName	CommonName	Code	TL_Celtic	TL_Northsj	TL_sj2001	TL_NSdas	TL_sjAequ	TL_median
Galeus melastomus	black-mouthed dogfish	DBM	-	-	-	-		3.75
Dalatias licha	Darkie Charlie (Kitefin shark)	DCH		-	-	-		4.22
Squalus acanthias	spurdog	DGS	3.4	3.2	-	-		3.31
Ebalia cranchii	Nut crab	EBA						3.20
Echinocardium cordatum	Sea potato	ECC				2.1	-	2.12
Echinoderms (mixed)		ECH				-	2.2	2.16
Eledone moschata		EDC				-	3.7	3.89
Echinus elegans		EEG				-	-	2.20
Anguilla anguilla	eel	ELE		-	-	4.8		4.80
Torpedo torpedo	electric ray	ELR		-	-	-		4.23
Dicentrarchus labrax	bass	ESB	4.5	-	-	-		4.24
Platichthys flesus	flounder	FLE	3.9	-	-	4.1		3.98
Enchelyopus cimbrius	four-bearded rockling	FRR	-	4.7	3.8	-		4.23
Galeorhinus galeus	tope	GAG	4.9	-	-	-		4.88
Belone belone	garfish	GAR			-	4.3		4.30
Gastropod molluscs (mixed)	Gastropods (mixed)	GAS				-	2.1	2.06
Phycis blennoides	forkbeard	GFB	3.8	-	-	-		3.97
Solen marginatus	Grooved razor shell	GRZ				2.3	-	2.26
Hyperoplus lanceolatus	greater sandeel	GSE			4.1	3.7		3.89
Eutrigla gurnardus	grey gurnard	GUG	3.6	4.3	4.4	3.9		4.10
Chelidonichthys obscurus	longfin gurnard	GUL		-	-	-		3.58
Aspitrigla cuculus	red gurnard	GUR	3.8	-	-	3.8		3.78
Melanogrammus aeglefinus	haddock	HAD	3.6	4.2	4.2	3.4		3.88
Clupea harengus	herring	HER	3.8	3.3	3.4	2.8		3.36
Pagurus prideax		HIA						3.10
Pagurus bernhardus	Hermit crab	HIW				3.4	-	3.68
Merluccius merluccius	hake	HKE	3.9	3.9	4.1	-		3.88
Modiolis modiolis		HML				-	-	2.60
Trachurus mediterraneaus	Mediterranean horse mackerel	HMM	-	-	-	-		3.63
Henricia sanguinolenta		HNS				-	-	2.50
Trachurus trachurus	horse mackerel	HOM	3.9	4.6	5.1	4.4		4.40
Coelorhynchus coelorhynchus	Hollowsnout grenadier	HRT	-	-	-	-		3.91
Holothuria tubulosa	Sea cucumber	HTZ				-	2.6	2.59
Hyperoplus immaculatus	Corbins sandeel	ISE	3.5	-	-	-		3.47
Arnoglossus imperialis	imperial scaldfish	ISF	3.1	-	-	-		3.09
Zeus faber	john dory	JOD	4.2	-	-	-		4.22

Annex 3 continued:

LatinName	CommonName	Code	TL_Celtic	TL_Northsj	TL_sj2001	TL_NSdas	TL_sjAequ	TL_median
Lampanyctus crocodilus	Jewel lanternfish	LAC	-	-	-	-		3.41
Homarus gammarus	Lobster	LBE					4.0	3.96
Lepidorhombus boscii	four-spot megrim	LBI	3.4	-	-	-		3.42
Luidia ciliaris		LDC				-	-	2.80
Lithodes maja	Spider crab	LDM						3.70
Microstomus kitt	lemon sole	LEM	3.7	3.9	3.9	3.5		3.79
Liocarcinus holstus	Swimming crab	LIC				3.7	-	3.52
Molva molva	ling	LIN	4.4	-	3.9	-		4.12
Loligo vulgaris	Squid	LLV				4.1	2.9	4.06
Macropipus spp.	Swimming crab	LMD				-	3.7	3.68
Scyliorhinus canicula	lesser spotted dogfish	LSD	4.3	3.8	4.0	3.5		3.97
Leptasterias muelleri		LSM				-	-	2.60
Argentina sphyraena	lesser argentine	LSS	3.4	-	3.8	-		3.44
Cyclopterus lumpus	lumpsucker	LUM	-	-	3.4	-		3.41
Scomber scombrus	mackerel	MAC	3.6	3.5	3.5	3.7		3.56
Lepidorhombus whiffiagonis	megrim	MEG	3.6	3.4	3.4	-		3.41
Maiidae	Spider crab	MJX				-	2.0	2.00
Brachyuran crabs (mixed)	Crabs (mixed)	MNC					3.0	2.99
Munida rugosa		MNR						3.00
Mora moro	Common mora	MOM		-	-	-		4.17
Lophius piscatorius	anglerfish	MON	4.1	4.2	4.4	-		4.20
Ammodytes marinus	Raitt's sandeel	MSE	-	3.5	3.9	-		3.68
Mullus surmuletus	red mullet	MUR	4.4	-	-	4.1		4.10
Mytilus galloprovincialis	Pacific mussel	MYG				-	2.2	2.24
Nephrops norvegicus	Norway lobster	NEP					3.2	3.49
Phrynorhombus norvegicus	Norwegian topknot	NKT			3.9			3.91
Trisopterus esmarki	Norway pout	NOP	3.9	3.7	3.9	-		3.85
Loligo forbesi		NSQ				-	-	3.70
Octopus vulgaris	Common octopus	OCV				-	3.5	3.54
Ophiura albida		OHA				-	-	3.20
Ophiothrix fragilis		OPF				-	-	2.70
Ostrea edulis	European oyster	OYF				-	2.4	2.38
Crassostrea gigas	Pacific oyster	OYG				-	2.4	2.36
Pagellus erythrinus	Common pandora	PAC		-	-	-		4.40
Processa canaliculata		PCC				-	-	3.00

Annex 3 continued:

LatinName	CommonName	Code	TL_Celtic	TL_Northsj	TL_sj2001	TL_NSdas	TL_sjAequ	TL_median
Sardina pilchardus	pilchard	PIL	3.6	-	-	-		3.46
Hippoglossoides platessoides	long rough dab	PLA	4.0	3.6	3.8	-		3.79
Pleuronectes platessa	plaice	PLE	3.7	4.0	4.4	3.6		3.84
Psammechinus milaris	Green sea urchin	PMM				2.6	-	2.83
Pontophilus spinosus		PNZ						3.10
Trisopterus minutus	poor cod	POD	3.7	4.2	4.9	-		4.20
Agonus cataphractus	pogge	POG		-	4.0	3.9		3.95
Pollachius virens	saithe	POK	4.1	4.1	4.3	-		4.11
Pomatoschistus	goby	POM			-	4.2		4.20
Porania pulvillus		PPV				-	-	3.10
Pandalus borealis		PRA						3.20
Pandalus montagui		PRM						3.20
Aequipecten opercularis		QSC				-	-	2.00
Helicolenus dactylopterus	bluemouth	RBM	3.9	-	-	-		3.83
Sebastes viviparus	norway haddock (redfish)	REV	-	3.6	3.5	-		3.56
Coryphaenoides mediterraneus	Mediterranean grenadier	RNG	-	-	-	-		3.25
Trachyrincus scabrus	Roughsnout grenadier	RNR		-	-	-		4.16
Alepocephalus rostratus	Risso's smooth-head	ROH	-	-	-	-		3.81
Neptunea antiqua		RWK				-	-	3.90
Pagellus acarne	Axillary seabream	SBA	-	-	-	-		4.40
Pecten spp.	Scallop	SCE				-	2.5	2.53
Arnoglossus laterna	scaldfish	SDF	-	4.4	4.3	-		4.36
Raja montagui	spotted ray	SDR	3.9	-	-	3.5		3.71
Mustelus asterias	starry smooth hound	SDS	4.0	-	-	3.8		3.90
Lepidopus caudatus	Silver scabbardfish	SFS		-	-	-		3.32
Macroramphosus scolopax	snipefish	SNI		-	-	-		4.17
Solea solea	sole	SOL	4.2	4.5	4.8	4.1		4.49
Solea lascarus	sand sole	SOS			-	4.1		4.10
Buglossidium luteum	solenette	SOT	-	4.3	4.1	3.4		4.12
Acanthocardia aculeata		SPC				-	2.2	2.23
Scorpaena porcus	Black scorpionfish	SPP	-	-	-	-		3.32
Sprattus sprattus	sprat	SPR	4.1	3.8	3.8	3.9		3.85
Todarodes sagittatus		SQE				-	3.5	3.48
Nezumia aequalis	Common Atlantic grenadier	SRL		-	-	-		4.53
Liparus liparus	seasnail	SSL			-	4.2		4.20

Annex 3 continued:

LatinName	CommonName	Code	TL_Celtic	TL_Northsj	TL_sj2001	TL_NSdas	TL_sjAequ	TL_median
Asterias rubens	Common starfish	STH				2.9	-	2.61
Gadiculus argenteus	silvery pout	SYP	2.9	-	3.2	-		3.18
Amblyraja radiata	starry ray	SYR		4.1	4.1	3.0		4.06
Microchirus variegatus	thick back sole	TBS	3.9	-	-	-		3.85
Raja clavata	thornback ray	THR		-	-	3.4		3.40
Balistes carolinensis	triggerfish	TRF		-	-	-		3.20
Ammodytes tobianus	lesser sandeel	TSE			-	3.6		3.60
Spisula solida	Thick trough shell	TTS				2.0	-	2.00
Chelidonichthys lucerna	tub gurnard	TUB		-	-	4.3		4.19
Echinus acutus		URN				-	-	2.60
Paracentrotus lividus	Mediterranean sea urchin	URP				-	2.0	2.03
Echinus esculentus		URS				-	-	2.40
Brosme brosme	tusk	USK			4.1			4.06
Etmopterus spinax	velvet-belly lantern shark	VBY		-	-	-		4.13
Lophius budegassa	black-bellied angler	WAF	-	-	-	-		4.16
Echiichthys vipera	lesser weaver	WEL	4.3	-	4.3	4.5		4.32
Micromesistius poutassou	blue whiting	WHB	3.1	-	3.2	-		3.18
Buccinum undatum	Whelk	WHE				2.8	-	2.82
Merlangius merlangus	whiting	WHG	4.9	4.8	4.2	4.6		4.70
Glyptocephalus cyanoglossus	witch	WIT	3.9	3.5	3.7	-		3.65

Annex 4: Cross-referencing table for Annexes 2 and 3, and ICES Statlant species names.

'nei'=not everywhere identified

ICES_Statlant	Annex 3 code	Annex 2 Fun. Group	Fun Group#	LatinName
Basking shark	HER	Baleen whales	1	Cetorhinus maximus
Spurdog	DGS	Spurdog	6	Squalus acanthias
Picked dogfish	DGS	Spurdog	6	Squalus acanthias
Smooth-hounds nei	SDS		6	
Smooth-hound	SDS		6	
Porbeagle	GAG	Large piscivorous sharks	7	
Blue shark	WHG	Large piscivorous sharks	7	Prionace glauca
Tope shark	GAG	Large piscivorous sharks	7	Galeorhinus galeus
Nursehound	DGS	Small sharks	8	
Small-spotted catshark	LSD	Small sharks	8	
Swordfish	WHG		8	
Dogfishes and hounds nei	DGS	Small sharks	8	
Dogfish sharks nei	DGS	Small sharks	8	
Lanternsharks nei	VBY		8	
Cartilaginous fishes nei	SDR		8	
Portuguese dogfish	DGS		8	
Various sharks nei	DCH	Small sharks	8	
Leafscale gulper shark	VBY		8	
Dogfishes nei	DGS	Small sharks	8	
Raja rays nei	SYR	Starry ray + others	10	
Shagreen ray	SYR	Starry ray + others	10	Raja fullonica
Skate and Rays	SYR	Starry ray + others	10	Raja spp.
Starry ray	SYR	Thornback & Spotted ray	11	Raja clavata and Raja montagui
Rays and skates nei	SDR		11	
Sandy ray	THR		11	
Thornback ray	THR	Thornback & Spotted ray	11	Raja clavata and Raja montagui
Spotted ray	SDR		11	
Blue skate	SYR	Skate + Cuckoo ray	12	Dipterus batis and Raja naevus
Longnosed skate	CUR	Skate + Cuckoo ray	12	
Cuckoo ray	CUR	Skate + Cuckoo ray	12	Raja naevus
Atlantic cod	COD	Cod (adult)	14	Gadus morhua
Whiting	WHG	Whiting (adult)	16	Gadus merlangus
Haddock	HAD	Haddock (adult)	18	Gadus aeglefinus

Annex 4 continued:

ICES_Statlant	Annex 3 code	Annex 2 Fun. Group	Fun Group#	LatinName
Saithe(=Pollock)	POK	Saithe (adult)	20	Pollachius virens
Northern bluefin tuna	WHG		20	
European hake	HKE	Hake	21	Merluccius merluccius
Blue whiting(=Poutassou)	WHB	Blue whiting	22	Micromesistius poutassou
Norway Pout	NOP	Norway pout	23	Trisopterus esmarkii
Tusk(=Cusk)	USK	Other gadoids (large)	24	
Gadiformes nei	COD	Other gadoids (large)	24	
Pollack	POK	Other gadoids (large)	24	Pollachius
Blue ling	LIN	Other gadoids (large)	24	M.dypterygia
Greater forkbeard	GFB	Other gadoids (large)	24	
Ling	LIN	Other gadoids (large)	24	Molva molva
Blackspot (=red)	SBA		25	
Capelin	HAD		25	
John Dory	JOD		25	
Pouting(=Bib)	BIB	Other gadoids (small)	25	
Argentine	LSS		25	
Porgies, seabreams nei	SBA		25	
Argentines	LSS	Other gadoids (small)	25	Argentinidae
Finfishes nei	POD	Other gadoids (small)	25	
Greater argentine	LSS	Other gadoids (small)	25	A.silus
Lophius Piscatorus	MON	Monkfish	26	
Monkfish	MON		26	
Monkfishes nei	MON		26	
Angler(=Monk)	MON	Monkfish	26	Lophius
Anglerfishes nei	MON	Monkfish	26	Lophius
Tub gurnard	TUB	Gurnards	27	Trigla lucerna
Grey gurnard	GUG	Gurnards	27	Eutrigula
Red gurnard	GUR	Gurnards	27	Aspitrigla cuclus
Gurnards, searobins nei	GUG	Gurnards	27	Triglidae
Atlantic searobins	GUG		27	
Gurnard and Latchet	GUG	Gurnards	27	Triglidae
Gurnards nei	GUG		27	
Gurnards	GUG		27	
Atlantic herring	HER	Herring (adult)	29	Clupea harengus
Clupeoids nei	SPR	Sprat	30	
European sprat	SPR	Sprat	30	Sprattus sprattus
Atlantic mackerel	MAC	Mackerel	31	Scomber
Atlantic horse mackerel	HOM	Horse mackerel	32	Trachurus
Jack and horse	HOM	Horse mackerel	32	Trachurus
Sandeels(=Sandlances)	TSE	Sandeels	33	Ammodytes spp
European plaice	PLE	Plaice	34	Pleuronectes

Annex 4 continued:

ICES_Statlant	Annex 3 code	Annex 2 Fun. Group	Fun Group#	LatinName
Flatfishes nei	PLE		34	
Common dab	DAB	Dab	35	Limanda limanda
Amer. plaice(=Long	PLA	Long-rough dab	36	
European flounder	FLE	Flounder	37	Platichthys
Common sole	SOL	Sole	38	Solea solea
Lemon Sole	LEM	Lemon Sole	39	Microstomus kitt
Witch flounder	WIT	Witch	40	Glyptocephalus
Turbot	PLE	Turbot and brill	41	Scopthalmus
Brill	LEM	Turbot and brill	41	Scopthalmus
Megrim	MEG	Megrim	42	Lepidorhombus
Megrims nei	MEG	Megrim	42	Lepidorhombus whiffiagonis
Atlantic halibut	HAD	Halibut	43	Hippoglossus hippoglossus
Greenland halibut	HAD	Halibut	43	Reinhardtius hippoglossoides
Atlantic wolffish	CAA	Catfish (Wolf-fish)	45	Anarrhichas lupus
Wolffishes(=Catfishes) nei	CAA	Catfish (Wolf-fish)	45	
Blackbelly rosefish	BKS	Large demersal fish	46	Spondyliosoma cantharus
Red mullet	MUR	Large demersal fish	46	Mullus surmuletus
Garfish	GAR	Large demersal fish	46	Belone belone
Black scabbardfish	SFS	Large demersal fish	46	Aphanopus carbo
European conger	COE	Large demersal fish	46	Congridae
European eel	ELE	Large demersal fish	46	Anguillidae
Black seabream	SBA	Large demersal fish	46	Sparidae
Sea trout	HAD	Large demersal fish	46	Salmo trutta trutta
Atlantic redfishes nei	COD	Large demersal fish	46	Sebastes spp
Golden redfish	COD	Large demersal fish	46	
Roundnose grenadier	RNG	Large demersal fish	46	Coryphaenoides rupestris
European smelt	COD	Large demersal fish	46	
		Large demersal fish	46	Zeus faber
European seabass	ESB	Large demersal fish	46	Dicentrarchus (morone) labrax
Atlantic Salmon	HAD	Large demersal fish	46	Salmo salar
Seabasses nei	ESB	Large demersal fish	46	
Mullets nei	MUR	Small demersal fish	47	Mugil cephalus
Marine fishes nei	HAD	Small demersal fish	47	
OTH		Small demersal fish	47	

Annex 4 continued:

ICES_Statlant	Annex 3 code	Annex 2 Fun. Group	Fun Group#	LatinName
Demersal percomorphs nei	POD	Small demersal fish	47	
Lumpfish(=Lumpsucker)	LUM	Small demersal fish	47	
European perch	BIB	Small demersal fish	47	Perca fluviatilis
		Small demersal fish	47	Labrus bergylta
Groundfishes nei	COD	Small demersal fish	47	
Baird's slickhead	HAD	Small demersal fish	47	
Orange roughy	COD	Small demersal fish	47	
Sand sole	SOS	Small demersal fish	47	Solea lascaris
	BIB	Small demersal fish	47	Labridae
European whitefish	ANE	Miscellaneous filter feeding pelagic fish	48	
European pilchard(=Sardine)	PIL	Miscellaneous filter feeding pelagic fish	48	Sardina pilchardus
		Miscellaneous filter feeding pelagic fish	48	
		Miscellaneous filter feeding pelagic fish	48	
Pelagic percomorphs nei	JOD	Miscellaneous filter feeding pelagic fish	48	
Pelagic fishes nei	HER		48	
European anchovy	ANE		48	
Miscellaneous filter	ANE		48	
European flying squid	LLV		49	
Common cuttlefish	CTC	Cephalopods	49	Sepia officinalis
		Cephalopods	49	
Octopuses nei	OCV	Cephalopods	49	Octopus vulgaris
Common squids nei	LLV	Cephalopods	49	Loligo vulgaris
Various squids nei	LLV	Cephalopods	49	Loligo spp
Cuttlefish,bobtail squids	CTC	Cephalopods	49	
Northern shortfin squid	LLV		49	
Octopuses, etc. nei	OCV	Cephalopods	49	
Broadtail shortfin squid	LLV		49	
European lobster	LBE	Large crabs	53	Homarus gammarus
Edible crab	CRE	Large crabs	53	Cancer pagurus
Velvet swimcrab	LMD		53	
Marine crustaceans nei	CRG		53	
Large crabs	CRE		53	
Natantian decapods nei	HIW		53	
Portunus swimcrabs nei	LIC	Large crabs	53	
Palinurid spiny lobsters	CRW		53	
		Large crabs	53	
Green crab	CRG	Large crabs	53	
Velvet swimming crab	LMD		53	
Spinous spider crab	MJX	Large crabs	53	Majidae
		Large crabs	53	

Annex 4 continued:

ICES_Statlant	Annex 3 code	Annex 2 Fun. Group	Fun Group#	LatinName
Red crab	CRE		53	
Norway lobster	NEP	Nephrops	54	Nephrops norvegicus
Nephrops	NEP	Nephrops	54	Nephrops norvegicus
Starfishes nei	STH		55	
Marine crabs nei	CRE	Epifaunal macrobenthos (mobile grazers)	55	
Periwinkles nei	GAS	Epifaunal macrobenthos (mobile grazers)	55	
Queen scallop	QSC	Epifaunal macrobenthos (mobile grazers)	55	Chlamys opercularis
Whelk	WHE	Epifaunal macrobenthos (mobile grazers)	55	Buccinidae
		Epifaunal macrobenthos (mobile grazers)	55	
Epifaunal macrobenthos (mobile grazers)	AAC		55	
Common periwinkle	GAS		55	
Great Atlantic scallop	SCE	Epifaunal macrobenthos (mobile grazers)	55	
Scallops nei	SCE	Epifaunal macrobenthos (mobile grazers)	55	
Common edible cockle	COC	Infaunal macrobenthos	56	
Marine molluscs nei	GAS	Infaunal macrobenthos	56	
Shrimp	PRA		57	
Common prawn	NEP		57	
Crangon shrimps nei	CRH	Shrimp	57	
Crangonid shrimps nei	CRH		57	
		Shrimp	57	
Aesop shrimp	CRH	Shrimp	57	
Palaemonid shrimps nei	CPR		57	
Northern prawn	PRA	Shrimp	57	
		Shrimp	57	
Pandalus shrimps nei	PRA		57	
Pandalus spp.	PRA	Shrimp	57	Pandalus spp.
Common shrimp	CRH	Shrimp	57	
European flat oyster	OYF	Sessile epifauna	60	Ostrea edulis
Striped Venus	OYF		60	
Grooved carpet shell	OYF		60	
Clams nei	OYF		60	
Sessile epifauna	OYF		60	
Atlantic surf clam	OYF		60	
Pullet carpet shell	OYF		60	
Razor clams	OYF		60	

Annex 4 continued:

ICES_Statlant	Annex 3 code	Annex 2 Fun. Group	Fun Group#	LatinName
Pacific cupped oyster	OYG	Sessile epifauna	60	
Mactra surf clams	OYF		60	
Blue mussel	MYG	Sessile epifauna	60	
Cupped oysters nei	OYF		60	
Manila clam	OYF		60	
Banded carpet shell	OYF		60	
Carpet shells nei	OYF		60	
Sea mussels nei	MYG		60	

Annex 5: Programming details

All data were archived in a MS Access database on Lowestoft server disc: MTIc3140 on 'LOWCLUS2 File Service (lowfile3)' /Data and analysis/MTI.mdb.

A5.1 Landings-based MTIs

This section describes calculation of the MTI values with ICES landings. The following tables (underlined) were created:

- LandingsUKseas holds the ICES Statlant retrieval of tonnages landed by region, nationality of vessel, and species.
- TrophicLevelsSM2 holds the Ecopath trophic levels data (from which Annex 2 was derived). It was taken from MTIc3140/Data and analysi/EwE Model TLs and MTIfromSM.xls supplied by Steve Mackinson.
- TrophicLevelsJP holds the N-isotope analysis trophic levels data (from which Annex 3 was derived). It was taken from MTIc3140/Data and analysi/STANDARD ISOTROPHS.xls supplied by John Pinnegar.
- SpeciesXgroupMap contains the mapping between these three files (from which Annex 4 was derived). This file was originally taken from MTIc3140/Data and analysi/EwE Model TLs and MTIfromSM.xls supplied by Steve Mackinson. Species codes for linking with TrophicLevelsJP were filled in manually using best judgement of which species belonged with which functional groups.

The following notes document the Access queries, names in **bold**, used (apologies for the confusing names):

1. **MTIeweICESlandings1** creates relational links between the Access tables: TrophicLevelsSM2, LandingsUKseas, and SpeciesXgroupMap. The output includes Region, Species, and Country from ICES Statlant, Functional Group name and number, and Median trophic level from TrophicLevelsSM2, a total tonnage landed for all years 1973 to 2005, then annual tonnages. The total 1973-2005 was used to check that all species landed in significant quantities were matched to a Median trophic level. Some species with less than 500 tonnes landed in the whole 23 year period were left with no Median trophic level if Access was not able automatically to locate one. Omission of these species from the MTI calculations created negligible errors. Other species were corrected by supplementing the original trophic level tables as shown in SpeciesXgroupMap. Note that seaweeds were sporadically landed, often by France, in large tonnages. These records were also omitted from the MTI calculations. This query may either be run without record-sifting criteria, or, to obtain regional estimates, insert e.g. 'Like "*IV*" ' in the Access Criteria box under the Region field in design view.
2. **MTIisoICESlandingsA** performed the same task as above using the table, TrophicLevelsJP, i.e. for N-isotope based trophic levels.
3. **ICESlandedTonnes2** sums annual tonnages from query (1) over all nationalities to produce summed results by ICES species, region and Ecopath functional group.
4. **ICESlandedTonnes3** condenses query (3) to a single line of annual tonnages summed over all species and ICES regions selected for the UK index.
5. **ICESlandedMTIewe1** multiplies Median trophic level figures with tonnages landed by ICES species, region and Ecopath functional group from query (3).

This disaggregated form allows checking that multiplications have executed correctly without duplicated records or other problems.

6. **ICESlandedMTIewe2** condenses the results from query (5) to a single line of annual Ecopath-based summed trophic levels x tonnages over all ICES species and regions selected for the UK index.
7. **ICESisolandedTonnesB** performs the same task as query (3) using MTIisoICESlandingsA.
8. **ICESisolandedTonnesC** performs the same task as query (4) using query (7). The results should be the same as with query (4)
9. **ICESlandedMTIisoA** does the same as query (5) using N-isotope median trophic levels in query (7).
10. **ICESlandedMTIisoB** condenses the results from query (9) to a single line of annual N-isotope-based summed trophic levels x tonnages over all ICES species and regions selected for the UK index. Cf. query (6).
11. **MTIeweStandardised** divides summed trophic levels x tonnages from query (6) by tonnages from query (4) to produce the MTI based on stomach contents analysis and Ecopath.
12. **MTIisoStandardised** divides summed trophic levels x tonnages from query (10) by tonnages from query (8) to produce the MTI based on N-isotope analysis.

A5.2 Survey-based MTIs

This section describes calculation of the non-size-based MTI values for Cefas surveys. The following tables (underlined) were created:

- Cruises2 holds survey names and annual code numbers, start and end dates, regions fished, etc.
- Categories holds measured catch weights and catch-sample weights by species and sex. Gear code is also recorded.
- Gearcodes provides the English descriptions linked with the 9-digit codes used to identify trawl variants on Cefas surveys.
- Lengths holds numbers-at-length (in mm) by species, sex, and station for each Cefas cruise used in this project. The numbers from catch-samples are raised to the catch level.
- Stations2 holds trawling and environmental variables associated with each fishing station.
- SurveySppXtrophicLevelMap maps all species found on the surveys with their Ecopath and N-isotope trophic levels.

Cefas surveys may deploy several different gears aside from the usual survey trawl so it is necessary to specify which were to be included in the analysis. They were as follows:

EGFS: Granton trawls (to 1991), codes 107010101, 107010201
GOV trawls (1992 onwards), codes 107030201, 107030701, 107030801, 107030901, 107031001.
ChannelBTS: 4m beam trawl, code 101030101
IrishSeaBTS: 4m beam trawl, code 101030101
SWBTS: 4m commercial trawl, codes 101030101, 101030102, 101030103, 101530102, 101530103. Note that Carhelmar cruises towed 2 nets (last digits 2 and 3), and Corystes towed only 1. Allowance must be made for this when calculating CPUE.

The following notes document the MS Access queries, names in **bold**, used:

1. **SurveyWts1** creates relational links between the Access tables: SPECIESCODES, Categories, and Cruises2. The name of the survey series to be retrieved is specified as a criterion, e.g. "ChannelBTS" under the Survey field in Design view. It is also necessary to specify the gear codes (shown above) to prevent retrievals of fish caught with sundry gears other than the main trawl. The output shows the total catch weights as kg for each species at each station in each year.
2. **SurveyWts2** accumulates the total weights from query (1) over all stations fished within each annual survey.
3. **SurveyTLs** creates relational links between **SurveyWts2**, **SurveySppXtrophicLevelMap**, **TrophicLevelsJP**, and **TrophicLevelsSM2**. The output gives the total catch weights (kg), the N-isotope and Ecopath trophic levels, and the products of weight and trophic level for each species for each annual survey.
4. **SurveyMTIs1** sums the total catch weights and weight x trophic level products from query (3) across species for each annual survey. [It also brings in the total towing minutes with the main trawl in each year using query (11), though this is not used for the MTIs in query (5).]
5. **SurveyMTIs2** forms the species-catch-weighted MTIs for the two methods, Ecopath and N-isotope, by dividing the sums of products by the total catch weight for each species on each annual survey.
6. **SpeciesEverMeasuredOnSurvey** provides an alphabetically sorted list of all species ever measured on a survey (specified in design view), as drawn from the Lengths table.
7. **StationsXcruise** gives fishing and station details for all stations in a survey specified by writing the survey name as a criterion under the Survey field.
8. **StationsXgear** list the exact trawl gear descriptors for all stations in each specified survey. The need, or otherwise, for specifying the right gear code in queries (1, 10) is demonstrated by this query.
9. **StationsXcruiseXgear** lists fishing, gear, and station details for every fished station in a survey series.
10. **SurveyEffort1** links Stations2, Categories, and Cruises2 in order to find survey effort at each station. By keeping this query separate from any catch details, one gets tow duration in minutes whether any fish were caught or not. It is necessary to specify the Survey name and gear code as for query (1).
11. **SurveyEffort2** finds the total minutes of towing with the specified gear for the given survey in each year from query (10).
12. **SpeciesEverOccurredOnSurvey** provides an alphabetically sorted list of all species ever weighed on a survey (specified in design view), as drawn from the Categories table. Species such as shellfish are often weighed but not measured and hence don't get into Lengths.
13. **StationsXcruise2** gives the number of prime stations and total towing minutes for a survey specified in design view.
14. **StationsXcruiseXgear2 (and 3 and 4)** summarises gear usage by station for each annual survey using query (13).

A5.3 Survey-based MTIs taking into account length

This section describes calculation of the size-based MTI values for Cefas surveys. Parameters *a*, *b*, *c*, and *d* (see section 2.2 and last 4 columns of Annex 6) were added to the Access table, SurveySppXtrophicLevelMap . The following notes document the Access queries, names in **bold**, used:

1. **SizeBasedMTI_1** links survey and gear details with numbers-at-length by species, and the parameters *a*, *b*, *c*, and *d*, many of which are missing because data do not exist for all species.
2. **SizeBasedMTI_2** computes the weight (Kg) of each fish-at-length using the allometric formula in section 2.2, sums these over all fish of the species in the length class, and then forms the $W.TL$ product for each species and length class. Note that species not having *a*, *b*, *c*, and *d* parameters are omitted.
3. **SizeBasedMTI_3** sums the weights and products over all length classes for each species.
4. **SizeBasedMTI_4** sums the weights and products over all species in each year of the survey.
5. **SizeBasedMTI_5** computes the weighted average MTI for each annual survey.

A5.4 ICES composite length indicator

This section describes computation of the composite length indicator of OSPAR and the ICES Advisory Committee on Ecosystems from survey data. The Access queries used were (in **bold**):

1. **ACEpropOver40cmByWt_1** makes relational links between tables Cruises2, Lengths, and SurveySppXtrophicLevelMap. The data include survey and gear details, numbers-at-length by species, and the parameters *c*, and *d* for estimating weight from length using the allometric growth formula given in section 2.2. It is necessary to specify in the query selection criteria the Survey name and the appropriate gear codes (see A5.2 above) for the main trawl of that survey. Output includes the total number at length, and Kg less than or more than or equal to the cut-off lengths of 30 and 40 cm by species and station.
2. **ACEpropOver40cmByWt_2** sums the results from query (1) across all species and stations to give one line of results per year of the survey.
3. **ACEpropOver40cmByWt_3** works out the proportions by weight greater than or equal to each cut-off length.

A5.5 Proportionate length indicator

This section describes computation of the proportionate length indicator presented in section 4.2.2. The Access queries (**bold**) were:

1. **ProportionateLIbyWt_1** links survey and gear details, numbers-at-length by species, and the parameters *c*, and *d* for estimating weight from length using the allometric growth formula given in section 2.2. It is necessary to specify in the query selection criteria the Survey name and the appropriate gear codes (see A5.2 above) for the main trawl of that survey. Output includes the proportions by weight within the proportionate length quantile matching the cm-length of the record for each species and station.

2. **ProportionateLIbyWt_2** sums the output from query (1) across lengths and stations by species.
3. **ProportionateLIbyWt_3** finds the proportions by weight in each proportionate length bin by species. Minor species occurring with "zero" weight are listed in the output as errors. They cause overflow problems in the next query. The problem can be avoided by excluding the offending species with the selection criterion for species, e.g. "Not In ("GPF", "NKT").
4. **ProportionateLIbyWt_4** averages these proportions across species for each annual survey.

Annex 6: Cross-referencing table for Annexes 2 and 3, and species names as used on Cefas surveys.

Cefas Species Code	Latin name	Common name	Ecopath functional group	N-isotope species code	Allometric coefficient	Allometric power	Size-based a	Size-based b
POG	Agonus cataphractus	Pogge (armed bullhead)		POG				
ATS	Alloteuthis subulata							
AAS	Alosa alosa	Allis shad						
TAS	Alosa fallax	Twaite shad						
MSE	Ammodytes marinus	Sandeel	33	MSE				
SAN	Ammodytes spp	Sandeels	33	GSE				
TSE	Ammodytes tobianus	Sandeel	33	GSE				
SAX	Ammodytidae	Sandeels	33	GSE				
CAA	Anarhichas lupus	Catfish (wolffish)	45	CAA				
ELE	Anguilla anguilla	European eel	46	ELE				
EEL	Anguillidae	Eels	46	ELE				
TPG	Aphia minuta	Transparent goby						
SCL	Apletodon microcephalus	Small-headed clingfish						
CLQ	Arctica islandica	Icelandic cyprina		SCE				
GSS	Argentina silus	Gt silver smelt	25					
LSS	Argentina sphyraena	Lsr silver smelt	25	LSS				
ARG	Argentinidae	Argentines	25	LSS				
ISF	Arnoglossus imperialis	Imperial scaldfish		ISF				

Cefas Species Code	Latin name	Common name	Ecopath functional group	N-isotope species code	Allometric coefficient	Allometric power	Size-based a	Size-based b
SDF	Arnoglossus laterna	Scald fish		SDF				
ARE	Artediellus europaeus							
GUR	Aspitrigla cuculus	Red gurnard	27	GUR				
GUL	Aspitrigla obscura	Long-finned gurnard	27	GUL				
SMT	Atherina presbyter	Sand smelt						
TRF	Balistes carolinensis	Trigger fish		TRF				
GAR	Belone belone	Garfish	46	GAR				
BBY	Blennius ocellaris	Butterfly blenny						
TBY	Blennius(parablennius)gattorugine	Tompot blenny						
POA	Brama brama	Rays bream (pomfret)						
USK	Brosme brosme	Tusk	46	USK				
JYG	Buenia jeffreysii	Jeffrey's goby		POM				
SOT	Buglossidium luteum	Solenette		SOT				
DTX	Callionymidae	Dragonets						
CDT	Callionymus lyra	Common dragonet	44	CDT				
SDT	Callionymus maculatus	Spotted dragonet						
RDT	Callionymus reticulatus	Reticulate dragonet						
CRE	Cancer pagurus	Edible crab	53	CRE				
CRC	Cancer pagurus (cock)	Male crab	53	CRE				
CRH	Cancer pagurus (hen)	Female crab	53	CRE				
BOF	Capros aper	Boar fish		BOF				

Cefas Species Code	Latin name	Common name	Ecopath functional group	N-isotope species code	Allometric coefficient	Allometric power	Size-based a	Size-based b
SMW	Centrolabrus exoletus	Small-mouthed wrasse						
CTL	Cephalopoda-sepiida	Cuttle-fishes	49	CTC				
RPF	Cepola rubescens	Red bandfish						
MTL	Chelon (crenimugil) labrosus	Thick lipped mullet		MUR				
RBF	Chimaera monstrosa	Rabbit fish(rat-tail)						
RRX	Chimaeridae	Rabbit fishes/ratfishes						
YBY	Chirolophis ascanii	Yarrel's blenny						
QSC	Chlamys opercularis	Queen scallop	55	QSC				
CYS	Chlamys septemradiata	Scallop	55	SCE				
FVR	Ciliata mustela	Five-bearded rockling		FRR				
NNR	Ciliata septentrionalis	Northern rockling		FRR				
HER	Clupea harengus	Herring	29	HER	0.007	3	6.85	-1.24
CLU	Clupeidae	Herrings		HER				
COE	Conger conger	European conger eel	46	COE				
CWG	Crenilabrus melops	Corkwing						
CLG	Crystallogobius linearis	Crystal goby		POM				
GDY	Ctenolabrus rupestris	Goldsinny						
LUM	Cyclopterus lumpus	Lumpsucker		LUM				
SGR	Dasyatis pastinacus	Sting ray	11	SDR				
ESB	Dicentrarchus (morone) labrax	European seabass	46	ESB				
BSE	Dicentrarchus (morone)	Basses	46	ESB				

Cefas Species Code	Latin name	Common name	Ecopath functional group	N-isotope species code	Allometric coefficient	Allometric power	Size-based a	Size-based b
	spp							
TSC	Diplecogaster bimaculata	Twp spotted clingfish						
PRL	Echiodon drummondi	Pearlfish						
FRR	Enchelyopus cimbrius	Four-bearded rockling		FRR				
ANE	Engraulis encrasicolus	European anchovy	48	ANE				
SKP	Entelurus aequoreus	Snake pipefish						
VBY	Etmopterus spinax	Velvet belly		VBY				
GUG	Eutrigla gurnardus	Grey gurnard	27	GUG	0.0062	3.1003	5.22	-0.29
SYP	Gadiculus argenteus	Silvery pout		SYP				
COD	Gadus morhua	Cod	14	COD	0.0175	2.8571	4.39	0.19
SRR	Gaidropsarus mediterraneus	Shore rockling		FRR				
ROL	Gaidropsarus spp	Rocklings		FRR				
TBR	Gaidropsarus vulgaris	Three-bearded rockling		FRR				
GAG	Galeorhinus galeus	Tope shark	7	GAG				
DBM	Galeus melastomus	Blackmouthed dogfish	6	DBM				
TSS	Gasterosteus aculeatus	Three-spined stickleback						
WIT	Glyptocephalus cynoglossus	Witch	40	WIT				
CFX	Gobiesocidae	Clingfishes						
GPA	Gobiidae	Gobies		POM				
FGX	Gobioidei	Gobies		POM				

Cefas Species Code	Latin name	Common name	Ecopath functional group	N-isotope species code	Allometric coefficient	Allometric power	Size-based a	Size-based b
GSV	Gobius gasteveni	Steven's goby		POM				
BLG	Gobius niger	Black goby		POM				
RKG	Gobius paganellus	Rock goby		POM				
TSG	Gobiusculus (chaparrudo) flavescens	Two-spot goby						
SMS	Gymnammodytes semisquamatus	Smooth sandeel	33	GSE				
RBM	Helicolenus dactylopterus	Blue-mouth redfish		RBM				
SNH	Hippocampus hippocampus	Sea horse (short snouted)						
PLA	Hippoglossoides platessoides	American plaice (lr dab)	36	PLA	0.0044	3.2039	3.61	0.39
HAL	Hippoglossus hippoglossus	Halibut	43					
LBE	Homarus gammarus	European lobster	53	LBE				
ISE	Hyperoplus immaculatus	Immaculate sandeel	33	ISE				
GSE	Hyperoplus lanceeolatus	Great sandeel	33	GSE				
SQI	Illex (loligo) illecebrosus	Northern shortfin squid	49	SQE				
WRA	Labridae	Wrasses						
BNW	Labrus bergylta	Ballan wrasse						
CUW	Labrus mixtus	Cuckoo wrasse						
SCF	Lepadogaster lepadogaster	Shore clingfish						
LBI	Lepidorhombus boscii	Four spot megrim	42	LBI				

Cefas Species Code	Latin name	Common name	Ecopath functional group	N-isotope species code	Allometric coefficient	Allometric power	Size-based a	Size-based b
MEG	Lepidorhombus whiffiagonis	Megrim	42	MEG				
SNB	Leptoclinus maculatus	Spotted snake blenny						
FSG	Lesueurigobius friesii	Frie's goby		POM				
DAB	Limanda limanda	Dab	35	DAB	0.0074	3.1128	3.24	0.62
SSL	Liparis liparis	Sea snail		SSL				
MSS	Liparis montagui	Montague's seasnail		SSL				
LPS	Liparis spp	Sea snails		SSL				
LDM	Lithodes maja	Stone crab	58					
MGN	Liza aurata	Golden mullet		MUR				
MTN	Liza ramada	Thin lipped mullet		MUR				
SQZ	Loliginidae	Squids (nei)	49	SQE				
NSQ	Loligo forbesi	Northern squid	49	NSQ				
SQC	Loligo spp	Common squids	49	SQE				
LLV	Loligo vulgaris	Squid	49	LLV				
WAF	Lophius budegassa	White-anglerfish	26	WAF				
MON	Lophius piscatorius	Anglerfish (monk)	26	MON	0.01362	2.984	3.38	0.47
SBY	Lumpenus lampretaeformis	Snake blenny						
LCS	Lycenchelys sarsi							
VLP	Lycodes vahlii	Vahl's eelpout						
MLP	Macropipus (liocarcinus) puber	Velvet swimming crab	53	MNC				

Cefas Species Code	Latin name	Common name	Ecopath functional group	N-isotope species code	Allometric coefficient	Allometric power	Size-based a	Size-based b
SNI	Macrorhamphosus scolopax	Snipe-fish						
SCR	Maia squinado	Spiny spider crab	53	MJX				
MJX	Majidae	Spider crabs	53	MJX				
PLS	Maurolicus muelleri	Pearlside						
HAD	Melanogrammus aeglefinus	Haddock	18	HAD	0.0157	2.8268	4	0.17
WHG	Merlangius merlangus	Whiting	16	WHG	0.0093	2.9456	4	0.39
HKE	Merluccius merluccius	European hake	21	HKE				
TBS	Microchirus variegatus	Thickback sole						
WHB	Micromesistius poutassou	Blue whiting	48	WHB				
LEM	Microstomus kitt	Lemon sole	39	LEM	0.0255	2.7643	2.73	0.77
BLI	Molva dypterygia	Blue ling	24	LIN				
LIN	Molva molva	Common ling	46	LIN				
MTG	Mugil cephalus	Grey mullet		MUR				
MUL	Mugilidae	Grey mullets		MUR				
MUR	Mullus surmuletus	Red mullet	46	MUR				
SDS	Mustelus asterias	Starry smooth hound		SDS				
SMH	Mustelus mustelus	Smooth hound	6	SDS				
BRT	Myoxocephalus scorpius	Bullrout		BRT				
HGF	Myxine glutinosa	Hagfish						
NEP	Nephrops norvegicus	Norway lobster	54	NEP				

Cefas Species Code	Latin name	Common name	Ecopath functional group	N-isotope species code	Allometric coefficient	Allometric power	Size-based a	Size-based b
OME	Ommastrephes (todaropsis) eblanae		49					
SQE	Ommastrephes(todarodes) saggittatus	Flying squid	49	SQE				
OPB	Ophidion barbatum							
SME	Osmerus eperlanus	Smelt(sparling)						
SCE	Pecten maximus	Escallop	55	SCE				
SCX	Pectinidae	Scallops	55	SCE				
SOS	Pegusa (solea) lascaris	Sand sole	47	SOS				
SLY	Petromyzon marinus	Sea lamprey						
LAM	Petromyzon spp	Lampreys-marine						
LAS	Petromyzonidae	Lampreys						
BTF	Pholis gunnellus	Butter fish						
NKT	Phrynorhombus norvegius	Norwegian topknot		NKT				
EKT	Phrynorhombus regius	Ekstroms topknot						
GFB	Phycis blennoides	Greater forkbeard	24	GFB				
FLE	Platichthys flesus	Flounder (european)	37	FLE				
PLE	Pleuronectes platessa	European plaice	34	PLE	0.0215	2.7901	5.17	-0.27
POL	Pollachius pollachius	Pollack	24	POK				
POK	Pollachius virens	Saithe	20	POK	0.0238	2.7374	3.67	0.31
GMG	Pomatoschistus microps	Common goby		POM				
SDG	Pomatoschistus minutus	Sand goby						

Cefas Species Code	Latin name	Common name	Ecopath functional group	N-isotope species code	Allometric coefficient	Allometric power	Size-based a	Size-based b
PTG	Pomatoschistus pictus	Painted goby		POM				
PTF	Pontophilus fasciatus							
SKT	Raja batis	Common skate	12	SDR				
BLR	Raja brachyura	Blonde ray	11	CUR				
SAR	Raja circularis	Sandy ray		SYR				
THR	Raja clavata	Thornback ray (roker)	10	THR				
SHR	Raja fullonica	Shagreen ray	10	SDR				
PTR	Raja microocellata	Painted ray	11	SYR				
SDR	Raja montagui	Spotted ray		SDR				
CUR	Raja naevus	Cuckoo ray	12	CUR				
LNS	Raja oxyrinchus	Long-nose skate	12	THR				
SYR	Raja radiata	Starry ray	10	SYR	0.0409	2.8965	3.49	0.32
UNR	Raja undulata	Undulate ray	10	THR				
SKA	Rajidae	Skates and rays	12	SDR				
LFB	Raniceps raninus	Lesser forkbeard						
TRS	Salmo trutta	Sea trout (brown trout)						
PIL	Sardina (clupea) pilchardus	Pilchard	48	PIL				
MAC	Scomber scombrus	(european) mackerel	31	MAC	0.003	3.29	5.12	-0.39
SAU	Scomberesox saurus	Saurey pike						
TUR	Scophthalmus maximus	Turbot	41					
BLL	Scophthalmus rhombus	Brill	41					

Cefas Species Code	Latin name	Common name	Ecopath functional group	N-isotope species code	Allometric coefficient	Allometric power	Size-based a	Size-based b
LSD	Scyliorhinus canicula	Lesser spotted dogfish	6	LSD				
DGN	Scyliorhinus stellaris	Nurse hound	6	DGS				
REG	Sebastes marinus	Norway haddock	25	REV				
REV	Sebastes viviparus	Redfish		REV				
CTC	Sepia officinalis	Common cuttlefish	49	CTC				
SPA	Sepiola atlantica	Little cuttle	49	CTC				
SPY	Sepiolidae		49					
SOL	Solea solea (s.vulgaris)	Sole (dover sole)	38	SOL				
SBG	Sparus auratus	Gilt-head seabream						
SSS	Spinachia spinachia	Sea stickleback						
BKS	Spondyliosoma cantharus	Black seabream	46	BKS				
SPR	Sprattus (clupea) sprattus	Sprat	30	SPR				
DGS	Squalus acanthias	Spurdog	6	DGN				
SSC	Sternaspis scutata							
GPF	Syngnathus acus	Great pipefish						
NPF	Syngnathus rostellatus	Nilsson's pipefish						
PFX	Syngnthidae	Pipe-fishes/seahorses						
SSN	Taurulus bubalis	Sea scorpion						
LSG	Thorogobius ephippiatus	Leopard spotted goby		POM				
MER	Torpedo marmorata	Marbled electric ray	10	ELR				
ECR	Torpedo nobiliana	Common electric ray	10	ELR				

Cefas Species Code	Latin name	Common name	Ecopath functional group	N-isotope species code	Allometric coefficient	Allometric power	Size-based a	Size-based b
WEL	Trachinus (echiichthys) vipera	Lesser weever fish		WEL				
WEG	Trachinus draco	Greater weever fish		WEL				
HOM	Trachurus trachurus	Horse-mackerel (scad)	32	HOM	0.0034	3.2943	4.84	-0.24
SNF	Trachyscorpia cristulata	Scorpion fish						
TUB	Trigla lucerna	Tub gurnard	27	TUB				
GUS	Trigloporus lastoviza	Streaked gurnard	27	GUR				
SPN	Triglops murrayi	Sculpin						
NOP	Trisopterus esmarki	Norway pout	23	NOP	0.0092	3.0265	4.17	-0.06
BIB	Trisopterus luscus	Whiting-pout (bib)	23	BIB				
POD	Trisopterus minutus	Poor cod	25	POD				
TKT	Zeugopterus punctatus	Topknot						
JOD	Zeus faber	John dory		JOD				
ELP	Zoarces viviparus	Eelpout/viviparus blenny						
EPX	Zoarcidae	Eel-pouts						

Annex 7. Compilation of comments received through external consultations

The following text is taken from the technical consultation document sent out on 15 November 2007 to the scientific, fisheries, and conservation communities concerning development of a UK marine trophic index. Replies received by 14 February 2008 have been cut and pasted at the end of each proposal below. Comments that are not specific to a proposal are collected together at the end. A contrasting font and a slight indentt have been used to distinguish the consultation text from the rest of this document. Proposals by Cefas are in italics.

Consultation text and replies:

Options for calculating a UK MTI

There are three main options for calculating an MTI for UK seas, based on data from commercial fisheries, from fish surveys, and from observers accompanying commercial fishing vessels. These are discussed in sections below. The Cefas reasoning and proposals in each case are labelled with a capital letter.

Please make clear your opinions and preferences for each option. It will be helpful to specify whether you 'strongly agree', 'agree', 'have no opinion', 'disagree', or 'strongly disagree' with each statement in italics. Please also refer to the questions on page 1.

MTI from landings data

A. Long time-series of landings data for fish and shellfish are available to describe annual changes in the trophic level of the entire UK marine environment while data on other components of the ecosystem are not collected frequently enough to be useful for this purpose.

As fish comprise a large part of the marine biomass, Cefas intends to use fish and shellfish landings data to calculate a MTI.

- Respondent 1: Do not agree. I am happy to agree that fisheries data can be used, but they need to be accompanied by other forms of data. I disagree that there are no other sources collected with sufficient frequency to be used in an integrated assessment
- Respondent 2: agree
- Respondent 3: Disagree, for the reasons set out in B!
- Respondent 4: disagree. We support the argument that landings data do not reflect the trophic state of a marine ecosystem because they are biased by fishing effort and regulations and also do not account fro illegal landings.
- Respondent 6: Agree – also can we compare the results using fisheries dependant and independent data. How is this affected by unreported / 'black market' landings?
- Respondent 7: I agree and that it should be part of an MTI but the smart aspect will be to create a modelling/multimetric approach and weight the various parts of the multimetric.
- Respondent 9: Agree, but precise the % of biomass represented, and keep the same species number across the time series

B. Landings data have the disadvantage of being affected by commercial, regulatory, and strategic factors unrelated to biodiversity of the ecosystem. There are also long-standing concerns that they are incomplete or inaccurate. Nevertheless, landings data were used by Pauly et al. for computing the original MTIs (Pauly *et al.* 1998a) as seen and adopted provisionally by the CBD.

Cefas proposes to compute an MTI based on landings data, despite their drawbacks, because this will be comparable with published MTI series and straightforward to accomplish in a monitoring environment.

- Respondent 1: Disagree. CEFAS is welcome to do this but it assumes that (i) Pauly was right and (ii) the adoption of this index as a standard is not misleading. The response also depends on how such an index is to be used in an overall ecosystem assessment. My view is that, on their own, they are not very useful because they say little about mechanisms and almost nothing about how to manage changes. There is a danger one creates an index that suggests greater rigour than actually exists and this will lead to the development of inappropriate policy.
- Respondent 2: strongly agree
- Respondent 3: Disagree, just because someone else is doing something wrong in a fashion that will have many unmeasurable biases, does not mean that we have to.
- Respondent 4: disagree. The concerns over the Pauly version of the MTI are relevant, and should not be supported by making calculations just because the numbers are available.
- Respondent 6: Agree but as above can we also consider the result using only fisheries independent data sets for comparison.
- Respondent 7: Sort of, but can we create a multimetric index of which parts can be used for geographical comparisons, with what has been achieved elsewhere, while at the same time covering wider trophic aspects and functioning.
- Respondent 9: Agree

C. English landings do not cover all trophic levels (e.g. few pelagic species) and are regionally highly diverse. Furthermore, an MTI is intended to describe an ecosystem, not a national fishery and so, for describing the seas around UK, should include landings data from all the several nationalities, and types of fisheries operating there.

Bearing in mind their better coverage of international fisheries, and the different types represented, Cefas prefers to use fishery statistics assembled by ICES, rather than those assembled nationally, for compiling a landings-based MTI for the UK.

- Respondent 1: Agree. Seems sensible.
- Respondent 2: agree
- Respondent 3: Neither agree nor disagree, if you have to develop an index using landings then ICES better than UK, but we also need regional indices.
- Respondent 4: disagree. Same argument as above.
- Respondent 6: Seems reasonable. Assume this means landings in other EU countries from boats fishing in UK waters?
- Respondent 7: yes, there are problems with national data and its coverage (and also with ICES data)
- Respondent 8: Potential spin off of this approach is method will be then be applicable to analysis by ‘region’ defined in the Marine strategy Directive.
- Respondent 9: Agree

D. The trophic level data collected from stomach contents analysis and Ecopath modelling are different in detail from those derived by analysis of nitrogen isotopes. However, computations for both of these options are straightforward once taxonomic groupings have been matched in the different data sets.

Cefas proposes to compute landings-based MTIs in two ways for initial comparisons: (i) with trophic levels based on stomach sampling and Ecopath, and (ii) with trophic levels based on isotope analysis.

- Respondent 1: Strongly disagree. I suggest that the use of Ecopath is not really helpful. To my knowledge Ecopath is a tool that has never been properly tested. It is only appropriate when combined with a braod suite of indices in an ecosystem assessment approach. This may also invalidate the MTI index as a single- or major-component of any assessment.
- Respondent 2: agree
- Respondent 3: I disagree with using Ecopath.
- Respondent 4: don't understand this proposal. Is trophic level set independent of species, only based on stomach sampling or isotope analysis? If so, what is the link between catch record and tropic level? And is this information realistically available?
- Respondent 6: Again seems reasonable
- Respondent 7: There are sufficient literature records to supplement the stomach analysis data and there are also newer studies on different trophic guilds hence giving a better coverage (Elliott et al 2007 Fish and Fisheries). Not sure about the way this will fit together - isotope analysis will give the links in the foodwebs and thus reinforce the information obtained from stomach analyses - but how to turn the model into an index. There are also other ways such as Ecological Network Analysis (Ulanowicz et al) which may be promising. I suspect that we may need a combination of quantitative with qualitative - e.g. check list approaches.
- Respondent 8: Strongly agree – using two approaches could give a more robust output. Some comparative comments on the practicality as well as efficacy of each would be helpful. If there is significant agreement in the trend or pattern shown between the two approaches would you recommend continuing with only one?
- Respondent 9: agree but 1) precise if the TL is fixed per species when using stomach sampling and Ecopath or if the TL will be updated temporally, 2) absolute values of TL from Ecopath and isotope analyses are not directly comparable (but the trend), 3) there are arbitrary choices in Ecopath that can bias the comparison (e.g. TL of detritus=1).

E. Allowing the trophic level for a species to be a function of size or age would give recognition to the fact that many species change their trophic level substantially as they grow older. Using size-based trophic levels would increase the sensitivity of the MTI series to changes in the ecosystem but would not provide new guidance on when management intervention is necessary (Jennings *et al.* 2002a). Size-based trophic levels would require access to all landings data in their original disaggregated form for all species, necessitating exchanges of very large amounts of data between countries, plus a major computing task to put everything together as a UK statistic. It would also require that available trophic level-versus-weight relationships can be consistently applied throughout UK waters and over time, both of which are significant assumptions.

Cefas proposes not to use trophic level-versus-weight relationships in computations of a landings-based MTI because they would add significantly to complexity and uncertainty without providing clearer guidance on when management action is needed.

- Respondent 1: Strongly disagree. While I recognise the need to try and come up with something that is tractable, you cannot simply ignore what may be fundamental principles just to achieve tractability! I suggest this well illustrates the reason why a single integrated index approach, such as the MTI, is very unwise.
- Respondent 2: strongly agree (making things more complex without any certainty of this allowing clearer management guidance is clearly undesirable)
- Respondent 3: Disagree. The management action point is a distraction. No idex gives you that on its own! I do not think that you should use landings, but should use size based metrics from surveys. Data handling job much smaller there.
- Respondent 4: Agree. There is still the fundamental problem of using landings for the calculation.
- Respondent 6: Don't feel qualified to comment on how the increases sensitivity is balanced by greater uncertainty – presumably the additional assumptions. It would

be a shame if we are loosing sensitivity just because of difficult data handling issues. (Resp. 6.2) I agree – would not be useful to have this to help refine the MTI?

- Respondent 7: Yes, ontogenetic changes are important so I don't agree to omit these aspects - the index/functioning model has to include/account for changes with different stages. However, if the analysis is based mostly on landings data then presumably it excludes the juvenile stages (where most ontogenetic aspects are evident) - I think that the MTI needs the juveniles to be included.
- Respondent 8: I presume you will be able to compare the results for 4.1 vs 4.2 for different 'regions'. Do you plan to do so to help compare the results of each approach rather than pooling and only doing so at a UK level?
- Respondent 9: Agree in a first step for a first approximation but the TL per species will greatly vary under fishing pressure if fish are omnivores. One way to account for that variability is to look at the TL versus weight relationship
-

MTI from surveys

F. The surveys around UK are not comparable with regard to gear used. The Scottish surveys use otter trawls east and west of Scotland. England has used a GOV trawl in the North Sea since 1992, and 4-metre beam trawls in the southern North Sea, Channel, Bristol Channel, and Irish Sea since the late 1980s. Surveys by Northern Ireland use an otter trawl in the Irish Sea. Otter trawls catch demersal roundfish with, depending on their design, varying amounts of pelagic species and flatfish. Beam trawls catch demersal flatfish and some shellfish with almost no pelagic species or demersal roundfish. Generally speaking, fish surveys catch fewer large fish than commercial fisheries; this may be related to the smaller numbers of fish caught overall, or there may be a selectivity problem for fast-swimming species associated with the short tow lengths used on surveys. For these reasons, survey-based MTIs would be non-comparable across gears and regions and, in each case, are only relevant for a restricted subset of the food chain. On the other hand, survey catches are free of the commercial, regulatory, and strategic influences that affect landings data. Barring deliberate changes to the survey designs for operational reasons, fishing techniques can be assumed to be constant from year to year. It is expected that survey-based MTIs will often display more variability of trend than landings-based MTIs because they sample fewer fish. Each survey will also show a different degree of bias because they sample relatively few trophic levels.

Cefas proposes to compute MTIs for the 3rd quarter North Sea otter trawl survey, and 3rd quarter beam trawl surveys in the southern North Sea, the Channel, southwestern approaches, Bristol Channel, and Irish Sea. Time series will be extended back over the period during which survey design was constant. The series will be presented separately to allow comparisons. Scottish and Northern Irish surveys will be analysed similarly within this project if time and resources permit.

- Respondent 1: Strongly disagree. You have to find ways of integrating across all data. Its very unwise just to throw data away on an adhoc basis. The only reason for rejection might be because of quality control issues, not because of inherent sampling bias.
- Respondent 2: agree but would press for Northern Irish Seas analysis as well
- Respondent 3: Agree. Biases are better known in these data sets.
- Respondent 4: Agree. Is it possible that although the absolute levels of the MTIs calculated are not comparable, the temporal development could be?
- Respondent 6: Agree. Also deals with issues raised above.
- Respondent 7: This illustrates the point that a combination of quantitative and qualitative aspects will be required - if the analysis doesn't cover the British Shelf area in its entirety then I think there will be difficulties in interpretation.
- Respondent 8: I presume the report will elaborate further on why you have chosen this particular survey
- Respondent 9: No opinion
-

G. The choice of trophic level data to use with survey data - whether based on stomach contents or nitrogen isotopes - rests on the same considerations as the choice for use with landings data. See proposition D above.

Cefas proposes to compute survey-based MTIs in two ways for initial comparisons: (i) with trophic levels based on stomach sampling and Ecopath, and (ii) with trophic levels based on isotope analysis.

- Respondent 1: Disagree. You need to use more than MTIs
- Respondent 2: agree as before
- Respondent 3: (no comment)
- Respondent 4: Don't know
- Respondent 6: (no comment)
- Respondent 7: I'm not sure that the best end points will be reached if the data treatment is so fragmented - i.e. the region-based MTIs are the most appropriate
- Respondent 9: Agree, same remark as for catch data.

H. Similarly, the decision on whether or not to take fish size into account when estimating trophic level with survey data rests on the same considerations as for landings data. See proposition E above.

Cefas proposes not to use trophic level-versus-weight relationships in computations of a survey-based MTI because they would add significantly to complexity and uncertainty without providing clearer guidance on when management action is needed.

- Respondent 1: This seems to be the same as E.
- Respondent 2: agree
- Respondent 3: Agree, but again management action point is not relevant. I disagree with using Ecopath.
- Respondent 4: Agree
- Respondent 6: As E above
- Respondent 7: Don't agree - the inclusion of juvenile stages will make this better than previous attempts and more responsive to future changes in stocks etc. The management advice and action re. juveniles and nursery areas is important/vital and even if the MTI has a semi-quantitative element for juveniles/small fishes then this will be valuable.
- Respondent 9: idem

MTI from observer data

I. An MTI could possibly be based on catch sampling data collected by observers travelling on commercial fishing trips. The advantage is that the whole commercial catch of a vessel is known, not just the landings. Fishing trips are sampled at quite low rates under the EC Regulation 1639/2001; approximately 0.5% of trips made are observed in England (Cotter *et al.* 2006). The locations and timings of observed trips cannot be ordered systematically because they are heavily dependent on the weather, fishing opportunities, and other practical factors. Quantities caught by the fleet must be estimated by first transforming to weights using standard formulae, then raising from trip to fleet. There can be substantial sampling and raising errors in this process. A significant disadvantage of observer data for estimating an MTI is that most sampling, north and south of the Scottish border, is restricted to demersal fisheries. Pelagic vessels, mostly Scottish-based in the UK, are observed at relatively low rates because slipping (i.e. discarding the entire catch without bringing it aboard) tends to take place and slipped fish cannot usually be accurately quantified, even though the presence of observers limits the activity. Vessels targeting shellfish are also observed rather seldom, in this case because many shellfish survive the discarding process. Consequently, the different trophic levels in the food chain are not evenly sampled by observers. Further uncertainties are that observers do not always have time to sample all species caught, and commercial fishing vessels less than 10 metres long are not observed for reasons of space and safety yet this group makes up a large part of the UK fleet.

Cefas proposes not to compute an MTI based on observer data because of the restricted part of the fish community observed caught, the irregularity of sampling patterns with respect to the marine ecosystem, and because sampling and estimation variance is likely to be high.

- Respondent 1: Disagree. Again I have great difficult with any approach that is throwing away potentially informative data.
- Respondent 2: agree
- Respondent 3: Agree
- Respondent 4: Agree. Seems to not solve the problem.
- Respondent 6: OK
- Respondent 7: Yes, I agree – better to use quality controlled and spatially extensive data.
- Respondent 9: Agree

Other indicators competing with MTI

The MTI is just one of many indicators that have been suggested for monitoring commercially fished marine environments in accordance with the ecosystem approach to fisheries management (EAFM). Most EAFM indicators, for example measures of size or maturity, require constant catchabilities. Only then will time series indicate changes in the wild populations rather than merely changes in fishing methods. For the UK, this implies standardised, broad-scale surveys using the same fishing gear and protocols. Size-based indicators are among the most easily measured catchability-dependent indicators available from fish surveys, and they are thought to be highly responsive to fishing pressures for reasons given below. They are therefore considered as strong competitors to the MTI for assessing fishing-induced changes on marine ecosystems.

However, a few indicators are available that are relatively independent of catchability. This property can make them more robust to varying sources of catch data. Two examples are discussed in 5.2 below. A third is the proportion of fish stocks harvested sustainably. This is already in use as a UK biodiversity indicator (under ‘sustainable use of biodiversity’) and so is not discussed further here.

Size-based indicators

Big fish of many species are highly vulnerable to commercial fishing, especially trawling, and they are mostly older than small fish so they have had more chances to be caught. Consequently, the size of individuals in fished populations tends to reduce (Jennings and Kaiser 1998) and can be monitored using size-based indicators. A particular advantage of some size-based indicators is that size-based processes can be modelled (Shin *et al.* 2005) implying that useful managerial information may be obtainable from the indicator values themselves. However, indices have to be regionalised for each survey to allow for varying catchabilities and selectivities among different surveys. Fudge factors to link different surveys are difficult to justify scientifically but may not be necessary if interest is restricted to relative changes over time in each specific, regional index.

J. One example of a size-based indicator is the ‘Proportion of fish > 40 cm by weight’ as proposed by OSPAR as an Ecological Quality Objective (EcoQO) for fish communities, and developed by ICES for North Sea trawl surveys. The 40 cm threshold restricts the influence of variable annual recruitments of large numbers of small fish on the proportions of large fish. Use of proportions by weight rather than by numbers of large fish was found to give clearer time trends. ICES notes the need to report how the community of large fish is changing, e.g. from teleosts to elasmobranchs, in addition to the value of the indicator itself. Also, the size threshold may need to be tailored for different marine areas to reflect varying recruitment effects. In a UK context, different thresholds are likely to be needed for otter and beam trawl surveys. Although there are reservations about this indicator, some characteristics of the size-based EcoQO are:

The proportion of large fish is an indicator of the state of the marine environment and is responsive to management of commercial fishing effort.
The indicator can be easily calculated using reliable sources of data.
Two reservations are
Some species are long without being large, e.g. rays, eel-like fishes.
Sampling for extreme sizes is prone to more sampling variability than sampling for middling sizes.

Other length-based indicators are worth considering. Length quantiles are an example. The L25 (i.e. the length just greater than 25% of the fish) records recruitment events while the L75 relates to big fish and is relatively insensitive to recruitment. Retaining and publishing the quantiles separately by species would be informative for the purposes of modelling and biological understanding. An overall UK index could then be produced by some weighted combination, or possibly a multivariate combination that helps to allow for correlated co-occurrences. For the latter, length quantiles by station can be used to estimate a correlation matrix, then principal components (or other multivariate techniques) might serve to distinguish different influences on size composition. The advantage of such an approach is that each station gets equal weighting rather than one or two stations dominating results, and more information is potentially available on the relationships among different size classes.

Cefas proposes to investigate the suitability as biodiversity indicators of the proportion of large fish, and length quantiles as derived from English 3rd quarter otter and beam trawl surveys (listed above). Time series will be compared with those for the MTI and other available indicators.

- Respondent 1: No opinion.
- Respondent 2: agree
- Respondent 3: Agree, but as you know, much of this has already been done by ICES as part of the EcoQO analysis. This is a better indicator than MTI.
- Respondent 4: Strongly agree. Respondent 4 is exploring using a size based MTI based on survey data.
- Respondent 6: Good
- Respondent 7: I agree - put as many functional attributes as possible into the index - split the species and sizes according to ecotrophic guilds and look at dynamics of each group - make sure factors operating outside the area or beyond the control of fisheries managers (global warming, temperature dependent fecundity, introduction of alien species, etc) are accounted for.
- Respondent 9: *strongly agree. Those two community indicators will complement the MTI because they are integrated across individual data (the MTI reflects variability in species composition as TL are fixed per species)*
-

Catchability-independent (or nearly so) indicators

K. Indicators also exist that offer a form of biodiversity monitoring comparable to that of an MTI whilst avoiding or reducing the need for rigorously constant catchabilities everywhere. This feature allows them to be applied over wide areas more or less independently of the survey design, or perhaps to use other catching methods to provide additional data. They therefore seem particularly relevant for the seas around UK where survey coverage is not uniform for gear and other aspects. They include:
The threat index of Dulvy et al. (2006) This is related to the IUCN red list of threatened species. It thus implies a degree of uniformity with assessments of threat for species living on land and, for that reason, is likely to be considered useful in the context of the CBD. In marine cases, threat is assessed from the size of observed declines in abundance. Possible sources of difficulty are that observed declines can depend arbitrarily on the start date of the survey series, and the conditions necessary for a species to be re-classified as unthreatened following a recovery are not well defined.
The species vulnerability index of Cheung et al. (2005) based at the University of British Columbia. In this method, each species (or taxonomic group) is rated for vulnerability to

fishing according to life history and ecological attributes. Cheung et al. (2007) applied this to global landings data to demonstrate gradual reduction of vulnerability since the 1950s, a similar trend to that seen with the MTI (Pauly *et al.* 1998a). This is thought to have happened because the most vulnerable species are fished out in the early stages of the development of a fishery which then has to rely on the less vulnerable survivors.

Cefas proposes to investigate and, if necessary, develop the threat and vulnerability indices for use with UK landing statistics and survey data. A case will be made for or against continuing use of them.

- Respondent 1: Broadly agree, especially because one needs to develop a range of summary indices to carry out an ecosystem assessment.
- Respondent 2: strongly agree
- Respondent 3: Agree
- Respondent 4: Strongly agree.
- Respondent 6: (no comment)
- Respondent 7: This all needs to be linked to some indication of habitat needs, conservations goals and habitat threats both in-situ and at marginal breeding and nursery areas. Need to separate the habitat influences from the fisheries influences - Q - will the MTI do this when based mostly on fisheries data?
- Respondent 8: Need to discuss cf similar analysis for the habitat, eg various methods for characterising sensitivity including those explored by Cefas, and the added (or better?) value the proposed index provides compared to those.
- Respondent 9: Agree

Other general comments received

Respondent 1:
There are some good features here but my experience with developing indices in the Southern Ocean has left me a little negative about some approaches. I'll be frank that I am not a fan of Ecopath so I guess I'm not likely to sign up to MTIs as a concept. I have no objection to them as one of a range of indicators but they really must be considered alongside such a suite within a generalised ecosystem assessment. The very real danger is that they could be quite misleading and they suggest to those unfamiliar with ecological complexity that there are simple solutions that can be interpreted in simple ways.

Respondent 2:
Generally, we are pleased to hear more about this work and to see it being taken forward. From a Welsh perspective we are keen that the Welsh Assembly Government (WAG) pick up on the MTI as a measure of 'ecosystem health' rather than developing their own indicator in isolation - particularly given the lack of resources for collecting / processing the sort of data likely to be required. The MTI should really be adopted by the Wales Environment Strategy (WES).

Overall, CEFAS seem to adopting a pragmatic approach to all of this, which we would support. However, there is a strong element of 'what can we do with existing data and programmes rather than what do we need?'. The assumption that fish landings records can tell us all that we need to know about the trophic structure of the ecosystem and that this can be related directly to biodiversity is tenuous. That said, there is real value in developing an indicator that we have long-term records for. Whilst we appreciate that the MTI assumes that fish are representative of wider biodiversity and that is quite an assumption, we strongly agree that it is looking at a chunk of biodiversity that is subject to fisheries, the major driver of change in the marine environment - and certainly an area where this sort of index is likely to have significant value in informing better management. Having said this, we would be cautious about assuming that the MTI can accurately measure pressures other than fishing.

We would certainly like to emphasise doing as much work/analysis in the Irish Seas as possible. We are pleased to see you will be investigating different forms of indices and would like to see a variety of indices being used if it is found that such an approach would give us a better breadth of understanding of what is going on in the marine environment, in a way that could usefuly inform management decisions/processes.

Respondent 4:
Firstly, I would like to acknowledge that the Respondent 4 very much welcomes this initiative. We have had a proposal to use the MTI as one of our indicators, and we quickly discovered that it was not easy to resolve how to arrive at a commonly agreed upon version. We are not experts in the field (although we work closely with ICES), and my comments are more reflective of how sound I find the arguments used, than any personal experience in calculating the MTI. At the Respondent 4, the MTI is viewed as a very powerful means of communicating marine biodiversity problems, and for this reason it would of course also be nice if you could be sure of the interpretation that you are communicating. My comments to your different proposals are highlighted in red in the attached document.

The Respondent 4 tries to provide a pan-European coverage of its indicators and it would be nice if the recommendations coming out of your study could additionally provide input on which data to use and how to perform the calculations in the other European seas.

Respondent 5:
I am sorry to tell that I am not going to fill in your questionnaire. I think that what is important is not whether I 'strongly agree' or 'disagree' with any of these statements, but for which reasons and arguments, many of which I have written in published papers. I do not clearly see how you are going to use the responses you will receive. I am not sure if it is wise to select a method for estimating an indicator based on a vote by selected experts...

Respondent 8:
re. "Which method is the most sensible strategic way of delivering a UK?" As far as fish go, 4.1C/D for landings and 4.2F/G seem most sensible (may be a more robust result if the different datasets give similar trend/pattern over time)
re. "How the indicators fit with other indicator frameworks, such as the Oslo-Paris Convention Ecological Quality Objectives (OSPAR EcoQO)." I particularly agree with the idea of comparing and contrasting the MTI with alternatives. A combination of one or more of these and the MTI might even give a more robust handle on trends. Therefore K and J seem worthy of consideration.
re. "Pauly et al. (1998a) used the Ecopath model (Christensen and Pauly 1992) to estimate trophic levels for numerous species of fish found in FAO global landing statistics." Depending on the intended audience for this report (I don't know what it is) I suggest some more explanation of why this approach has been adopted over the more intuitive 'traditional' approach mentioned at the start of the paragraph, particularly as it may inform response to the different options put forward.
re. use of fisheries data to calculate an MTI: Are you quite sure there are not sufficient samples of biota collected by SEPA, EA, eg Mytilus, Nereis for pollution monitoring? These will be from a few locations only but may provide decent time series for a couple of other feeding types and trophic levels if data is pooled for whole of UK?
re. Options for calculating a UK MTI: I see merit in exploring several of the options and comparing them. If there is agreement in the results form each this may give more confidence in the trend/pattern identified; if this were the case will you discuss whether to use all the datasets in the future or concentrate on only one? If there is disagreement you will presumably assess which seems to best explain what has occurred or what you expected.
re

Cefas

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Head office
Centre for Environment,
Fisheries & Aquaculture Science
Pakefield Road, Lowestoft,
Suffolk NR33 0HT UK

Tel **+44 (0) 1502 56 2244**
Fax **+44 (0) 1502 51 3865**
Web **www.cefas.co.uk**

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