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Assessment of the “State” of the Demersal Fish Communities in UK waters

Simon P.R. Greenstreet, Helen M. Fraser, John Cotter and John Pinnegar

Introduction and Methods

To date, OSPAR has largely been responsible for the development of an ecosystem approach to the management of marine natural resources. Ten Ecological Quality Issues have been identified, with the intention of setting Ecological Quality Objectives (EcoQOs) for each issue. Since 2000, this scheme has been developed and piloted in the North Sea. Fish Communities is the fifth in the list of Ecological Quality Issues, and is considered to be one of three community-level issues. In addressing concerns regarding anthropogenically induced change in fish communities therefore, a community-level approach has been widely adopted. This has generally involved the application of univariate metrics to groundfish survey data to quantify change in various aspects of the community's composition, structure and function. The element of Ecological Quality for the North Sea fish community focuses on “changes in the proportion of large fish and hence the average weight and average maximum length of the fish community”, thus clearly identifying the need for a community size composition metric as the “indicator” on which to base an EcoQO for the “fish community” Ecological Quality Issue. The chosen metric, the Large Fish Indicator (LFI) was eventually defined as “the proportion by weight of fish greater than 40cm in length”, based on ICES first quarter (Q1) International Bottom Trawl Survey (IBTS) data.

The LFI was intended to be an indicator of the “general health” of the demersal fish community. Indeed DEFRA have adopted the LFI as a means of monitoring change in the trophic structure of demersal fish communities, since in marine systems, ontogenetic change and inter-specific variation in diet is so strongly linked to predator body-size. However, other aspects of the composition, structure and functioning of fish communities, such as abundance, biomass, productivity, species richness, species diversity and mean life-history trait composition, can also be summarised using univariate metrics. Any one, or all, of these alternative metrics might also be considered to be indicative of the “health” of fish communities. The LFI was chosen ahead of these alternative metrics because it was believed to be particularly sensitive to variation in fishing pressure, and therefore to indicate directly the effect of fishing on state of the fish community. But this raises the question as to whether one indicator is sufficient to inform on the general health of the demersal fish community, or is a suite of indicators necessary in order to provide information on various different aspects of a community's composition, structure and function? In this assessment of the state of the demersal community in UK waters, fifteen univariate metrics are applied to groundfish survey data to quantify changes in five main aspects of community

composition, structure and function: abundance/biomass/productivity; size composition; species richness; species diversity; and life-history trait composition (Table 1).

Bottom trawl surveys have been carried out as part of the traditional annual fisheries management process for several decades. These surveys routinely provide point estimates of the abundance at length of each species sampled; therefore providing the ideal data sets for the application univariate community metrics. Many of these surveys have run for two or three decades now, providing ideal time series with which to evaluate changes in the composition, structure and function of fish communities. Furthermore, most coastal European nations have been involved in survey activity, providing data from most western continental shelf waters. In this assessment, otter trawl survey data is analysed to assess changes in the demersal fish communities present in the sea area that constitutes the UK's Exclusive Economic Zone (EEZ). The UK EEZ has been divided into nine principal sub-regions (Figure 1), and assessment of the state of the fish community in each sub-region was required. However, one of the sub-regions, the Scottish Continental Shelf, straddled the boundaries between OSPAR Regions II and III, and between ICES area IV and VI. Consequently, none of the groundfish surveys, which are normally aligned with the ICES designated marine regions, covered the entire Scottish Continental Shelf sub-region. A single assessment for the Scottish Continental Shelf was therefore not possible. The sub-region had to be further sub-divided in line with the data available for analysis, and three separate assessments made for the southwestern and northeastern sectors of this large area (Figure 1).

To assess the state of the demersal fish community and make a judgement on the changes observed, it was necessary to decide what constituted "beneficial" and "detrimental" change. Emphasis is generally placed on conserving and restoring biodiversity; implying that declines in species diversity (both richness and evenness) are detrimental. The converse was therefore also assumed to hold. The life-history trait composition responses of populations and communities to anthropogenically raised levels of mortality have recently received considerable attention. Declines in population age and length at maturity, decreased community average ultimate body length, and increased in community average growth rate are all considered to be detrimental consequences. Improved management would therefore be expected to induce the opposite, beneficial trends.

Established population dynamics theory predicts that size-related fishing mortality reduces the mean size and proportion of large fish in exploited populations (including non-target species taken as by-catch). This concept underpins development of the LFI as the basis for the OSPAR North Sea Fish Community EcoQO. Reductions in LFI are therefore considered detrimental. Changes in LFI were generally inversely correlated with changes in the abundance, biomass and (growth) productivity of the fish community, implying that declining abundance, biomass and productivity are indicative of a fish community returning to more natural undisturbed state. The von Bertalanffy growth equation makes it clear that larger fish, closer to their ultimate body length (L_{∞}), have lower daily specific growth rates. Large fish exert a strong

predation loading on small fish abundance. Since trophic transfer efficiency is around 10%, every kg of production by larger fish requires 10kg of production in their smaller prey fish populations. Specific growth rates among smaller fish are approximately twice that of larger fish, so 5kg of prey fish are required to support every kg of larger fish. Reductions in the abundance of larger fish, with the consequent reduction in predation loading on smaller prey fish, would therefore tend to result in a rapid increase in the abundance and biomass of small fish; a typical trophic cascade effect.

In assessing of the state of the demersal fish community, two questions were addressed. Firstly, how has the state of the community changed over the last decade, from 1999 to 2008; the period of particular interest to the current report. Secondly, how does the state of the community over the period 2004 to 2008 (ie. now) compare with that prevalent during the eight-year period when data were first available for analysis. Detrimental trends were assigned a “red” colour code and beneficial trends “green”. Where no discernable trend was apparent, an “orange” colour code was applied. Five separate aspects of composition, structure and function of the demersal fish community were considered, and a judgement was made based on the trends observed in the 15 univariate community metrics applied to the groundfish survey data. Linear regression was used to make an assessment of metric trends over the last decade. In comparing the current situation with the earlier “reference period”, mean metric values over the period 2004 to 2008 were determined and the assessment was scored red or green depending on whether the recent mean value differed by more than one standard deviation either side of the mean value determined for the earliest possible “reference period”.

To determine an overall regional assessment, weighted average scores for each aspect of the demersal fish community composition, structure and function were calculated. In the individual sub-region assessments, red cells were given a value of 1, orange a value of 2, and green a value of 3, and cells were then weighted by the number of ICES statistical rectangles in each sub-region. For the final regional assessment, weighted average scores greater than 2.35 were considered good and assigned a “green” code; scores of less than 1.65 were considered poor and assigned a “red” code; while scores of 1.65 to 2.35 were deemed to indicate little change and assigned an “orange” code.

Sub-Regional Assessments (Table 2)

Northern North Sea

In the Northern North Sea, trends in the 15 univariate community metrics suggested little change in the composition, structure and function of the demersal fish community over the last decade; a decrease in the abundance/biomass/productivity aspect was indicated, which was interpreted as beneficial. Over the longer period, both species richness and species evenness are currently higher than when data were first available for analysis, but the community is has become more dominated by smaller sized fish.

Southern North Sea

In the Southern North Sea, demersal fish species richness and species evenness have increased over the last decade, but the community has at the same time become more dominated by fish belonging to species with opportunistic life-history trait characteristics. Size composition and abundance/biomass/productivity show no systematic trend over the last ten years. However, compared with the mid to late 1980s, community size composition has shifted towards smaller sized fish and species richness has increased. Metric values for the other three aspects of demersal fish community's composition, structure and function are little different now to those prevalent when data first started to be collected.

Eastern Channel

A possible methodological problem makes assessment of the 15 univariate trends difficult in the Eastern Channel sub-region. However, taking the data at face value suggests that over the last decade the size composition of the fish community has improved, particularly in the last few years. But little in the way of any systematic trend was apparent in any of the four other aspects of the composition, structure and function of the demersal fish community. Interpretation of longer-term trends was most problematic. Here there was some suggestion that species evenness and species richness may have declined, but this could easily be an artefact caused by the possible methodological problem. The data suggest that other aspects of the community's composition, structure and function are little different now than in the late 1980s to early 1990s.

Western Channel and Celtic Sea

Over the recent decade, species richness, species evenness, and life-history trait composition of the demersal fish community in the Western Channel and Celtic Sea sub-region have all improved so that the current state is now better than during the mid to late 1980s, when data were first available. However, the size composition and biomass/abundance/productivity metrics all suggest long-term deterioration in these two aspects of the composition, structure and function of the community, although the decline in size composition may have ceased over the last decade.

Irish Sea

The state of the demersal fish community in the Irish Sea has improved over the last decade, with metrics related to biomass/abundance/productivity, species richness, species evenness, and size composition aspects of the community all indicating an improvement, while life-history trait metrics showed little change. As a result, the community is now in better state than during the 1990s when surveys started. Improvement was indicated in all aspects of the community's composition, structure and function except for biomass/abundance/productivity, for which the situation now is similar to that when data were first available.

Minches and Western Scotland

Over the recent decade, trends in the fifteen metrics suggest improvements in all five aspects of the composition structure and functioning of the demersal fish community in the Minches and Western Scotland sub-region. As a consequence of which, the abundance/biomass/productivity, size composition, and species richness aspects are now on a par with the situation observed when data were first available, while the species evenness and life-history composition aspects would appear to be better.

Scottish Continental Shelf (southwest)

Over the recent decade, trends in the fifteen indicators suggest improvements in all five aspects of the composition structure and functioning of the demersal fish community in the southwestern sector of the Scottish Continental Shelf sub-region. As a consequence of which, the abundance/biomass/productivity and size composition aspects are now on a par with the situation observed when data were first available, while the species evenness and life-history composition aspects would appear to be better. However, despite recent improvements, demersal fish species richness is still currently lower than at the start of the time series.

Scottish Continental Shelf (northeast)

Trends in the fifteen univariate community metrics in the northwestern sector of the Scottish Continental Shelf sub-region portray a picture of variability, but very little systematic trend. Over the last decade no obvious trend was apparent in any of the five aspects of community composition structure and functioning. Over the longer term, only species richness showed any real difference, being slightly higher now than at the start of the time series.

Rockall trough and Bank

Metric trends over the last decade impart a mixed message. The species diversity and size composition aspects of the Rockall Bank demersal fish community have improved, whilst abundance/biomass/productivity appears little changed. However, the life-history trait composition metrics suggest a decrease in “climax community” species and an increase in the abundance of “opportunistic” species. A similar story emerges with regard to longer-term change in the composition, structure and function of the Rockall Bank demersal fish community, except that recent changes in size composition have simply achieved parity with the earlier data. Given the scarcity of data, particularly the gap between 1986 and the start of the systematic surveys in 2001, confidence in these assessments is low.

Overall Regional Assessment

Over the last ten years, all aspects of the composition, structure and function of the demersal fish community in UK waters, with the exception of life-history

trait composition, have improved. Life-history trait composition has shown little or no change. As a result of these changes, species diversity (richness and evenness) of the UK's demersal fish communities is now generally better than during the early 1980s and 1990s, abundance, biomass, productivity and life-history trait composition are about on a par, but size composition is still disturbed towards smaller fish. Improvement in this latter aspect is still therefore necessary, requiring that the current improving trend be maintained.

Metric	Abbreviation	Metric calculation	Terminology
Biomass	B	$B = \sum_{s=1}^S \sum_{l=\min}^{l=\max} \sum_{n_{s,l}=1}^{N_{s,l}} c_s l^{b_s}$	Where S is the total number of species, l is the length class, $N_{s,l}$ is the total number of individuals in each length class of each species. The constants c_s and b_s are the constant and exponent values respectively in the species-specific weight at length relationship.
Abundance	N	$N = \sum_{s=1}^S \sum_{l=\min}^{l=\max} n_{s,l}$	Where S is the total number of species, l is the length class, and $n_{s,l}$ is the number of fish in each species and length class.
Daily growth production	P	$P = \sum_{s=1}^S \sum_{l=\min}^{l=\max} \sum_{n_{s,l}=1}^{N_{s,l}} c_s b_s l^{b_s-1} \frac{k_s}{365} [l_{\infty,s} - l]$	Where S is the total number of species, l is the length class, $N_{s,l}$ is the total number of individuals in each length class of each species. The constants c_s and b_s are the species-specific weight at length relationship constant and exponent values respectively. The constants k_s and $l_{\infty,s}$ are the species-specific von Bertalanffy growth function growth and ultimate body length values respectively. k_s is divided by 365 to convert and annual parameter to a daily parameter.
Daily production to biomass ratio	P/B	$"P/B" = \frac{P}{B}$	Where P is the total daily growth production and B total biomass of the fish community (see above).
Large fish indicator	LFI	$"LFI" = \frac{\sum_{s=1}^S \sum_{l>40cm}^{l=\max} \sum_{n_{s,l}=1}^{N_{s,l}} w_{s,l}}{B}$	For term explanations, see "Biomass" above. Note that in the numerator, the summation is carried out across lengths >40cm only.
Mean weight of fish	W	$W = B/N$	Where B is the total biomass and N the total number of fish in the sample (see above).
Species count	S	S	Where S is the count of the number of species in the sample.
Margalef's species richness	S _{Marg}	$S_{Marg} = \frac{(S-1)}{\text{Log}N}$	Where S is the total number of species and N the total number of individuals in the sample (see above)
Pielou's evenness	J	$J = \frac{-\sum_{s=1}^S N_s / N \log N_s / N}{\text{Log}S}$	Where N_s is the number of individuals belonging to species s , N is the total number of individuals of all species in the sample, and where S is the total number of species recorded in the sample (see above).

Hill's N1 diversity	N1	${}^{\prime}N1{}^{\prime}=e-\sum_{s=1}^S\frac{N_s}{N}\log\frac{N_s}{N}$	Where N_s is the number of individuals belonging to species s , N is the total number of individuals of all species in the sample, and where S is the total number of species recorded in the sample (see above).
Hill's N2 dominance	N2	${}^{\prime}N2{}^{\prime}=\frac{1}{\sum_{s=1}^S\frac{N_s}{N}}$	Where N_s is the number of individuals belonging to species s , N is the total number of individuals of all species in the sample, and where S is the total number of species recorded in the sample (see above).
Mean ultimate body length	L_{∞}	$L_{\infty}=\frac{\sum_{s=1}^S\sum_{n_s=1}^{N_s}l_{\infty,s}}{N}$	Where $l_{\infty,s}$ is the von Bertalanffy ultimate body length of each species s . S is the total number of species recorded in the sample and N_s is the total number of individuals of each species caught. N is the total number of individuals recorded in the sample.
Mean growth coefficient	K	$K=\frac{\sum_{s=1}^S\sum_{n_s=1}^{N_s}k_s}{N}$	Where k_s is the von Bertalanffy growth parameter for each species s . S is the total number of species recorded in the sample and N_s is the total number of individuals of each species caught. N is the total number of individuals recorded in the sample.
Mean length at maturity	L_{mat}	$L_{mat}=\frac{\sum_{s=1}^S\sum_{n_s=1}^{N_s}l_{mat,s}}{N}$	Where $l_{mat,s}$ is the length at maturity of each species s . S is the total number of species recorded in the sample and N_s is the total number of individuals of each species caught. N is the total number of individuals recorded in the sample.
Mean age at maturity	A_{mat}	$A_{mat}=\frac{\sum_{s=1}^S\sum_{n_s=1}^{N_s}a_{mat,s}}{N}$	Where $a_{mat,s}$ is the age at maturity of each species s . S is the total number of species recorded in the sample and N_s is the total number of individuals of each species caught. N is the total number of individuals recorded in the sample.

Table 1. Descriptions, abbreviations and derivations of the fifteen univariate community metrics applied to the groundfish survey data.

Aspect of Fish Community Composition, Structure and Function	Abundance, Biomass and Productivity	Size Composition	Species Richness	Species Evenness	Life-history Trait Composition
Assessment of Trend Since 1999					
Northern North Sea					
Southern North Sea					
Eastern Channel					
Western Channel and Celtic Sea					
Irish Sea					
Minches and Western Scotland					
Scottish Continental Shelf (southwest)					
Scottish Continental Shelf (northeast)					
Rockall trough and Bank					
UK EEZ ASSESSMENT	2.362	2.447	2.609	2.609	1.843
Comparison of State of Fish Community in Last Five-year Period with First Eight-year Period in Time Series					
Northern North Sea	1983-1990	1983-1990	1983-1990	1983-1990	1983-1990
Southern North Sea	1983-1990	1983-1990	1983-1990	1983-1990	1983-1990
Eastern Channel	1988-1995	1988-1995	1988-1995	1988-1995	1988-1995
Western Channel and Celtic Sea	1984-1991	1984-1991	1984-1991	1984-1991	1984-1991
Irish Sea	1992-1998	1992-1998	1992-1998	1992-1998	1992-1998
Minches and Western Scotland	1986-1993	1986-1993	1986-1993	1986-1993	1986-1993
Scottish Continental Shelf (southwest)	1986-1993	1986-1993	1986-1993	1986-1993	1986-1993
Scottish Continental Shelf (northeast)	1983-1990	1983-1990	1983-1990	1983-1990	1983-1990
Rockall trough and Bank	1986	1986	1986	1986	1986
UK EEZ ASSESSMENT	1.881	1.617	2.719	2.749	2.153

Table 2. Assessment of changes in the composition, structure and function of the demersal fish community in each sub-region of the UK's EEZ and overall assessment for the entire EEZ. Green cells indicate beneficial changes. Red cells indicate detrimental changes. Where no discernable trend is apparent, cells are coded orange. Sub-regional "reference periods" are indicated in the lower half of the table. Values in the overall regional assessment rows indicate weighted average scores. Two assessments for the Scottish Continental Shelf are shown; northeast refers to the IBTS based assessment and southwest refers to the assessment based on the Scottish West Coast Groundfish Survey.

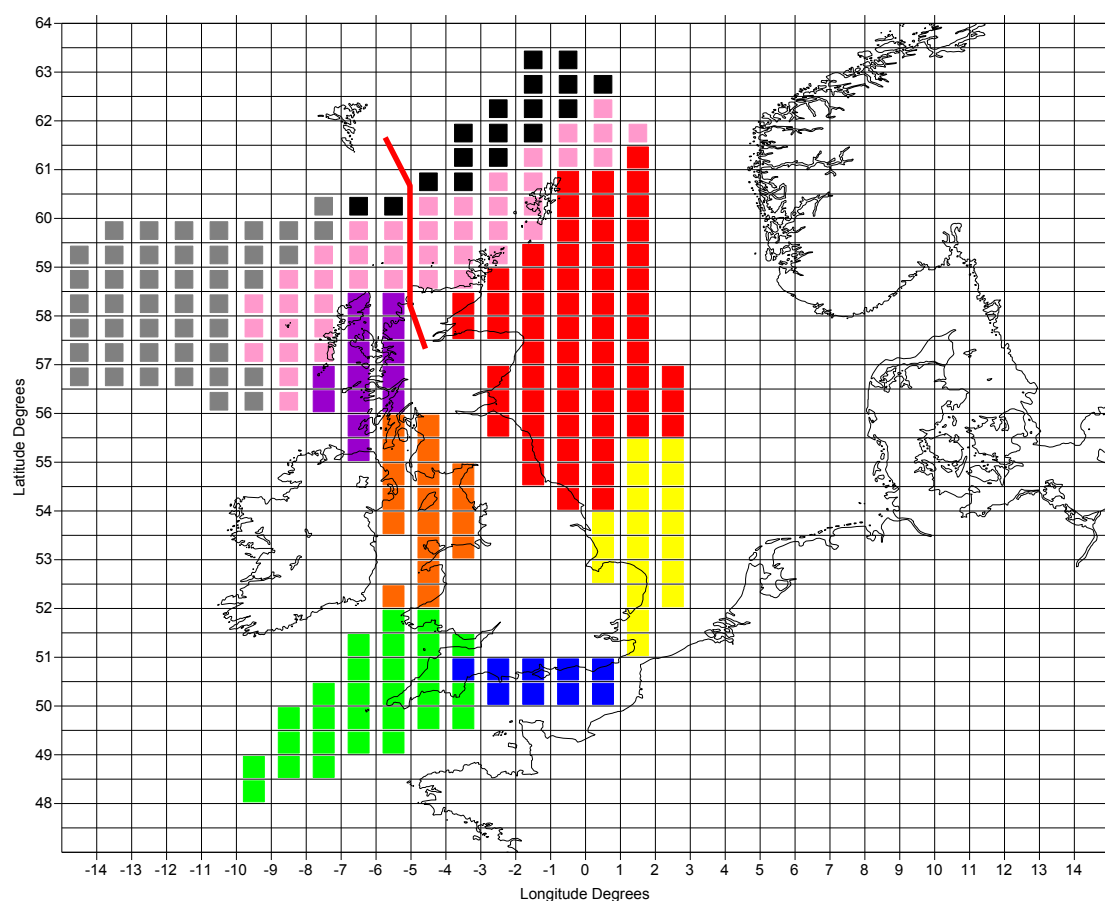


Figure 1. Chart showing ICES rectangles assignments to Charting Progress II sub-regions. (Northern North Sea – red; Southern North Sea – yellow; Eastern Channel – blue; Western Channel and Celtic Sea – green; Irish Sea – orange; Minches and Western Scotland – purple; Scottish Continental Shelf – pink; Rockall Trough and Bank – grey; Faroe-Shetland Channel – black). Red line indicates sub-division of the Scottish Continental Shelf sub-region for analytical purposes.

Supplementary Material Annex 1: Analyses of groundfish survey data in sub-regions of the UK's Exclusive Economic Zone to examine trends in the “health” of the demersal fish community.

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This annex provides descriptions of the data available in each sub-region and presents the results of the analyses applied to these data. The results of these analyses, the trends in the 15 univariate community metrics, provide the basis for the sub-regional and regional overview presented in the main body of the report.

Sub-Regional Assessments

Northern North Sea

Two main international groundfish surveys co-ordinated through ICES, the International Bottom Trawl Surveys (IBTS), have been carried out across most of ICES area IV, the North Sea, in the first (Q1) and third (Q3) quarters of each year. The Q1 time series covers the period 1983 to 2008, while the Q3 survey only commenced in 1991 (as a co-ordinated survey) and 2008's survey data were not yet available for analysis. These surveys utilise a Grande Ouverture Verticale (GOV) trawl and sample tows are generally of 30min duration. Trawl samples are quantified to provide estimates of the numbers of each 1cm length class of each species caught at each sample location. Catch numbers were converted to densities by dividing by the area swept by the trawl (mean distance between the wings multiplied by distance the gear was towed). Where wing-spread distance was not known, this was estimated using a depth dependent relationship derived for the standard GOV.

Correspondence between metric time series derived from the Q1 and Q3 survey data was generally high and, in 12 of the 15 cases, was improved by the introduction of a plus 1-year time lag to the Q3 data (Table S1). No clear trend in LFI over the last decade was provided by either data set, while mean fish size has varied markedly, but shown no systematic trend over the ten years. Both metrics, however, suggest that community size composition has shifted towards smaller fish now compared with the start of the time series. However, abundance, biomass and productivity have all declined over the last ten years and are currently at similar levels to those present during the mid to late 1980s. Little consistent trend was apparent in any of the five metrics of species richness and species evenness over the last decade, but all five metrics indicate higher species diversity now than during the 1980s. Life-history trait metrics have oscillated in value throughout the time series, with no systematic trend obvious over the last decade, and little to suggest that the community life-history composition is any different now than at the start of the time series. There is perhaps some evidence of a recent increase in fish age at maturity (Figure S1).

Southern North Sea

Data from the same two North Sea surveys that provided information for the Northern North Sea were analysed to determine metric trends in the Southern North Sea.

Correspondence between the metric time series was generally poor, and in this instance not markedly improved by the introduction of a time lag to the Q3 data (Table S2). Despite this apparent dichotomy in the detailed temporal variation in the two time series, trends in both data sets were generally consistent (Figure S2). Over the last decade the LFI has declined sharply, but then recovered, while little trend was apparent in the mean size of fish. Biomass, abundance and productivity all showed opposite changes to the LFI, such that over the 10 year period, no trend was obvious. While abundance, biomass and productivity are currently at similar levels to those prevalent in the mid to late 1980s, the proportion of large fish and mean weight of fish are both markedly lower. The recent recovery therefore needs to be maintained. Both surveys suggest recent increases in demersal fish species richness and evenness. Species evenness is currently about on a par with levels present at the start of the time series, while species richness is currently higher. Trends in the four life-history metrics were variable, but tend to suggest that the community now contains a higher percentage of individuals of opportunistic species, and fewer climax species fish. Over the longer term, however, there was no obvious difference between now and the start of the time series. This recent trend therefore needs to be reversed before a problem emerges.

Eastern Channel

French Groundfish Survey of the Channel (FGSC) has been undertaken in the fourth quarter of the year over the period 1988 to 2008. This survey utilises a Grande Ouverture Verticale (GOV) trawl and sample tows are generally of 30min duration. Trawl samples are quantified to provide estimates of the numbers of each 1cm length class of each species caught at each sample location. Catch numbers were converted to densities by dividing by the area swept by the trawl (mean distance between the wings multiplied by distance the gear was towed). Where wing-spread distance was not known, this was estimated using a depth dependent relationship derived for the standard GOV.

Few obvious trends were apparent in any of the fifteen univariate metrics applied to the data, but some evidence of a major methodological change in 1998 was apparent making interpretation difficult. The analysis provided no evidence to suggest that any major changes in the composition, structure, and functioning of the demersal fish community had occurred in the eastern English Channel during the last decade, although fish size may have increased, particularly in the last few years (Figure S3). Comparison of the current state of the community with the situation at the start of the time series was hampered by the apparent methodological problem, however, taken at face value, the data suggest the current community is more dominated by a few species, and consists of smaller fish. Species evenness may also be

lower now than at the start of the time series, but the possible methodological issue may have influenced these apparent long-term trends.

Western Channel and Celtic Sea

Data from three surveys using a GOV trawl were available for the Western Channel and Celtic Sea sub-region. Two commenced comparatively recently, both carried out in the fourth quarter (Q4) of the year; the French Celtic Sea Groundfish Survey (FCSGS) started in 1997, while the English Southwest Bottom Trawl Survey (ESWBTS) only started in 2003. Both surveys are still extant and the FCSGS at least covers the decade of main interest for this report. The third survey, the English Celtic Sea Groundfish Survey (ECSGS), carried out in Q1, provides a longer time series, extending back to 1984, but coverage of this sub-region by this survey ceased in 2004. Trawl samples were quantified to provide estimates of the numbers of each 1cm length class of each species caught at each sample location. Catch numbers were converted to densities by dividing by the area swept by the trawl (mean distance between the wings multiplied by distance the gear was towed). Where wing-spread distance was not known, this was estimated using a depth dependent relationship derived for the standard GOV. Correspondence between the metric trends derived from these three surveys was generally weak. When comparing Q1 and Q4 trends, introduction of a plus one-year lag to the Q4 data had marginal effect: eight correlations were improved, while seven decreased. However, for two metrics, the LFI and the P/B ratio, introduction of the lag resulted in significant correlations between the Q1 ECSGS and Q4 FCSGS data (Table S3).

Despite the lack of detailed (year on year) agreement between the different metric time series, examination of the general trends provided greater similarity between the metric signals (Figure S4), rendering an assessment of the state of the demersal fish community in the sub-region possible. Biomass, abundance and productivity all appear to have increased, with a clear increase in the last ten years evident. A long-term increase in the P/B ratio was clearly indicated. These changes have been associated with a marked reduction in the proportion of large fish and mean weight of fish in the demersal fish community. This trend may have been halted in the last decade, but not reversed. The French Q4 survey suggests an increase in both species richness and species evenness over the last decade, a change that is to some extent corroborated by the shorter five-year span of the English Q4 time series. Because of this, demersal fish species diversity (evenness and richness) may well now be higher than when data were first available. However, this involves a qualitative comparison of these two surveys with the longer lived, but now ended, English Q1 data. The four life-history trait metrics suggest a recent return to a more “climax” type community with increases in average ultimate body-length, age and length at maturity and decreased average growth rate all indicated. These four metric time series all indicate long-term improvement in this aspect of the composition, structure and function of the demersal fish community in the sub-region.

Irish Sea

Data from three surveys were available for the Irish Sea sub-region, all of which commenced comparatively recently. Two surveys conducted in Q1 and Q3 by Northern Ireland, the Northern Irish Groundfish Survey (NIGS) commenced in 1992. The third survey, carried out in Q1 by Scotland (the SWCGS) provides data since 1996, but this survey ceased coverage in this sub-region in 2006. These surveys use a GOV trawl. Trawl samples were quantified to provide estimates of the numbers of each 1cm length class of each species caught at each sample location. Catch numbers were converted to densities by dividing by the area swept by the trawl (mean distance between the wings multiplied by distance the gear was towed). Where wing-spread distance was not known, this was estimated using a depth dependent relationship derived for the standard GOV. Correspondence between the two Irish surveys was relatively weak, although the four abundance/biomass/productivity metric time-series were all significantly correlated. Adding a plus one-year time lag to the Q3 data weakened these four correlations, but strengthened eight of the remaining eleven relationships, rendering the LFI, average ultimate body length, growth rate and length at maturity correlations statistically significant. Twelve of the fifteen correlations between metric time series derived from the NIGS and SWCGS Q1 data sets were positive, and seven of these significantly so (Table S4).

Over the last decade, the abundance, biomass and productivity of the demersal fish community in the Irish Sea have all declined in line with an increase in the proportion of large fish present. At least one of the three surveys indicates an increase in species richness and all three time series suggest that species evenness has increased in recent years. Of the four life-history trait metrics, only age at maturity appears to have increased, while no trend is apparent over the last ten years in the other three metrics. Over the longer term, species diversity (richness and evenness) appears higher now than when data were first available. The four life-history metrics all suggest a shift towards a more mature community. The abundance, biomass and productivity metrics suggest a current situation similar to that prevalent when surveys began, while the proportion of large fish may be higher now than in the 1990s (Figure S5).

Minches and Western Scotland

Scotland operates two surveys in the southwestern part of the Scottish Continental Shelf, the Scottish West Coast Groundfish Surveys (SWCGS) carried out in the fourth (Q4) and first quarters (Q1) of the Year. Data from the Q1 survey were available from 1986 to 2008 and in Q4 from 1996 to 2007. These surveys utilise a Grande Ouverture Verticale (GOV) trawl and sample tows are generally of 30min duration. Trawl samples are quantified to provide estimates of the numbers of each 1cm length class of each species caught at each sample location. Catch numbers were converted to densities by dividing by the area swept by the trawl (mean distance between the wings multiplied

by distance the gear was towed). Where wing-spread distance was not known, this was estimated using a depth dependent relationship derived for the standard GOV.

Trends in each of the community metrics were again generally positively correlated, and the level of correlation tended to be enhanced by the introduction of a 1 year time lag to the Q4 data so that $Q4_{year=x+1}$ was related to $Q1_{year=x}$ (Table S5). Trends in the 15 metrics generally indicate an improving situation for the demersal fish community in the Hebridean Continental Shelf sub-region. Since 2000, the proportion of large fish in the area has increased. Species diversity appears to have increased; both surveys indicate increased evenness of abundance and reduced dominance and the Q4 survey indicates an increase in species richness. Trends in average life-history trait composition in the community are more equivocal; variation was high and little trend was discernable (Figure S6). Over the whole period for which data are available, species evenness and life-history trait composition of the demersal fish community appear to be in better state now than at the beginning of the data time series. There is however, some suggestion that species richness in the sub-region is currently lower than when surveys first began. The abundance/biomass/productivity and size composition aspects of community composition, structure and function appear to be little different now than when data were first available (Figure S6).

Scottish Continental Shelf

This sub-region straddled the boundary between ICES areas IV and VI, and because of this none of the groundfish surveys available for analysis adequately represented the situation across the entire region. Differences in survey design and timing precluded aggregation of the different data sets. It was necessary therefore to further sub-divide the sub-region into two separate areas and assess the state of the demersal fish community in each area using the different survey data sets available.

(Southwest)

Scotland operates two surveys in the southwestern part of the Scottish Continental Shelf, the Scottish West Coast Groundfish Surveys (SWCGS) carried out in the fourth (Q4) and first quarters (Q1) of the Year. Data from the Q1 survey were available from 1986 to 2008 and in Q4 from 1996 to 2007. These surveys utilise a Grande Ouverture Verticale (GOV) trawl and sample tows are generally of 30min duration. Trawl samples are quantified to provide estimates of the numbers of each 1cm length class of each species caught at each sample location. Catch numbers were converted to densities by dividing by the area swept by the trawl (mean distance between the wings multiplied by distance the gear was towed). Where wing-spread distance was not known, this was estimated using a depth dependent relationship derived for the standard GOV.

Trends in each of the community metrics were generally positively correlated, and the level of correlation tended to be enhanced by the introduction of a 1 year time lag to the Q4 data so that $Q4_{year=x+1}$ was related to $Q1_{year=x}$ (Table

S6). Trends in the 15 metrics generally indicate an improving situation for the demersal fish community in the Hebridean Continental Shelf sub-region. Since 2000, the proportion of large fish in the area has increased. Species diversity appears to have increased; both surveys indicate increased evenness of abundance and reduced dominance and the Q4 survey indicates an increase in species richness. The proportion of larger-sized, slow-growing, late-maturing species has increased. As a consequence of these changes, abundance and growth productivity have declined (Figure S7). Over the whole period for which data are available, species evenness and life-history trait composition of the demersal fish community appear to be in better state now than at the beginning of the data time series. The other three aspects of community composition, structure and function appear to be little different now than when data were first available (Figure S7).

(Northeast)

Two main international groundfish surveys, co-ordinated through ICES, the International Bottom Trawl Surveys (IBTS), have been carried out across most of ICES area IV, the North Sea, in the first (Q1) and third (Q3) quarters of each year. The Q1 time series covers the period 1983 to 2008, while the Q3 survey only commenced in 1991 (as a co-ordinated survey) and 2008's survey data were not yet available for analysis. These surveys utilise a Grande Ouverture Verticale (GOV) trawl and sample tows are generally of 30min duration. Trawl samples are quantified to provide estimates of the numbers of each 1cm length class of each species caught at each sample location. Catch numbers were converted to densities by dividing by the area swept by the trawl (mean distance between the wings multiplied by distance the gear was towed). Where wing-spread distance was not known, this was estimated using a depth dependent relationship derived for the standard GOV.

Correspondence between the two survey trends was generally low but, with the exception of the biomass, abundance, productivity and P:B ratio metrics, this was markedly improved by the introduction of a plus 1-year time lag to the Q3 time series (Table S7). Over the last decade, variability in the LFI has increased in both data sets, but generally the data suggest an increase in the proportion of large fish in the community; a result corroborated by the mean weight index. Both data sets suggest that biomass, abundance, productivity and the P/B ratio all declined at first and then increased, so that over the 10 year period no real trend was observed. Similarly, over the recent decade, no obvious trends in the two species richness, three species evenness, and four life-history trait metrics was discernable in either of the two survey time series (Figure S8). Comparison of the current situation with state of the demersal fish community at the start of the time series reveals a similar story. Values of most metrics over the last five years were similar to those observed in the first 8 years when data were available; only species richness appears higher now than during the mid to late 1980s (Figure S8).

Rockall trough and Bank

The Rockall Trough and bank sub-region covers a large area, much of which consists of deeper, non-continental shelf waters. Very little systematic monitoring of fish communities has been carried out in the region and only one set of survey data were available for analysis of trends in the health of the fish community in the region; the Scottish Rockall Groundfish Survey (SRGS). This survey was first undertaken in 1986, but biannual surveys only commenced in 2001, later becoming annual surveys in 2005. 2008 data were not available at the time of writing. The survey essentially operates on the Rockall bank, so does not really cover deep water as such. Some trawl samples were taken from water in excess of 250m depth, but too few for serious analysis. All trawl samples collected from depths >250m were therefore excluded from analysis to avoid these unusual samples influencing the values of the metrics calculated from the rest of the data. The sub-region in which this survey operates is shown in Figure S9, but in essence the trawl samples collected by the SRGS were obtained from a much more restricted area. Being essentially a shallow plateau, the area surveyed is totally unrepresentative of the fish communities that occupy the more wide-spread deeper parts of the sub-region.

The survey utilises a Grande Ouverture Verticale (GOV) trawl and sample tows are generally of 30min duration. Trawl samples are quantified to provide estimates of the numbers of each 1cm length class of each species caught at each sample location. Catch numbers were converted to densities by dividing by the area swept by the trawl (mean distance between the wings multiplied by distance the gear was towed). Where wing-spread distance was not known, this was estimated using a depth dependent relationship derived for the standard GOV.

Trends in the fifteen metrics applied to the SRGS data set suggest that the proportion of large fish on the Rockall plateau has increased in recent years, associated with declines in the abundance, biomass and productivity metrics. Mean fish size appears slightly down. The five species richness and species diversity metrics all suggest increasing trends, but the four life-history trait metrics all imply that the community has become increasingly composed of opportunist rather than climax community species. A similar story emerges with regard to longer-term change in the composition, structure and function of the Rockall Bank demersal fish community, except that recent changes in size composition have simply achieved parity with the earlier data. Given the scarcity data, particularly the gap between 1986 and the start of the systematic surveys in 2001, confidence in these assessments is low (Figure S10).

Tables and Figures

Survey 1	IBTS Q1	IBTS Q1
Survey 2	IBTS Q3	IBTS Q3
Metric	No Lag	1y lag
B	0.300	0.708
N	0.273	0.534
P	0.356	0.755
P/B	0.189	0.824
LFI	-0.104	-0.086
W	0.488	0.836
S	0.315	0.129
S _{Marg}	0.566	0.411
J	0.256	0.478
N1	0.449	0.683
N2	0.370	0.681
L _∞	0.185	0.469
K	0.348	0.427
A _{mat}	0.374	0.546
L _{mat}	0.031	0.693
No. years	17	17

Table S1. Pearson correlation coefficients for comparisons between metric time series derived from the International Bottom Trawl Surveys (IBTS) undertaken in the first (Q1) and third (Q3) quarters of the year in the Northern North Sea sub-region. In columns headed 1y lag, a plus one-year lag was introduced to the Q4 survey time series. The row marked “No years” indicates the number of years overlap between the two series in the correlation analysis. Coefficients in bold are statistically significant ($P < 0.05$) in a one-way test (only positive relationships considered significant).

Survey 1	IBTS Q1	IBTS Q1
Survey 2	IBTS Q3	IBTS Q3
Metric	No Lag	1y lag
B	0.633	0.572
N	-0.118	0.054
P	0.499	0.532
P/B	0.399	0.343
LFI	0.197	0.335
W	0.064	-0.027
S	-0.228	0.522
S _{Marg}	-0.296	0.486
J	-0.422	-0.295
N1	-0.358	-0.147
N2	-0.249	-0.152
L _∞	0.605	0.290
K	-0.096	0.268
A _{mat}	-0.061	-0.027
L _{mat}	0.528	0.372
No. years	17	17

Table S2. Pearson correlation coefficients for comparisons between metric time series derived from the International Bottom Trawl Surveys (IBTS) undertaken in the first (Q1) and third (Q3) quarters of the year in the Southern North Sea sub-region. In columns headed 1y lag, a plus one-year lag was introduced to the Q4 survey time series. The row marked “No years” indicates the number of years overlap between the two series in the correlation analysis. Coefficients in bold are statistically significant ($P < 0.05$) in a one-way test (only positive relationships considered significant).

Survey 1	ESWBTS Q4	ECSGS Q1	ECSGS Q1
Survey 2	FCSGS Q4	FCSGS Q4	FCSGS Q4
Metric	No Lag	No Lag	1y lag
B	-0.241	0.487	-0.307
N	-0.400	-0.254	-0.549
P	-0.700	0.453	0.100
P/B	0.151	-0.011	0.744
LFI	0.697	0.426	0.719
W	-0.278	0.016	-0.317
S	0.783	-0.181	0.463
S _{Marq}	0.631	-0.458	-0.202
J	-0.330	-0.058	-0.487
N1	-0.117	-0.117	-0.442
N2	-0.016	0.147	-0.652
L _∞	-0.033	-0.267	-0.119
K	0.308	0.196	0.217
A _{mat}	0.577	-0.037	0.604
L _{mat}	-0.154	0.225	0.338
No years	5	8	7

Table S3. Pearson correlation coefficients for comparisons between metric time series derived from the French Celtic Sea Groundfish Survey (FCSGS) undertaken in the fourth (Q4) quarter of the year, the English Southwest Bottom Trawl Survey (ESWBTS) undertaken in the fourth (Q4) quarter of the year, and the English Celtic Sea Groundfish Survey (ECSGS) undertaken in the first (Q1) quarter of the year in the Western Channel and Celtic Sea sub-region. In columns headed 1y lag, a plus one-year lag was introduced to the Q4 survey time series. The row marked “No years” indicates the number of years overlap between the two series in the correlation analysis. Coefficients in bold are statistically significant ($P < 0.05$) in a one-way test (only positive relationships considered significant).

Survey 1	NIGS Q1	NIGS Q1	NIGS Q1
Survey 2	NIGS Q3	NIGS Q3	SWCGS Q1
Metric	No Lag	1y lag	No Lag
B	0.602	0.226	0.514
N	0.463	0.295	0.751
P	0.539	0.313	0.599
P/B	0.542	0.300	0.381
LFI	0.180	0.468	-0.298
W	-0.089	0.367	0.016
S	-0.190	-0.440	-0.148
S _{Marg}	-0.025	-0.256	-0.148
J	0.258	0.356	0.740
N1	0.320	0.339	0.717
N2	0.239	0.234	0.551
L _∞	0.141	0.547	0.211
K	0.136	0.586	0.806
A _{mat}	0.236	0.341	0.725
L _{mat}	0.060	0.552	0.468
No years	16	16	11

Table S4. Pearson correlation coefficients for comparisons between metric time series derived from the Northern Irish Groundfish Survey (NIGS) undertaken in the first (Q1) and third (Q3) quarters of the year and Scottish West Coast Groundfish Survey (FCSGS) undertaken in the first (Q1) quarter of the year in the Irish Sea sub-region. In columns headed 1y lag, a plus one-year lag was introduced to the Q3 survey time series. The row marked “No years” indicates the number of years overlap between the two series in the correlation analysis. Coefficients in bold are statistically significant ($P < 0.05$) in a one-way test (only positive relationships considered significant).

Survey 1	SWCGS Q1	SWCGS Q1
Survey 2	SWCGS Q4	SWCGS Q4
Metric	No Lag	1y lag
B	0.323	0.715
N	0.218	0.803
P	0.216	0.768
P/B	0.319	0.350
LFI	0.672	0.584
W	0.003	-0.076
S	-0.494	-0.045
S _{Marg}	-0.138	0.466
J	0.195	0.549
N1	0.334	0.631
N2	0.254	0.660
L _∞	0.248	0.483
K	0.273	0.529
A _{mat}	0.197	0.538
L _{mat}	-0.041	0.103
No. years	10	10

Table S5. Pearson correlation coefficients for comparisons between metric time series derived from the Scottish West Coast Groundfish Survey (SWCGS) undertaken in the first (Q1) and fourth (Q4) quarters of the year in the Minches and Western Scotland sub-region. In columns headed 1y lag, a plus one-year lag was introduced to the Q4 survey time series. The row marked “No years” indicates the number of years overlap between the two series in the correlation analysis. Coefficients in bold are statistically significant ($P < 0.05$) in a one-way test (only positive relationships considered significant).

Survey 1	SWCGS Q1	SWCGS Q1
Survey 2	SWCGS Q4	SWCGS Q4
Metric	No Lag	1y lag
B	0.559	0.574
N	0.330	0.268
P	0.619	0.539
P/B	0.428	0.641
LFI	0.251	0.502
W	0.443	0.657
S	-0.350	-0.677
S _{Marg}	-0.043	0.130
J	0.460	0.500
N1	0.575	0.579
N2	0.488	0.661
L _∞	0.242	0.376
K	0.249	0.435
A _{mat}	0.527	0.500
L _{mat}	0.224	0.335
No. years	10	10

Table S6. Pearson correlation coefficients for comparisons between metric time series derived from the Scottish West Coast Groundfish Survey (SWCGS) undertaken in the first (Q1) and fourth (Q4) quarters of the year in the southwestern sector of the Scottish Continental Shelf sub-region. In columns headed 1y lag, a plus one-year lag was introduced to the Q4 survey time series. The row marked “No years” indicates the number of years overlap between the two series in the correlation analysis. Coefficients in bold are statistically significant ($P < 0.05$) in a one-way test (only positive relationships considered significant).

Survey 1	IBTS Q1	IBTS Q1
Survey 2	IBTS Q3	IBTS Q3
Metric	No Lag	1y lag
B	0.198	-0.136
N	0.358	0.095
P	0.392	-0.077
P/B	0.631	0.519
LFI	0.106	0.345
W	0.224	0.497
S	-0.058	0.060
S _{Marg}	0.128	0.220
J	-0.012	0.690
N1	0.037	0.613
N2	-0.157	0.444
L _∞	-0.320	0.120
K	-0.307	0.119
A _{mat}	-0.159	0.065
L _{mat}	-0.444	0.034
No. years	17	17

Table S7. Pearson correlation coefficients for comparisons between metric time series derived from the International Bottom Trawl Surveys (IBTS) undertaken in the first (Q1) and third (Q3) quarters of the year in the northwestern sector of the Scottish Continental Shelf sub-region. In columns headed 1y lag, a plus one-year lag was introduced to the Q4 survey time series. The row marked “No years” indicates the number of years overlap between the two series in the correlation analysis. Coefficients in bold are statistically significant ($P < 0.05$) in a one-way test (only positive relationships considered significant).

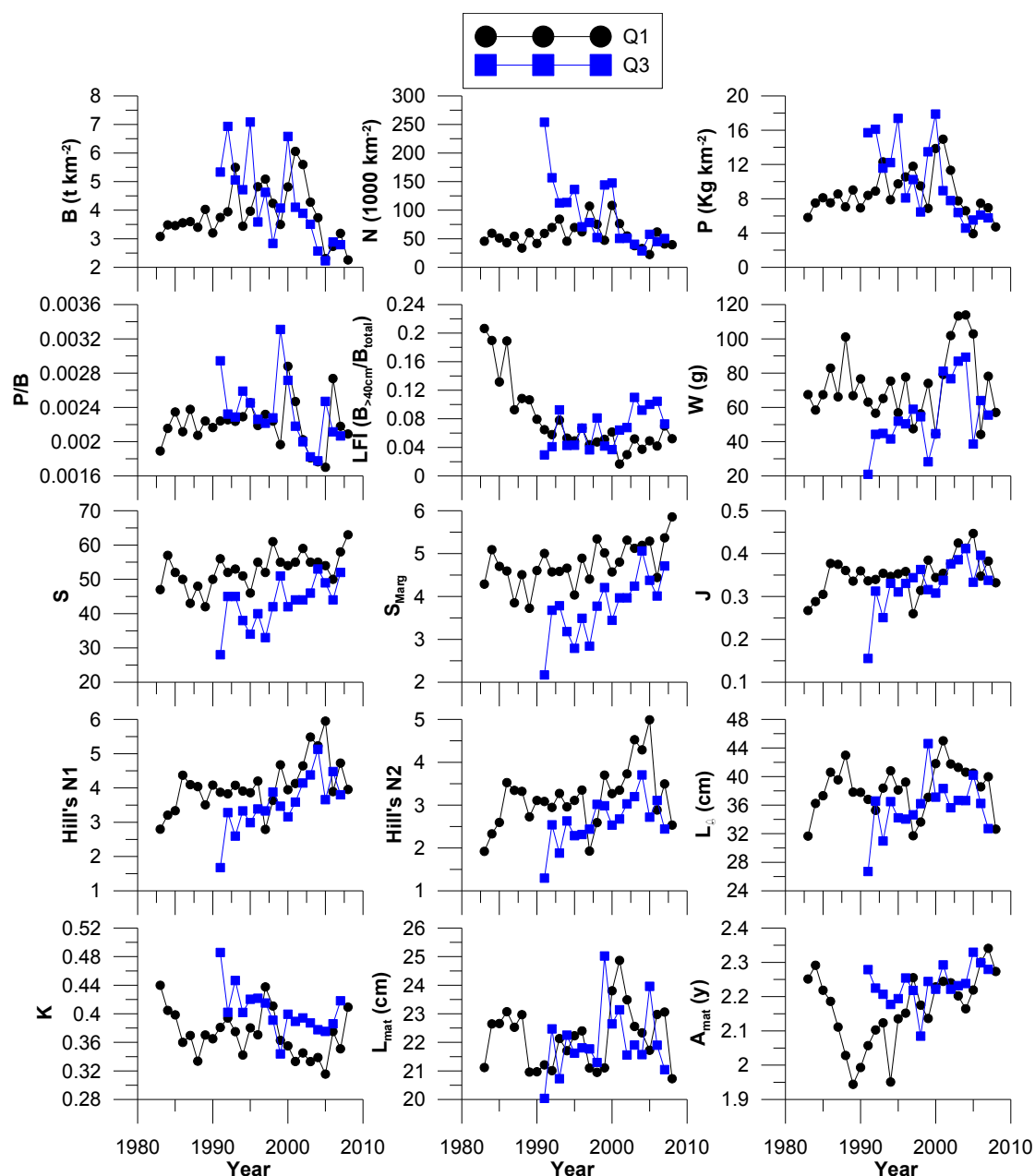


Figure S1. Trends in fifteen metrics quantifying different aspects of the composition, structure and functioning of the demersal fish assemblage in the Northern North Sea sub-region. Metrics are applied to data derived from ICES co-ordinated International Bottom Trawl Surveys carried out in the first (Q1) and third (Q3) quarters of the year. See Table 1 (in main body of report) for explanation of metrics (y axis labels).

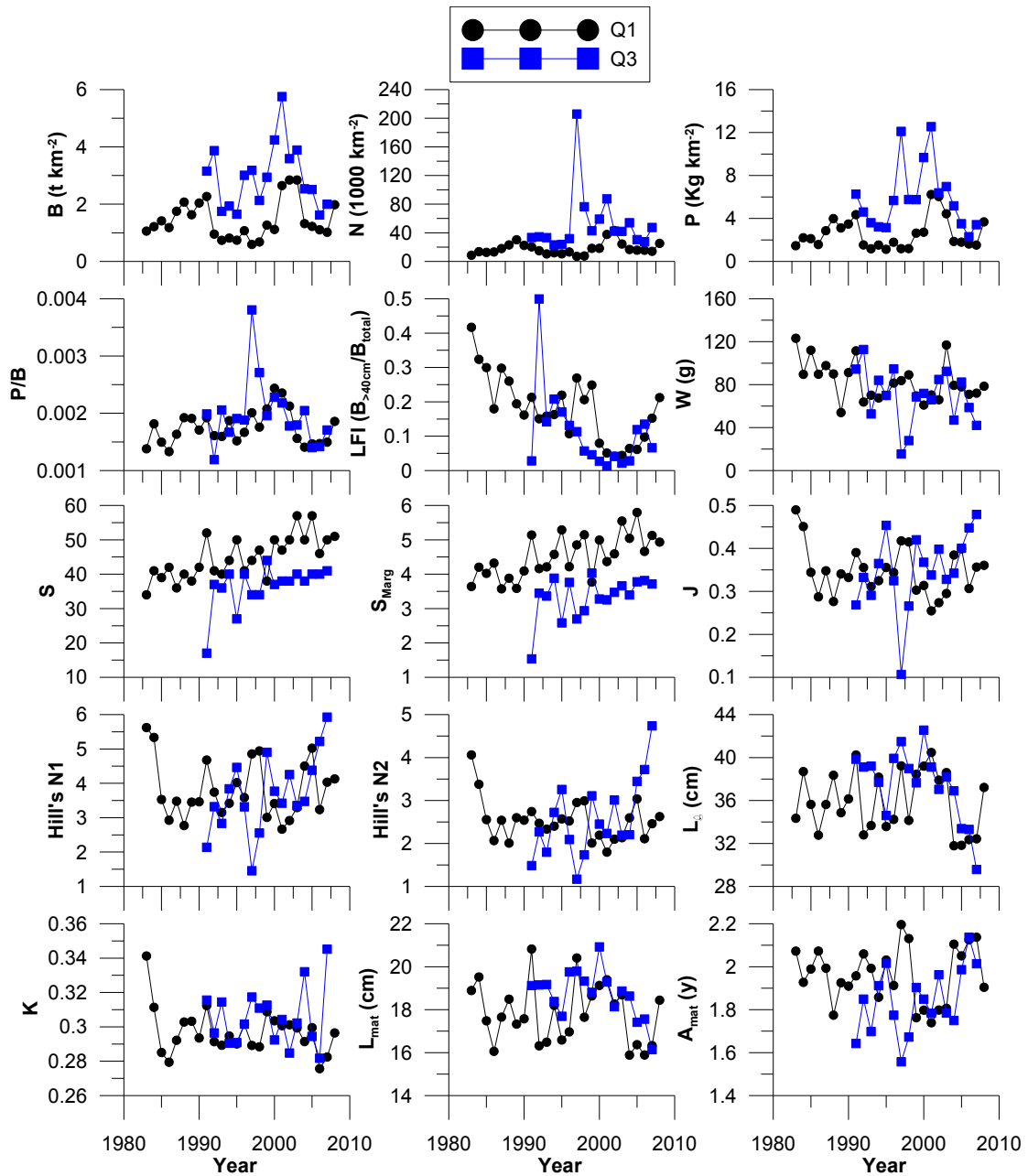


Figure S1. Trends in fifteen metrics quantifying different aspects of the composition, structure and functioning of the demersal fish assemblage in the Southern North Sea sub-region. Metrics are applied to data derived from ICES co-ordinated International Bottom Trawl Surveys carried out in the first (Q1) and third (Q3) quarters of the year. See Table 1 (in main body of report) for explanation of metrics (y axis labels).

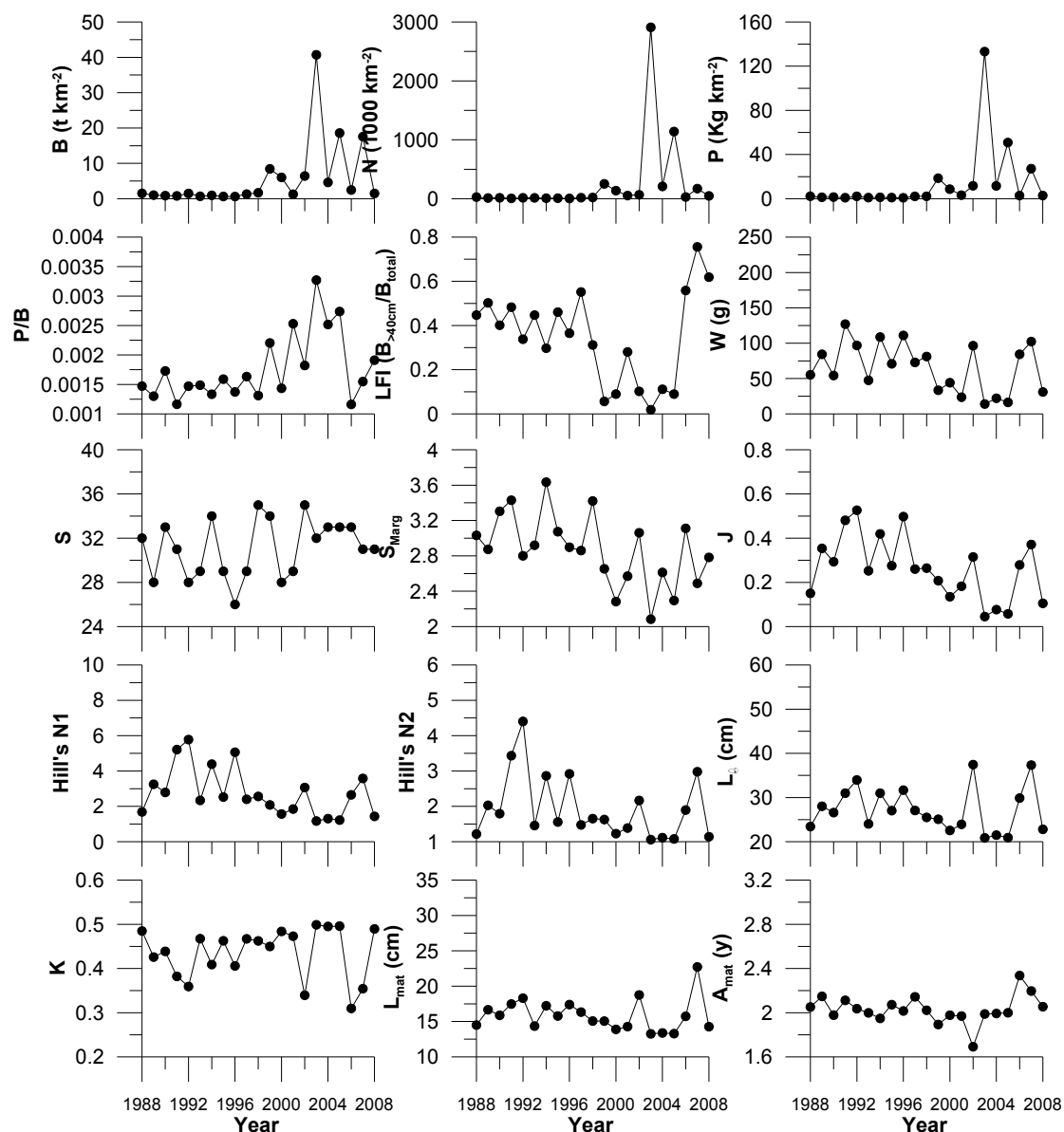


Figure S3. Trends in fifteen metrics quantifying different aspects of the composition, structure and functioning of the demersal fish assemblage in the Eastern Channel sub-region. Metrics are applied to data derived from French Groundfish Survey of the Channel (FGSC) carried out in the fourth (Q4) quarter of the year. See Table 1 (in main body of report) for explanation of metrics (y axis labels).

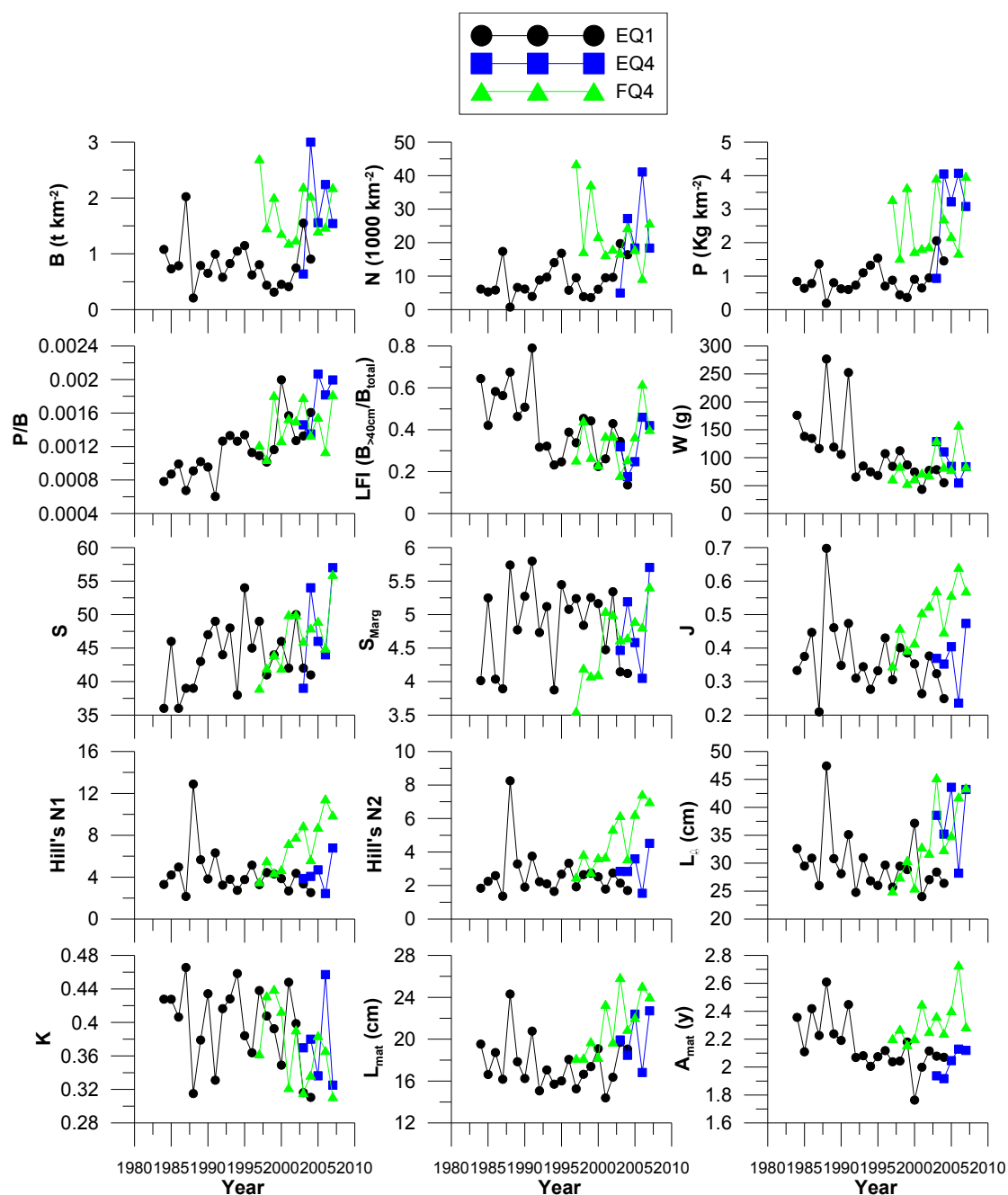


Figure S4. Trends in fifteen metrics quantifying different aspects of the composition, structure and functioning of the demersal fish assemblage in the Western Channel and Celtic Sea sub-region. Metrics are applied to data derived from ICES co-ordinated International Bottom Trawl Surveys carried out in the first (Q1) and third (Q3) quarters of the year. See Table 1 (in main body of report) for explanation of metrics (y axis labels).

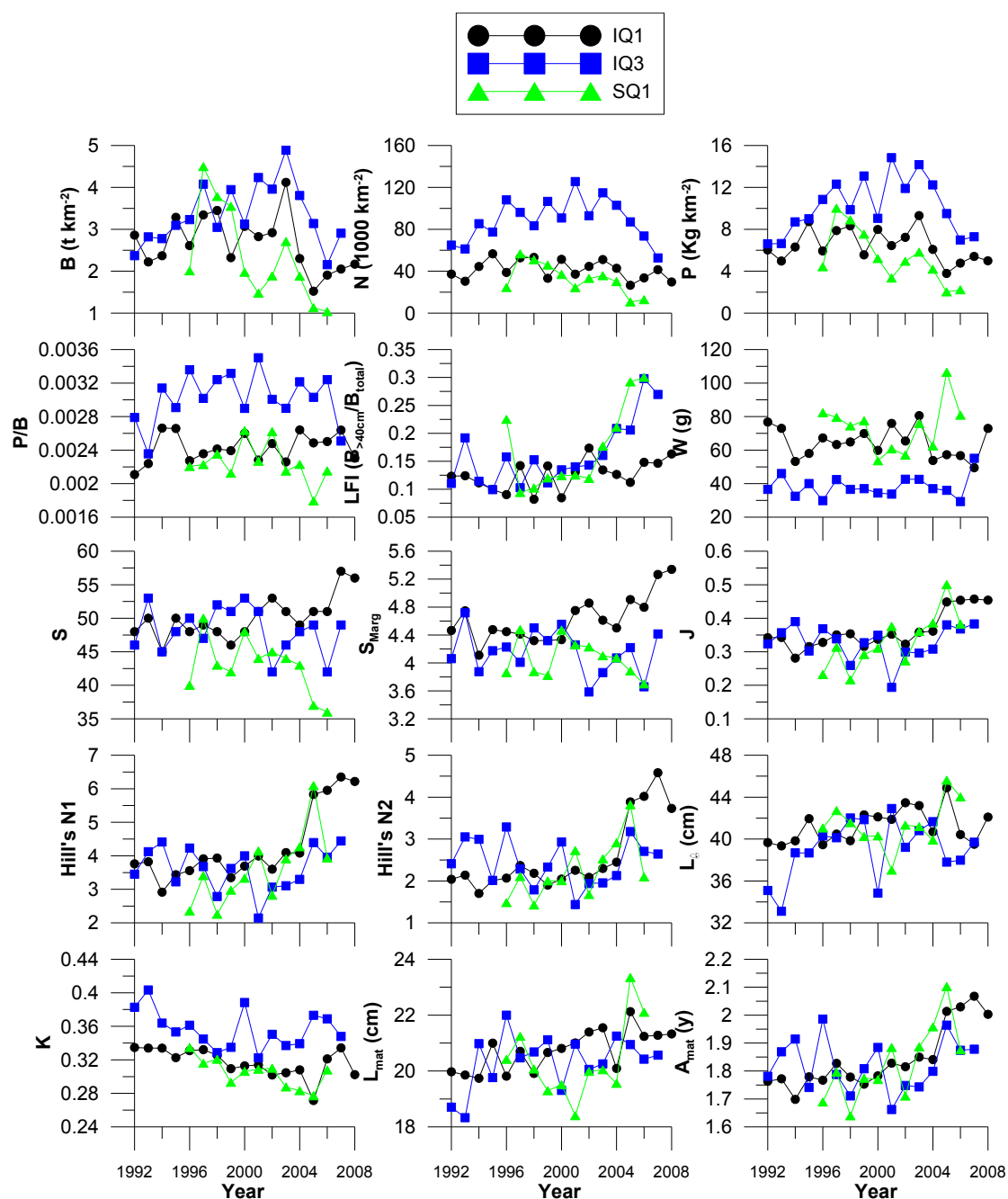


Figure S5. Trends in fifteen metrics quantifying different aspects of the composition, structure and functioning of the demersal fish assemblage in the Irish Sea sub-region. Metrics are applied to data derived from ICES co-ordinated International Bottom Trawl Surveys carried out in the first (Q1) and third (Q3) quarters of the year. See Table 1 (in main body of report) for explanation of metrics (y axis labels).

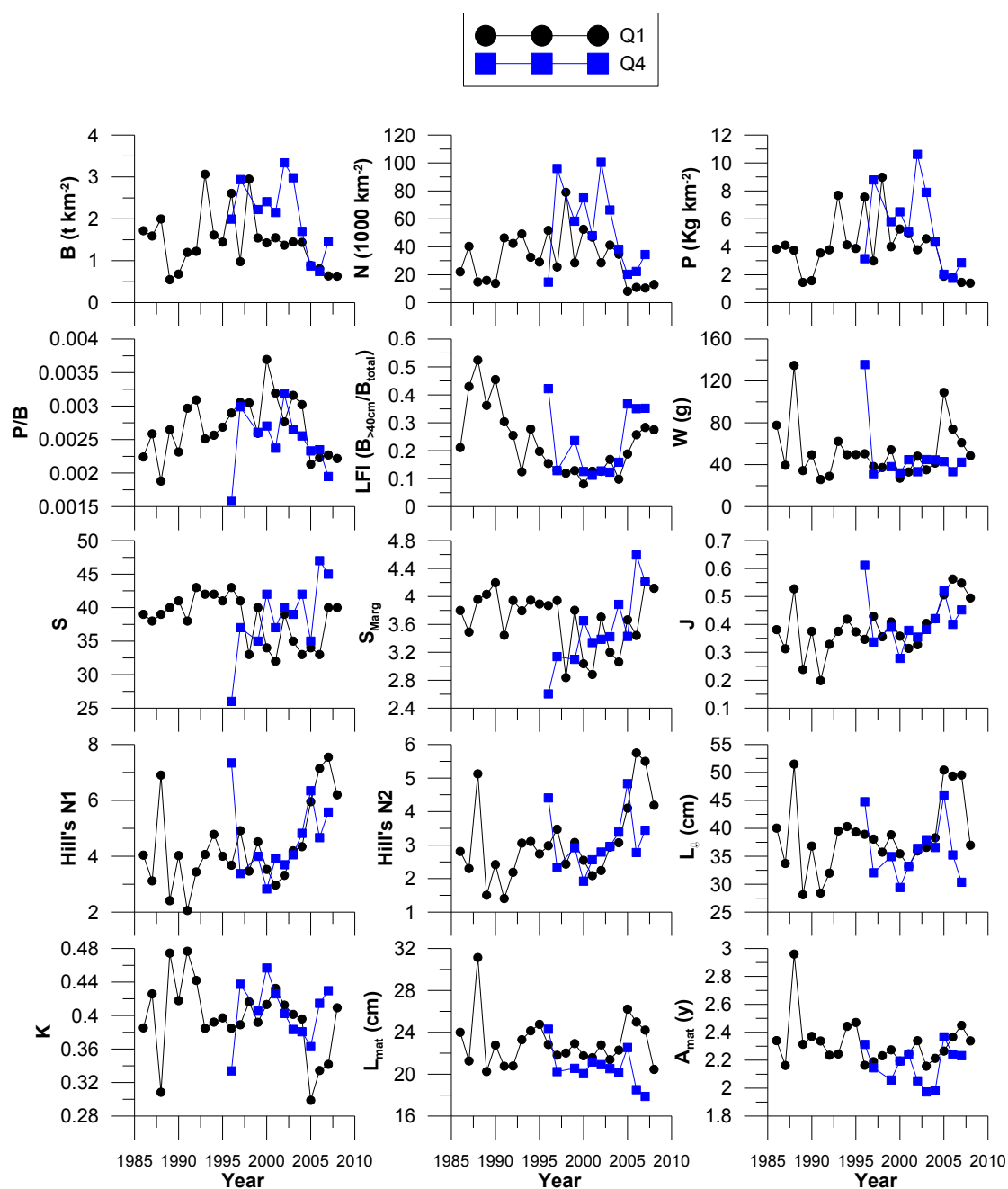


Figure S6. Trends in fifteen metrics quantifying different aspects of the composition, structure and functioning of the demersal fish assemblage in the Minches and Western Scotland sub-region. Metrics are applied to data derived from Scottish West Coast Groundfish Surveys carried out in the fourth (Q4) and first (Q1) quarters of the year. See Table 1 (in main body of report) for explanation of metrics (y axis labels).

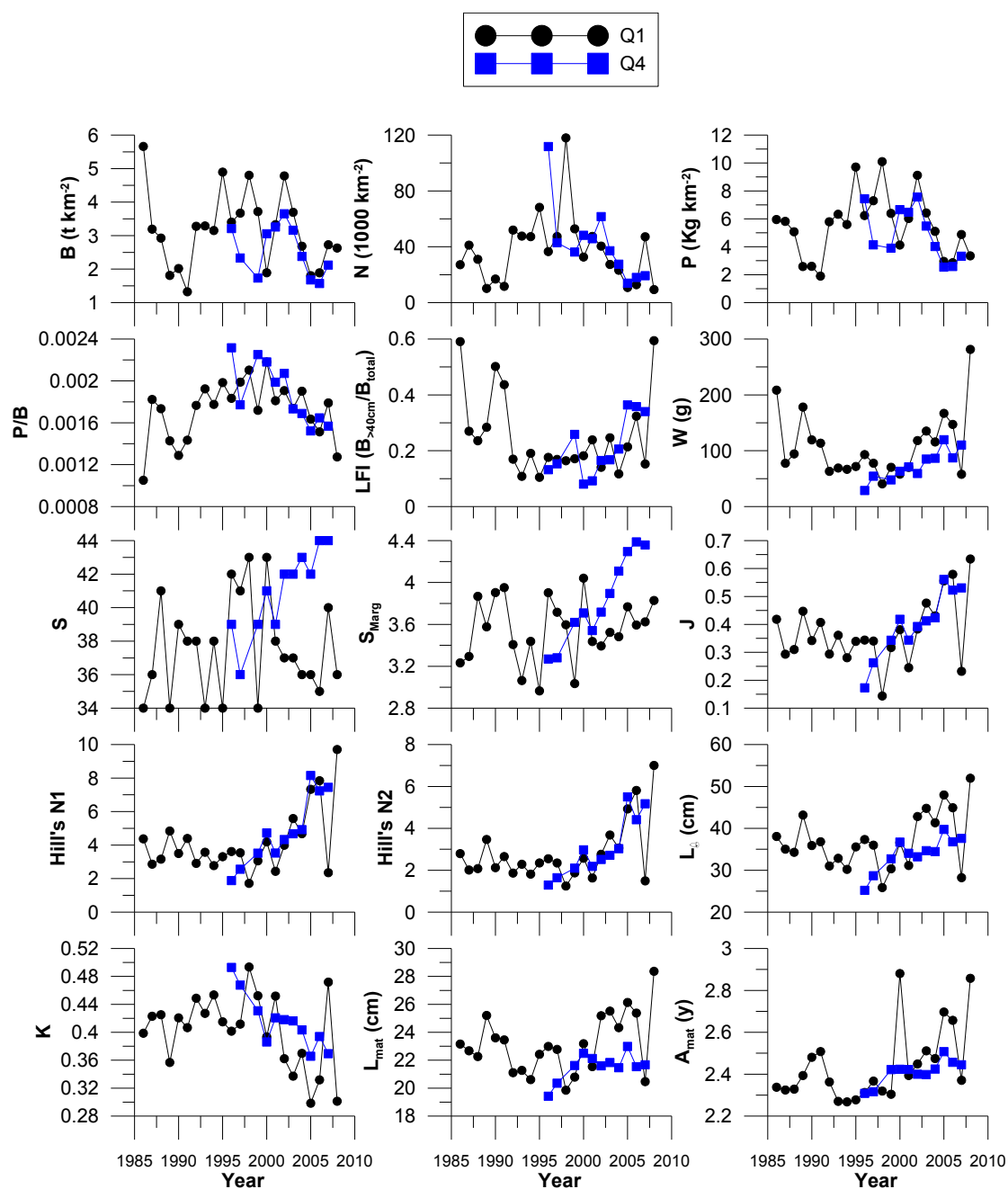


Figure S7. Trends in fifteen metrics quantifying different aspects of the composition, structure and functioning of the demersal fish assemblage in the southwestern sector of the Scottish Continental Shelf sub-region. Metrics are applied to data derived from Scottish West Coast Groundfish Surveys carried out in the fourth (Q4) and first (Q1) quarters of the year. See Table 1 (in main body of report) for explanation of metrics (y axis labels).

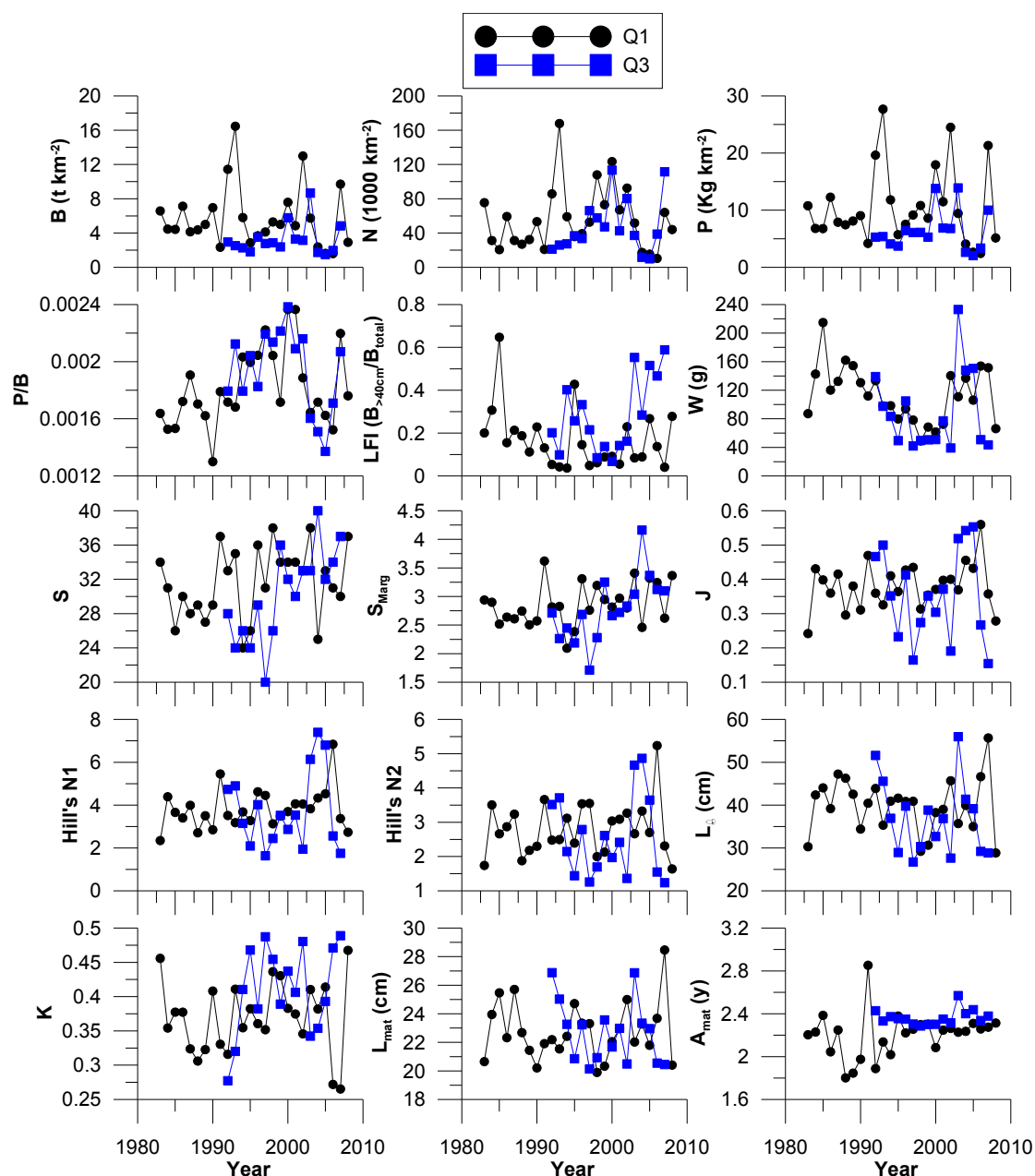


Figure S8. Trends in fifteen metrics quantifying different aspects of the composition, structure and functioning of the demersal fish assemblage in the northeastern sector of the Scottish Continental Shelf sub-region. Metrics are applied to data derived from ICES co-ordinated International Bottom Trawl Surveys carried out in the first (Q1) and third (Q3) quarters of the year. See Table 1 (in main body of report) for explanation of metrics (y axis labels).

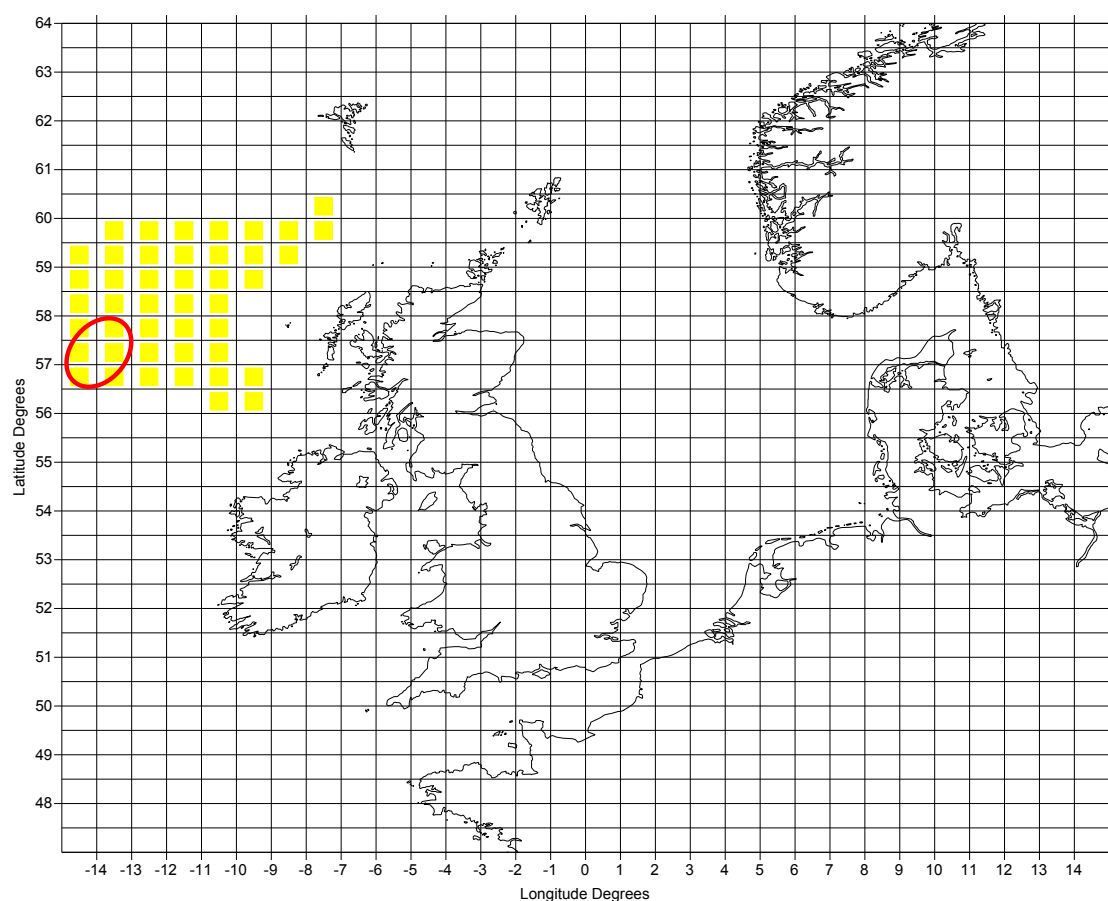


Figure S9. Rockall Trough and Bank sub-region covered by the SRGS. Circle indicates the plateau region covered by the survey, and for which data are analysed in this annex.

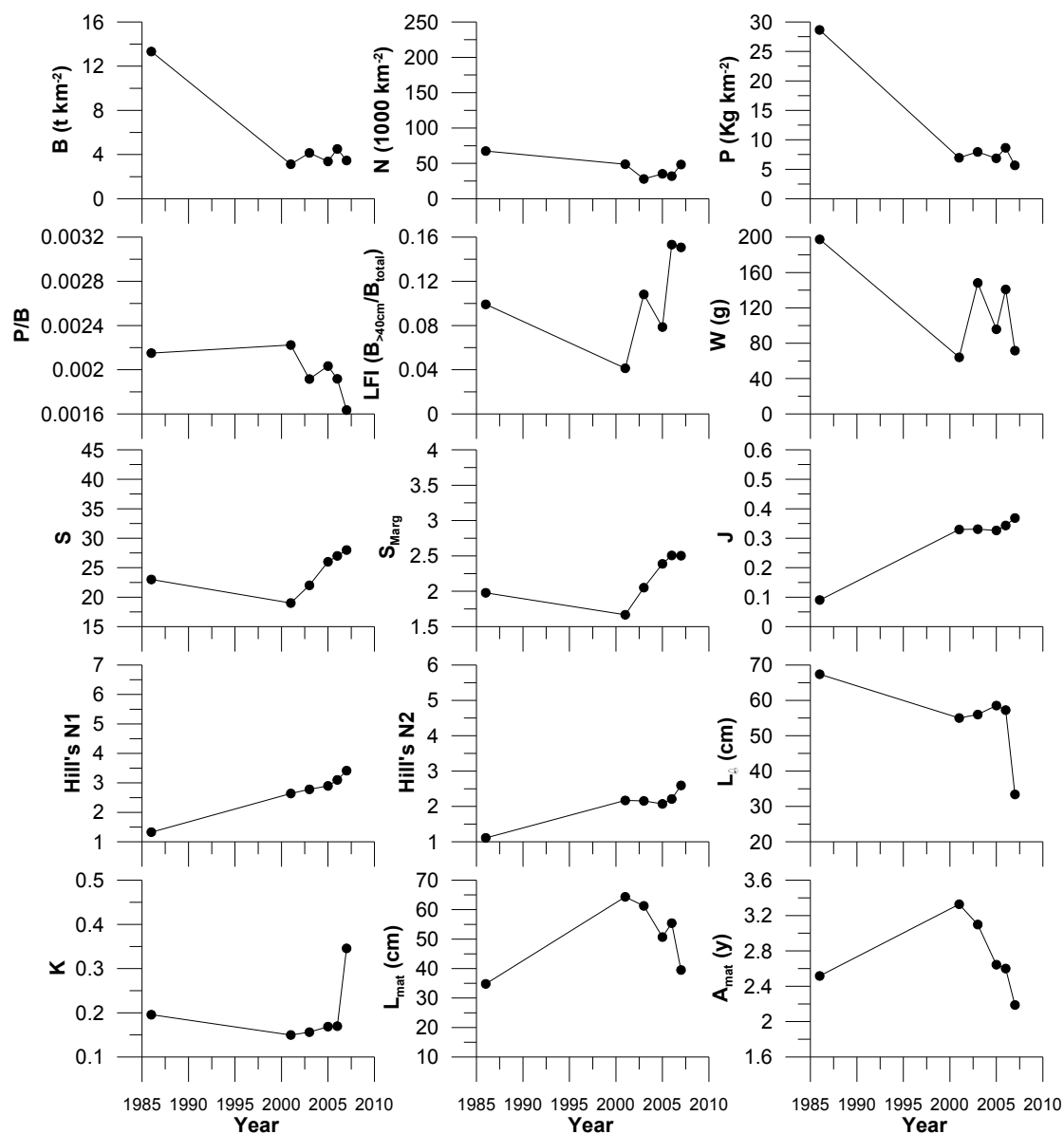


Figure S10. Trends in fifteen metrics quantifying different aspects of the composition, structure and functioning of the demersal fish assemblage in the Rockall sub-region. Metrics are applied to data derived from Scottish Rockall Groundfish Surveys carried out in the third (Q3) quarter of the year. See Table 1 (in main body of report) for explanation of metrics (y axis labels).