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Long-term changes in the benthic communities on North Sea fishing grounds

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The North Sea has been subjected to fishing activity for many centuries. However, improvements in both fishing vessels and trawling gears since the early 1900s have meant that fishing intensity has increased. A resultant increase in the areas trawled and the use of heavier and potentially more destructive gears probably had effects on the marine community. Information on benthic communities within the North Sea, from both published and unpublished sources, has been compiled to provide a long-term data set of changes in the marine benthos on five selected fishing grounds over 60 years. In two of these (Dogger Bank and Inner Shoal), there was no significant difference in community composition between the early 1920s and late 1980s. In the remaining three areas (Dowsing Shoal, Great Silver Pit, and Fisher Bank) significant differences were observed. However, these were the result of changes in abundance of many taxa rather than large-scale losses of sensitive organisms. These results suggest that fishing has influenced benthic communities in the North Sea. The possibility remains that fishing-induced changes had occurred at the Dogger Bank and Inner Shoal prior to the 1920s.

Key words: benthos, broad scale, community structure, fishing, impacts, indirect effects, long-term, North Sea.

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Introduction

In marine ecosystems fishing represents the biggest anthropogenic impact (Dayton *et al*., 1995), is widespread, and has occurred since pre-history (Desse and Desse-Berset, 1993). Fishing impacts the populations of target species, other species captured in the net (the by-catch), and potentially all the other species in the community with whom they interact (Dayton *et al*., 1995). In addition, bottom fishing gears impact on the sea floor, causing mortality and injury to surface-living and shallowly-buried fauna (Tuck *et al*., 1998), altering physical habitat features (Auster *et al*., 1996), sedimentation (Churchill, 1989), and nutrient cycling (Mayer *et al*., 1991). In the short term such disturbed areas may attract mobile scavengers and predators (Kaiser and Spencer, 1994). It is difficult to assess the impact of these changes at the scale of the ecosystem (Thrush *et al*., 1998) and the lengthy time scales over which exploitation has occurred.

It has been suggested that there have been long-term changes in benthic communities of the North Sea (Reise, 1982). Several causes have been proposed such as the impacts of towed fishing gears, especially on the heavily fished areas of the eastern and southern North Sea, along with the effects of climatic and salinity fluctuations, eutrophication, and changes in zooplankton abundances. However, further evidence is required to determine whether anthropogenic influences, as opposed to natural or cyclical events affecting the benthos, are responsible for any changes, if indeed any real changes have occurred.

Establishing whether long-term changes have occurred in the benthos of the North Sea, requires

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Table 1. Data sources, mesh size used, and number of sample locations in each ICES statistical rectangle: 35F1, Dowsing Shoal; 36F1, Great Silver Pit; 38F2, Dogger Bank; 40F4, Inner Shoal; 41F5, Fisher Bank (see Fig. 1).

Source	Mesh size (mm)	ICES rectangle 35F1	36F1	38F2	40F4	41F5
Davis (1923, 1925)	15, 5, 1.5	5	2	77	24	112
ICES (1986)	0.5		1	3	4	4
SHELL Barque (1988)	1, 0.5		13			
SHELL Clipper (1988)	1, 0.5	12				
C&M Coal Pit (1993)	0.5		20			
BP Hyde (1992)	0.5		21			

analysis of historical data, whether these are times-series data or occasional samples. Several studies have been carried out over the past 150 years, which may prove suitable for such comparisons. These range from local fauna collections by amateurs through sampling exercises across the whole of the North Sea (for example, the 1986 benthic survey; Duineveld *et al*., 1991).

The first collectors of comprehensive amounts of data were amateur naturalists. Subsequent professional collectors used adapted oyster dredges as sampling devices, introduced by O. F. Müller in 1773 (Petersen, 1918). Möbius and Bütschli (1875) and Michaelsen (1896) used such devices to collect data across the whole of the North Sea. Dredging expeditions undertaken by fisheries laboratories, and also by individual enthusiasts, resulted in numerous descriptions of benthic communities (Johnston, 1835; Alder, 1854; Hodge, 1871; McIntosh, 1875; Henderson, 1884). However, such records often came from the easily accessible intertidal and inshore ares. Data from fishing grounds are available when unusual finds were landed by fishermen or when the by-catch was brought ashore for natural historians. The quality of data provided by historic sampling exercises is variable. This is caused by the limited expertise of the earliest workers, and differences in taxonomic nomenclature over time. Direct comparison of data sets can be difficult as a result of differences in sampling techniques, sample treatment methods, and short-term natural variability in benthic population densities.

Later investigations were more reliable owing to the adoption of quantitative sampling. Quantitative gear was pioneered by Petersen, who used a device attached to a pole to sample areas 0.1 m^2 and 60–80 mm deep as early as 1896 (Petersen and Boysen-Jensen, 1911), but this work was carried out in the Limfjord and Kattegat, and not in the open North Sea. More studies were continued with heavier apparatus, 40 kg in weight, in the period 1908–1910 (Petersen, 1918). This device was capable of being suspended from a cable to allow samples to be taken in deeper water. Boysen-Jensen (1919) and Blegvad (1930) also carried out studies with this gear, mostly in the Skaggerak, Kattegat, Limfjord, and German Bight (see also Hagmeir, 1925).

Blegvad (1922) took samples along a transect across the North Sea and later carried out extensive research in the central part. This work was published by Davis (1923, 1925). Stephen (1923, 1930, 1933) also took grab samples in the period 1922–1925.

More recent samples have been taken by a number of workers (McIntyre, 1958; Buchanan, 1963; Salzwedel *et al*., 1985). However, the greatest amount of offshore sampling in the 1970s, 1980s, and 1990s has undoubtedly resulted from benthic studies prior to the installation of oil and gas rigs and when applying for sand and gravel extraction licences. Although many of these data sets are not in the public domain, it has been possible to obtain data from three studies from the oil and gas industry, and one pre-gravel dredging survey.

This study sets out to assess the extent of changes in the benthic communities in five regions of the North Sea where fishing has increased during the period considered. Five ICES statistical squares containing fishing grounds, where samples were taken across time, were selected (names are taken from Lee and Ramster, 1981): 35F1, Dowsing Shoal; 36F1, Great Silver Pit; 38F2, Dogger Bank: 40F4, Inner Shoal; and 41F5, Fisher Bank. The number of samples, and the original source of the data obtained in these areas, are given in Table 1.

At each location quantitative data are available for the period immediately after World War One and after the peak in fish landings in the late 1980s. Comparisons are initially made at the community level and subsequently at the level of individual taxa identified as being potentially sensitive and responsive to fishing disturbance (MacDonald *et al*., 1997; Thrush *et al*., 1998).

Methods

Literature searches and extensive personal contacts were used to assemble a database of North Sea benthic data sets. Data sets were characterized by location, date of sampling, number of samples, gear and mesh size used, and by quantitative vs. presence/absence data. For the analyses presented here quantitative data with multiple sample locations before 1925 and after 1978 were selected. Multiple sample locations within an ICES statistical rectangle were used to gain information on the spatial variability. Benthic communities are to a large extent controlled by the physical environment – sediment grain size, organic content, and depth (Pearson and Rosenberg, 1986). The use of multiple locations therefore serves as a means of gauging the variability of the benthos attributable to these factors (Thrush *et al.*, 1998).

These criteria yielded the surveys and locations given in Table 1. Given the diversity of sources used and changes in sampling techniques, consideration must be given to means of reducing the influences of technique on the data. Two approaches have been adopted. First, a conservative approach was applied to determining change, where multiple samples (i.e., replicate grabs were available) are used to derive mean values for a location and then multiple locations are used to define the "benthos of the ICES rectangle". Changes over time in this aggregate benthos are assessed. Secondly, the four principal problems were reduced pragmatically. These were identified as: (i) changes in sampling gear; (ii) changes in sample processing (principally mesh size used); (iii) changes in taxonomy; and (iv) seasonal effects.

Several comparisons of different sampling gears have been carried out (see for bibliography, Holme and McIntyre, 1984). In North Sea studies, the most commonly used grabs have been the van Veen, Smith-McIntyre, Day, and Petersen grabs, which in most sediments show similar performance (Holme and McIntyre, 1984). Two sizes have commonly been employed, 0.2 and 0.1 m^2. We express all abundances as individuals per square metre and restrict analysis to the more abundant (>5% of individuals in a sample) species and so overcome the difference in sampling efficiencies of the two sampler areas.

The treatment of samples tends to differ widely between surveys. In the earliest surveys, meshes with apertures of up to 1.5 mm were used (Davis, 1923). Subsequent surveys have used smaller meshes with apertures of around 1 mm, but aperture sizes of 0.5 mm employed in more recent surveys were adopted by many workers as late as the 1970s. The problem of comparing data derived using different meshes has long been recognized (Mare, 1942; Reish, 1959). For example, Rees (1984) noted that a 1 mm mesh retained 77% of the individuals and 69% of the species recorded on a 0.5 mm mesh. At present there appears to be no satisfactory way of predicting, using data derived from a small mesh, what would have been sampled by a larger mesh. The sensitivity of our analyses to the differences in mesh sizes used was determined in two ways. First, data were obtained from a 1988 baseline survey of the Clipper field. This 12-station survey used both 1 mm and 0.5 mm meshes on the same samples and recorded the data separately. This allowed a direct comparison between the data collected in the area by Davis on a 1.5 mm mesh in the 1920s and the 1.0 mm data set collected in 1988 (the Barque survey also used two mesh sizes but only aggregated data were available). Secondly, in our comparisons of data sets derived from both 1.5 mm and 0.5 mm meshes any "not significant" differences over time were assumed to indicate that differences arising due to the different mesh sizes were less than the range of differences between stations within the ICES rectangle.

To reduce inconsistencies in taxonomy, all species data were coded by Howson (1987) species codes; any species names not coded were regarded as synonyms and appropriate taxonomic works were consulted to find the correct designation. Given the difficult taxonomy of some groups at the species level and to reduce problems caused by changing taxonomy, data were combined at the genera level prior to analysis. Such aggregation of data has been shown to cause minimal loss of information when assessing impacts (Somerfield and Clarke, 1995).

Seasonality is controlled for at all sites by only making comparisons between samples collected around the same period of the year, defined as three calendar months.

For each ICES statistical rectangle, comparisons were made of changes in the generic composition of the community by means of non-metric multi-dimensional scaling (MDS) (Clarke and Warwick, 1994) on the transformed (double square root) genera abundance matrix after removal of rare (<5% of individuals in any sample) genera. Subsequently, comparisons (Kruskall-Wallis tests) were made of the abundance of individual genera, which might be considered as sensitive (MacDonald *et al.*, 1997) or opportunistic and hence benefiting from disturbance by fishing gears.

Results

Cluster analysis (Bray-Curtis similarity) followed by non-metric multi-dimensional scaling showed distinct differences between samples from the 1920s and those post-1985 in three of the five rectangles (Fig. 2).

The principal confounding factor in these analyses was the discrepancy in mesh size used. This effect will have been reduced by removal of the rare species whilst the use of double root transformations will have reduced any subsequent influence of changes in absolute abundances. The lack of a significant (ANOSIM, $p>0.05$) difference across time at the Dogger Bank and Inner Shoal confirms that the analysis as applied was not

Table 2. The significance of changes in abundance (Kruskall–Wallis) between the 1920s and 1986–1993 for taxa (adult size indicated) which contributed more than 2% to the dissimilarity (Bray-Curtis) in the genera composition of macrobenthos in three ICES rectangles (35F1, Dowsing Shoal; 36F1, Great Silver Pit; and 41F5, Fisher Bank; n.s., not significant; —, not recorded).

Taxa	Adult size (mm)	35F1	36F1	41F5
Exogone	10	0.001	n.s.	—
Glycera	75	0.003	n.s.	—
Hesionidae	75	0.001	n.s.	—
Nemertea		0.001	0.015	<0.001
Nephtys	>100	0.001	0.004	—
Oligochaeta		0.001	n.s.	—
Ophelia	15	0.001	n.s.	<0.001
Scoloplos	20	—	0.007	<0.001
Spiophanes	60	—	0.030	<0.001

Table 3. The significance of changes in abundance (Kruskall–Wallis) between the 1920s and 1986–1993 for taxa considered *a priori* to be sensitive to fishing or opportunistic in behaviour (Bray-Curtis) in three ICES rectangles (see legend to Table 2).

Taxa	35F1	36F1	41F5
"Sensitive" species			
Cnidaria	n.s.	n.s.	0.001
Arctica	—	n.s.	0.012
Echinocardium	n.s.	n.s.	n.s.
Echinocyamus	0.001	n.s.	—
Sabella	n.s.	n.s.	n.s.
"Opportunistic" species			
Capitella	0.001	n.s.	0.012
Notomastus	n.s.	n.s.	<0.001

strongly influenced by the shift from 1.5 to 0.5 mm mesh. In two of the rectangles, Great Silver Pit and Fisher Bank, where significant shifts (ANOSIM $p=0.001$ and $p=0.039$, respectively) in community composition had occurred over time, the comparisons were also based on data from 1.5- and 0.5-mm mesh. At Dowsing Shoal there was also a significant shift in composition based on the comparison of data derived from 1.5 and 1.0 mm. This pattern of changes does not appear, therefore, to be a response to mesh size used in sample processing.

Some 35 taxa contributed more than 2% to the dissimilarity between sample groups in at least one of the three rectangles showing temporal changes. Of these, nine taxa made a contribution of more than 2% to the dissimilarity in two or more areas (Table 2). Two were multi-generic taxa with individuals ranging in size, but the remaining seven were genera in which the majority of adult specimens would be retained even by the larger mesh used. In all cases where the change in abundance was significant (Table 2), abundances were higher in the later surveys.

Five taxa were considered *a priori* to be sensitive to fishing impacts (Table 3). These were burrowing echinoderms, slow-growing bivalves (*Arctica*), and structure-building species (sea pens and *Sabella*). In only three out of the 13 valid comparisons did they show a significant change in abundance over time, and in each case they increased in abundance. Of the two opportunistic taxa (the polychaetes *Capitella* and *Notomastus*), there was a significant increase in both taxa on the Fisher Bank, no significant change in either species in the Great Silver Pit, and a significant increase in *Capitella* at Dowsing Shoal (Table 3). Given the small body size of *Capitella* and the fragility of *Notomastus*, these changes must be treated with caution.

Discussion

The existence of short-term, small-scale changes in the benthos following fishing is well established (Dayton *et al.*, 1995; Thrush *et al.*, 1995; Kaiser *et al.*, 1997; Ramsay *et al.*, 1998). The difficulty of extending the findings of these types of study to the time and spatial scales of fishing is also recognized (Thrush *et al.*, 1998). We have used the limited amount of data available from around the time the North Sea fleet was mechanized to consider whether changes in the benthos of fishing grounds have occurred over the long term. We conclude that in three of the five areas considered there is definite evidence for a shift in the composition of the benthos over the last 60 years, concurrent with the increase in catching power of the fleet.

That no significant changes were detected in the other two areas is seen as confirmation that the checks and balances employed have been conservative and the differences are not an artefact of the different sampling protocols used. Given the high levels of fishing activity on the Dogger Bank, it seems feasible that the lack of change is not indicative of an absence of impact, but that

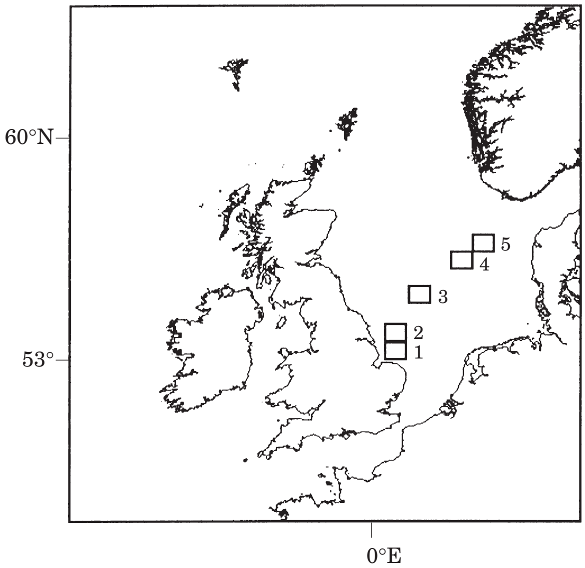

Figure 1. Locations of the ICES statistical rectangles used: 1. 35F1 – Dowsing Shoal; 2. 36F1 – Great Silver Pit; 3. 38F2 – Dogger Bank; 4. 40F4 – Inner Shoal; and 5. 41F5 – Fisher Bank.

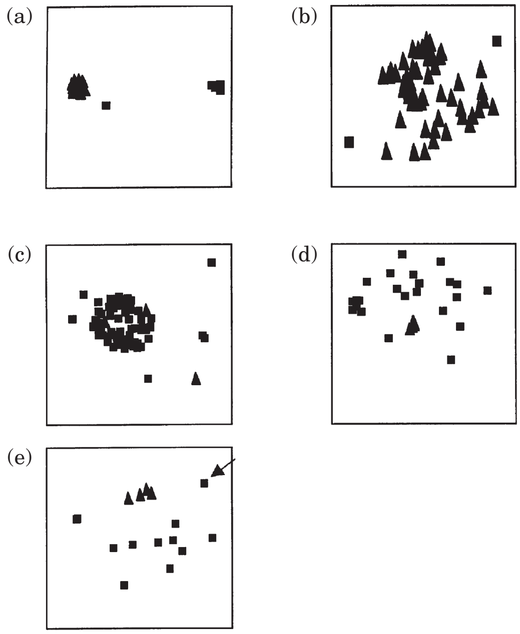

Figure 2. MDS ordinations of the similarity in the composition of the macrobenthic community between the 1920s (▲) and after 1986 (■) in five ICES statistical rectangles. (a) 35F1, Dowsing Shoal, stress=0.0.01. (b) 36F1, Great Silver Pit, stress=0.20. (c) 38F2, Dogger Bank, stress=0.33. (d) 40F4, Inner Shoal, stress=0.17. (e) 41F5, Fisher Bank, stress=0.12. Arrowed sample had a similarity (Bray Curtis) to the remaining samples of <5%.

such impacts had already occurred prior to 1923. This may also be true for Inner Shoal. Developments in analytical techniques may in future allow further information to be gained from these and other historic data sets, which may provide information on the previous ecological status of our coastal seas (Frid and Hall, 2000).

While there were clear differences in the composition of the benthic community at three of the five areas considered, these changes were not driven by the disappearance of sensitive taxa or the increase in opportunistic taxa. Short-term experimental studies have demonstrated profound effects on certain taxa (Thrush *et al*., 1995, 1997; Kaiser *et al*., 1997; Ramsay *et al*., 1998; Tuck *et al*., 1998), generally slow growing fragile species (MacDonald *et al*., 1998).

We considered five taxa as being potentially sensitive, and none showed significant decreases in abundance. While impacts by the gear are undoubtedly catastrophic for the injured individual they do not appear to be significant at the larger scale. This may be the result of the population being sustained by individuals persisting in patches not impacted by gears even in areas heavily fished (Kaiser *et al*., 1997, Rijnsdorp *et al*., 1998).

The dead and injured fauna left on the sea floor or exposed in trawl tracks, and the addition to the benthos of offal and dead/moribund by-catch, increases opportunities for mobile scavenger/predators (Kaiser and Spencer, 1994; Kaiser and Ramsay, 1997). The continual disturbance of the sea floor may also benefit opportunistic infauna. The lack of response in opportunistic small-bodied polychaetes such as *Capitella* is therefore noteworthy. The physical disturbance of the sea floor, the enhanced levels of organic matter from dead and moribund individuals left in the trawl tracks and discards and the use of small mesh sizes would lead to the expectation of greater abundances of these in the later samples. While numbers had increased, the effects were not present in all areas. This adds further weight to the argument that changing mesh size is not a dominant factor in our analyses and may imply a rapid utilization of discards and trawl-damaged specimens by fish and epibenthic scavengers (Kaiser and Spencer, 1994; Kaiser and Ramsay, 1997).

The results show that at least in certain areas of the North Sea the benthos has undergone changes in composition since the widespread mechanization of the fishing fleet. The lack of control areas, or even data on fishing intensity, make it impossible to link these changes directly with fishing. Other explanations for such long-term changes include climatic variation and eutrophication (Kröncke, 1990). However, the timing and prevalence of the changes implies that a fisheries link exists. However, the observed changes are rather different in character from those predicted by recent short-term studies (Thrush *et al*., 1995, 1997; Kaiser *et al*., 1997; Ramsay *et al*., 1998; Tuck *et al*., 1998).

There is no evidence for the disappearance of large slow-growing bivalves, fragile echinoids, or cnidarians. Rather there has been a shift in the relative abundance of many taxa. We interpret this to indicate that many species have been affected, some suffering direct mortality of impacted individuals, others by indirect effects such as altered food availability or competitive interactions. When judged at the scale of the fishery and over the period of mechanized fishing, the effects of fishing appear to be widespread and to involve a large part of the benthic community. If this is the case then we need to develop a different protocol for monitoring these impacts as well as regulations to control them (Dayton *et al.*, 1995; Dayton, 1998; Thrush *et al.*, 1998). This may represent a new set of challenges for marine ecologists in that fisheries management will need to draw on ecosystem models, which explicitly include benthic communities and the interaction between such communities, fish populations, and the fishing process.

We have used rather formal data-handling procedures to get a conservative answer to the question of whether fishing has altered benthic communities over long time scales. The adoption of a precautionary approach to ecosystem management may in future mean that the degree of proof required when addressing such questions is less. That we have shown a change in the benthos of some North Sea fishing grounds even using such conservative criteria adds weight to the calls for a re-evaluation of the wider ecological impacts of fisheries (Dayton *et al.*, 1995).

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