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Long- and short-term consequences of a *Nephrops* trawl fishery on the benthos and environment of the Irish Sea

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Short-term effects of fishing on benthos from a mud patch in the northwestern part of the Irish Sea were investigated in 1994–1996 by means of samples taken both before and shortly after (ca. 24 h) fishing activity. No quantitative historical benthos data are available for the period prior to commencement of the fishery, although limited qualitative data exist. Therefore, studies of medium to long-term effects involved sampling the fauna of areas around wrecks (i.e., unfished pseudo-control sites) for comparison with fished grounds. Attempts were made to calculate the short, medium, and long-term impact of the fishery on the benthos and surrounding environment. Direct (short-term) effects were not quantifiable at a heavily fished offshore site (75 m depth); however, some changes were visible in a less fished, shallow (35 m depth) site. Medium to long-term effects were more discernible at the offshore site. Only minor changes were observed at the inshore location, suggesting that it is fishing intensity *per se*, rather than the direct impact from passage of the gear, that constitutes the major factor controlling long-term negative trends in the benthos of the Irish Sea *Nephrops* grounds.

Key words: benthos, demersal trawling, fishing intensity, impact, *Nephrops*.

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Introduction

Since the 14th century, there have been complaints about the presumed damage to fishing grounds by trawling (de Groot, 1984), although these were often expressed by other fishermen and may have been driven by economic or political agendas rather than objective observations. However, recent research supports some of these concerns, indicating that a variety of trawling gears, such as beam and otter trawls, can influence benthic life in a negative way (de Groot, 1984; Bergman and Hup, 1992; Jones, 1992; Lindeboom and de Groot, 1998).

The principal demersal fishery in the Irish Sea is an otter-trawl fishery targeting Norway lobster (*Nephrops norvegicus* L.). The fishery is concentrated on a mud patch in the northwestern part. Fishing intensity is high, and on average the bottom may be trawled five to 10 times per year (Fox *et al.*, 1996), having increased by a factor of 2.5 since the 1970s (Brander, 1980). The fishery commenced in the early 1940s as a small-scale summer fishery, but the season has now extended to all year round.

Nephrops is a burrowing crustacean. Owing to behavioural adaptations to ambient light, burrow emergence (and therefore catch rates and fishing effort) is highest at dawn and dusk in shallower grounds, and gets closer to midday in deeper waters (Chapman, 1980). As a consequence, the shallower grounds are generally fished on the way to and from port, while the deeper grounds are fished during the day, and are subject to greater effort. No quantitative benthos data are available for the period prior to commencement of the fishery, although limited qualitative data exist (Massy, 1912).

Studies of the benthos were undertaken over the period 1994–1996 at sites in both the shallow and deep sections of the *Nephrops* grounds. Short-term effects of fishing on the benthos were investigated by means of samples taken both before and one day after fishing activity. Studies of the medium to long-term effects involved sampling the fauna of areas around wrecks, serving as unfished pseudo-control sites, for comparison with fished grounds. Attempts were made to calculate the short, medium, and long-term impact of the fishery on the benthos and surrounding environment.

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Materials and methods

Direct mortality of benthic organisms caused by a *Nephrops* otter trawl was studied at two experimental sites consisting of one or two parallel strips with a length of 1500 m and a width of 40 m. The offshore site (53°38′N 5°45′W; depth 75 m) is heavily trawled by commercial trawlers, while the inshore site (53°40′N 5°58′W; depth 35 m) is fished less frequently, mainly at dawn and dusk. Initial positioning and subsequent repositioning of the transect strips was achieved by means of a differential global positioning system (DGPS), and ROV video was used for confirmation when relocating the trawl strips. A standard procedure was adopted for Day grab sampling at both sites. To estimate the initial density of invertebrate macrobenthic species (t_0-sampling), 10–20 grab samples were each taken in one or two strips. Within 24 to 48 h after t_0-sampling, the strips were trawled experimentally with a *Nephrops* otter trawl (25 fathom length, 70 mm diamond mesh, one light tickler chain). Each track was trawled twice. At least 24 h after experimental trawling, again 10–20 day grab samples were taken in the strips (t_1-sampling). Direct mortality was estimated from the difference between initial and final density.

The sediment at the inshore station comprised fine sand and silt-clay, quite similar to that of the offshore station though somewhat coarser (55% fine sand/40% silt-clay at the inshore vs. 44% fine sand/55% silt-clay at the offshore).

Two shipwreck sites were selected to investigate medium to long-term fishing impacts. The "Iron Man" is located at 53°40.3′N 5°59.22′W in the area of the inshore fishery, on a muddy fine sand substrate in approximately 35 m water depth. The wreck "41 Fathom Fast" lies at 53°32.37′N 5°43.79′W in the offshore area, on a sandy silt substrate in approximately 75 m water depth. While the exact dates of the sinking of the vessels are not available, both appear to have been in place for more than 50 years and are avoided by all trawlers.

Surveys were carried out in May 1995 ("Iron Man") and April 1996 ("41 Fathom Fast"). For the "Iron Man" site, transect length was about 400 m. Because the observations suggested that transect length may not have been sufficient to extend into the fishing area, transects of about 500–700 m were used for the "41 Fathom Fast" site. Six to eight stations with two grabs per station were included in each transect. Samples were also collected from the offshore and inshore fishery sites, near to the wreck locations, to allow comparison with a fished area.

To facilitate the investigation of possible changes along the transects, the samples taken at a similar distance from the wreck were grouped together. At the "Iron Man" wreck, six replicates were used from each of three positions (Near 125 m, Middle 260 m, Far 400 m). At the "41 Fathom Fast" wreck, three replicates were used from each of three positions (Near 50 m, Middle 250 m, Far 500 m).

The effects of fishing disturbance on infauna were tested for in several ways. Changes in the total numbers of individuals, total number of species, total biomass, and abundance of selected individual species (after ln[x + 1] transformation), were examined using ANOVA. Measures of diversity were also calculated, while the PRIMER package was used to carry out multivariate analysis on the infaunal community data. A cluster analysis using Bray–Curtis similarity index was performed on 4th-root transformed data. The resultant similarity matrices were used to carry out non-metric multidimensional scaling, with differences between sites and dates tested with an *a priori* analysis of similarities randomization test (ANOSIM; Clark & Green, 1988).

Results

Offshore fishery

At the offshore station, with the exception of *Nephrops*, the benthic macrofauna is sparse and dominated by small polychaetes with a few crustaceans and bivalves. Though abundance was low, the species composition corresponds to the mud community (type 27) of Holt *et al.* (1990), which comprises crustacean megafaunal burrowers, such as *Nephrops*, *Goneplax rhomboides* (both common in the experimental trawl catches), and thalassinid shrimps (*Calocaris macandreae*, *Jaxea nocturna*). The fauna composition also corresponds to Jones's (1950) Boreal offshore muddy sand association, which is a modification of Petersen's *Brissopsis chiajei* community (Petersen, 1913) and comprises polychaete species such as *Nephtys incisa*, *Glycera rouxi*, and *Notomastus latericeus*, the crustaceans *Eudorella truncatula* and *C. macandreae*, the molluscs *Abra nitida*, *Nuculoma tenuis*, and *Nucula sulcata*, and the echinoderms *Amphiura chiajei* and *Brissopsis lyrifera*.

Most of the individuals collected in the grab samples represented either species with a small adult size or juveniles of larger species. The paucity of the fauna and associated low biomass (mean biomass 24 gm^{-2}) has rendered any quantitative assessment of the short-term effects of trawling impossible.

Table 1 provides the community metrics for the three positions along a transect from the "41 Fathom Fast" wreck and from the nearby fished grounds before and after experimental trawling. Number of species and number of individuals showed a decrease as one moved away from the wreck, from near to far sites. All parameters measured showed a significant decrease between the wreck sites and the fished ground, prior to experimental trawling. Within the fishing grounds, there

Table 1. Mean community metrics for three locations (Near, Middle, Far) along transects sampled in the vicinity of the "41 Fathom Fast" wreck and from nearby offshore *Nephrops* trawling grounds before (Control) and 24 hours after (Impact) experimental trawling.

Parameter	Fishing grounds Control	Fishing grounds Impact	"41 Fathom Fast" wreck Near	"41 Fathom Fast" wreck Middle	"41 Fathom Fast" wreck Far
Total species	50	37	71	71	62
Total individuals	687	513	3463	2847	2850
Biomass (g m^{-2})	21	19	40	189	30
Species richness	5.2	4	5.95	6.1	5.32
Shannon's Diversity	3.62	3.88	4.5	4.31	4.31
Evenness	0.64	0.75	0.73	0.70	0.72

were further decreases in most of these parameters 24 h after experimental trawling.

The species that were more abundant near the wreck and those more abundant in the offshore fishing grounds are shown in Lindeboom and de Groot, 1998 (page 259, Table 3.7.12). Some 62 of the species found at the wreck site are not found at the offshore site. A total of 31 of these are polychaetes including carnivores (e.g., *Nereis longissima*, *Nephtys hombergi*, and *Nephthys kersivalensis*) or deposit feeders (e.g., *Terebellides stroemi*, *Ampharete falcata*, *Monticellina dorsobrachialis*). A further 16 were crustaceans (e.g., *Pseudorachna hirsuta*, *Protomedia fasciata*, *Pleurogonium rubicundum*, *Diastylis lyrifera*); 12 molluscs (e.g., *Cylichna cylindracea*, *Thyasira flexuosa*, *Corbula gibba*, *Phaxas pellucidus*, *Myrtea spinifera*, *Montacuta ferruginosa*), and three echinoderms (e.g., *B. lyrifera*, *Echinocardium cordatum*, *Amphiura* sp.). In particular, large specimens of some of the molluscs (*P. pellucidus*, *C. cylindracea*) and echinoderms (*A. chiajei*, *B. lyrifera*, *E. cordatum*) are quite common along the transects. By contrast, while juveniles of some of these species were occasionally taken at the offshore trawling station, large specimens were never found. In comparison, only nine species were recorded exclusively at the offshore site. Seven were polychaete species (large carnivores and small opportunists) while the other two were small crustaceans.

MDS plots of the fauna from the wreck and offshore station areas are shown in Figure 1a. There is a very clear separation between the wreck stations and those from the offshore station both before and after experimental trawling.

Inshore fishery

The fauna at the inshore station represents a species-rich version of that found at the offshore station. The species composition resembles Holt's (1990)) muddy sand community (type 23), characterized by seapens (*Virgularia mirabilis*), *Amphiura* spp., *Turritella communis* (common in the grab samples) and *Astropecten irregularis* (commonly found in the experimental trawl catches). The

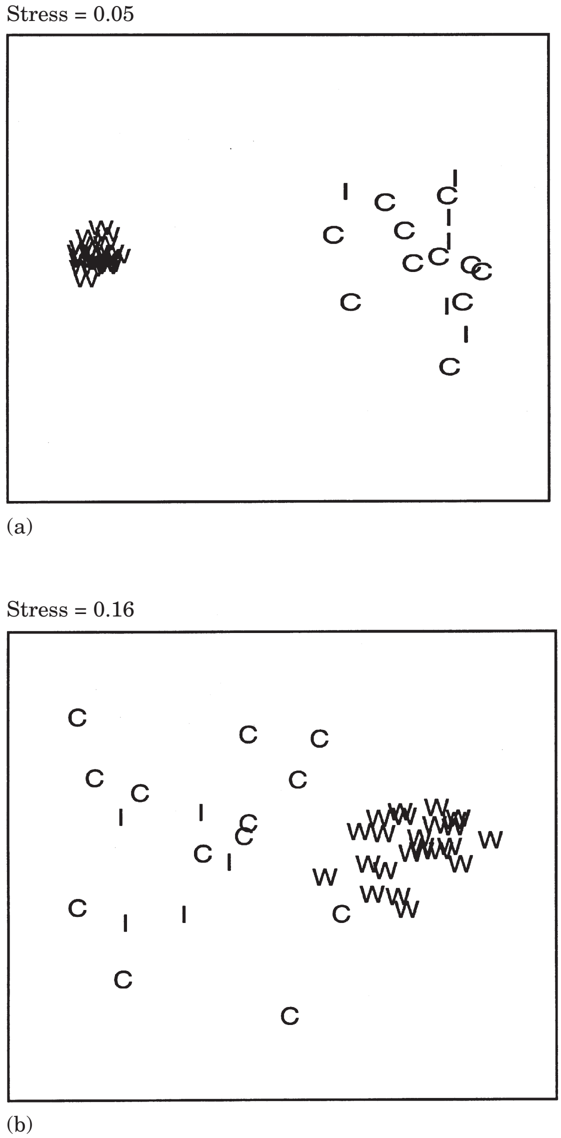

Figure 1. MDS ordination plots of the wreck stations (W) with pre (C) and post-trawling (I) fishery stations. (a) "41 Fathom Fast" and offshore fishing grounds; (b) "Iron Man" and inshore fishing grounds.

Table 2. Initial densities (D in ind. m^{-2}) and direct mortality estimates (M in % of initial density) of small-sized species sampled with a Day grab in two studies at the inshore *Nephrops* trawling ground (only species that occurred at a density of >10 ind. m^{-2} are included; bold: statistically significant at $p<0.05$).

	Size (mm)	1995 D	1995 M	1996 D	1996 M
Bivalvia					
Abra sp.	(1–15)	256	6	1161	20
Corbula gibba		22	29	146	**58**
Thyasira flexuosa	(1–5)	10	0	57	28
Dosinia lupinus	(1–28)	11	87	20	3
Nuculoma tenuis	(1–5)	17	59		
Mysella bidentata	(1–4)			21	72
Gastropoda					
Cylichna cylindracea	(1–6)	29	37	59	1
Crustacea					
Tanaids		21	**93**	29	58
Copepoda		42	93	231	67
Amphipoda		21	60		
Protomedia fasciata		10	100		
Pariambus typicus				23	34
Annellida					
Nephtys hombergii	(3–90)	58	**70**	70	7
Laonice cirrata		10	57	4	17

inshore site also corresponds in some ways to the *Amphiura* community (Thorson, 1957) or Boreal offshore muddy sand association described by Jones (1950).

Most species at the inshore station showed a decrease in numbers following experimental trawling, although very few were statistically significant (Table 2). By contrast, most of the polychaete species increased in numbers following trawling. These are generally either small opportunistic species such as *Chaetozone setosa* (52%), *Prionospio fallax* (149%) and *Scolelepis tridentata* (457%), or were large scavengers like *N. incisa* (16%). An increase in numbers of *C. setosa* was also noted in trawling impact studies from other locations (Tuck *et al.*, 1998).

The number of individuals and biomass showed a significant decrease between the wreck sites and the fished ground, prior to experimental trawling (Table 3). Within the fishing grounds, there was a significant decrease in number of species, biomass, species richness, and Shannon's diversity 24 h after experimental trawling.

The species that were more abundant near the wreck and those more abundant in the inshore fishing grounds are given in Lindeboom and de Groot, 1998 (page 257, Table 3.7.10). Of the species found at the wreck site, 49 are not found at the inshore site. These include 24 polychaetes, the most important of which were the suspension feeders *Spiophanes bombyx* and *Minuspio cirrifera*, the carnivores *Sthenelais limicola* and *Phyllodoce rosea*, and the deposit feeding tube dwellers *Ampharete lindstroemi* and *A. falcata*. Some 18 crustacean species were found exclusively at the wreck site, most of which were relatively isolated in occurrence, apart from *Jassa pusilla* and *Microjassa ambrensis*, as were four molluscs, including the fairly common *M. ferruginosa*, and two large echinoderms, *B. lyrifera* and *E. cordatum*. By comparison, 19 species were found on the fished grounds that were not found at the wreck site. These were predominantly polychaetes occurring in relatively low numbers, including *Phyllodoce longipes*, *Ampharete acutifrons*, *Eumida bahusiensis*, and *Mediomastus fragilis* (typical of enriched/disturbed muds).

MDS plots of the fauna from the wreck and inshore station areas are shown in Figure 1b. There is a clear separation between these wreck stations and those from the inshore station prior to experimental trawling and even more so after trawling. Both sets of stations do, however, show a widely scattered distribution.

Discussion

The results show that the biomass and numbers of species returned in grab samples at the offshore site are insufficient to assess the direct impacts of trawling on the benthos.

Table 3. Mean community metrics for three locations (Near, Middle, Far) along transects sampled in the vicinity of the "Iron Man" wreck and from nearby inshore *Nephrops* trawling grounds before (Control) and 24 hours after (Impact) experimental trawling.

Parameter	Fishing grounds Control	Fishing grounds Impact	"Iron Man" wreck Near	"Iron Man" wreck Middle	"Iron Man" wreck Far
Total species	113	72	96	100	96
Total individuals	1551	1578	3009	2572	3413
Biomass (g m^{-2})	61	36	119	243	66
Species richness	10.6	6.68	8.22	8.74	7.84
Shannon's Diversity	5.09	4.53	4.75	4.97	4.59
Evenness	0.75	0.74	0.72	0.75	0.70

Many of the species that are common at the inshore site and for which estimates of mortality were calculated (e.g., *Dosinia lupinus*, *C. gibba*, *T. flexuosa*, and *Mysella bidentata*) are uncommon or totally absent on the offshore fishing ground. While the depth varies between the two fishing gronds, the sediment structure was quite similar. Thus, the major difference between the sites appears to be the intensity of fishing effort. This suggests that these species are sensitive to trawling pressure and is strengthened by the occurrence of many of these "sensitive" species at the offshore wreck site.

Most of the species for which high mortality rates were calculated were seldom found in the by-catch of *Nephrops* trawls. Apart from the large and fragile echinoderms *B. lyrifera* and *E. cordatum*, damaged animals were seldom seen in grab samples or trawl catches. This suggests that mortality of infaunal invertebrates may occur primarily on the seabed and is caused by disturbance and passage of the net rather than by damage or by-catch. Owing to the low catch efficiency of trawls for invertebrate benthos, direct mortality appears to occur more generally mainly in the trawl path (Lindeboom and de Groot, 1998).

The results allow some observations to be made on the apparent medium to long-term impacts of *Nephrops* trawling on the benthos of the northwestern Irish Sea. There is some indication of disturbance at the inshore trawling grounds (the disappearance of *B. lyrifera* and the reduced number of individuals and mean infaunal biomass) when compared with the presumably unfished wreck site. However, the trawling grounds still contain some large molluscs, and the number of species and Shannon's diversity do not differ significantly from the wreck site, suggesting the continued presence of a diverse and species rich benthic infauna. It is possible that in this dawn and dusk fishery there is insufficient fishing pressure to cause marked long-term changes. However, the immediate short-term effects of fishing on this species-rich area are a cause for concern. The numbers of species, species richness and biomass had all dropped after 24 h of experimental trawling.

At the deeper offshore location, the results are more dramatic. All community metrics showed a reduction on the fishing grounds when compared with the wreck site. In particular, there is a complete absence of large benthic infauna (with the exception of the target species *Nephrops*). The short-term fishing effects are less obvious, with a small decrease in number of species following experimental trawling. There is also no clear pattern between trawled and untrawled stations from the MDS plots. This appears to reflect the very low initial species and biomass numbers in the trawling grounds, and the composition of the fauna comprising mainly small opportunistic polychaetes (adapted to disturbance).

The comparison between trawling grounds and wreck sites is based on the assumption that they only differ in terms of fishing intensity. However, wrecks may have additional effects because they change current patterns and sedimentation and therefore may affect the benthic community in their neighbourhood. Therefore, they can be considered only as pseudo-control sites and any differences cannot unambiguously be attributed to the effects of fishing.

Schwinghamer *et al.* (1996) showed that high-resolution video images of sediment surfaces before and after otter trawling indicate that trawling reduces the overall surface roughness of the seabed. It has been further suggested that intensive dredging leads to a more homogenous environment, in a manner analogous to a tractor ploughing a field (Brand *et al*., 1991). In soft mud communities, a large proportion of the fauna lives in burrows up to 2 m deep, below the penetration depth of most fishing gears (Atkinson and Nash, 1990). As described for *Nephrops*, however, diel variation in behaviour may periodically increase the vulnerability of some species to fishing activities (Chapman, 1980). Deep bioturbators (e.g. *Jaxea nocturna*) have an important role in maintaining the structure and oxygenation of muddy sediment habitats (Reise, 1981; Fenchel, 1996). Consequently, any adverse effects of fishing on these organisms would presumably lead to changes in habitat complexity and community structure (Jennings and Kaiser, 1998).

We assume that the species-rich fauna of the shallow and deep wreck sites may resemble the natural undisturbed fauna characteristic of this region, prior to the commencement of the *Nephrops* fishery (Massy, 1912). Observed differences between the fauna of the two wreck sites may reflect variations in water depth or slight changes in sediment composition, while observed differences between the wreck sites and nearby fished sites would appear to reflect genuine effects of fishing. The smaller impact observed at the less heavily fished inshore area when compared to the main offshore fishing grounds could suggest that the reduced diversity at the latter is a function of fishing intensity. However, there may equally be some other as yet undetermined variable.

Given the intensity of trawling throughout the *Nephrops* area, it is difficult to make definitive statements on the impacts of trawling on the benthos. MacDonald *et al.* (1996) have suggested a sensitivity index for disturbance of benthic species by fishing activity. They point out that further research is required to calculate the disturbance of multiple gear contacts with sensitive species, but most of the sea bed around the UK coast has already been affected by fishing and sensitive species may no longer be present in such areas. Considering the work on areas fished and areas closed to fishing carried out elsewhere, it is clear that mobile fishing gears alter seafloor habitats, reduce habitat complexity, may lead to increased predation on juveniles of marine species, and seem to affect ecosystem productivity (Sainsbury, 1987; Auster *et al*., 1996). Such work is not possible in Irish waters because the only unfished sites are connected to wrecks, which may not be entirely comparable. This highlights the pressing need for a long-term monitoring site which would allow for manipulative experiments on fisheries impacts, and which could equally serve as a monitoring site for anthropogenic inputs (pollution) independent of fishing (Lindeboom, 1995).

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