



## The effect of scallop dredging on Irish Sea benthos: experiments using a closed area

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### Abstract

A 2 km<sup>2</sup> area off the southwest coast of the Isle of Man (Irish Sea) has been closed to commercial fishing with mobile gear since March 1989. This area was heavily fished for *Pecten maximus* (Linnaeus, 1758) prior to closure, and the seabed immediately surrounding the closed area is still one of the most heavily dredged in the Irish Sea. Two methods have been used to study the effect of scallop dredging on the benthos in this closed area and adjacent fished areas. Firstly, twice-yearly grab sampling of experimental plots inside and outside the closed area since 1995 has enabled comparisons of the benthic infauna and epifauna of experimentally dredged plots, undredged control plots and plots exposed to commercial dredging. Secondly, divers have carried out visual transect surveys of *P. maximus* numbers regularly since closure. Communities of experimentally disturbed plots have become less similar to adjacent undisturbed control areas and more similar to commercially dredged areas. At each sampling date, similarity between dredged samples was greater than between undredged samples. Since 1989, there have been increases in the mean numbers of *P. maximus* in the closed area. The age structure of the closed area *P. maximus* population is also different to that outside, with a higher mean age due to the presence of large, old individuals.

These results present strong evidence that scallop dredging alters benthic communities and suggest that the closure of areas to commercial dredging may allow the development of more heterogeneous communities and permit the populations of some species to increase. A common problem with studying fishing disturbance is the lack of good control sites and this work also demonstrates the value of closed areas to scientific studies of demersal fishing.

### Introduction

Bottom fishing is known to have an impact on benthic fauna: the short term effects include damage and death to bycatch species, injury and death on the seabed due to contact with the gear (especially of large fragile animals e.g. urchins, starfish), influxes of predators and scavengers feeding on damaged or dead animals, turnover of the sediment and attached animals, and smothering of animals by resuspended sediment (see Jones, 1992; Dayton et al., 1995; Jennings & Kaiser, 1998; Lindeboom & De Groot, 1998 for reviews of the subject). Impacts vary with different seabed types (Shepard & Auster, 1991; Jones, 1992; Kaiser & Spencer, 1996), different fishing gear (e.g. Kaiser et al., 1996) and level of background disturbance (e.g.

Hall et al., 1990; Hall, 1994; Kaiser, 1998). Several previous studies have taken an experimental approach (e.g. Eleftheriou & Robertson, 1992; Thrush et al., 1995; Currie & Parry, 1996), but these studies concentrated mostly on the effects of short-term, small-scale or one-off dredging events, or had inadequate control sites. In this paper, we present results from a 5-year long experimental investigation.

The scallop, *Pecten maximus* (Linnaeus, 1758), and queen scallop, *Aequipecten opercularis* (Linnaeus, 1758), have formed the basis of an important fishery in the north Irish Sea around the Isle of Man (Fig. 1) for the last 60 years. The fishery began in the late 1930s, close inshore off the SW coast and consisted of only nine small boats towing between one and three dredges. The fishery did not start expanding until

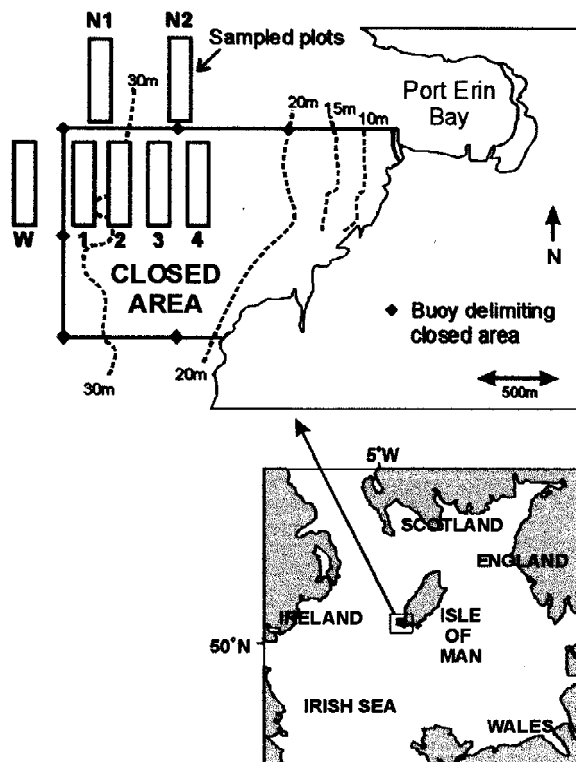


Figure 1. Map showing layout and location of the sampling plots in the closed area. Plots 2 and 4 have been undredged since 1989, plots 1 and 3 experimentally dredged every two months since 1995, and plots N1, N2 and W are exposed to commercial scallop dredging. Inset shows location of the Isle of Man in the Irish Sea.

the mid 1950s, reaching a maximum of c. 70 boats in 1983–4. The development of larger and more powerful boats with improved gear has enabled the fishery to exploit rougher fishing grounds and move further offshore. There are currently around 30 Manx boats, each fishing 12–24 dredges. Boats from Ireland, Northern Ireland, Wales, England and Scotland also now fish for scallops in the north Irish Sea (Brand et al., 1991). In 1998, the combined tonnage of queens and scallops landed on the Isle of Man was 1696t, worth £1.2 million (equivalent to 62% of the value of all fisheries on the island) (Brand & Beukers–Stewart, 2000).

Conservation legislation in operation since 1943 restricts fishing for scallops to an open season that currently runs from 1 November to 31 May inclusive; queens may be fished all year round. Other legislation includes a minimum landing size of 110 mm shell length for scallops and restrictions on boat size, gear type and gear width (Brand et al., 1991).

Scallops live on, or partly buried in, the surface sediments and are fished with 2' or 2'6" (61 or 76 cm)

spring-toothed, Newhaven-type scallop dredges with metal belly rings, fished in gangs of 6–12 each side. The gear penetrates the upper layers of the seabed to rake out the partially buried scallops and in so doing disrupt the benthos (e.g. Caddy, 1973; Eleftheriou & Robertson, 1992; Thrush et al., 1995; Hall–Spencer & Moore, 2000a, b).

The seabed around the Isle of Man comprises a mixture of mud and sand with a variable amount of dead shell and stone, especially at the surface. Small-scale patchiness of the seabed provides a heterogeneous substrate with many habitat niches. Coarse stone and shell fragments can provide shelter for mobile animals and also support a rich sessile community (e.g. hydroids, bryozoans, tunicates), which in turn provide attachment surfaces, shelter or food for other animals. These species are thought to be especially sensitive to overturning by dredges and smothering by sediment (Dayton et al., 1995; Bradshaw et al., 2000).

An exclusion zone of nearly 2 km<sup>2</sup> off the south-west of the Isle of Man (Fig. 1) has been closed to commercial fishing by dredge or trawl (though not to static gear) since March 1989 under Isle of Man legislation. The area had been heavily dredged for 50 years prior to closure, and the surrounding area, known as the Bradda Inshore fishing ground, continues to be one of the most intensively fished grounds in the Irish Sea, with a mean annual effort (1982–1995) of 7919 m h (Hill et al., 1997), equivalent to 43% of the seabed being dredged each year. Maximum water depth in the closed area is 40 m at the outer edge and the seabed is a mixture of gravel, sand and mud. This closure was implemented initially to enable Port Erin Marine Laboratory (PEML) scientists to investigate the feasibility and effectiveness of scallop cultivation and stock enhancement, but subsequently provided an opportunity to monitor the numbers of benthic species after the cessation of dredging and to carry out controlled experiments into the effect of dredging on benthic communities.

This study investigates the effect of scallop dredging on infaunal and epifaunal communities using controlled experiments in, and monitoring of, the closed area. In 1994, 5 years after closure, a programme of experimental dredging began in the closed area. The abundance of *P. maximus* throughout the closed area has also been monitored by diver survey since closure.

## Materials and methods

### Experimental design

The NW corner of the closed area was chosen as the site for the experiment, due to its reasonably uniform water depth and sediment type. The experimental layout (Fig. 1) consists of four parallel plots of c. 500 m length and c. 100 m width, running in a north–south direction, two of which are experimentally dredged ('treatment' plots 1 and 3) and two of which are undredged (controls 2 and 4). Three identically sized plots are located outside the closed area, two to the north (N1 and N2) and one to the west (W). These latter three plots are exposed to commercial scallop dredging. The two treatment plots have been experimentally dredged approximately every 2 months since January 1995, using two sets of four spring-toothed, Newhaven-type scallop dredges, towed 10 times along each line.

### Sampling

The benthic community of all seven plots has been sampled twice a year starting in 1995, in the spring (immediately before the closed season for scallops) and autumn (immediately after the closed season). On each plot, 0.1 m<sup>2</sup> Day grab samples were taken, in three groups of four up to 1998 and subsequently in four groups of six. Three groups of two 0.1 m<sup>2</sup> Day grabs were also taken for sediment analysis (grain size distribution and organic carbon content). Depth and dGPS-fixed sample positions were recorded simultaneously with the grab sampling using 'Microplot' software (Sea Information Systems, Aberdeen). In months where experimental disturbance and sampling coincided, sampling was always carried out first to avoid picking up short-term effects.

Grab samples were sieved immediately over a 1 mm mesh, covered with 35 ppt MgCl<sub>2</sub> and 4 ppt Rose Bengal for 1–3 h to relax and stain the animals before fixing in 4% formalin. All the animals were extracted from each sample by hand, preserved in 70% alcohol and subsequently identified as far as taxonomically possible (mostly to species).

An additional monitoring programme has used divers to carry out surveys of *Pecten maximus* densities since 1989 throughout the closed area and in a control (commercially fished) area 1 km to the north. Each survey consisted of a pair of divers counting scallops along two parallel 2 m × 50 m belt transects. Counts from the two divers were pooled into

animal numbers per 200 m<sup>2</sup>. The number of surveys completed each year varied from four to 20. In 2000, additional data from longer dive surveys carried out as part of another study in the same area were also used and standardised to numbers per 200 m<sup>2</sup> (unpublished data, Beukers–Stewart & Jenkins).

To measure the age structure of scallops in the area, samples of *Pecten* were obtained from 1 km north of the closed area using a standard commercial scallop dredge. Three 1-h tows at a speed of 2.5 knots were taken, and all commercial-sized scallops measured and aged. These data were compared with similar data from scallops obtained from an illegal fishing event in the NE corner of the closed area in April 2000 (unpublished data, Beukers–Stewart & Jenkins).

### Data analysis

The naturally patchy distribution of fauna on the seabed makes variability high between replicates; groups of grabs were, therefore, pooled [into 3 groups of four grabs (pre-1998), or 4 groups of 6 grabs (March 1998)] before any analysis. Sample numbers were increased in 1998 in order to improve the power of univariate tests. Count data were  $\sqrt{4}$  transformed to reduce the effect of very abundant species and presence–absence transformation used for colonial species data and combinations of count and colonial data. All data were reduced by 3% to eliminate bias from infrequently occurring species and standardised to account for different sample volumes.

Multivariate analyses were performed with PRIMER software (Plymouth Marine Laboratory, U.K.). The data were clustered using group-average clustering and the Bray–Curtis measure of sample similarity, and plotted using non-metric multi-dimensional scaling (MDS). ANOSIM (analysis of similarities) was used to test the significance of differences in composition of communities from dredged and undredged sites and SIMPER (similarity percentages) to determine which species contributed most to these differences. The Index of Multivariate Dispersion (IMD; Warwick & Clarke, 1993) was calculated to investigate levels of variability in dredged and undredged plots.

Univariate analyses were restricted to one-way and two-way ANOVA tests and subsequent multiple comparisons tests (Tukey's parametric or Dunn's non-parametric) on species number, Shannon–Wiener diversity ( $\log_2$ ), species richness, Pielou's Evenness and Simpson's dominance. Differences between dredged and undredged lines were tested separately for each

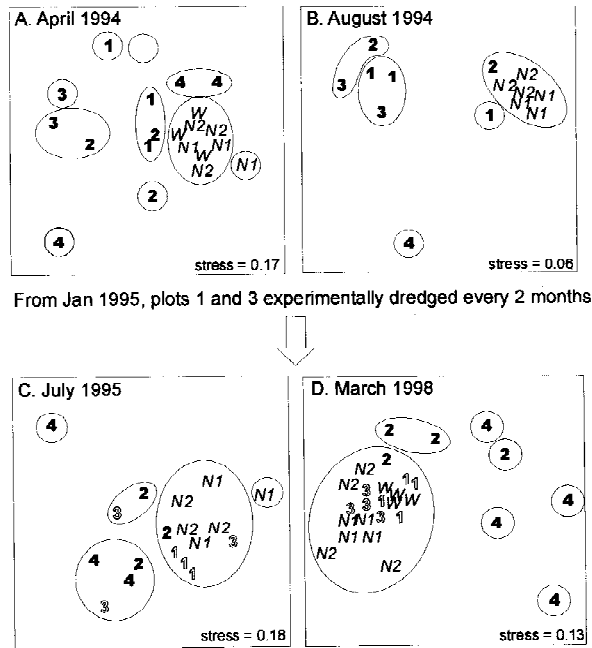


Figure 2. MDS plots of benthic community data before and after experimental dredging. For all dates, dredged plots cluster separately from, and are more tightly clustered than, undredged plots. Italicised text represents commercially dredged plots outside the closed area; bold letters, undredged plots inside the closed area; open letters, experimentally dredged plots inside the closed area (after Jan 1995). Plots are based on standardised, 3% reduced, 4√ transformed, pooled count data (see 'Methods').

sampling occasion. More detailed analyses were performed on the March 1998 data, due to this having a higher level of replication and being the most-recent in the time series. For these two reasons, any significant results were most likely to be found in this dataset.

**Results**

*Experimentally dredged plots in the closed area are more similar to commercially dredged plots outside the closed area than undredged controls within the closed area*

Cluster analysis of samples taken before experimental dredging began (April and August 1994) shows that the plots outside the closed area (exposed to commercial fishing) cluster separately from those inside (all undredged) (Fig. 2a,b). In January 1995, experimental dredging first took place on plots 1 and 3. The samples taken 6 months later, in July, indicate that the fauna of plots 1 and 3 were now more similar to the commer-

Table 1. Comparison of the indices of multivariate dispersion (IMD) for undredged, commercially dredged and experimentally dredged plots. Values of relative dispersion are shown for each sampling period. Higher values indicate greater variability and therefore greater heterogeneity. IMDs were calculated from Bray–Curtis similarities of the 5% reduced dataset, which had been presence–absence transformed and standardised. Note: April and August 94 are pre-experimental dredging; plots 1–4 were undredged on those occasions

Date	Undredged	Commercially dredged	Experimentally dredged
Mar 98	1.65	0.98	0.40
Apr 97	1.49	0.68	1.28
Aug 94	1.15	0.72	–
Apr 94	1.31	0.44	–

cially dredged plots outside the closed area (N1, N2 and W) (Fig. 2c).

Experimental dredging continued approximately every 2 months on plots 1 and 3, and samples taken over the next three years continued to show the same trend of experimentally dredged plots (1 and 3) being more similar to commercially dredged plots (N1, N2 and W) than undredged plots in the closed area (2 and 4) (e.g. March 1998: Fig. 2d). However, no significant differences between treatments were identified using ANOSIM, and SIMPER analyses did not show any clear trends of particular species or groups of species being responsible for these groupings.

To see if these changes were reflected in changes in species number or diversity, Kruskal–Wallis one-way ANOVA on ranks were performed on various univariate indices calculated from the March 1998 data. No significant differences in total species number or species richness were found between treatments. Diversity (Shannon–Wiener) was slightly higher in the experimentally dredged than the undredged plots, and Pielou’s evenness and Simpson’s Dominance were both higher in the commercially dredged plots than the experimentally dredged and undredged plots. These rather confusing results suggest that condensing complex data with high levels of variability such as these into single indices can mask clear trends in community change shown by multivariate methods.

*Undredged plots are more heterogeneous than dredged plots*

The MDS plots of data from 1994 (April and August; Fig. 2a,b) show that undredged plots (1–4) are less

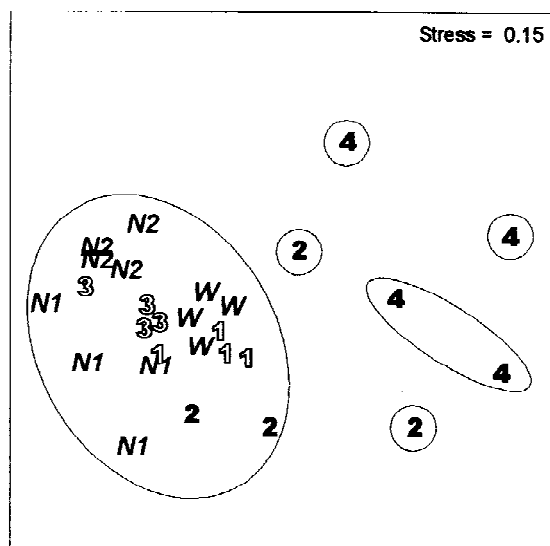


Figure 3. MDS plot of sessile benthos data from March 1998. Dredged plots (both experimentally and commercially dredged) cluster separately from, and are more tightly clustered than, undredged plots. Data has been standardised, 3% reduced, presence-absence transformed and pooled into 4 groups of six replicates for each experimental plot (see 'Methods').

tightly clustered than commercially dredged plots (N1, N2 and W). This is also the case after the experimental dredging regime began: July 1995 and March 1998 show that plots 1 and 3 are now more tightly clustered than 2 and 4 (Fig. 2c,d). Calculation of the Index of Multivariate Dispersion confirms this, with highest values for the undredged plots, followed by commercially and experimentally dredged (Table 1). These results imply that dredging reduces heterogeneity in these communities.

#### Sessile species

As sessile epifaunal species might be considered especially sensitive to dredging disturbance, more detailed multivariate analyses were done on the sessile species subset of the March 1998 dataset. The pattern of dredged and undredged plots clustering separately, and of dredged plots being more similar to each other, is still seen in these cluster analyses (Fig. 3). The sessile species that contribute most to similarity amongst samples in the dredged plots (experimentally and commercially dredged) are encrusting bryozoans, encrusting sponges and small ascidians. Those that make the undredged samples similar to each other are upright forms, such as the bryozoans *Cellaria* spp Ellis & Solander, 1786 and *Crisidia cornuta* (Lin-

naeus, 1758), and the hydroids *Halecium* spp Oken, 1815. It is these differences in morphology that contribute most to the dissimilarities between undredged-experimentally dredged and undredged-commercially dredged (Fig. 4; Table 2).

#### Population structure of *Pecten maximus* in the closed area

There are upward trends in numbers of the scallop *Pecten maximus* both inside and outside the closed area (Fig. 5a). However, the densities of scallops in the closed area are consistently higher than those outside (though this not statistically significant, due to high variability in numbers). There are also striking differences in the population structure of scallops in the two areas (Fig. 5b). Mean age inside the closed area is 6.5 years, compared with 5.3 years outside, due to the presence of large, old individuals (>9 years old) in the closed area, in contrast to the dominance of 4–5 year olds outside. In comparison, the mean age of scallops fished off Bradda in 1937 was 9.9 years, ( $n=294$  scallops fished by commercial boats), with three scallops over 20 years old.

## Discussion and conclusions

#### Community changes

From this study, it is clear that ongoing scallop dredging over a period of 5 years alters benthic communities. We have shown that is possible to experimentally drive a benthic community from one state to another through regular scallop dredging. Previous work has demonstrated that communities change after one-off experimental dredging; however, in this study we subjected the benthos to the cumulative effects of 5 years of ongoing dredging, a level similar to that occurring on commercially fished grounds.

There is evidence from this work that dredging makes benthic communities more homogeneous (see also Bradshaw et al., 2000). Similar results have been shown by (Auster et al., 1996), who recorded reduced habitat complexity due to mobile fishing gear in the Gulf of Maine. Closure of areas to commercial dredging in this study, therefore, allows the development of more heterogeneous communities. Heterogeneity of communities, and the associated increased habitat complexity, has important implications for success of larval settlement and species diversity (Roberts

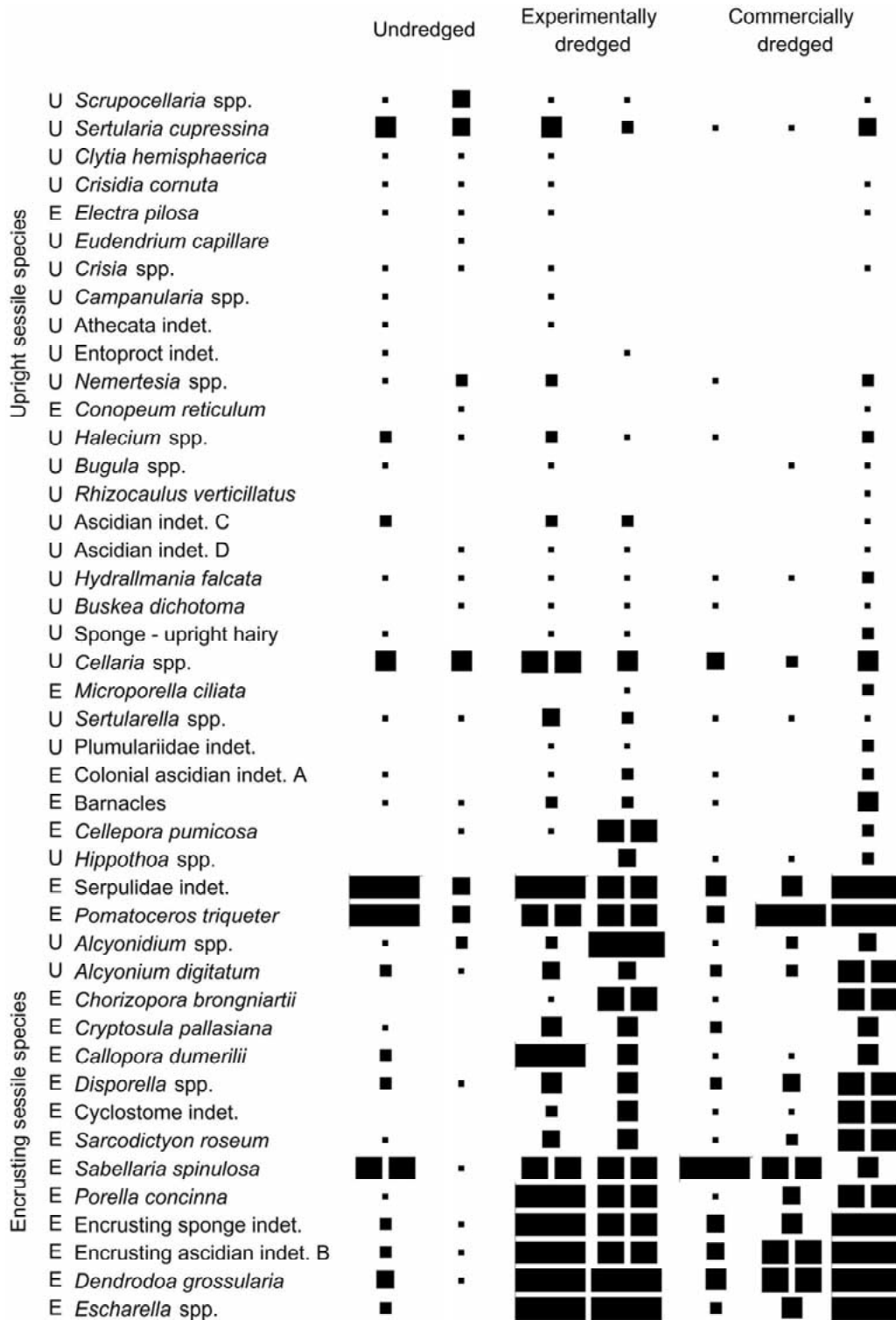


Figure 4. Shade diagram of sessile species abundances for March 1998. Species more common in the undredged plots are upright (U) species, whereas those more common in the dredged plots have an encrusting morphology (E). The data has been pooled for each plot and the relative abundance of each species estimated from the number of replicates which contained that species. Darker shading indicates higher abundance. The species have been ranked by the degree of difference between the abundances between undredged and combined commercially- and experimentally-dredged plots.

Table 2. Species identified by SIMPER analysis as contributing most to the differences between treatments. In both cases, encrusting sessile species are more abundant in the dredged plots, while upright forms flourish in the undredged plots. UD = undredged (plots 2 & 4), ED = experimentally dredged (plots 1 & 3), CD = commercially dredged (plots N1, N2, W). The analysis is based on Bray–Curtis similarities from the full dataset from March 1998, with standardisation and presence-absence transformation. ‘enc.’ = encrusting

Top 10 species that contributed most to the dissimilarity between undredged and experimentally dredged plots			Top 10 species that contributed most to the dissimilarity between undredged and commercially dredged plots		
Species	Life form	Relative abundance	Species	Life form	Relative abundance
<i>Cryptosula pallasiana</i>	enc. bryozoan	ED>UD	<i>Escharella</i> spp	enc. bryozoan	CD>UD
<i>Cyclostome</i> spp	enc. bryozoan	ED>UD	<i>Porella</i> spp	enc. bryozoan	CD>UD
<i>Escharella</i> spp	enc. bryozoan	ED>UD	<i>Crisidia cornuta</i>	upright bryozoan	UD>CD
<i>Porella</i> spp	enc. bryozoan	ED>UD	<i>Scrupocellaria</i> spp	upright bryozoan	UD>CD
<i>Sarcodictyon roseum</i>	enc. octocoral	ED>UD	<i>Sarcodictyon roseum</i>	enc. octocoral	CD>UD
<i>Cellepora pumicosa</i>	enc. bryozoan	ED>UD	<i>Halecium</i> spp	upright hydroid	UD>CD
<i>Schizomavella</i> spp	enc. bryozoan	ED>UD	<i>Clytia hemisphaerica</i>	upright hydroid	UD>CD
<i>Chorizopora brongiartii</i>	enc. bryozoan	ED>UD	<i>Cyclostome</i> spp	enc. bryozoan	CD>UD
<i>Crisidia cornuta</i>	upright bryozoan	UD>ED	<i>Schizomavella</i> spp	enc. bryozoan	CD>UD
<i>Clytia hemisphaerica</i>	upright hydroid	UD>ED	<i>Cryptosula pallasiana</i>	enc. bryozoan	CD>UD

& Polunin, 1991; Auster et al., 1996). The use of complex habitats may also increase the survival of mobile species (Auster et al., 1996).

#### Closure changes the population structure of *P. maximus*

Not surprisingly, numbers of the target animal, *Pecten maximus*, show a consistent significant increase in the closed area since 1989. Although numbers have also been increasing outside the closed area over this time, numbers are consistently (though not significantly) higher inside the closed area (Fig. 5a). Rice et al. (1989) found the same trend for quahog clams [*Mercenaria mercenaria* (Linnaeus, 1758)] in a closed area in Narragansett Bay, as did Murawski et al. (2000) for *Placopecten magellanicus* (Gmelin, 1791) on Georges Bank. The present study clearly shows that the average age of the scallops is greater in the closed area (Fig 5b), a trend also described by Rice et al. (1989) and Murawski et al. (2000). However, the average age of *P. maximus* in our closed area is nowhere near as high as the 1937 population measured by Tang (1941), right at the start of the scallop fishing industry on the island. This suggests that the scallop population in the closed area is slowly changing to more closely resemble a natural population.

#### Sessile species

Studies to date have generally indicated that sessile epifaunal species are adversely affected by bottom fishing (e.g. Bridger, 1970; Caddy, 1973; Dayton et al., 1995; Auster et al., 1996). However, this experimental study shows that the situation is more complex than that, with upright species (mainly hydroids) less abundant in dredged plots, while encrusting species (bryozoans, sponges, small ascidians) flourish in dredged areas. We hypothesise that upright species are more prone to being directly damaged and buried by overturning of their attachment substrata, whereas the stone on which a sponge or an encrusting bryozoan is growing may be completely overturned, but there need only be a small portion of the colony remaining above the sediment surface for asexual growth to extend the colony back up on to the new top or side surfaces. Kaiser et al. (1999) also showed that not all epifauna are adversely affected by bottom fishing. After experimental beam trawling, Kaiser’s study could not detect any changes in numbers or sizes of serpulid worms, which are opportunistic species and may rapidly recover from fishing disturbance.

It is likely that upright forms, which are worst affected by dredging, are also important in increasing structural complexity and habitat heterogeneity of the

seabed, and thus also increasing diversity (Auster et al., 1996; Collie et al., 1997; Watling & Norse, 1998). In the closed area, upright hydroids provide an attachment surface for other hydroids [e.g. *Lafoea dumosa* (Fleming, 1828), *Diphasia rosacea* (Linnaeus, 1758)], bryozoans [e.g. *Buskea dichotoma* (Hincks, 1862), *Conopeum reticulatum* (Linnaeus, 1767)], barnacles [e.g. *Scalpellum scalpellum* (Linnaeus, 1767)] and sponges [e.g. *Scypha ciliata* (Fabricius, 1780)] and also for the dwelling tubes of certain worms [*Eunice pennata* (O F Müller, 1776), spirorbid]. Scallop spat have also been seen to settle on these upright species (Bradshaw & Veale, pers. obs.). Other animals use the biogenic structures for shelter [e.g. spider crabs, pea crabs *Pisidia longicornis* (Linnaeus, 1767), sea spiders] and to some they are an important food source (e.g. various nudibranch species). Thus, the destruction of biogenic substrate also impacts on other species, as observed on *Ostrea edulis* Linnaeus, 1758 reefs (Reise, 1982; Riesen & Reise, 1982; Reise & Schubert, 1987, other papers in this volume), *Sabellaria spinulosa* Leuckart, 1849 reefs (Reise & Schubert, 1987), sponge-coral communities (Van Dolah et al., 1987), mixed epifaunal communities (Kaiser et al., 2000) and maerl beds (Hall-Spencer & Moore, 2000a,b). There is some evidence that patches of high diversity or structural complexity, such as biogenic epifauna, may also enhance recruitment of a range of invertebrates and fish (Auster et al., 1996; Smith & Witman, 1999).

### Ecology

The response of an area to dredging, or any other form of disturbance, depends on many variables related to life-history characteristics of all the species, as well as local hydrography, intensity, frequency and time of year of dredging (e.g. Caswell & Cohen, 1991; Auster et al., 1996; Dial & Roughgarden, 1998; Lindeboom & De Groot, 1998). We evidently need to know much more about the ecology and life histories of individual benthic species in order to fully explain or predict the effects of dredging. If dredging kills individuals of a species, the potential to recolonise is the most important factor in its survival in the community. The success of recolonisation depends on larval supply and successful recruitment (Carr & Reed, 1993). If dredging only damages a species, its regenerative powers are more important, whether through asexual reproduction (e.g. colonial bryozoans) or regrowth of damaged parts (e.g. sponges, starfish). Other factors

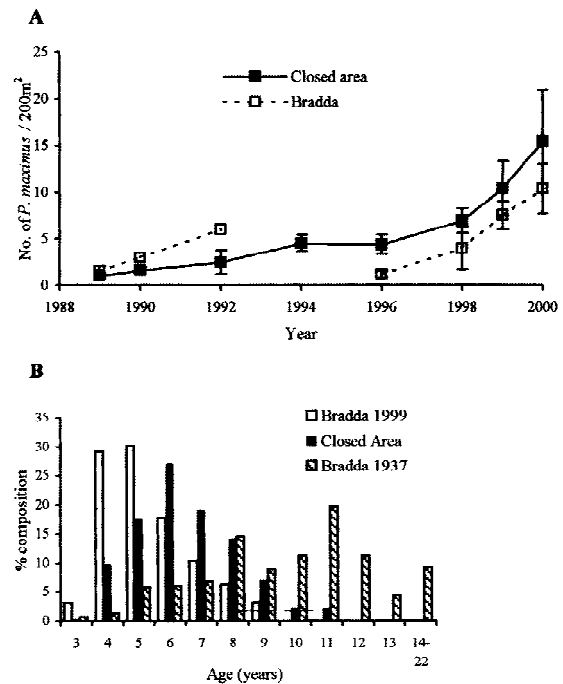


Figure 5. (A) Densities and (B) age composition of *Pecten maximus* inside and outside the closed area. Densities are expressed as numbers per 200 m<sup>2</sup>, the area of a standard diver survey. Data in (B) are based on legal commercial sized (>110 mm) scallops only, and 1937 data are from Tang (1941).

such as the ability of individuals to right or rebury themselves or to shed settled sediment are also important in these non-fatal casualties of dredge disturbance. Even apparently undamaged animals have been shown to suffer increased predation after dredging (Ramsay & Kaiser, 1998). Changes in community structure through repeated disturbance will also alter other ecosystem processes such as competition and predation (Caswell & Cohen, 1991; Auster et al., 1996; Dial & Roughgarden, 1998).

### Advantages of closed areas

A major problem encountered by scientists attempting to study the effects of bottom fishing has been the lack of suitable unfished control sites (e.g. Auster et al., 1996; Lindeboom, 2000). Areas may be unfished because they are intrinsically different to fished areas, if only in the absence of the target species, are near underwater obstructions (which may in themselves alter the immediate environment) or may have been fished (and therefore probably altered) in the past (Collie et al., 1997). Our work demonstrates that even a small closed area, such as in this study, is of great value

to scientific studies of bottom fishing. Apart from the scientific benefits of closure, there are also potential ecological and fisheries benefits, both for the target species and other species. These may include protection of habitat (with implications for increased habitat complexity, and increased genetic and biological diversity as discussed above), increased abundance, size and age of the target species, increased productivity (and enhanced recruitment), increased catches in adjacent areas, insurance against fisheries stock collapse and formation of sources to reseed other areas (Roberts & Polunin, 1991; Dugan & Davis, 1993; Clarke, 1998).

However, closed areas cannot be seen as a panacea for all fisheries problems, and may actually create new problems of their own. For the closure of an area to be successful, there must be clear objectives (e.g. conservation of habitat, protection of particular species; Lindeboom, 2000). If a target species is to be protected, careful planning is required with regard to the biology of the species; protection of nursery grounds, spawning grounds or adult populations may have widely differing results. Among other factors to be considered are the required size of the area, the position of the area relative to other potential impacts (e.g. pollution) and the requirements of all the stakeholders in the area.

Care must be taken that fishing effort is not simply deflected elsewhere, resulting in increased fishing pressure on other stocks or other species (Horwood, 2000; Murawski, 2000); closures must fit into a wider fisheries management programme. Closures may be ineffective or unfeasible for mobile, wide-ranging species like North Sea cod (Horwood, 2000), but species with relatively static adults and mobile larvae, such as scallops, are perhaps most likely to benefit from closures through protection of brood stock. Additional measures, such as the seeding of the seabed with juvenile or adult scallops, have had mixed results, but proved successful in a number of cases [e.g. Ansell et al., 1991 (France); Ito, 1991 (Japan); Hatcher et al., 1996 (New Zealand)]. In combination with closures, this could potentially be a successful strategy for improving stocks of relatively immobile species such as these.

There is much evidence that closures can benefit habitats and fisheries and provide important scientific resources, despite the complications described above. With the current widespread problems of overfishing and habitat destruction, serious consideration should be given to the establishment of closed areas.

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