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Effect of closed areas on distribution of fish and epibenthos

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The high blue mussel catches in a fjord system in Denmark, the visible effects of dredging by resuspension of bottom sediment and the possible destruction of benthic flora and fauna have all raised concerns about the impact on the ecosystem. As a consequence, a formerly lucrative blue mussel fishing area in the fjord was closed on dredging in 1988. This made it possible to investigate changes in the distribution of fish and benthos based on experimental fishing with trawl, set net and traps, and scuba diving during 1981–1998. The investigations showed no long-term effects of mussel dredging on the distribution of fish and epibenthic invertebrates, and the closed area appeared to have had no influence on the demersal fish and epibenthic fauna. Factors other than mussel dredging appear to determine the observed spatial and temporal variability in the ecosystem.

Key words: closed fishing areas, effects of mussel dredging, epibenthos, *Mytilus edulis*.

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Introduction

Growing fishing effort and technical developments have raised concerns about the impact of fisheries on marine ecosystems. Dredges and beam and otter trawls are largely responsible for the fishery-induced impact on the seabed and benthic communities (Jennings and Kaiser, 1998). However, the true impact of fishing is difficult to assess because of the complexity of benthic communities and their variable response to natural and anthropogenic factors (Gislason, 1994). Because most marine ecosystems are exploited, access to unaffected ecosystems that can provide a reference for the structure and variability under unexploited conditions is very limited.

The northern part of Jutland (Denmark) is transected by the Limfjord. The fjord has an opening to the North Sea in the west, and the water flows through the narrow eastern part into the Kattegat. It is less than 150 years since the sea broke through the dunes in the west and formed a typical estuarine fjord system with many semi-closed and mutually connected waterways. The total area is 1500 km^2, with a mean depth of about 7 m. Salinity ranges from 15 to 33 and summer temperature varies from 16 to 22°C. During winter, temperature drops to 0°C with ice cover for shorter or longer periods in some years.

The ecosystem has changed markedly during the last 25 years under the influence of increased anthropogenic activities. Washout of nitrogen from surrounding farmland has more than doubled, followed by an increase in primary production. Oxygen depletion occurs every year over smaller or larger areas, leading to mass mortality of benthic organisms (Jørgensen, 1980; Dolmer *et al.*, 1999).

From the start of this century until the beginning of the 1970s, a commercial fishery for herring (*Clupea harengus*), eel (*Anguilla anguilla*), plaice (*Platessa platessa*), and cod (*Gadus morhua*) has existed, with annual landings of around 4000 t. Since then the landings have declined markedly to less than 200 t annually in recent years. When the faith disappeared from the fjord, many fishermen shifted to mussel dredging (*Mytilus edulis*), which formerly took place only on a very limited scale. Today, 51 licensed vessels catch about 70 000 to 100 000 t of mussels (net weight) annually. The vessels are relatively small (8 GRT, 175 HP) and use one of two dredges of the Dutch type (Kristensen, 1997). Mussel grounds are fished heavily for 2–4 weeks and then left untouched for at least two years (Dolmer, 1998).

The increased catches of mussels, the visible effects of dredging by the resuspension of bottom sediment, and the potential destruction of benthic fauna and flora have generated great interest in the impact of dredging on the ecosystem (Hoffmann, 1994). The fishery is being held responsible for changes in species distribution and densities and even for the decrease in landings of finfish,

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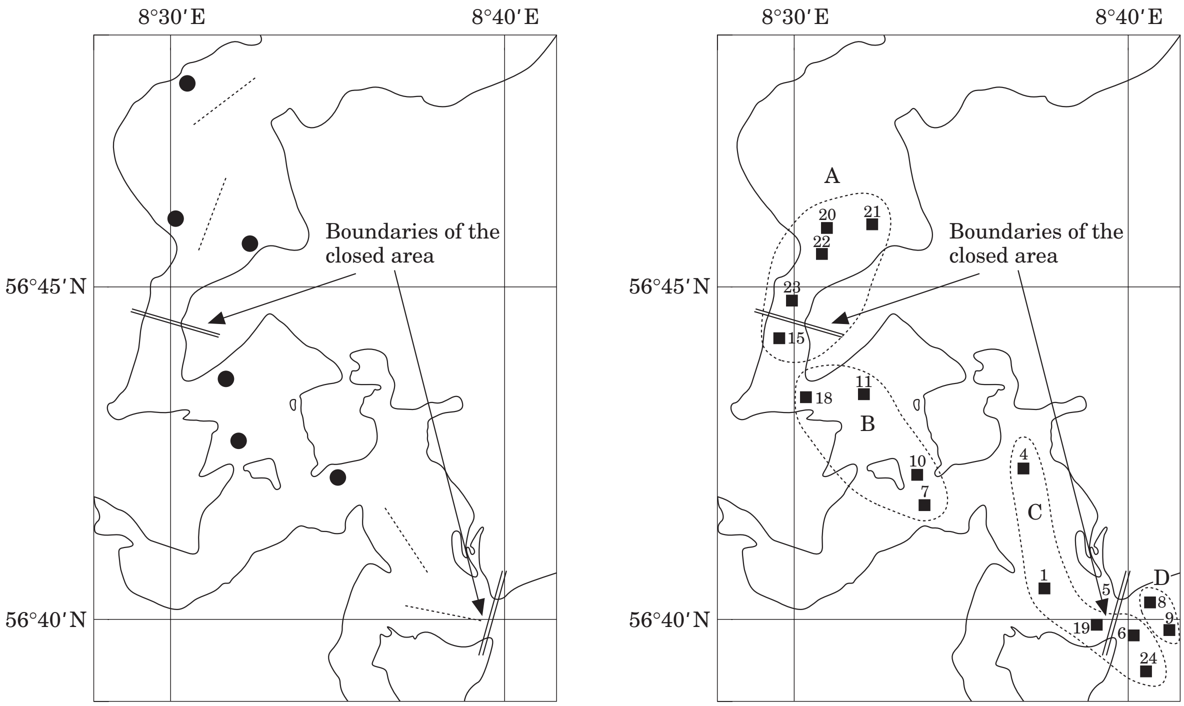

Figure 1. Maps showing sampling sites within and outside the closed area in the Limfjord, Denmark. (Left) trawl stations (stippled lines) and stations for set nets and traps (dots); (Right) scuba diver stations (squares) for epibenthic invertebrates and their clustering (A-B-C-D) based on a similarity dendrogram and MDS plotting (see Fig. 3).

and local authorities and NGOs have demanded regulations in the mussel fishery such as the introduction of quotas, closed areas, and even a total ban on dredging. As a consequence, a formerly lucrative fishing area was closed to all towed gears in 1988. The idea behind the ban on dredging was a belief that the ecosystem would recover to the conditions prior to the initiation of the extensive mussel fishery, with the implicit assumption that degradation and restoration represent a reversible process. The area closure enabled an investigation of the long-term effects of mussel dredging on fish and epibenthic invertebrates to test the postulated effects of dredging.

Methods and materials

The area closed for towed fishing gear is 40 km^2 (Fig. 1). Before 1988, commercial fisheries used poundnets, trawls, and mussel dredges, but since the closure, only static fishing gears have been allowed. Fishing areas for mussels are situated directly north and south-east of the closed area. Commercial dredging for mussels was carried out in the northern area during the experimental period (1995–1997) with annual catches between 10 000 and 28 000 t.

An annual trawl survey has been carried out in the entire Limfjord since 1981, during which 26 stations were fished several times in August/September every year. The two stations within and the two just outside the closed area are shown in Figure 1. The survey was carried out by RV "Havfisken", a standard Danish trawler (20 GRT and 175 HP) equipped with a standard TV3-520 trawl with a small-meshed (10 mm) codend. All hauls were conducted at a depth of 4–10 m.

In 1995, 1996, and 1997, experimental fishing with fixed set nets and eel traps in shallow water (1–4 m) was carried out at three locations within and at three locations outside the closed area (Fig. 1). Each set net had a combination of different mesh sizes ranging from 10 to 40 mm. The nets were hauled after 6–8 h and the traps after 48–72 h.

The composition of epibenthic assemblages of invertebrates within and outside the closed area was analysed in September 1997. The infauna were sampled at 17 stations subdivided over four areas (Fig. 1): area I, north of the closed area (stations 20, 21, 22, 23); II, the northwestern part of the closed area (stn 5, 18, 11, 10, 7); III, the southeastern part of the closed area (stn 4, 1, 19, 5); and IV, south of the closed area (stn 6, 8, 9, 24). The water depth at the stations ranged from 2 to 7 m. At each station, a scuba diver identified and counted the

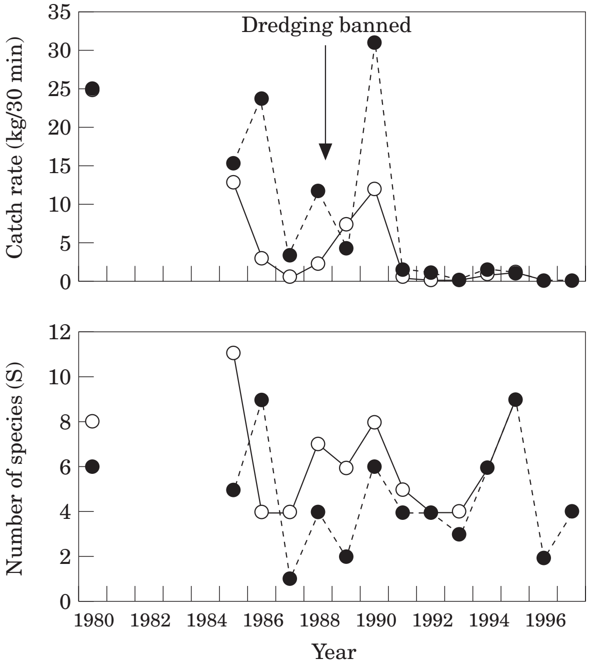

Figure 2. Catch rate (upper panel) and number of species (lower panel) from closed area (open circles) and from fished areas (filled circles) based on trawl surveys, 1980–1997.

Table 1. Number of replicates (n), catch (C; g/fishing unit) and number of species (S) in the fishing experiments with traps and set nets.

	Closed area		Fished area	
	Set nets	Traps	Set nets	Traps
1995				
n	5	6	6	6
C	212	480	915	788
s	5	5	8	6
1996				
n	7	7	8	7
C	52	320	851	132
s	4	5	4	5
1997				
n	11	6	11	6
C	37	486	487	715
s	3	8	7	8

Table 2. P-values from pairwise tests for differences between (A) areas and (B) clusters.

	p
A	
Area I–II	0.016
Area II–III	0.008
Area III–IV	0.143
B	
Cluster A–B	0.008
Cluster B–C	0.010
Cluster C–D	0.036

epifauna inside a frame (area=0.24 m^2; n=10). Species that could not be identified by the diver were brought to the laboratory for identification. The species compositions were analysed by use of the PRIMER-package (Clarke and Warwick, 1994). The H_0 hypothesis (no difference in species composition among areas I-IV) was tested by a one-way ANOSIM on Bray-Curtis similarity indices calculated on 4th root transformed data. Afterwards, pair-wise tests for differences between areas were carried out to investigate whether rejection of the H_0 hypothesis was caused by variability within the closed or fished areas (spatial variability) or by variability between fished and closed areas (fishery effect).

By means of a similarity dendrogram and a multidimensional scaling plot (MDS) separate clusters were identified. The SIMPER procedure identified which taxa had contributed to the dissimilarity among clusters, and the significance of the clusters was tested by one-way ANOSIM-tests.

Results

The results from the trawl surveys are summarized in Figure 2. Catch rates (range: 0.2–31.3 kg per 30 min tow) and number of species (range: 1–11) in the closed and the fished areas were in the same order of magnitude and followed approximately the same pattern. Prohibition of mussel dredging in 1988 had apparently no effect on these parameters. A drastic decline in catch rate was observed after 1990 in both areas as well as in other parts of the Limfjord.

In the experimental fishery with set nets and traps in shallow water, catch rates were higher in the fished area than in the closed area, whereas there was no difference in the number of species (Table 1). The difference in catch rates was more pronounced in set nets than in the traps.

Overall, 18 species and two higher taxa of sessile and mobile epibenthic invertebrates were observed by scuba divers. The difference in species composition among the four areas was highly significant (one-way ANOSIM, $p<0.0005$), and the H_0 hypothesis was rejected. The pair-wise tests (Table 2A) showed a significant difference in species composition between the fished (I) and closed (II) areas to the northwest, whereas the difference in the southwestern part (III and IV) was not significant. Inside the closed area, the difference between areas II and III was also significant.

The dendrogram and the MDS plot (Fig. 3) indicate a clustering of the stations in four groups that surpass the borders between fished and closed areas (Fig. 1). A

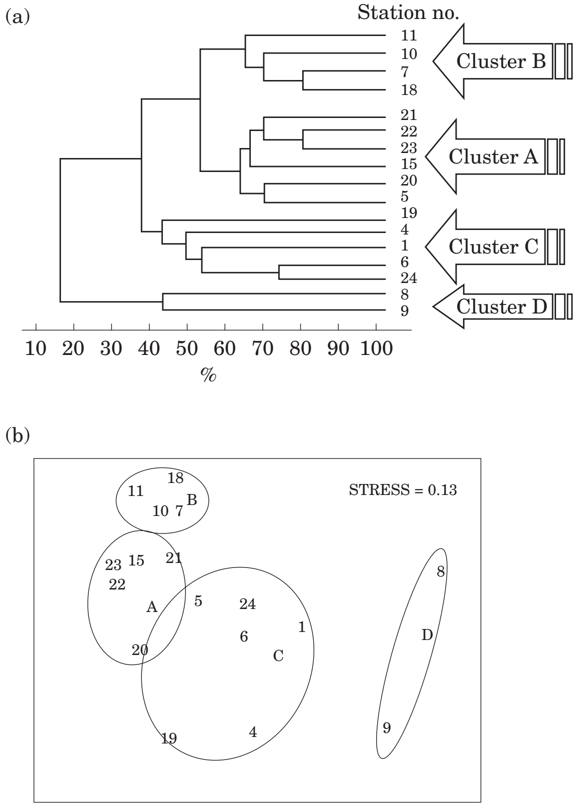

Figure 3. Clustering of epibenthic invertebrates in 4 groups (A-B-C-D; see also Fig. 1). (a) dendrogram; (b) MDS plot based on Bray Curtis similarity indices.

Table 3. Density of the taxa that contributed most to the species composition dissimilarity (%; ranked) between the four clusters observed.

	Density (ind m^{-2})		%
Cluster	A	B	
Mytilus edulis	640.6	5.4	23
Halichondria panicea	1.3	22.3	10
Metridium senile	2.1	38.5	7
Anthozoa	2.5	0.0	7
Ciona intestinalis	14.3	28.2	6
Asterias rubens	1.1	7.0	6
Ascidiella aspersa	16.8	62.3	5
Styela clava	2.2	6.4	5
Cluster	B	C	
Halichondria panicea	22.3	0.0	13
Ascidiella aspersa	62.3	1.0	12
Ciona intestinalis	28.2	0.1	11
Metridium senile	38.5	0.1	10
Styela clava	6.4	0.3	7
Mytilus edulis	5.4	28.7	6
Macropodia rostrata	5.5	1.0	5
Cluster	C	D	
Asterias rubens	0.6	0.0	11
Crangon crangon	1.3	1.5	11
Ascidia	2.6	0.0	11
Carcinus maenas	3.2	0.6	10
Hinia reticulata	0.7	0.0	10
Ophiura texturata	2.2	1.0	9
Macropodia rostrata	1.0	0.0	9
Ascidiella aspersa	1.0	0.0	8
Mytilus edulis	28.7	0.0	6

northern cluster (A) included the fished area (I) and one station in the closed area, a central cluster (B) consisting of four stations in area II, a southern cluster (C) including three stations in the closed area (III), and two stations in the southeastern fished area (IV), and a cluster (D) of two stations in area IV. Station 5 was clustered in A in the dendrogram, while the MDS plot indicated that it was somewhat more closely connected to cluster C. The ANOSIM test indicated significant differences in species compositions between all four clusters (Table 2B).

The SIMPER analysis provides the contribution of each taxon to the dissimilarity between the four clusters (Table 3). Species such as *M. edulis* and *Ascidiella aspersa* contributed to the dissimilarity between all clusters, whereas other species such as *Halichondria panicea* and *Metridium senile* contributed to the dissimilarity between two or three clusters only. The ranks of the species in relation to their contribution differ between clusters, indicating a large spatial variability in species composition. The species contributing to the dissimilarity between cluster A-B and B-C were dominated by sessile invertebrates, whereas the dissimilarity between cluster C-D was dominated by mobile species.

Discussion and conclusions

The local counties around the Limfjord imposed the ban on towed gears in 1988 in the expectation that the area would gradually be restored to more natural conditions not affected by mussel fishing. Also, the area was intended to serve as a control site for fishing impact studies, and thereby to increase the knowledge of the local effects of dredging.

We could not demonstrate any causality between mussel dredging and the decrease in fish landings. The number of fish species caught has not changed since 1980, and no differences in abundance were found between fished and closed areas. The significant and widespread decline in catch rate after 1990 could not be attributed to mussel dredging. Furthermore, no long-term effect on the epibenthic assemblages of invertebrates was observed in fished areas when compared with the closed area. The tests identified a significant difference in species compositions of benthic invertebrates within the closed area, but it was not possible to identify the boundaries between fished and unfished areas in the species composition at the different stations. These results agree to some extent with other observations. Lindegarth *et al*. (2000) investigated the impact of shrimp (*Pandalus borealis*) trawling in Gullmarsfjord (Sweden), but could not measure significant changes in the benthic community when comparing experimentally trawled and control areas. The introduction of the "plaice box" in the south-eastern North Sea in 1989 also seems to have failed to fulfil its purposes. The final goal was to enhance plaice recruitment, but instead a substantial decrease in yield and spawning stock biomass has been observed. This unexpected event may be explained by a number of coinciding factors. Among these were a decrease in growth rate of juvenile plaice and a change in the coastal ecosystem in the late 1980s and early 1990s (ICES, 1999; Pastoors *et al*., 2000). Jennings and Kaiser (1998) discussed the use of closed marine areas, and they concluded that "small reserves may not operate as desired . . . if the protected habitat is impacted by pollution and other anthropogenic activities".

In the Limfjord, the closed area appears to have had no significant influence on the demersal fish and epibenthic fauna, suggesting that other factors than mussel dredging may determine the observed spatial and temporal variability in the ecosystem. The washout of nitrogen from the surrounding farmland has more than doubled over the past 25 years followed by an increase in primary production. Because oxygen depletion occurs nearly every year (Dolmer *et al*., 1999), eutrophication and possibly also climatic events may be important determinants of the environmental condition, affecting the distribution of demersal fish and epibenthic fauna.

The management strategy for the future mussel fishery in the Limfjord is to reduce the fishing effort by reducing the number of vessels and to increase the number of closed areas in the fjord. The primary goal is to protect the epifauna and to increase species diversity. Another important goal is to re-establish fish stocks as well as a commercial and recreational fishery on them. The measures are not taken to protect the mussel stock but exclusively to protect the benthos and dependent fauna.

Although sampling intensity was limited and the results refer to a small closed area, no evidence is provided that mussel dredging controls the structure of the ecosystem in respect of epibenthic invertebrates and fish fauna, or affects these animals to any large extent. Other factors such as oxygen depletion apepars to have a much greater impact. Meanwhile, it is important to develop more sustainable aquaculture techniques to avoid future impacts when water quality is improved by a reduction in nutrient releases. New techniques such as long-line culture and transplantation of mussel seed from areas with low growth to areas with high growth may contribute to this. Activities in this field have already been initiated.

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