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Community structure and production of the macrobenthic infauna in relation to the micro-distribution of trawling effort

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Summary

The longer term effects of beam trawl fisheries depend on the benthic species composition and the life history characteristics. Beam trawling may have caused a shift in the benthic community from low-productive, long-lived species to high-productive, short-lived species. The effects may be inferred from comparisons of areas under different levels of fishing disturbance. Craeymeersch et al. (2000) focused on two subareas on the Dutch Continental Shelf. The authors indeed found a significant difference in species composition between intensively fished and less heavily fished areas but the found relationship might be largely correlative. It has been suggested that the scale at which the study was done was too small. A re-analysis of the data on a larger scale did not result in a significant relationship between species composition and fishing effort. There seems to be no straight relationship between fishing effort and infaunal productivity. It is concluded that this not necessarily points to the non-existence of such relationship but to the need of more detailed analyses taking into account the temporal and spatial dynamics of fishermen, target species and benthic species.

Introduction

The long-term impact of bottom fisheries on a particular species depend on the direct mortality at each fishing event, the distribution of the fishing effort, the distribution of that species and its life history characteristics such as longevity and fecundity. Long-living species with a low fecundity will be affected more than short-living species with high fecundity. Benthic scavengers may benefit from the additional food supply from discards or animals damaged in the trawl path (Kaiser & Spencer 1994; Lindeboom & de Groot 1998; Collie et al. 1997; Groenewold & Fonds 2000; Fonds 1999; Ramsay et al. 1999).
The longer term effects of fisheries on the benthic species composition and community structure are mostly evaluated from long term trends in benthos or by-catch data (Philippart 1998), or from a comparison of fished and un-fished areas (Hall et al. 1993; Lindeboom & de Groot 1998; Tuck et al. 1998). In areas where there is detailed information on the spatial distribution of both the fishing fleet and the benthic fauna, inferences might be made from comparisons of the benthic fauna of areas under different levels of fishing disturbance. Craeymeersch et al (2000) indeed found a significant difference in species composition between intensively fished and less heavily fished locations in two areas on the Dutch Continental Shelf. The authors concluded, however, that the found relationship might be largely correlative and not causal, and that the patterns found are likely due to one or more environmental variables determining both species composition and fishing effort distribution. It has been suggested that at the scale studied, sediment characteristics might have been indirectly related to such factor. Partialling out the effect of differences in grain size then resulted in at least an underestimation of the effect of fishing effort. This chapter reports on a re-analysis of the data on a larger scale.
Beam trawling may also have caused a shift in the benthic community from low-productive, long-lived species to high-productive, short-lived species (Rijnsdorp and van Beek 1991). Thus, opportunistic species may have benefited from the disturbance of the seabed. Indeed, Craeymeersch et al (2000) found an increase of the total density of spionids with increasing fishing disturbance. The effects of fishery disturbance on the benthic productivity is, however, not unequivocal (Groenewold and Fonds 2000; Jennings et al. 2001). In the western North Sea, Jennings et al (2001) found a decrease in productivity with increasing fishing effort. In this chapter we will evaluate the situation on the Dutch Continental Shelf.

Material and methods

Biotic and abiotic data

During the last quarter of the twentieth century the macrobenthic infauna on the Dutch Continental Shelf (DCS) was surveyed in great detail. In the period 1985-1993, samples were taken at about 800 stations. All surveys were carried out in Spring and used the same type of sampling equipment. In most surveys a Reineck boxcorer was used and sometimes Van Veen grabs. The content of the boxcorer or grab was washed over a sieve with round holes of 1 mm diameter. The work resulted in an atlas describing the occurrence and distribution of the most common species, together with relevant information on their ecology (Holtmann et al. 1996a). We refer to this atlas for more information on the different surveys. Most of the data used were from 1991 to 1993. There were no data for the most southern part of the DCS. Data for the Doggerbank were only used for the ordination analyses because for most species only density values are known.

The micro-scale distribution of the beam trawling activities of a representative samples of the Dutch fleet has been studied since 1993 (Rijnsdorp et al. 1998). In the period 1993-1995, 25 beam trawl vessels (24 of them with an engine power > 300 Hp or ≈ 221 kW) were equipped with and automated position registration system (APR) which records position every 6 minutes at an accuracy of 180 m. In 1996 another 6 vessels (5 of them with an engine power < 300 Hp) were equipped with an APR. By calculating vessel speed it is possible to estimate the fishing position of the sampled vessels, assuming a fishing speed of respectively 4.3 and 6 $Nm.h^{-1}$ for ships with an engine power of respectively less and more then 300 Hp. For the present study the total number of APR data recorded in each 1x1 Nm rectangle during a 4-year period (1993 -1997) were used. We assume that trawling effort in the period of macrobenthic sampling was similar.

Sediment data (median grain size, silt content), depth data and bottom temperature data (February, July) were made available as grid features in the GIS package ArcView by respectively NITG, RIKZ, and dr. J.G. Hiddink of Bangor. The latter were based on temperature data stored by ICES.

Estimates of environmental variables at locations were done in ArcView, using extension 'Get Grid Value' (v2), written by Jeremy Davies.

Because of the poor representation of smaller vessels (< 300 Hp), we excluded the coastal area (12 nm-zone) and the Plaice Box of the analyses. The area covered is shown in figure 1.

Ordination

To determine whether there is a relationship between fishing effort distribution and infaunal community structure, a direct gradient analysis was performed. In a direct gradient analysis the species composition is directly related to measured environmental variables: the first axes of the ordination are constructed in such a way as to explicitly optimise the fit to the supplied environmental data (ter Braak and Prentice 1988). In a partial canonical ordination, the effect of one or more covariables can be factored out. The result is an ordination of the residual variation in the species data that remains after fitting the effects of the covariables. This is especially interesting in our study, as we are not interested in environmental variation but want to focus on the species responses to fishing disturbance. Here we removed possible effects of depth and sediment characteristics (silt content, median grainsize) in a partial Canonical Correspondence Analysis (CCA). Species density data square-root transformed. All analyses were done with the CANOCO program of ter Braak (1988), version 3.10.

Production estimates

Production was estimated by the empirical relationship published by Tumbiolo and Downing (1994), relating production of marine benthos to biomass, maximum individual body mass and annual mean bottom temperature:

$$\log P = 0.18 + 0.97 * \log B - 0.22 * \log W_m + 0.04 * T_b - 0.014 * T_b * \log(Z+1)$$

with :

B = annual mean biomass (g dry mass m^{-2})
W_m = maximum individual body mass (mg dry mass)
T_b = annual mean bottom temperature (°C)
Z = depth (m)

under following assumptions:

- body mass data from May are representative for the whole year. Probably true in temperate regions as long as samples do not cover the seasonal recruitment peak (pers comm. Brey).
- Annual mean bottom temperature calculated as mean from February and July data.

For the conversion from Ash Free Dry Weight to (Shell Free) Dry Weight a reduction of 34% was used for Arthropoda, a 35% reduction for Echinodermata, a 17% reduction for Annelida, a 15% reduction for Mollusca and a 17% reduction for all other groups was used (Maurer and Robertson, 1999; Rumohr et al, 1987). Dry weight was converted to Carbon as follows: 1g DW = 0.5 g C (Waters, 1977).

Results

Ordination

The co-variables (median grain size, silt content, depth) explain a significant part of the total variance in species composition (first 3 axes explain 7.6 % of total variance of species data; p = 0.001). Effort does not account for a significant part of the variance (p = 0.512; 0.4% of total variance of species data explained).

Production estimates

Figure 1 shows the estimated production at all locations in the studied area superimposed on the fishing effort data. Since empirical conversion factors were applied, estimates of secondary production essentially reflect biomass patterns.
At first sight, high production estimates are indeed found in areas with high fishing intensity: southern part of study area and on Frisian front (?). But the Oystergrounds are characterized by low fishing effort and relatively high production figures. And many locations in the area west of Texel have low production values but are experiencing higher fishing disturbance. Thus, there seems to be no straight relationship between fishing effort and infaunal productivity.

Discussion

The re-analysis of the data on a larger scale than the previous analyses (Craeymeersch et al., 2000) did not result in a significant relationship between species composition and fishing effort. This might simply be due to the fact that the most vulnerable infaunal species already have decreased in earlier years (i.e. before the eighties).

It might also be due to the fact that our choice of enlarging the spatial area was not a good choice. If the effect of fishing disturbance depends on the community structure (i.e. the species composition) different effects might be expected in different communities. Based on the macrobenthos data mentioned above, the Dutch Continental Shelf can be divided into 4 subareas (Holtmann et al. 1996b): the southern part of the Dogger Bank, the Oyster Ground, the southern offshore area and the coastal area. Thus, the present study covers three of these areas.

But most probably, a positive relationship between fishing effort and both species composition does only hold for part of the year. The main target species of the Dutch trawlers are sole and plaice. The distribution of these bottom feeding flatfish species is only part of the year related to their prey distribution. During the other part of the year, their distribution is related to spawning activities or overwintering. Plaice stop feeding between December and March when they are gathered on the spawning grounds in the southern and southeastern North Sea (Rijnsdorp, 1989; Rijnsdorp and Vingerhoed, 2001). The fishery is, therefore, not a one-to-one 'mirror' of the prey-items of these flatfishes. Thus, only effort data of the time window the fishes are predating should be used. The same holds, of course, for the relationship between productivity and fishing effort. When plaice and sole are harvested during their non-feeding period, this will not be in the feeding grounds and, consequently, not in the areas of high production of their prey items.

The impact of bottom trawling on the benthos may also differ between months in relation to the seasonality of the benthic organism. At least for some species, a difference between burying depth in summer and winter has been shown (Zwarts, 1996). Thus, it can be expected that the vulnerability of benthic organisms for the bottom trawl disturbance differs according to the season the bottom is disturbed.

And, finally, any model relating fishing effort to benthic productivity should, besides the above mentioned dynamic processes, take into account other factors that influence the spatial distribution of the beam trawlers (e.g. distance to harbour)

In conclusion, the fact that we haven't found a clear relationship between fishing effort and benthic species composition or productivity is not pointing to a non-existence of such relationship but to the need of more detailed analyses taking into account the temporal and spatial dynamics of fishermen, target species and benthic species. This will lead to more detailed understanding of the spatial and temporal patterns of disturbance by fishing and, consequently, a better understanding of the consequences to benthic diversity and productivity.

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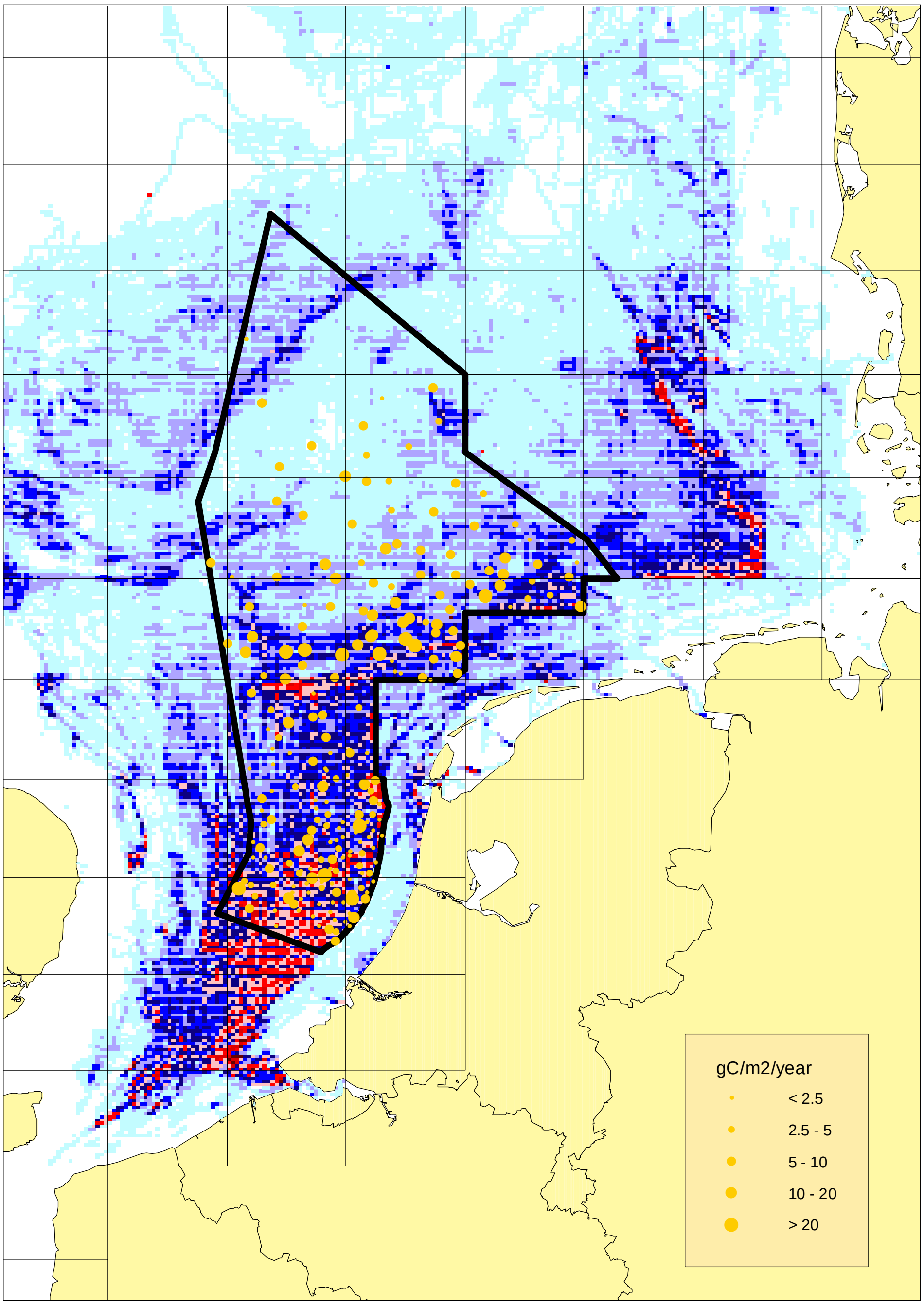

Figure 1. Production estimates of macrobenthic infauna superimposed on fishing effort