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Changes in the Barents Sea fish community induced by environmental change and fishery

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A spatio-temporal analysis of Barents Sea survey data from the deeper parts of the Barents Sea shows a sudden change in fish community structure and abundance taking place in the mid 1980s and 1990s. The change in fish community structure is concomitant with climatic change and increasing fishing effort. Fishery may amplify the effects of climate forcing, and oppose recovery from the impact of climatic events. To characterize the effects of climate and fishery, survey trawl data, temperature data and log book data from the shrimp fishery are analyzed for the period 1980-2007. The climate regime shifts in the mid 80s and 90s with decline in North Atlantic Oscillation and temperature resulted in abrupt decline in fish abundance, decline in biodiversity and increase in pelagic demersal ratio. The shrimp stock also declined and the response of the shrimp industry was a reduction in effort. As the standardised fishing effort is our only measure of fishing impact it becomes difficult to separate between the two impact factors temperature and fisheries. Yet, preliminary results indicate that the shrimp fishery has minor influence on the fish community. The fish community in the Barents Sea has changed into a more North Sea like pelagic-dominated ecosystem. The sudden changes in abundance and diversity reveal that the Barents Sea fish community is sensitive to environmental change. High precaution is needed in the management of all human activities in the Barents Sea due to its low species diversity and resilience.

Keywords: Barents Sea, climate change, fish community, fisheries

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Introduction

Significant structural changes, and sudden alterations, i.e. regime shifts, may occur in large marine ecosystems. The evidence for regime shifts in the oceans, consisting of biomass and structural changes over several trophic levels, is growing, and includes the North Pacific (Hsieh *et al.*, 2005), the Northwest Atlantic (Frank *et al.*, 2005), and the North Sea (Beaugrand, 2004; Kirby *et al.*, 2009). These regime shifts are often related to climatic regime shifts and overfishing (Lees *et al.*, 2006), and may be difficult to reverse.

The Barents Sea is considered ecologically 'healthy' (Anon., 2002; Anon., 2006), and this large marine ecosystem has been carefully monitored, and annually approximately 500 survey days are spent in the area. Yet, changes in the ecosystem, expected on the basis of changing climate and harvest regimes (Lees *et al.*, 2006), may have gone undetected due to the strong focus on oceanography and commercial species of monitoring programs.

As the shrimp fishery has been an important fishery in the deep Barents Sea since the late 70's, our focus is on the effect of this fishing fleet on the fish community. The Norwegian shrimp fleet has experienced a technological creep and in the late 90's vessels increased in size and the use of double and triple trawls became more common. In the early 90's the Nordmøre grate became mandatory and thereby changed the selection pattern of the shrimp trawlers as by-catch of fish reduced remarkably.

In a previous study we detected signs of ecological regime shift in the mid 90's (Aschan *et al.*, in review). By studying a longer time series we may detect if a shift really occurred. The main objective of this study is to document the spatial and temporal changes in the deeper Barents Sea fish assemblages in relation to environmental parameters and fisheries in the period 1980-2007.

Material and Methods

Data on fish species abundance and biomass was collected during the annual shrimp surveys conducted by the Norwegian Institute of Fisheries and Aquaculture (NIFA) and the Institute of Marine Research (IMR), in the Barents Sea from 1982 until 2004 (Aschan and Sunnanå, 1997). Data from 2005-2007 was received from the Ecosystem survey conducted in autumn by IMR. The study area ranged from 70°N to 77°N and from 15°E to 36°E, and the depth at stations sampled varied between 100 m and 495 m (Fig. 1). In 1982-1990 stratified random sampling was applied but since 1991 stations were placed on a grid with 20‒30 nautical miles distance between stations (Harbitz *et al.*, 1998), and at ecosystem surveys 20-40 nm between stations. A total of 41700 stations were sampled in the 26 year period. The standard survey trawl used in all demersal surveys in Norway (Campelen 1800) was towed at 3 knots for 20 minutes, thereby covering a distance of one nautical mile (1.856 km). The mean door spread was 47 m and the wingspread was 14 m (Aschan and Sunnanå 1997). The survey trawl, a shrimp trawl by design, is widely used in ground fish surveys (e.g. in the Barents Sea, the North Sea and off Newfoundland), and has a good catchability for demersal fish. However, also several species with a more pelagic habitat are regularly caught in this trawl. The mean depth was registered for each haul. A temperature sensor (Scanmar) was attached to the head-rope of the survey trawl to ensure a bottom temperature estimate at each station in1992-2004.

The temperature sensor was calibrated against CTD measurements. Only the Vardø section is presented for the whole time series (1980-2007).

During the surveys all fish were identified, counted, and weighed by species. The dataset was standardised to ensure that sampling effort and station distribution did not bias results between years: stations shallower than 200 m were excluded.

Diversity measures were estimated using this standardised data set consisting of 4 stations and 79 taxa. All statistical analyses were run with the software R 2.6.0 (R Development Core Team, 2007), using the package “vegan” (Oksanen, 2008), for multivariate analyses. Several community indicators have been established, and we first used abundance, species richness, diversity and a pelagic-demersal (P/D) ratio. The abundance (*A*), the species richness (*S*) given as number of species present, and the Shannon diversity index were estimated by station and year. The Shannon–Wiener diversity index (*H’*) (Hulbert, 1978) is defined as

$$H' = -sum\ p_i\ log_2\ p_i,$$

where p_i is the proportional abundance of species *i* and *2* is the base of the logarithm.

The structural variation of the fish community in space and time was modelled as a function of geographic position, depth, temperature, shrimp fishing effort and year by direct ordination, using a Canonical Correspondence Analysis (CCA). The CCA model was tested by Monte Carlo permutation (Legendre and Legendre, 1998; Oksanen, 2008). Due to inconsistencies in identification it was appropriate to group species for the ordination analysis; the redfish *Sebastes mentella*, *S. marinus*, *S. viviparous* and *S.* spp. were all treated as one variable (Se_spp). All *Rajidae* (Ra_spp), all *Triglops* (Tr_spp) and some of the *Lycodes* (Ly_spp) were treated as one taxon respectively (Table 2). Species occurring in at least 12 of the 26 years were included in. This reductions left 30 taxa for the ordination analysis, for which abundance estimates were log(*x*+1)-transformed.

As a coarse metric of fish community structure, the P/D ratio was calculated from the standardized data set as the sum of pelagic fish divided by the sum of demersal fish (Moreno *et al.*, 2000; Collie *et al.*, 2008). Following the approach introduced by Caddy et al. (1998) we used the “small pelagic fish” category as an index of annual planktonic productivity. Information for the classification of species habitat was obtained from FishBase (Froese and Pauly, 2007), and was used to broaden our definition of “small pelagics” to include largely planktivorous species that are demersal in habit, but during night leave the bottom to feed on plankton. Species characterized as bathydemersal (P-D) were excluded, and when generic names hindered the separation between species with different habitat preference (e.g. *Sebastes spp*.) the species group was excluded from the P/D ratio calculation.

The North Atlantic Oscillation (NAO) and temperature are considered important drivers for the marine ecosystem (Lees *et al.*, 2006). The NAO index from the National Centre of Atmospheric Research, USA (Hurrell, 1995), is a much used, but crude indicator of the south-westerly winds in the Norwegian and Barents Sea, and has significant effect on the Barents Sea temperatures (Ingvaldsen *et al.*, 2003).
Fishing pressure is given as the standardised effort of the shrimp fleet the previous year. Logbook data were analysed to show the spatial and temporal distribution of the fishery. Catch-per-unit-effort (CPUE) data from Norwegian vessels were used in a general linear

model to calculate standardized annual catch rate indices and the standardized effort was derived by dividing total catch by the standardised CPUE in each location.

The CPUE indices included the following variables: (1) vessel size grouped by engine size, (2) spatial availability of shrimp, (3) gear type (single, double or triple trawl) and (5) annual mean CPUE. The area definition used is the statistical location defined by the Norwegian Fisheriesdirectorate (Fig. 2). The multiplicative model was represented in logarithmic form as:

$$CPUE_{mikh} = A_m + Y_i + V_k * G_h$$

Where $CPUE_{mikh}$ is the mean CPUE for vessel-group *k*, fishing in area *m* during year *i* with geartype *h* (k = 1,...,n; m = 1,…,a; i = 1,…,y; h=1,2,3); A_m is effect of the m^{th} area ; Y_i is the effect of the i^{th} year V_k is the effect of the k^{th} vessel-group; G_h is the effect of gear type *h*.

Results and discussion

Mean annual temperature from the Vardø-North section along 31°13'E, between 50–200 m depth, from 72°15'N to 74°15'N, show annual variation but the trend is increasing. A sudden drop in temperature occurs in the mid 80's and the mid 90's and these have previously been considered to be climate regime shifts (Lees *et al.*, 2006). Both the temperature reductions seem to be caused by a drop in NAO that is more dramatic in 1996 (Fig. 3).

The standardised annual shrimp fishing effort (hours) by location in the Barents Sea for 1992-1994, estimated from Norwegian log book statistic, reveal that the Hopen Deep is an area within the study area where the effort is highest (Fig. 4). The Standardised annual effort (hours) of the Norwegian shrimp fleet show a drop in 1987 and in 1994 due to lower shrimp abundance, while the low effort in recent years is also due to low market price on shrimp and high fuel prices (Fig. 5). The annual standardised effort was rather high during two periods 1983-1991 and 1998-2002. In the first period no grates were used and the by-catch consisted of commercial and non commercial fish species of all sizes. After 1992 when the Nordmøre grate was introduced, larger fish (>20cm) was excluded and only juvenile fish and small species were caught.

The species richness (number of species) is relatively lower the first four years, as a consequence of poor species determination. In the period 1984-2007 the annual mean varies between 8 and 13 species. Although the number of species varies between stations there is no obvious regional pattern. The abundance shows a drop in the mid 80s and the mid 90s as a response to low NAO and low temperature (Fig. 6). The Shannon–Weaver biodiversity also respond to the temperature drops with a decrease. The highest diversity is observed in the south-western Barents Sea and increase towards the north in warmer periods.

As mentioned above the reliability of the data before 1984 is not good. The mean annual P/D-ratio in the Barents Sea 1984-2007 reveals high variation with a top in the late 80's and an oscillating increase since the lowest level observed in 1996 (Fig. 7). The P/D ratio increase because demersal species belonging e.g. to *Cottidae* and *Rajidae*, as well as the *Gadidae*, *Gadus morhua* and *Melanogrammus aeglefinus* become less abundant, while pelagic species such as *Mallotus villosus*, *Boreogadus saida* and *Micromesistius poutassou* increase in abundance.

The abundance, diversity and the P/D ratio increase after the temperature drops in the mid 80s and 90s. However, in the first period the demersal component seems to recover and the P/D ratio declines within 3-4 years, while the P/D ratio continues to increase after 1996. These changes in P/D ratio may be considered natural fluctuations, but the species composition is different as the increase in Atlantic species is more dominant in the second period. This supports our hypothesis (Fossheim *et al.*, 2009; Aschan *et al.*, in review) that the Barents Sea has gone through an ecological regime shift. The Barents Sea is turning into a more North Sea like pelagic-dominated ecosystem (Loeng and Drinkwater, 2007; Yaragina and Dolgov, 2009). Forecasts have predicted a temperature increase that is believed to result in a production increase followed by a higher fish production in the Barents Sea (Drinkwater *et al.*, 2005; Cheung *et al.*, 2008). The observed increase in abundance and diversity since 2001 also support this prediction. The Barents Sea may not be as 'healthy' and resilient as previously believed, as it shows trends towards increasing pelagic dominance. This suggests greater precaution in the management of all human activities in the area (shipping, fishing, oil and gas industry).

Previous studies have shown that depth and temperature are important factors structuring the fish community and that temporal change is mainly due to temperature change (Fossheim *et al.*, 2006; Fossheim *et al.*, 2009; Aschan *et al.*, in review). We also examine the possible impact of the shrimp fisheries measured as standardised effort the previous year at each station. Yet, the shrimp fishing effort is dependent on the availability of shrimp and the shrimp stock respond to sudden temperature decline with decreased stock size (Aschan and Ingvaldsen, 2009), as does most other species in the Barents Sea (Fig. 6). Thereby it becomes very hard to separate between the temperature induced community change and the fisheries induced change. A preliminary CCA analysis (not shown here) including the most dominant species and previously identified indicator species reveal that the shrimp fishing effort has a low explanatory value, however this has to be further studied.

Conclusions

-The Barents Sea fish community has undergone structural change as a consequence of climate regime shifts in the mid 80s and 90s. After the second climate shift in 1996 the fish community has changed into a more North Sea like pelagic-dominated ecosystem.

- It is at this stage not possible to separate the fishing impact on the fish community from the temperature impact as the fishing effort is dependent on the shrimp stock abundance that is influenced by temperature.

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Figures:

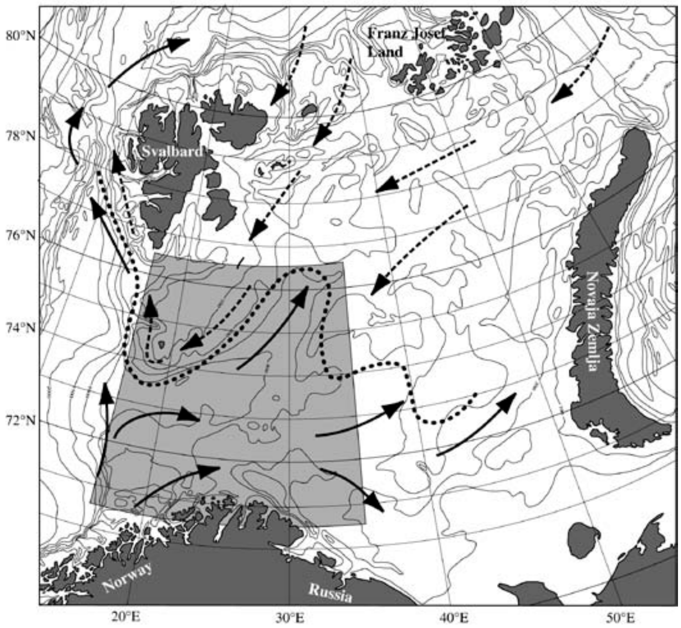

Fig. 1. The Barents Sea with main surface currents (*a*). Atlantic currents (**—**>), Arctic currents (**---**>) and the mean position of the Polar Front (**• • •**).

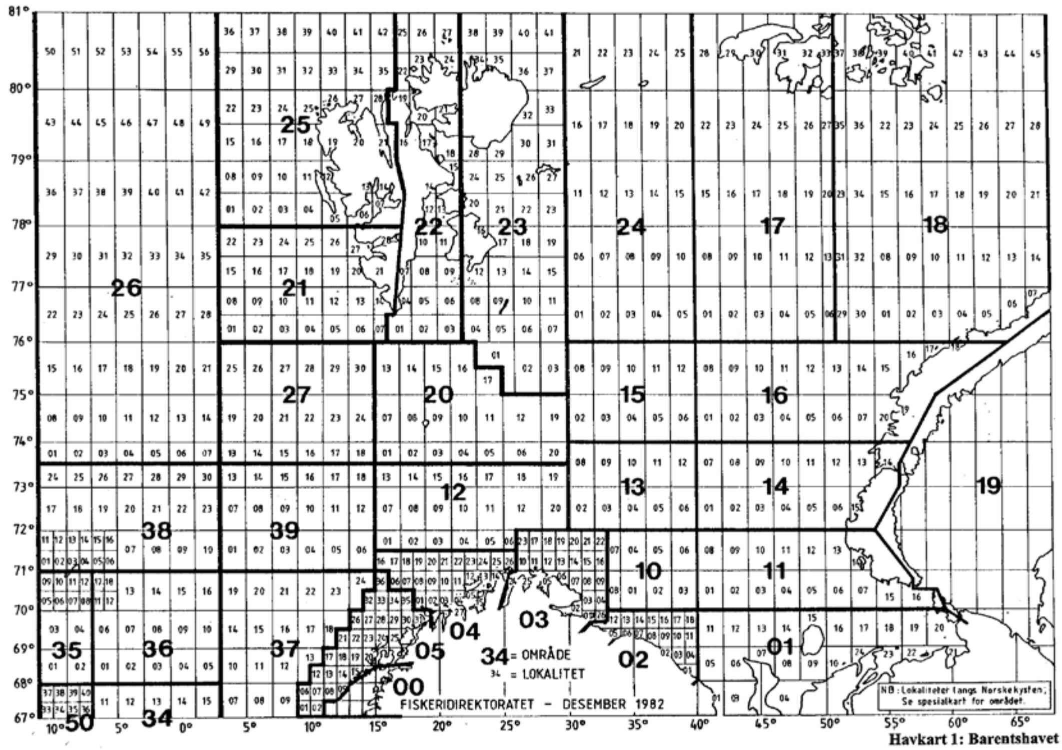

Fig. 2. The Barents Sea with main statistical areas (01-50) and locations (squares within areas) defined by the Norwegian Fisheries directorate.

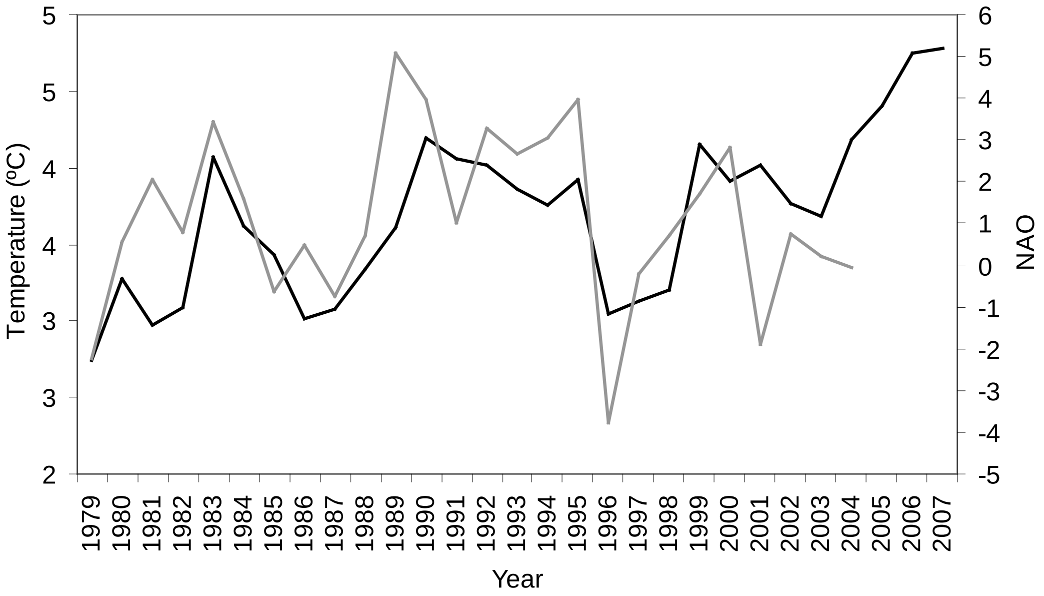

Fig. 3. Mean annual temperature from the Vardø-North section along 31°13'E, between 50–200 m depth, from 72°15'N to 74°15'N, (Aschan and Ingvaldsen, 2009). B. The NAO index from the National Centre of Atmospheric Research, USA (Hurrell, 1995).

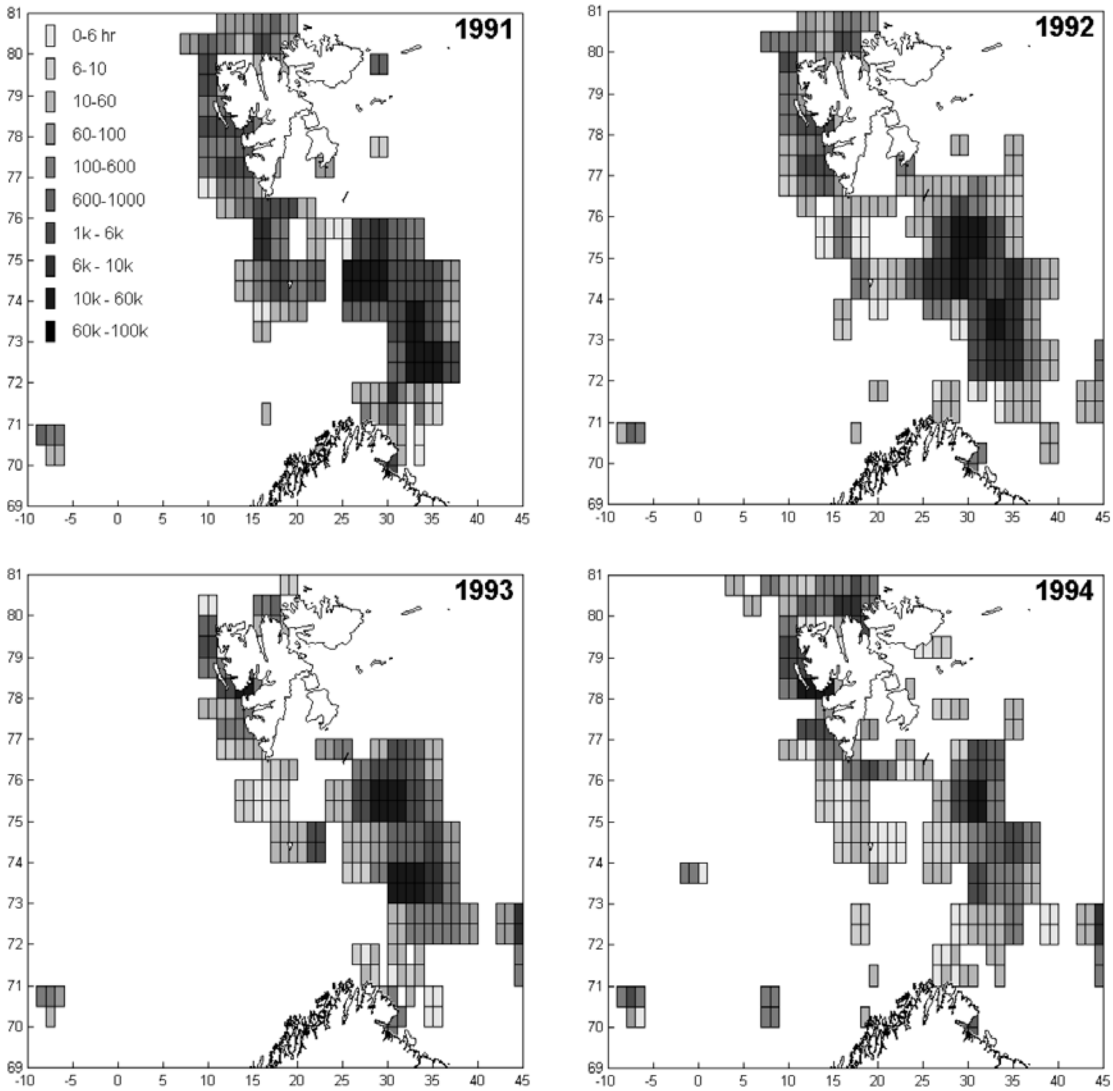

Fig. 4. Standardised annual shrimp fishing effort (hours) by location in the Barents Sea for 1992-1994, estimated from Norwegian log book statistic.

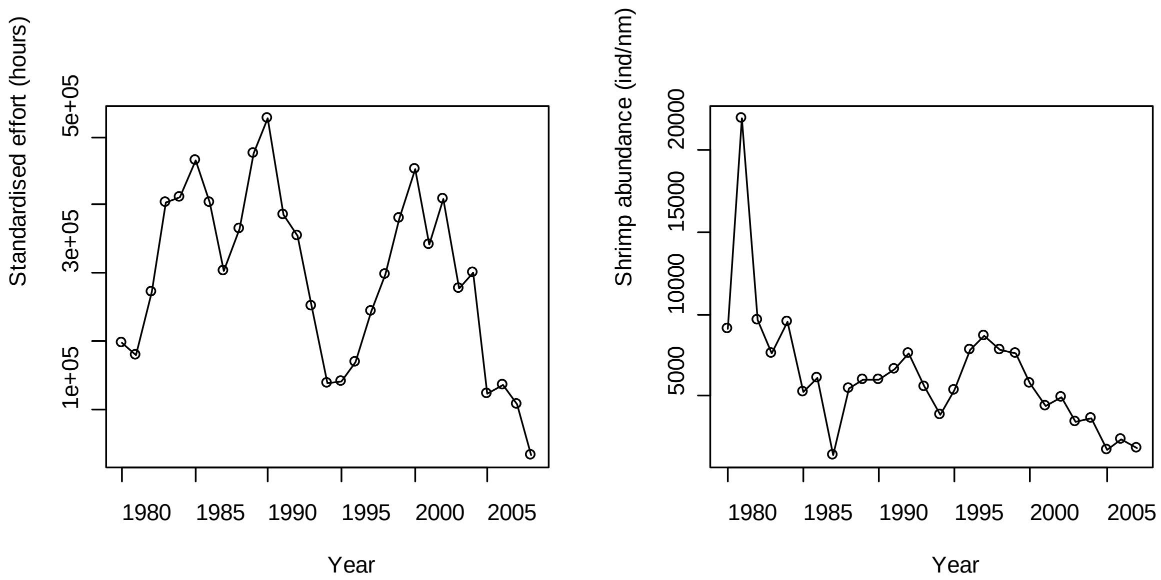

Fig. 5. Standardised effort (hours) of the Norwegian shrimp fleet in the Barents Sea. Left panel: annual effort of all fishing grounds. Right panel: Mean shrimp abundance/nm in the study area.

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Fig. 6. Log abundance and Shannon–Weaver diversity for fish communities observed at each station in the deeper Barents Sea presented by year for the period (1980-2007).

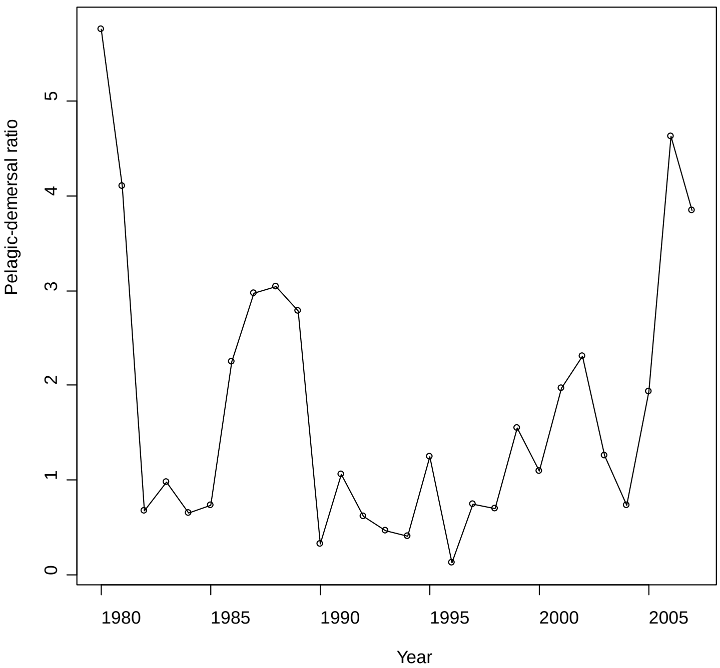

Fig. 7. The mean annual P/D ratio in the Barents Sea 1980-2007.