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Spatial variation and structural change of the Barents Sea fish community

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We document the spatial patterns found in the Barents Sea fish community in relation to environmental parameters, analysing data from the ecosystem surveys covering the Norwegian part of the Barents Sea during 2004-2008 and comparing with earlier investigations of the deeper areas from the period 1992-2004. Changes in the ecosystem, expected on the basis of changing climate and harvest regimes may often go undetected due to strong focus on oceanography and commercial species of monitoring programs. Fish species that are not targeted by fishery are included in the analyses, providing valuable, additional ecological information on structural alterations. We identified species assemblages associated with different water masses and range of productivity of sea areas. Major changes in the structure of the fish community occur in this previously thought healthy, resilient and well-managed large marine ecosystem. The spatio-temporal analyses of the Barents Sea survey data from this decade shows that a new fish community structure is in place compared to the general community structure of the previous decades. An ecological regime shift in the 90-ies might be speculated. The change is concurrent with a climatic regime shift and may be persistent.

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Introduction

Structural changes in marine communities may become more common because of climate change. In the Arctic, local warming is twice the global average (Anisimov et al. 2007), posing a large threat to the Arctic communities. The Barents Sea ecosystem has previously been considered ecologically 'healthy' (Anon. 2002, 2006), but major changes are expected due to the rapid climate warming, as has been observed in adjacent ecosystems such as the North Sea (Beaugrand 2004, Beaugrand et al. 2009).

Detecting climate change effects on local organisms and communities is a difficult task. Climate change effects in marine ecosystems have mainly been studied for single commercial fish species since they are intensively monitored and subjected to annual stock assessments. These species have been studied for decades and their response to each other, main prey and predator species and the environment is regularly reviewed. However, when investigating climate change effects, single species responses might not give a good indication of possible changes in the ecosystem due to the large inter-annual variability of single stocks, and also, the effect of fishing, might obscure any effect of climate change. Furthermore, the effect of climate on the whole community can be very different from the effect on single populations (Jennings and Brander 2009).

Marine fish communities can be characterised by rather simple metrics such as relative measures of abundance or biomass, diversity indices, size structure, indices for food chain relationships, slope of size spectra, etc. Marine fish communities will generally be restricted by borders in the abiotic environment, such as hydrographical fronts, topographical barriers, and sediment types.

The Barents Sea fish fauna and the biogeographical distribution patterns of individual fishes are well known from rather extensive taxonomical studies for more than 100 years (e.g. Zenkevich 1963). Fish community studies, i.e. descriptions of assemblages of species inhabiting specific habitats or sub-areas of the Barents Sea, are however relatively few and limited in geographical scope and time (Burgos 1989; Nilssen and Hopkins 1992; Fossheim 2000, Fossheim *et al.* 2006; Byrkjedal and Høines 2007; Dolgov 2007, Bogstad *et al.* 2008). These studies show that communities can be defined in these subareas, but they only provided information on large scale spatial patterns, not on variability in time and space.

The main objective of this study is to document the spatial and temporal changes in the Barents Sea fish assemblages in relation to environmental parameters. Fish species that are not targeted by fishery are included in the analysis, providing valuable, additional ecological information on structural alterations (Kaiser et al. 2004). Spatial and temporal changes in the Barents Sea fish communities will be investigated by focusing on i) abundance and biodiversity patterns, ii) driving factors and iii) species distribution change.

In this paper results from the spatial analyses will be given and based on the spatial patterns for 2004-2008, a comparison with previous studies in the area (Fossheim et al. 2006, Aschan et al. in review) will be qualitatively evaluated with regard to temporal change in community structure in the Barents Sea. Results from the temporal analyses will however be presented at the ICES ASC 2009.

Material and methods

In the present study, fish community data from the Norwegian part of the Barents Sea shelf are presented, including the northern (around Svalbard) and eastern part. The data was collected on the ecosystem survey, run jointly by the Institute of Marine Research Norway (IMR) and the Polar Research Institute of Marine fisheries and Oceanography (PINRO) from 2004-2008. This survey has covered most of the shelf area of the Barents Sea in August and September, the period of the year with the least ice coverage. Furthermore, the years have been warm, exposing new areas to investigation. The data set from this survey is spatially extensive, allowing the study of the distribution of fish communities over the entire area. At the ecosystem survey abiotic and biotic data were sampled synoptically, allowing the study of the relationship between fish communities and habitat characteristic. Fish abundance data were sampled with bottom trawl and environmental parameters with CTD. Stations deeper than 1000 m were omitted from the analyses.

Over 100 fish species were identified during the five survey years but due to interannual variation in the classification, the number of species groups was reduced to 80 by merging species on higher taxonomical levels (abbreviated xx_spp in Table 1). Abundance data were standardized to 1 nautical mile and $\log_{10}$ (a+1)-transformed prior to statistical analyses, with the purpose of downscaling very abundant species and reducing skewness (ter Braak 1997).

Cluster analysis was used to group stations with similar species composition and a hierarchical method was chosen, based on an Euclidean distance matrix. Ward's method was chosen to minimize the variance within clusters. The structural variation of the fish community in space was modelled as a function of geographic position, depth, temperature and salinity by direct ordination, using a Canonical Correspondence Analysis (CCA). The CCA model was tested by Monte Carlo permutation (Legendre and Legendre 1998, Oksanen 2008).

Table I. List of species (spp denotes species groups, i.e. merged species) identified on the ecosystem survey 2004-2008.

Latin name	Abb.	Latin name	Abb.
Amblyraja hyperborea	am_hy	Leptoclinus maculatus	le_ma
Amblyraja radiata	am_ra	Limanda limanda	li_lim
Ammodytes spp	am_spp	Liparidae	li_spp
Anarhichadidae	an_spp	Liparis fabricii	li_fa
Anarhichas denticulatus	an_de	Liparis gibbus	li_gi
Anarhichas lupus	an_lu	Lophius piscatorius	lo_pi
Anarhichas minor	an_mi	Lumpenus lampretaeformis	lu_la
Anisarchus medius	an_me	Macrourus berglax	ma_be
Arctogadus glacialis	ar_gl	Mallotus villosus	ma_vi
Argentina silus	ar_si	Maurolicus muelleri	ma_mu
Artediellus atlanticus	ar_at	Melanogrammus aeglefinus	me_ae
Bathyraja spinicauda	ba_sp	Merlangius merlangus	me_me
Boreogadus saida	bo_sa	Merluccius sp.	me_sp
Brosme brosme	br_br	Micromesistius poutassou	mi_po
Careproctus sp.	ca_sp	Microstomus kitt	mi_ki
Chimaera monstrosa	ch_mo	Molva molva	mo_mo
Clupea harengus	cl_ha	Myctophidae	my_spp
Cottidae	co_spp	Nansenia groenlandica	na_gr
Cottunculus microps	co_mi	Paralepididae	pa_spp
Cyclopteridae	cy_spp	Phycis blennoides	ph_bl
Cyclopterus lumpus	cy_lu	Pleuronectes platessa	pl_pl
Dipturus batis	di_ba	Pollachius pollachius	po_po
Dipturus linteus	di_li	Pollachius virens	po_vi
Dipturus oxyrinchus	di_ox	Raja clavata	ra_cl
Enchelyopus cimbrius	en_ci	Rajella fyllae	ra_fy
Entelurus aequoreus	en_ae	Rajidae	ra_spp
Etmopterus spinax	et_sp	Raniceps raninus	ra_ra
Gadiculus argenteus thori	ga_at	Reinhardtius hippoglossoides	re_hi
Gadidae	ga_spp	Sebastes marinus	se_ma
Gadus morhua	ga_mo	Sebastes mentella	se_me
Gaidropsarus argentatus	ga_ar	sebastes sp	se_spp
Gaidropsarus vulgaris	ga_vu	Sebastes viviparus	se_vi
Gasterosteus aculeatus	ga_ac	Somniosus microcephalus	so_mi
Glyptocephalus cynoglossus	gl_cy	Triglops murrayi	tr_mu
Gymnocanthus tricuspis	gy_tr	Triglops nybelini	tr_ny
Hippoglossoides platessoides	hi_pl	Triglops pingelii	tr_pi
Hippoglossus hippoglossus	hi_hi	Triglops sp.	tr_sp
Icelus bicornis	ic_bi	Trisopterus esmarkii	tr_es
Lepidorhombus whiffiagonis	le_wh	Zeugopterus norvegicus	ze_no
Leptagonus decagonus	le_de	Zoarcidae	zo_spp

Results and discussion

Spatial patterns

The most extensive sampling in the Barents Sea during the ecosystem survey years was performed in 2007. This is also the warmest year ever recorded in this area, with no sea ice in the Barents Sea (internal shelf).

The grouping of stations with similar species composition shows a four-group pattern (Figure 1), consistent between years (but only shown for 2007). The spatial extension of the four groups in the map are named and interpreted (Figure 1):

1) Northern (Svalbard) – *blue circles*
2) North and east of the Polar front – *green circles*
3) Polar front (deep) – *yellow circles*
4) Southern (coastal and shallow) – *red circles*

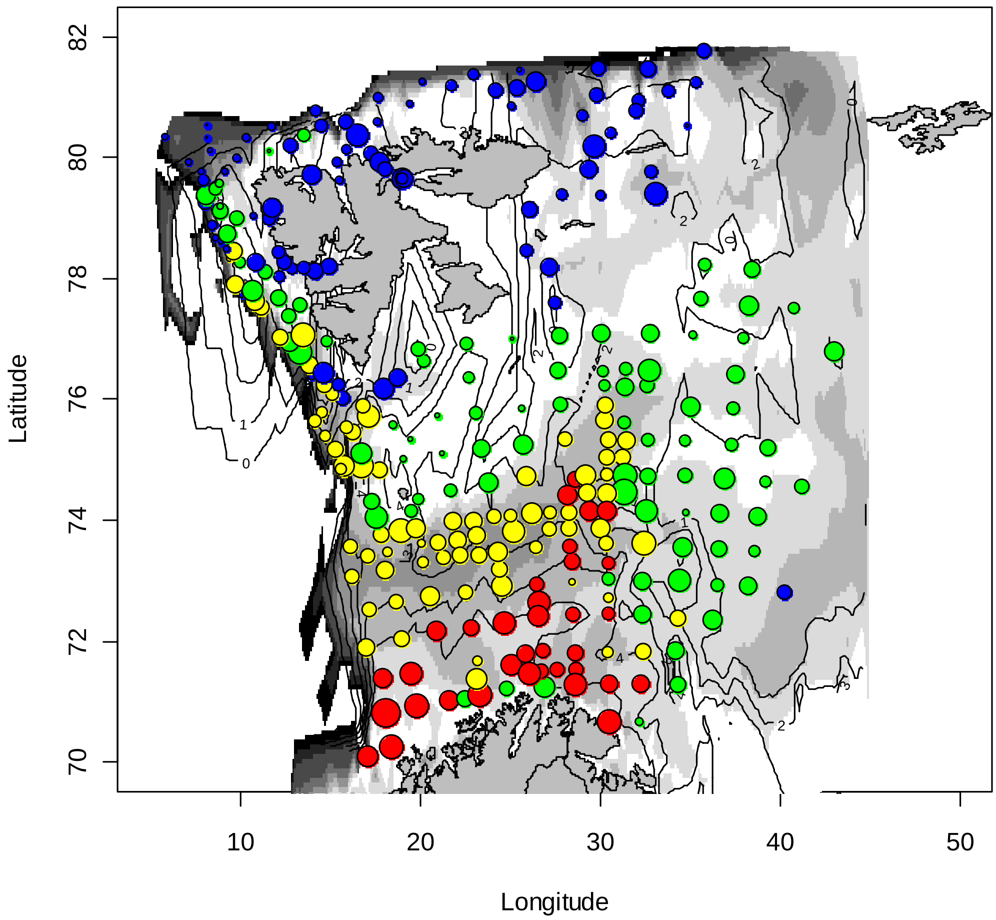

Figure 1. Map of the Barents Sea showing the bathymetry (grey scale), temperature (isolines) and stations in 2007 (circles), cluster group affiliation (circle colour) and species richness (circle size).

The 3-4°C isoline in the central part of the Barents Sea in Figure 1 is interpreted as the Polar front. This isoline separates the northern clusters (blue and green circles in Figure 1) from the deep (yellow) and southern (red) clusters. Thus, the Polar front clearly represents a biogeographical boundary for the fish community, as previously identified by Fossheim et al. (2006).

In the north the separation of the Svalbard versus eastern Barents Sea fish communities is striking. The area around Svalbard is typically warmer than the eastern Barents Sea due to the inflow from the left branch of the North Atlantic Current. However, deeper stations are also sampled here, and the difference between the northern communities might therefore have several explanations. In the south the two communities are clearly separated with regard to depth, but also with the distance to the mainland coast.

Species richness varies and is highest in the southern and coastal area, but there is no clear *gradient* in species richness with latitude. An interesting feature is that the species richness varies more *within* sub-communities than between. This finding shows that the internal dynamics in sub-communities have the potential to be equally complex with regard to trophic interactions in the Arctic communities as further south.

Explaining spatial patterns

The first two constrained ordination axes, accounting for 8.22 % and 5.76 % of the total variation, summarize the spatial component of variation correlated with latitude and temperature (CCA1), and depth and longitude (CCA2), respectively (Figure 2). The total variation captured by the CCA was 21 %, which can be expected for such an extensive dataset sampled over a heterogeneous environment. A Monte Carlo permutation test showed that the model with all five constraining factors was significant ($p<0.01$).

Three distinct fish assemblages, previously defined by Fossheim et al. (2006) were identified in the CCA-model: a northern component (CCA1>0.5), a southern component (CCA1<−0.8), and a deep component (CCA2<−1) (Figure 2). Pelagic species such as *Boreogadus saida* and *Mallotus villosus* were associated with the northern component and *Clupea harengus* were associated with the southern component.

The water mass distribution and characteristics in the Barents Sea have a major influence on the production processes, and particularly the position of the Polar Front constitutes a clear zoogeographical boundary in this area (Figure 1, Bergstad et al. 1999), but the assemblages and their distribution patterns cannot only be explained by abiotic factors included in this study. The three fish assemblages probably constitute different ecological groups with internal dynamics. These components should be monitored to track responses to changes in the environment that are more comprehensive and faster than patterns detected when studying single species.

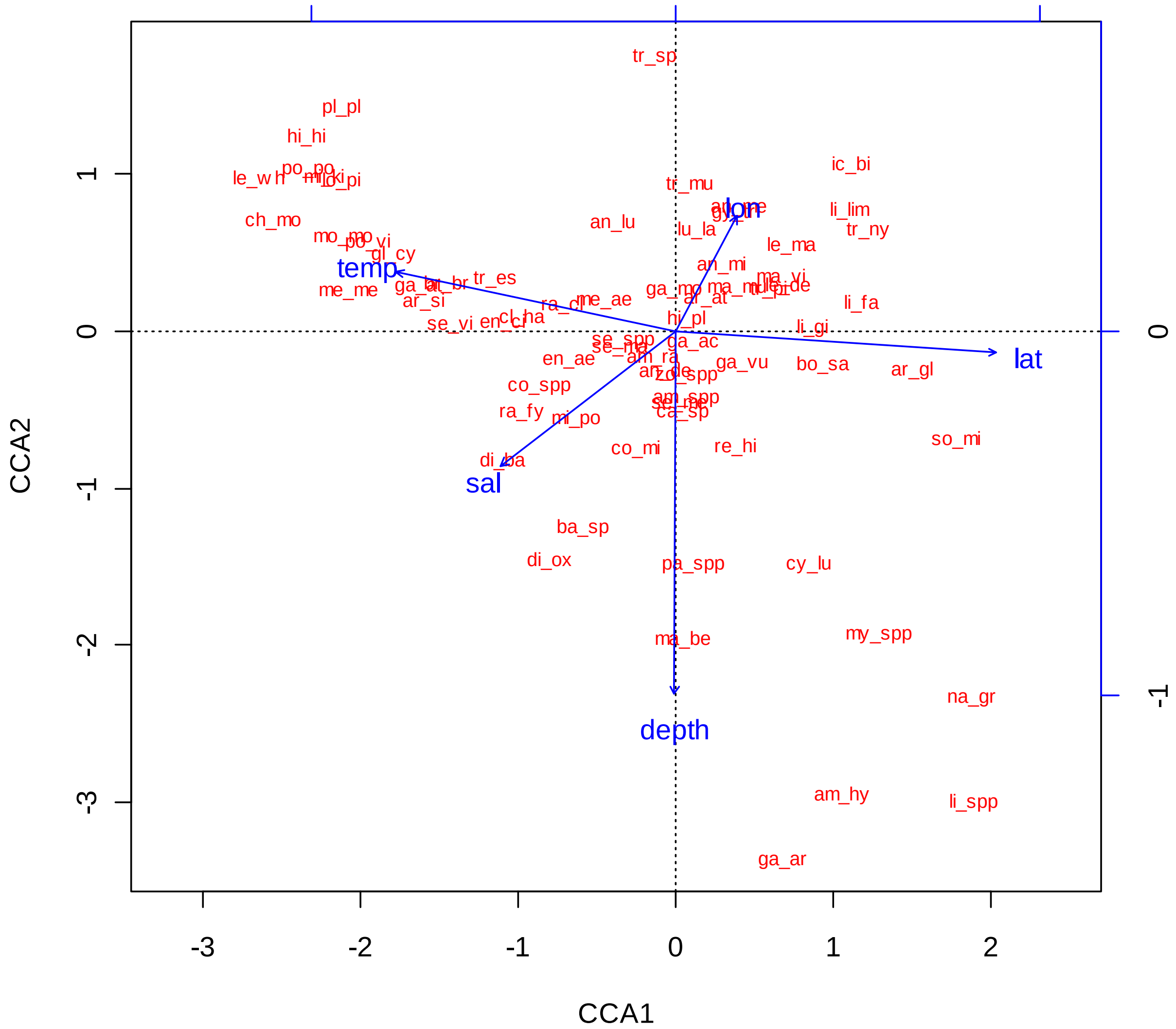

Figure 2. Biplot of CCA results showing ordination axes I (8.22 %) and II (5.76 %), taxa (red abbreviations, see table I) and explanatory factors (arrows; lat=latitude, lon=longitude, depth=bottom depth, temp= temperature, sal=salinity) for 2007.

Temporal change

Aschan et al. (in review) identified an abrupt temporal change in fish community structure indicative of an ecological regime shift in the Barents Sea in the late 90-ies (i.e. 1997). Since their analysis was based on data from 1992-2004, a ten year period without recovery after the change, a criteria defining regime shifts, could not be verified. We therefore seek to verify or reject this criteria by prolonging the data series, by including the ecosystem survey data series from 2004-2008, covering the area investigated by Aschan et al. (in review).

Our preliminary analysis of individual years suggest that a recovery has not taken place, since the years 2004-2008 are comparable and stable within the area investigated by Aschan et al. (in review), supporting our claim that the Barents Sea has gone through an ecological regime shift.

A reestablishment may be hindered by increasing temperatures, as the Barents Sea is turning into a more North Sea like pelagic-dominated ecosystem (Loeng and Drinkwater 2007, Yaragina and Dolgov 2009). Forecasts predict a temperature increase that is believed to result in a production increase followed by a higher fish production in the Barents Sea (Cheung et al. 2008, Drinkwater et al. 2005), and production of fish communities is considered predictable if the rate of primary production is known and is not strongly influenced by temperature (Jennings and Brander 2009). Yet, these studies do not evaluate the interactions between species and may therefore turn out to be too optimistic.

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