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Interannual correlation between hemispheric climate and northern Norwegian wintering stocks of two *Calanus* spp.

Stig Skreslet and Angel Borja

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Calanus finmarchicus and *Calanus hyperboreus* were sampled by five replicate Juday net tows from bottom to surface in February and October 1983–2000 in two deep fjord basins with different sill depths. *C. finmarchicus* was an order more abundant than *C. hyperboreus* in both fjords. Seasonal stock changes probably expressed the difference between rates of mortality and immigration. The interannual variability in abundance was about an order of magnitude. Only *C. finmarchicus* was positively correlated with North Atlantic Oscillation, in opposite phase with its abundance in the North Sea, possibly due to changing winds that generated latitudinal shifts in the *C. finmarchicus* base population of the Northeast Atlantic. However, latitudinal shifts in westerly storm tracks possibly also forced vernal river flow from Norway to regulate the neritic plankton productivity and growth in the population of *C. finmarchicus*. Positive correlation between Arctic Oscillation and both species may be due to forcing of advected recruitment. Arctic Oscillation possibly also regulated population size in *C. hyperboreus*.

Keywords: Arctic Oscillation, *Calanus finmarchicus*, *Calanus hyperboreus*, ecology, immigration, mortality, North Atlantic Oscillation.

S. Skreslet: Faculty of Fisheries and Natural Sciences, Bodø College, N-8049 Bodø, Norway (tel: +47 7551 7496; fax: +47 7551 7484; e-mail: stig.skreslet@hibo.no). A. Borja: Department of Oceanography, AZTI, 20110 Pasaia, Spain. Correspondence to S. Skreslet.

Introduction

Calanus finmarchicus and *Calanus hyperboreus* form wintering stocks in Norwegian coastal waters (Figure 1). This study tests the hypothesis that their stock sizes reflect effects of climate on their population systems.

Material and methods

Saltfjord and Mistfjord (Figure 1) were selected for sampling. They are 382 and 297 m deep, and separated from the Vestfjord by 220 and 34 m deep sills, respectively. At one station in each fjord, twice each year in 1983–2000, five replicate vertical tows from about 10 m above the bottom to the surface were made using a 180 μm 0.1 m^2 Juday net. *Calanus helgolandicus* and *Calanus glacialis* were not distinguished from *C. finmarchicus* and *C. hyperboreus*, respectively, but represent little contamination of our abundance estimates (Skreslet et al., 2000; K. Olsen pers. comm.).

We correlated abundance estimates from stereomicroscopic counts with indices of North Atlantic Oscillation (NOA) (Lamb and Peppler, 1987) and Arctic Oscillation (AO) (Thompson and Wallace, 1998) obtained from http://www.cgd.ucar.edu/jhurrel/nao.html and http://jisao.washington.edu/data/annularmodes/Data/ ao_index.html. Though there was no autocorrelation, we corrected the degrees of freedom according to Quenouille (1952).

Results

Differences in abundance between replicates of both species were within an order of magnitude, while the interannual variability exceeded an order of magnitude (Figure 2). *C. finmarchicus* was more abundant than *C. hyperboreus* in both fjords. Their abundance usually declined from October to February. *C. finmarchicus* was usually more abundant in Saltfjord than Mistfjord, and *C. hyperboreus* the opposite. All significant correlations of abundance with either NAO or AO were positive (Table 1). *C. hyperboreus*

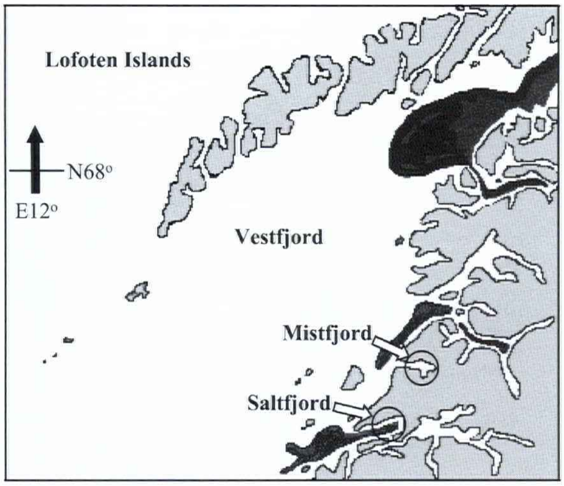

Figure 1. The Vestfjord area, north Norway (68°N 14°E). The 200 m depth contour is indicated. Dark: Wintering habitats of *Calanus finmarchicus* and *C. hyperboreus*, and spawning habitats of *C. hyperboreus*. Hatched: Main spawning of *C. finmarchicus* and post-spawning of *C. hyperboreus* in April. Sea surface isotherms for 3, 3.5, and 5°C in Mar–Apr 1922 (after Sømme, 1934). Arrows: sampling stations 1983–2000.

was significantly correlated only with AO. *C. finmarchicus* was significantly correlated with both, but its Mistfjord abundances in October and February were inconsistent, being correlated with AO in different years. In both fjords, the October abundance of *C. finmarchicus* was correlated with NAO averaged over March–July of the same year. Its February abundance in Mistfjord was correlated with the same average. In Saltfjord, the October abundance of both species was correlated with the average AO of July–September. In Mistfjord, the abundance of *C. hyperboreus* in both October and the next February was correlated with the same annual average of AO.

Discussion

Shelf water advects *C. finmarchicus* into the Saltfjord during September–October (Skreslet *et al.*, 2000). The accumulated stock is part of a larger population system in the Nordic Seas (Heath *et al.*, 2000). That may also be the case with *C. hyperboreus*.

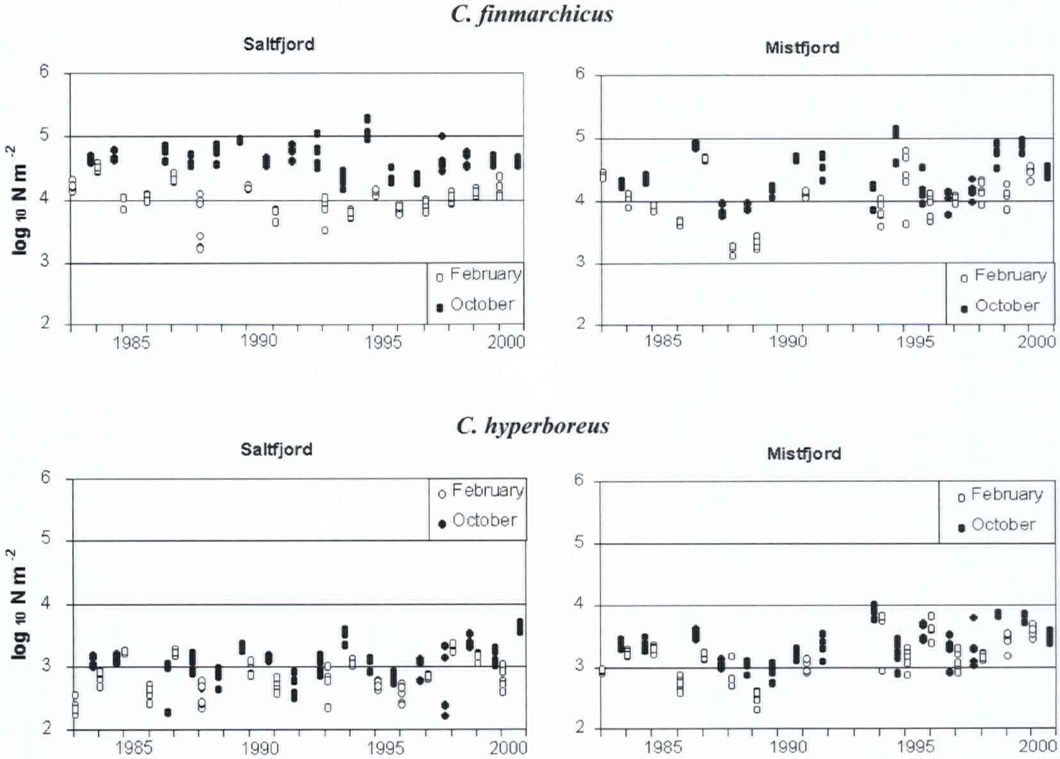

Figure 2. Abundance of *Calanus finmarchicus* and *C. hyperboreus* per square meter sea surface in five intended replicate samples.

Table 1. Significance levels (p) of correlation (r) between the abundances of two *Calanus* spp. in October and February, and the best average North Atlantic Oscillation and Arctic Oscillation indices of different seasons or the whole year. The lag indicates whether the abundance refers to an average index of the same (0) or the previous (−1) year. NS = No significant correlations with any season or year.

Species/site	Abundance month	NAO				AO			
		Season	Lag	r	p	Season	Lag	r	p
C. finmarchicus									
Saltfjord	Oct	Mar–Jul	0	0.717	0.01	Jul–Sep	0	0.587	0.05
	Feb	–	–	–	NS	–	–	–	NS
Mistfjord	Oct	Mar–Jul	0	0.738	0.01	Jul–Sep	−1	0.833	0.01
	Feb	Mar–Jul	−1	0.723	0.01	Oct–Dec	−1	0.586	0.05
C. hyperboreus									NS
Saltfjord	Oct	–	–	–	NS	Jul–Sep	0	0.832	0.01
	Feb	–	–	–	NS	–	–	–	NS
Mistfjord	Oct	–	–	–	NS	Year	0	0.687	0.01
	Feb	–	–	–	NS	Year	−1	0.602	0.05

In both fjords, both species had a patchy distribution that may have been caused by predation or predator avoidance. The winter season change in abundance was probably a function of both import and mortality rates.

Positive correlation between NAO and abundance of *C. finmarchicus* in both fjords contrasts with negative correlation in the North Sea (Fromentin and Planque, 1996), probably due to a common process. Positive NAO forces westerly winds to advect seawater northwards along the Norwegian shelf (Dickson *et al.*, 2000), and may shift the copepod's base population towards the north. During negative NAO, northerly winds develop over the Northeast Atlantic and may favour accumulation of *C. finmarchicus* in the North Sea. In Scandinavia, positive NAO also increases the winter precipitation (Dickson *et al.*, 2000) and accumulation of snow that causes meltwater discharge in early summer. Thus, the observed correlation with March–July NAO is in accordance with a model where vernal river flow generates proportional production in plankton communities along the coast of Norway (Skreslet, 1997).

It is possible that AO exerted independent influence on both *Calanus* spp., preferably by effects on processes that advected them into their wintering habitats. In *C. hyperboreus* the absence of any correlation with NAO may indicate that its population system was weakly affected by Atlantic forcing, while its correlation with annual AO in Mistfjord suggests Arctic forcing on the population level.

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