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North Atlantic Oscillation (NAO) Index – Environmental Variability Effects on Marine Fisheries?

By

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Abstract

Based on recent studies which highlight the dominating influence of the North Atlantic Oscillation (NAO) on climatic changes in the North Atlantic Ocean, and their potential influences on biotic processes in the ocean, the paper analyses existing time series of recruitment of cod (*Gadus morhua*) off Greenland, air temperatures of Nuuk/West Greenland, subsurface ocean temperature on Fylla Bank, and the winter (December to February) NAO Index. As a **first objective** the paper outlines a causal nexus from NAO to recruitment of cod. It is shown how the increasing complexity of the system when moving from the NAO Index to the water temperature and recruitment through the air temperatures might complicate the existence of a direct relationship between the first and the last step of the system, which leads to a decreasing correlation from the top (NAO index) to the bottom (recruitment). The **second objective** of the paper is to reveal by means of the example of Greenland cod recruitment, water temperatures in June on Fylla Bank, air temperatures at West Greenland, and the winter NAO index that a causal nexus can explain how **Environmental Variability Effects (EVE)** act on marine fisheries. Future fisheries management considerations should realise that the EVE aspect has to be incorporated in models and management decisions.

Keywords: North Atlantic Oscillation, NAO Index, recruitment, cod, temperature, fishery, management

Introduction

In a recent paper (**Rätz et al., in press**), water temperature was identified as a significant factor influencing the production of cod (*Gadus morhua*) stocks off Greenland. From the investigations carried out by the authors, recruitment and growth of this species off Greenland were observed to be positively correlated to water temperature in June at the oceanographic station 2 of the Fylla Bank Section (West Greenland). All variables considered, i.e. recruitment at age 3, length at age 4 and 5, and water temperature, showed a declining trend which began in the early-1970s, and extended to the end of the 1980s. By means of water mass stability analysis **Stein and Lloret (1995)** showed that an advective coupling through the wind/thermohaline driven current system instead of low stability coupling may explain the variability of cod recruitment in West Greenland waters from the early-1970s onwards.

As observed by **Colbourne *et al.* (1994)** and **Drinkwater (1996)** in the Labrador Sea, cold air and sea temperatures, heavy ice and strong north-west winds are associated with a high positive North Atlantic Oscillation

(NAO) Index. This index, which is a measure of the large-scale circulation, was defined by **Rogers (1984)** as the difference in winter (December, January and February) sea level pressures between the Azores and Iceland, and hence is a measure of the strength of the westerly winds over the northern North Atlantic. Recently, **Hurrell (1995)** used the pressure difference (December through March) between Iceland and Lisbon. Although there are minor differences between the two indices, the overall trends are similar. A high NAO index corresponds to an intensification of the Icelandic Low and Azores High (**Drinkwater *et al.*, 1997**). This physical process can potentially affect marine fisheries in the North Atlantic over a wide range of scales, and is associated with variations in wind strength over the entire North Atlantic Ocean, and with sea surface temperature anomalies **(Bjerknes, 1962; Rogers and van Loon, 1979)**.

The first objective of the present investigation is to identify how a strong environmental signal, the winter NAO Index, might be linked to the water temperatures in June on top of Fylla Bank (West Greenland), and hence influences the thermal conditions in the oceanic environment which are vital for the success/failure in the production of cod stocks off Greenland **(Buch and Hansen, 1988; Hansen and Hermann, 1965; Hovgard and Buch, 1990; Rätz *et al.*, in press; Stein and Lloret , 1995)**.

The second objective is to initiate a discussion in NAFO about how strong environmental signals can be incorporated into future models for fisheries management

Materials and Methods

The time-series of water temperatures in June on top Fylla Bank/West Greenland (Standard Oceanographic Station 2: 63°58´N, 52°44´W) was sampled by the Greenland Fisheries Institute in Nuuk (formerly Godthaab). The Northwest Atlantic Oscillation (NAO) Index as defined by **Rogers (1984)**, i.e. the difference in winter (December, January and February) sea level pressure between the Azores and Iceland, was taken. Other climatic data used in this paper were mean air temperatures in Nuuk/West Greenland (64°11´N, 51°44.5´W) from January to April, i.e. the time period for preconditioning of water temperature in June, and the mean air temperature in Nuuk from June to August, i.e. the time period for conditioning of water temperature in summer. The biological investigations cover the period from 1955 to 1989. This time-span was chosen to facilitate comparison of our results with those obtained by **Rätz *et al.* (in press)** on the effects of water temperature on cod recruitment and growth. Time-series of recruits at age 3 and length at age 4 and 5 for cod off Greenland as described in **Rätz et al. (in press)** to compare with the NAO index covered the same period.

All correlations were calculated with the statistical package Statistica for Windows 5.1 (StatSoft Inc., 1996).

Results

The NAO-Recruitment Model

The general thermal conditions of the West Greenland area for the time period 1955-89 are given in Fig.1, based on mean water temperature in June on Fylla Bank, and mean air temperature from June to August. The data are compared to the mean winter (DJF) NAO index (same figure). According to the downward trend in mean air temperatures from late-1960s onwards, the climate of the region was characterised by a continuous cooling period. This downward trend is also observed in water temperature. By contrast, the mean winter NAO index showed an upward trend during that time.

Correlation analyses carried out (Table 1) between NAO Index (independent variable) and mean air temperature from January to April (dependent variable) displayed a significant negative correlation ($r = -0.69$, $r^2 = 0.48$, $p<0.05$). Furthermore, the correlation of mean air temperature from January to April (independent variable) with the mean air temperature from June to August, and with water temperature in June (dependent variables) yield in both cases a positive and significant result ($r = 0.49$, $r^2 = 0.24$, $p<0.05$, and $r = 0.40$, $r^2 = 0.16$, $p<0.05$ respectively). In addition to this, correlation between mean air temperature June- August (independent variable) and water temperature in June (dependent variable) displayed also a highly positive and significant correlation ($r = 0.77$, $r^2 = 0.59$, $p<0.05$). Water temperature in June has been demonstrated to be positively related to recruitment and length at ages 4 and 5 for cod off Greenland (**Rätz *et al.*, in press**). Nevertheless, the NAO index was not significantly correlated with mean air temperature June-August, nor with water temperature in June ($r = -0.01$, $r^2 = 0.00$, $p>0.05$, and $r = 0.01$, $r^2 = 0.00$, $p>0.05$, respectively), and also not with recruitment at age 3 and length at ages 4 and 5 ($r = 0.12$, $r^2 = 0.01$, $p>0.05$; $r = 0.01$, $r^2 = 0.00$, $p>0.05$, and $r = -0.07$, $r^2 = 0.00$, $p>0.05$ respectively).

Conclusions

The first objective: NAO is a large-scale climatic effect. On a hemispheric space scale, changes in wind stress alter the ice formation processes and thus change the salinity properties of the upper ocean, which in turn alter the large-scale advective flows. As shown by **Stein and Lloret (1995)**, cod recruitment variation might be attributed to the advective regime of the Greenland Current system.

Correlation analysis performed for the available climatic and oceanographic time series reveal the short-term (annual) influence of the NAO on the mean air temperatures from January to April, which will precondition the mean air temperatures in June-August, and hence the water temperatures in June, which finally influences cod recruitment and growth off Greenland.

By contrast, the NAO index is not directly correlated to the water temperatures in June, nor with recruitment and length at ages 4 and 5. In Fig. 2 we try to manifest a causal nexus from NAO to recruitment of cod. The increasing complexity of the system when moving from the NAO Index to the water temperature and recruitment through the air temperatures might complicate the existence of a direct relationship between the first and the last step of the system, which leads to a decreasing correlation from the top (NAO index) to the bottom (recruitment). Therefore, we expect the NAO index to be a major atmospheric event in the North Atlantic Ocean, driving the overall system atmosphere-ocean-cod production off Greenland (Fig. 2). The path of the causal nexus is marked by the r^2, which is all significant (see Table 1). Since the data are from the North-west Atlantic we follow in Fig. 2 the negative NAO Index condition which leads to positive atmospheric, oceanic and hence positive recruitment results.

The stated conclusions are confirmed when looking to the overall long-term trend for all variables during the time period 1955-1989 (Figure 1). The upward trend of the NAO index from late 1960s contrasted with the downward trend of the air and water temperatures and also the downward trend of the recruitment at age 3 and lengths at ages 4 and 5 (**Rätz *et al.*, in press**). The increasing of the NAO index corresponds to an intensification of the Icelandic Low, which probably must have resulted in an intensification of the polar current (which brings cold-low salinity water to West Greenland) and the northwesterly winds (which also bring cold air to the area). This might explain the observed cooling of the atmosphere and surface of the ocean which has been demonstrated to influence in a negative way the recruitment and growth of cod off Greenland during that period (**Rätz et al, in press**), although these biological variables were mainly determined by the spawning stock biomass (SSB) and the abundance of that stock, respectively. Furthermore, the results agree with the observed increasing stability of water masses at West Greenland during the period 1965-1989 (**Stein and Lloret, 1995**) which was related by the authors to the increasing advection of low salinity water to the area, a fact that might have been due to the expected intensification of the Icelandic Low and the Polar current.

The second objective: It has been shown with the example of the Greenland cod recruitment, the water temperatures in June on Fylla Bank, the air temperatures at West Greenland, and the winter NAO index that a causal nexus can explain how Environmental Variability Effects (EVE) act on marine fisheries. **Hofmann and Powell (1998)** discuss in four case histories EVE impacts on marine fisheries. They argue that *"there is an awareness in scientific and general communication that traditional fisheries management approaches do not work. Failure of existing models and management practices ... shows that a more holistic view of how fisheries operate is needed, especially in their interactions with the environment."*

From the history of the Greenland cod the lesson may be learned that during times of favourable climate, in the 1940s to 1960s, at times of a low NAO index, the conditions for the Greenland cod stock were also favourable. Every 3 to 5 years a strong year-class appeared, specifically in 1942, 1945, 1947, 1950, 1953, 1957, 1961, 1965 and 1968 (**Stein and Messtorff, 1990**). Catches were high and nobody thought about the potential impacts of heavy fishing and an environment changing for unfavourable climatic conditions. Of course, the cause/effect question could only be dealt with on the broad basis of long-term time series. We are now beginning to understand, based on statistically proved correlations, parts of the complex chain of interaction from the hemispherical space scale of the NAO to the regional and local scale of recruitment.

Future fisheries management considerations should realise that the EVE aspect has to be incorporated in models and management decisions. A promising example is given by the Fisheries-Oceanography Co-ordinated Investigations (FOCI) research programme seeking to understand the recruitment of Walleye pollock (*Theragra chalcogramma*) spawning in the Gulf of Alaska (**Kendall *et al.*, 1996**). Year-class strength is forecast as weak, average or strong 2 and 3 years before the year class recruits to the fishery. The model uses pollock spawning biomass, precipitation, wind mixing, Pacific pressure index, and fish predators (pollock, Pacific cod, arrowtooth flounder, and Pacific halibut) biomass to forecast recruitment of walleye pollock. The results are used in the stock management with good results.

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Table 1. Results of statistical analyses, 1955-1989.

AirT JFMA = Mean air temperature from January to April in Nuuk.
AirT JJA = Mean air temperature from June to August in Nuuk.
Water T June = Mean water temperature of top oceanographic station Fylla Bank.

Dependent var.	Independent var.	r	r^2	p	n
Air T JFMA	NAO Index	-0.69	0.48	<0.05	35
Air T JJA	Air T JFMA	0.49	0.24	<0.05	35
Water T June	Air T JFMA	0.40	0.16	<0.05	35
Water T June	Air T JJA	0.77	0.59	<0.05	35
Water T June	NAO Index	0.01	0.00	>0.05	35
Air T JJA	NAO Index	-0.01	0.00	>0.05	35
Recruitment at age 3	NAO Index	0.12	0.01	>0.05	35
Length at age 4	NAO Index	0.01	0.00	>0.05	22
Length at age 5	NAO Index	-0.07	0.00	>0.05	22

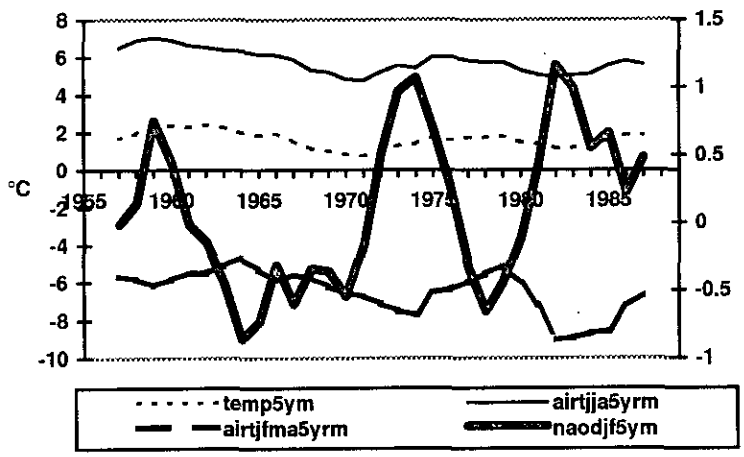

Fig. 1. 5 year running mean NAO index, air temperature (mean January to April and mean June to August), and mean water temperature (0-40m) oceanographic station Fylla Bank 2, 1955-1989.

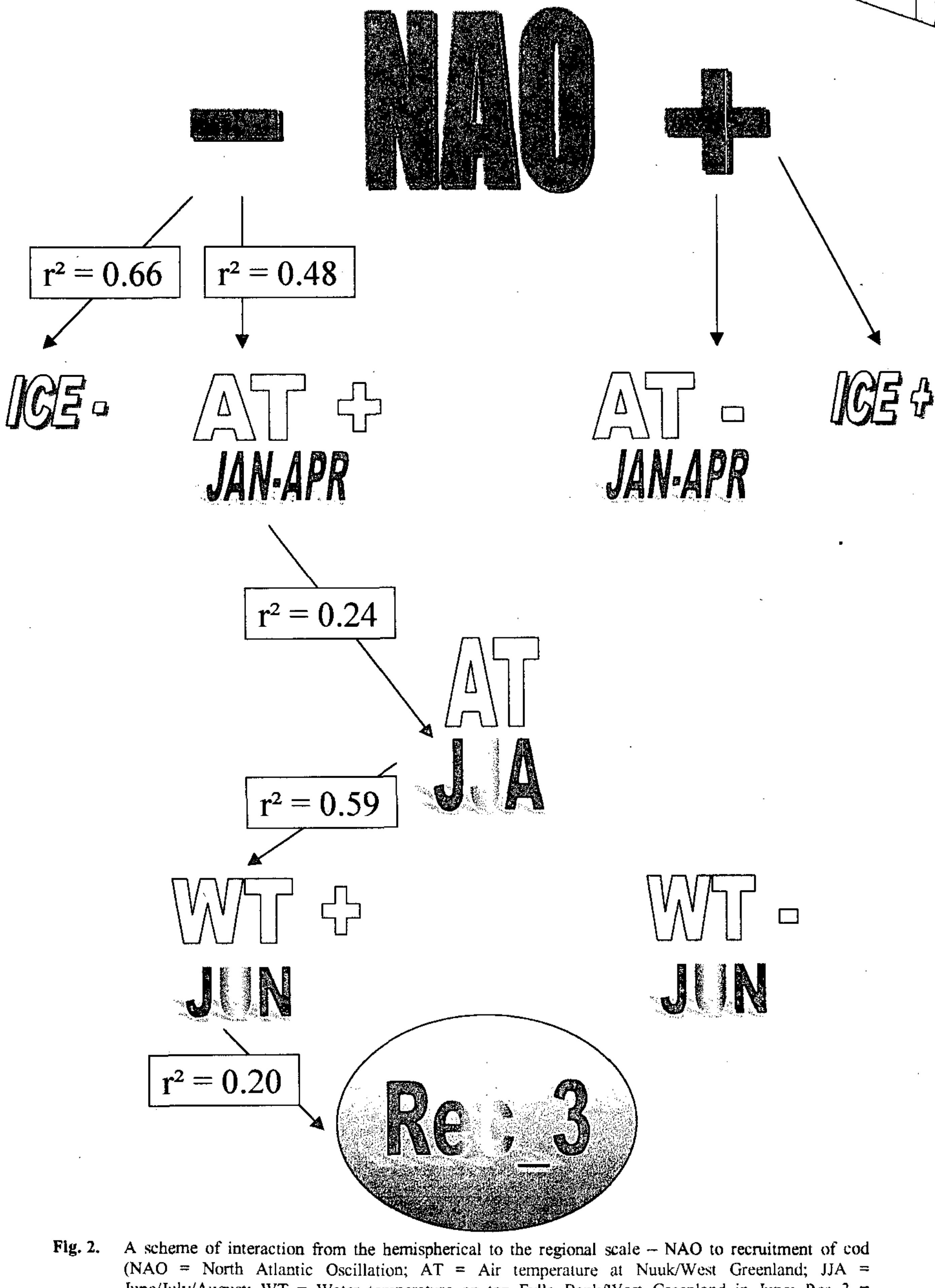

Fig. 2. A scheme of interaction from the hemispherical to the regional scale – NAO to recruitment of cod (NAO = North Atlantic Oscillation; AT = Air temperature at Nuuk/West Greenland; JJA = June/July/August; WT = Water temperature on top Fylla Bank/West Greenland in June; Rec_3 = Recruitment of cod at age 3; r^2 = explained variability along path of the causal nexus, $p<0.05$)