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# Climatic/human impact on hydro - biological conditions in Icelandic waters

by

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**Abstract**

The paper includes information on hydro-biological variability in Icelandic waters during the period 1952-2000 with some remarks to pan-North Atlantic climatic conditions. Different hydrographic conditions in Icelandic waters and their impact on biological conditions are outlined. Attention is drawn to the up and down trends in the stocksize and catches of Icelandic cod in relation to hydrographic conditions, as well as to the general overall downward trend in the stock during the period 1952-2000 when yearly catches declined from 400-500 thousand tonnes to 150-250 thousand tonnes. It is stated that climatic variations alone cannot be blamed, the human involvement of different consequences of fishing load must as well be considered. At last thoughts are given to operational oceanography and predictability of ocean climate for use in fish stock assessment.

Keywords: Icelandic waters, climate, hydro-biological, conditions, cod-stock conditions, operational oceanography, predictability.

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## Introduction

Icelandic waters are located at the boundary between warm Atlantic water from the south and cold Arctic and Polar water from the north, i.e. the oceanic polar front in the northern North Atlantic and Nordic Seas (Fig. 1) The warm Irminger Current flows northwards into two branches west of Iceland. The western branch meets the cold East Greenland Current and flows southwards into the Irminger Sea. The eastern branch flows north and eastwards off Northwest Iceland into North Icleandic waters (Iceland Sea) and disperses off the eastern coast of Iceland. (Stefánsson 1962). This latter inflow is vital for the living conditions in North Icelandic waters, both as regards transporting larvae from the spawning grounds south and west of Iceland and further continuing as a supporting element for nursing and feeding the growing fish stocks. The cold and low saline water masses are those of the East Greenland (Polar) current, flowing southwards through the Denmark Strait, and the East Icelandic Current flowing southwards north and east of Iceland (Malmberg 1984, 1985). The circulation is complicated by north-south fluctuations, even west-east ones, of the boundary zone from year to year expressed by the presence of Atlantic, Polar and Arctic water in North and East Icelandic waters (Blindheim and Malmberg 1994; Malmberg et. al. 1996). These shifts in the location of the oceanic polar front impact on the climate and ecology in Iceland as well as in the surrounding seas. Iceland has an environment sensitive to climatic changes. Arctic/Subarctic research and conditions are thus of great importance in Iceland, both regionally as well as from the aspect of Global Change.

## Hydrography

Research from long term hydrographic investigations in North Icelandic waters show a great variability of different character. Thus Atlantic water dominated during the periods 1924-1964, 1972-1974, in 1980, in 1984-1987, 1991-1994 and 1999-2001 (Fig.2). The late 1960´s as well as shorter periods there after (1975-1979, 1982, 1988 and 1996-1998) were more or less dominated by Polar influence in the upper layers, while conditions were characterized as Arctic in 1981-1983, 1989-1990 and 1995. The Arctic conditions in 1981-1983 have been related to the so-called "Great Salinity Anomaly" (Dickson et al. 1988), and those in 1989-1990 to a second "Salinity Anomaly" (Belkin et al. 1998). These anomalies were traced back to arctic/subarctic waters in the Iceland Sea in the 1960´s (polar years) and to the waters between Greenland and Labrador in the early 1980´s.

Thus three different hydrographic regimes have been obeserved in North Icelandic waters;

a) Atlantic conditions associated with inflow of warm and saline Atlantic water ($t>3°C$; $S>34.9$) from the Irminger Current.
b) Polar conditions associated with polar water inflow by the cold and low saline East Greenland (Polar) Current ($t<0°C$; $S<34.4$) and East Icelandic (Arctic/Polar) Current ($<2°C$; $S<34.7$).
c) Conditions neither of Atlantic nor Polar character, but with a relatively homogenous and moderate cold and saline water character ($t\sim1-3°C$; $S\sim34,7-34,9$) possibly associated with the Arctic Intermediate Water from the West Spitsbergen Current and influenced by the salinity anomalies (GSA).

Polar conditions were characterized by cold and fresh surface layers. Maxima in temperature and salinity in intermediate and surface layers characterize Atlantic conditions and may also occur in subsurface layers during Polar years. During Arctic conditions these intermediate maxima are less pronounced. The variations are reflected in time series of maximum salinity observed in the 0-300 m level in North Icelandic waters (Fig.3). The results clearly show the periods of relatively low salinity in this layer during the Arctic years in 1981-1983 and 1989-1990. The Arctic conditions lead to a relatively weak stratification in the upper layers and hence homogenity of the whole water column, which again may lead to poor living conditions. Also clearly demonstrated in the variability of the maximum salinity is a general lowering in salinity of about 0,15 from 1950 to 1970 and a weak reversal in the 1990´s.

## Hydrography and fish

The different hydrographic conditions in North Icelandic waters are reflected in the biological conditions such as phyto - as well as zooplankton concentrations (Thórdardóttir1977, Ástthórsson et al. 1983, Ástthórsson and Gíslason 1998). Thus the development in the 1960's in the so-called "cold tongue" of the East Icelandic Current when changing from being an ice-free Arctic Current to a Polar Current transporting and preserving drift-ice, changed the feeding summer migration of the Atlanto-Scandian herring in the Norwegian Sea (Jakobsson and Østwedt 1999). Also depending on the hydro-biological variability is the Icelandic capelin stock (both stock size and growth) which feeds in the Iceland Sea north of Iceland as well as the weight of cod in Icelandic waters which feeds to a large degree on capelin (Fig. 4; Vilhjálmsson 1983, 1997, Malmberg 1986, Malmberg and Blindheim 1994). Recruitment of Icelandic cod too seems to be dependent on the hydrographic conditions being frequently relatively higher during Atlantic conditions on the feeding and nursing grounds in North Icelandic waters than during Polar conditions (Fig. 5). The fishing stocks thus vary periodically depending, besides on biological conditions, on variations in the hydrographic conditions which again to a certain degree may be reflected in the NAO index and the GSA´s, not discussed at this place (Malmberg and Valdimarsson 2002). Thus both warm water inflow from the south and cold and fresh water from the north play a significant role in this aspect. Especially the recruitment seems to rise just at the transition from Polar/Arctic to Atlantic periods. Thus after a usually poor recruitment period during a cold polar/arctic phase of the hydrographic conditions along with a minimum in stock size, the recruitment may rise again at the interface to warm Atlantic conditions. This may explain the frequently misunderstood situation that small stocks seem to produce stronger year-classes than large stocks. This is not because the stocks are small, but rather the latent power of life when environment again favours possibilities for a strong recruitment. It has been shown by estimates of the number of mature fish for each age group (Shannon index) that the stocksize and composition account for 31% of the total variations in recruitment of the Icelandic cod stock (Marteinsdóttir and Thórarinsson 1998). The question arises to what degree the environmental conditions account for the other 70%. The recruitment later on influences the stock size and catches (Fig.5). It is noteworthy that the relatively strong year-classes of 3-years old recruits of cod from 1983 and 1984 appear as maximum catches just after and prior to a following small spawning stock maximum. Thus the stock was cought before it was mature to a greater extent than before, and the catches were definitely higher than the spawning stock biomass.

In general, there was a dramatic decline in the cod stocks in the northern North Atlantic and Nordic Seas during the latter half of the 20th century (Jakobsson 1992, Malmberg and Blindheim 1994). Parallel to climatic changes in these waters during

the same period, the spawning, feeding and fishing grounds of cod in these waters declined since the 1960´s during a period of increased interannual and decadal variability of NAO as well as hydrographic conditions. Furtermore, cold years in North Icelandic waters as well as off Newfoundland, Labrador and West Greenland and in the Barents Sea seem generally to give weak year classes of cod. Thus the hydro-biological changes in the 1960's followed by the GSA in the 1970´s in the northern North Atlantic (Dickson et al. 1988) had an overall natural impact on the environmental conditions as regards distribution of favourable conditions for cod in these waters. It is thus quite natural that the stocks and catches in Icelandic waters as well as elsewhere are not of the same strength after the 1960's as before.
Ecological oceanographers may have been aware of the trends in fisheries in relation to environmental variations during the past decades in the latter half of the 20th century, but their physical understanding which was more or less only explained qualitatively, seems not to reach the management community. The NAO index being a quantitative one seems to be better understood, being a rather simple but important parameter explaining large scale features. Though it must be emphasized that the variable location and track of the Iceland Low is an important feature as regards different ocean regions and their hydro-biological conditions when considering decadal scale climatic variations in the northern North Atlantic (Malmberg and Valdimarsson 2002). Thus, when looking further into the relationship between 5-years running means of the winter NAO and the salinity maximum at Si-3/0-300 m in North Icelandic waters (Fig. 6) three groups appear; one for the years prior to the ice-years in the 1960's; one for the ice-years 1965-1971; and at last one for the years after the ice-years or 1972-1996. This may possibly reveal different tracks of the Iceland Low.
All three periods may show a slight positive relationship between the 5-years running means of the NAO winter index and maximum salinity at station Si-3/0-300 m. This certainly also reveals the high salinities found prior to the ice-years, but lower ones both during the ice-years and during extreme positive NAO since after the ice-years. These three periods or phases of the hydrographic and atmospheric conditions may again reflect the observed climatological periods referred to above, i.e. warm Atlantic, cold Polar and moderate Arctic conditions, related to different amplitudes of NAO and tracks of the Iceland Low. Generally, the flow of the westerlies in the northern North Atlantic changed in the 1960's after decades of being relatively northwards bounded and zonal (Rossby waves of "small" amplitudes) to a shifting more meridional flow with different phases (Rossby waves of "large amplitudes" and shifting phases; Cushing 1978). This also is well demonstrated in the winter NAO index in the twentieth century. Thus the three periods or groups once more express the different conditions found in sea (North Icelandic waters) and air (annual mean air temperatures in North and South Iceland; Malmberg and Desert 1999; Malmberg and Valdimarsson 2002). These periods are the years a) before the ice-years in the late 1960's with a steady strength of warm water (S>35.0) in spring north of Iceland; b) the cold and low saline ice-years themselves (1965-1971); and since than c) the unstable strength of the warm water (S~34.8-34.9) with its struggle with the cold water from the north. These periods have been classified into Atlantic, Polar and Arctic periods (Malmberg and Blindheim 1994; Malmberg et al. 1996).

Finally, as has been observed, the hydrographic conditions in Icelandic waters have changed towards the very end of the 20th century again over to "warm and saline" conditions almost similar to those during the 1920´s to the 1960´s. The question arises, are we back to the "good old days" prior to the cold ice-years in the 1960´s as regards hydrographic conditions in the northern North Atlantic and Nordic Seas with all their positive impact on climate and living marine conditions? This question is still unanswered.

## Operational oceanography, predictability and fish stock assessment

At present times more and more attention is paid to environment in connection with fish stock assessment. In the following the problem is outlined from the view of physical oceanography. So-called operational oceanography and predictability of ocean climate is considered. The regular monitoring of environmental conditions carried out for decades in different areas of the northern North Atlantic was frequently used operationally and linked to biological conditions and variability. But a direct statistical or parameterized use of the environmental data in connection with fish stock assessment has been a difficult task and therefore poorly used. The question also arises, how-far are we from being able to predict climate including ocean climate. Links between hydro-biological conditions and fish stocks are stated in many cases, and new visions on the use of physical conditions for predictions are around the corner (e.g. GOOS, CLIVAR). But the recent and even still present state for fish stock assessment is primarly monitoring and understanding the physical marine environment and its potential of variability; and secondly link it with the biological variability into the future. From that point of view current physical hydrographic conditions have a predictive value for fish stock assessment which should not be neglected.

Generally, the further outlook may be the following: Understand the potential of climatic conditions with prediction in mind, qualitatively as well as quantitatively. Look for upstream in time and space physical conditions near-by and remote with pattern recognition or prospects for downstream hydro-biological predictions in time and space. In short, detect and forecast the effects of climate variability on biological conditions and variability. From a fishery point of view in the northern North Atlantic and Nordic Seas temperature or hydrographic conditions, nutrients and zooplankton are the most important factors to consider. Thus the northward transport and especially the distribution of warm nutrient-rich sub-tropical water plays an important role in the pre-conditions for biological processes in the sub-arctic and sub-polar regions. Understanding these processes so that future conditions can be anticipated if not predicted may therefore be of major importance. To do this ICES oceanographers need to maintain the existing operational networks, and even establish additional regular and systematic measurements of current and hydrographic conditions in new ways, e.g. satellites, buoys, floats, ships of opportunity. At last, the prognostic possibilities of the time series should be born in mind, both as regards climate as well as biological conditions with emphasis on fish stock assessment. Further, the fish stocks assessment should not only focus on fisheries as such, but on the human impact including socio-economic aspect to ensure sustainable development of the marine environment and its resources as stated in the scientific objectives of ICES.

## Summary and concluding remarks

In general, the distribution of warm Atlantic water decreased in the latter half of the 20th century in the northern North Atlantic after the period of its extensive distribution from 1920 to 1960 (Smed 1975, Rodewald 1967, 1972). Thus a general cooling trend occurred since the 1950´s-1960´s from West Greenland and Newfoundland waters in the west to the Barents Sea in the east. In North Icelandic waters this brought about a more variable and generally weaker Atlantic inflow.

Instead periods with cold and fresh Arctic and Polar water were prevailing, occasionally even with heavy drift ice as in the late 1960´s and some single years there after. There are strong indications that this widespread cooling entailed adverse effects on cod stocks in the northern North Atlantic and Nordic Seas as a whole. While this is most clear for the northern stock of Newfoundland and the West Greenland stocks, there was a drastic decrease in the abundance also of other North Atlantic cod stocks. Was this decrease only due to overfishing, or did the detoriating environment also play a role? Yes, it must be considered as quite obvious that climatic changes were involved. This is mainly important for areas north and west of the oceanic Arctic/Polar fronts as off Labrador/Newfoundland, West Geenland and also in North Icelandic waters and occasionally in the Barents Sea. In these areas stocks and catches cannot be expected to be of the same strength as before the mid or late 1960' except if the environment changes to former conditions. Then even new regimes may occur. Clearly stated is the strong impact of the variable location of the oceanic Polar front, being steered by meteorological and oceanographic forces from the north and south, on biological conditions and then fish resources in Icelandic waters as well as elsewhere, this being for Iceland as a whole and regionally for other countries, the main stake of sustainable economic existence.

Thus, at last, the above discussed hydrographic conditions in the northern North Atlantic and Nordic Seas during the latter half of the 20th century influencing the feeding conditions and changing the favorite areas for cod no doubt had an impact on the cod stocks together with fishing. Thus the great decrease in the Icelandic cod stock in the 1950´s and 1960´s (Fig. 5) goes along with the overall downward trend in the hydrographic conditions, as well as the periodic variability after that. The steady downward trend both in stock size (60-70%) and catches (40%) since then despite regulations and periodic relatively good recruitment and environmental conditions must be due to the fishing load. Thus a less decrease in catch than in stock size indicates an increasing fishing load from 1960 to 2000 (Schopka 1994). This decline in stocks and fisheries may be due to different impacts of so-called overfishing as increased fishing efforts through technological development, throw away of small fish and other bycatch due to quota regulations and fish prices, immature fish catches and hence poor spawning stocks, or possibly not at least the huge increase in the total sum-up of catches of different species of the living world of the sea like for instance capelin (Fig.7) including changes in the habitat. Predation of marine mammals may also be involved due to its strict monitoring.

Concluding these speculations a reference to an article in ICES Newsletter, 37, 2001 on "Exciting new approach to fish stock assessment" may be appropriate. There it says "Most stocks in the ICES area are overexploited and in some cases depleted." Yes, this statement by the author is ironic, but, it is time to react to an obvious general failure in the outcome, despite the fact that we are dealing with the even most investigated but also the most exploited area of the world ocean, the northern North Atlantic. One must take the nature or environment into account in stock assessments, especially when it is deteriorating, but it is also quite obvious that we cannot blame neither the nature nor the fishery-biological sciences alone for the unsuccessful outcome. The anthropological impact must be taken into account with its overall fishing effort.

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Fig. 1. Main ocean currents and hydro-biological sections in Icelandic waters.

Fig. 2. Temperature and salinity at 50 m depth at a hydrographic station in North Icelandic waters (Siglunes 3) in May-June 1952-2000. (Malmberg and Valdimarsson 2002).

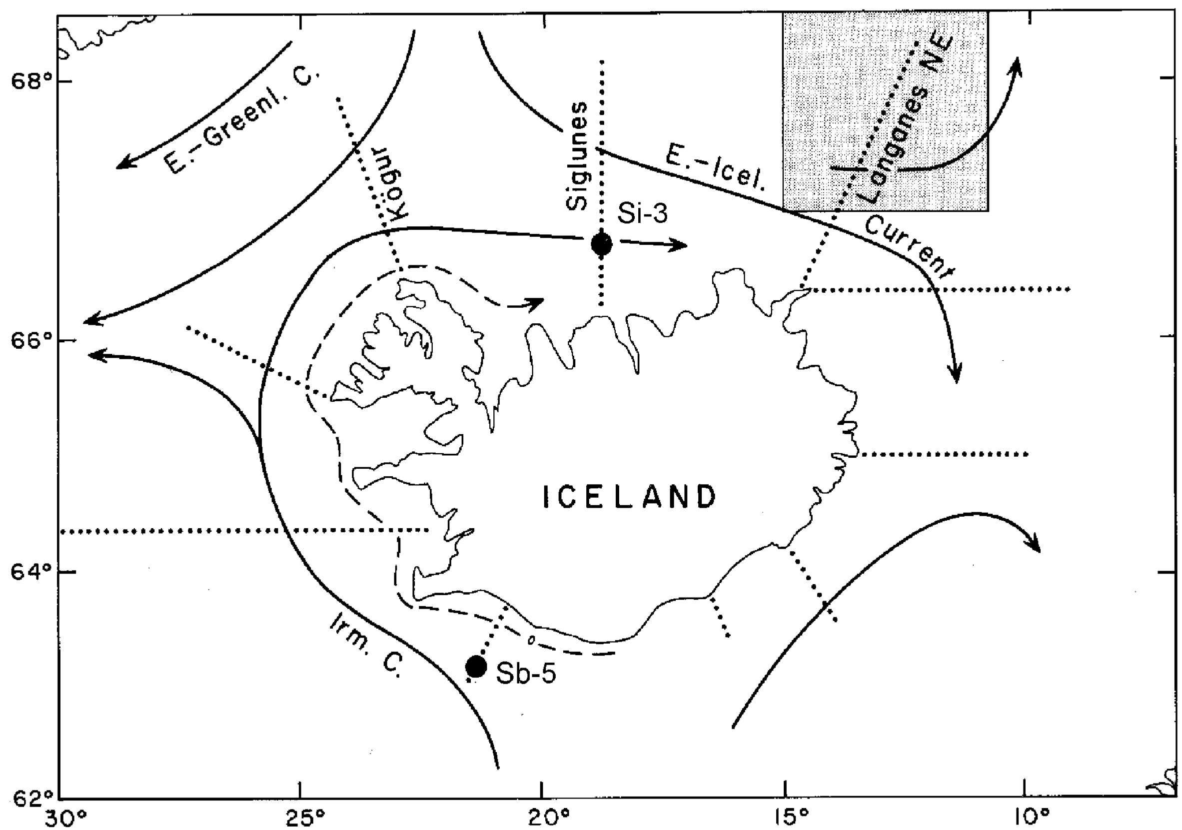
Fig. 3. Maximum salinity in spring 1952-2000 in the upper 300 m at station Siglunes 3 together with a 5-years running mean. (Malmberg and Valdimarsson 2002).

Fig. 4. a) Maximum salinity in the upper 300 m at Station Siglunes 3 in spring 1977-1992 (solid thin line)
b) The abundance of the Icelandic capelin stock in 1978-1992. (Solid thick line)
c) Weight of five-year old cod in Icelandic waters in 1977-1992. (Broken line). (Malmberg and Blindheim 1994).

Fig. 5. Conditions of Icelandic cod-stock 1955-2000.
a) 3-year recruitment in millions by number (year-class).
b) Spawning stock biomass in thousand tonnes.
c) Fishing stock biomass in thousand tonnes.
d) Catches in thousand tonnes (Anon 2000).

Fig. 6. Relationship between 5-year running means of maximum salinity in spring in the 0-300 m layer at Station Siglunes 3 and the 5-year running mean of the winter NAO index during the period 1952-1999. (Malmberg and Valdimarsson 2002).

Fig. 7. Icelandic catches in the years 1905-2000. (Icelandic Fisheries in Figures, Ministry of Fisheries 2001).

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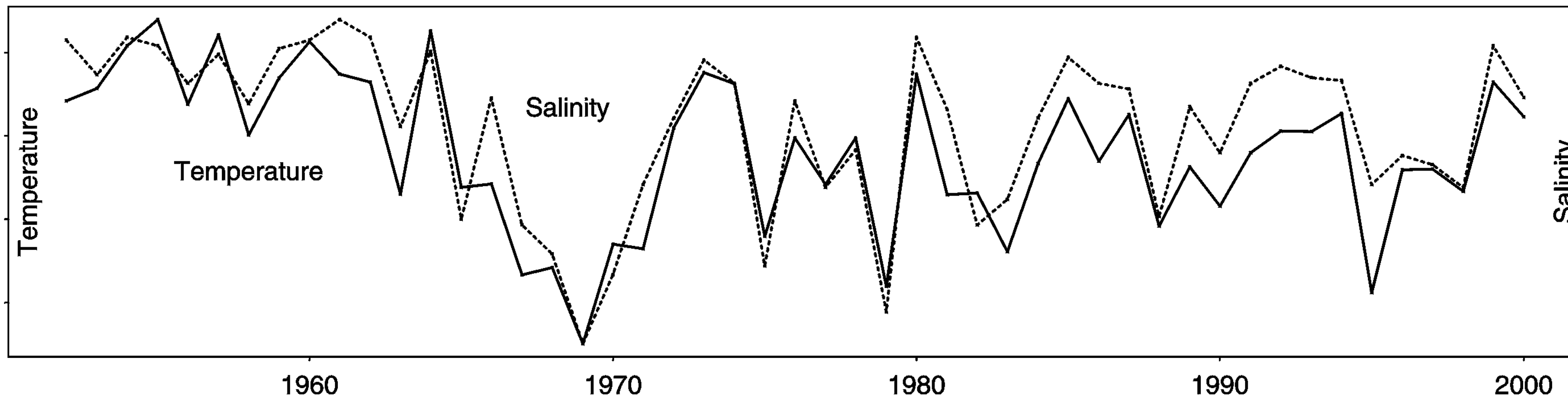
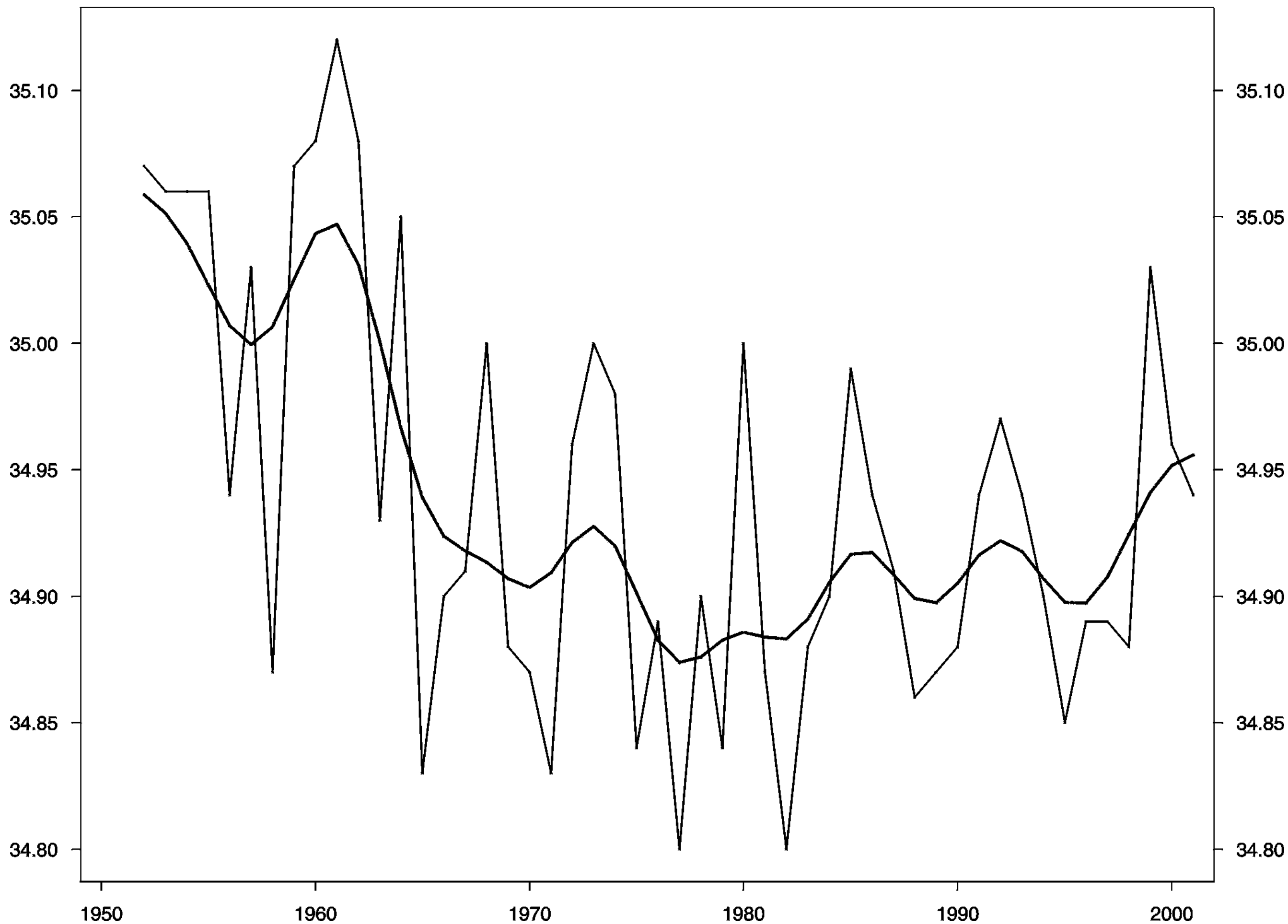



**Fig. 2.** **Temperature and salinity at 50 m depth at a hydrographic station in North Icelandic waters (Siglunes 3) in May-June 1952-2000. (Malmberg and Valdimarsson 2002).**

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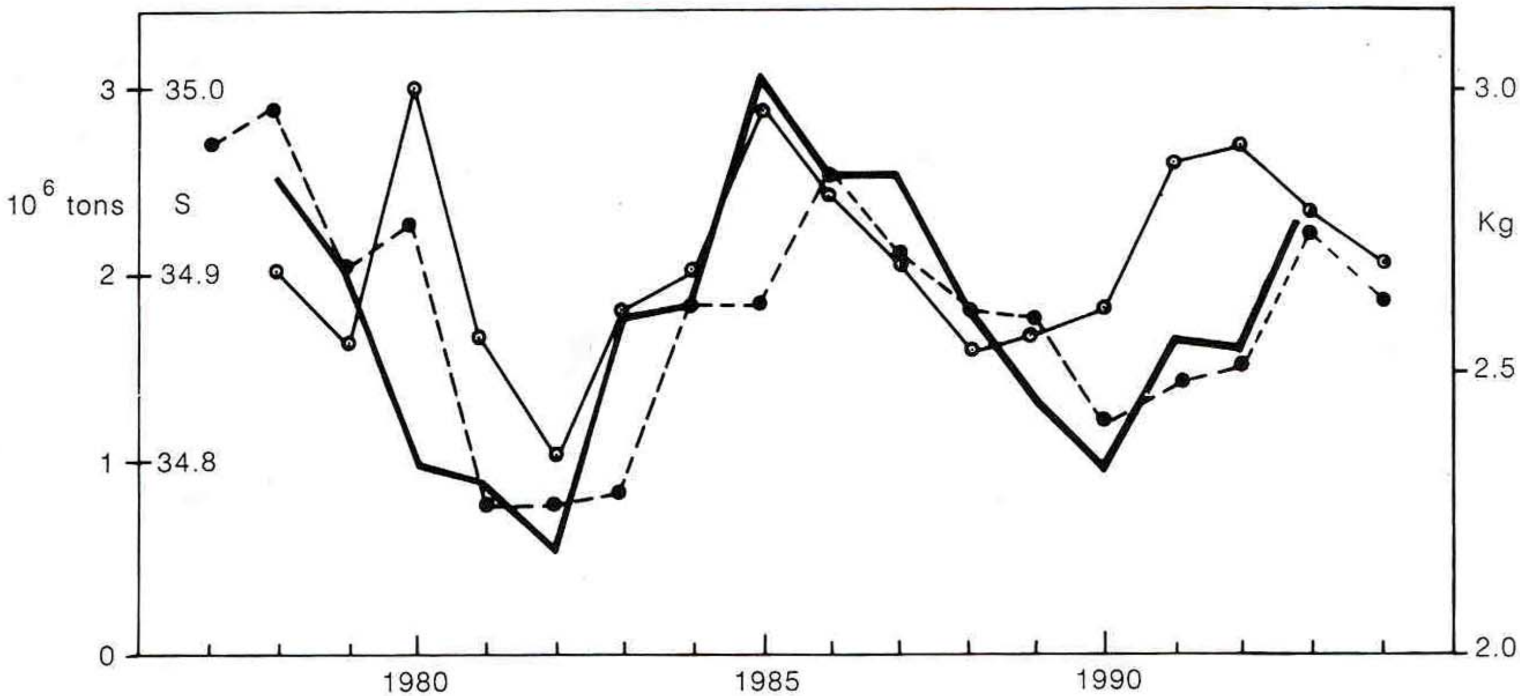


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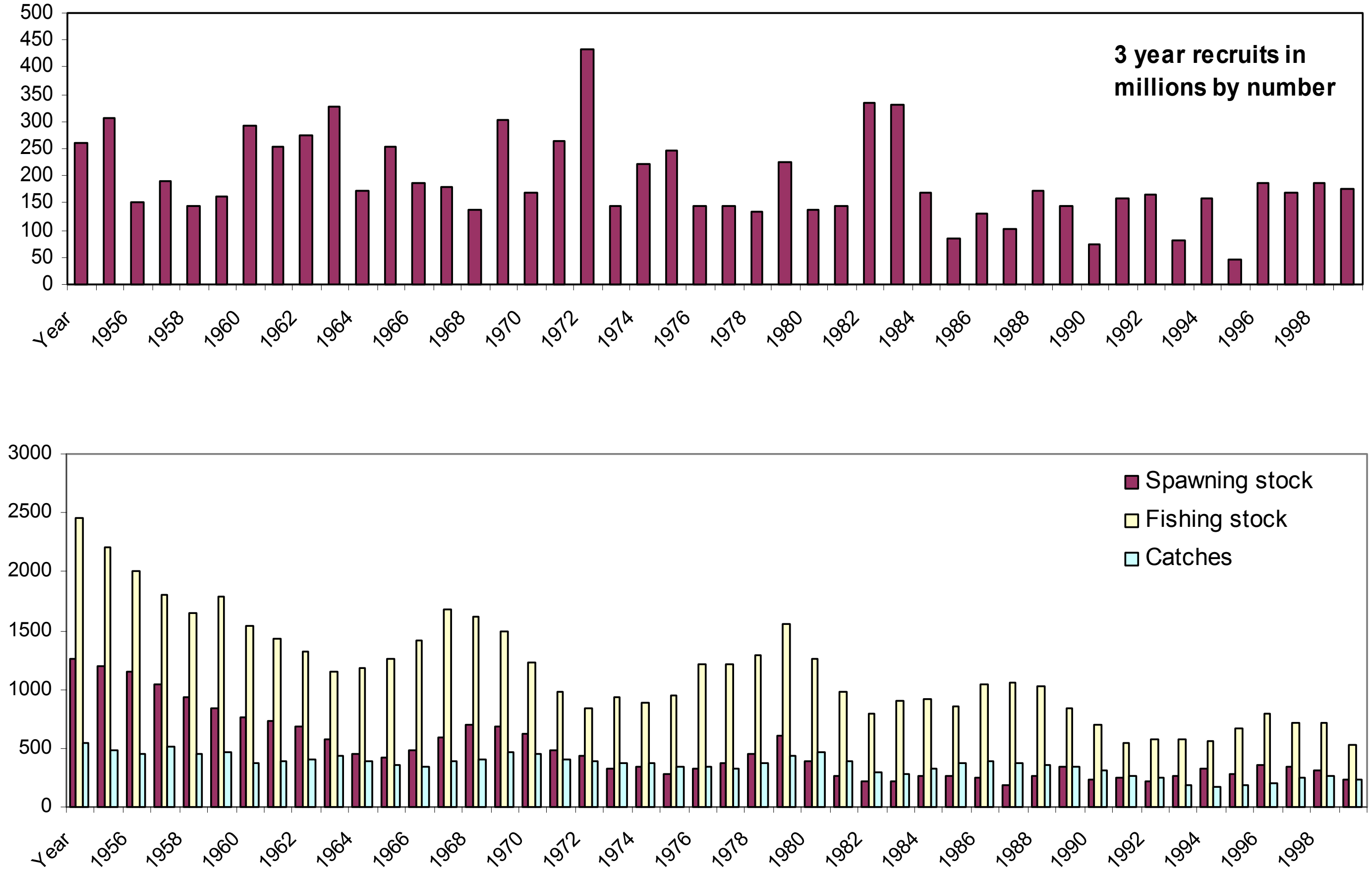


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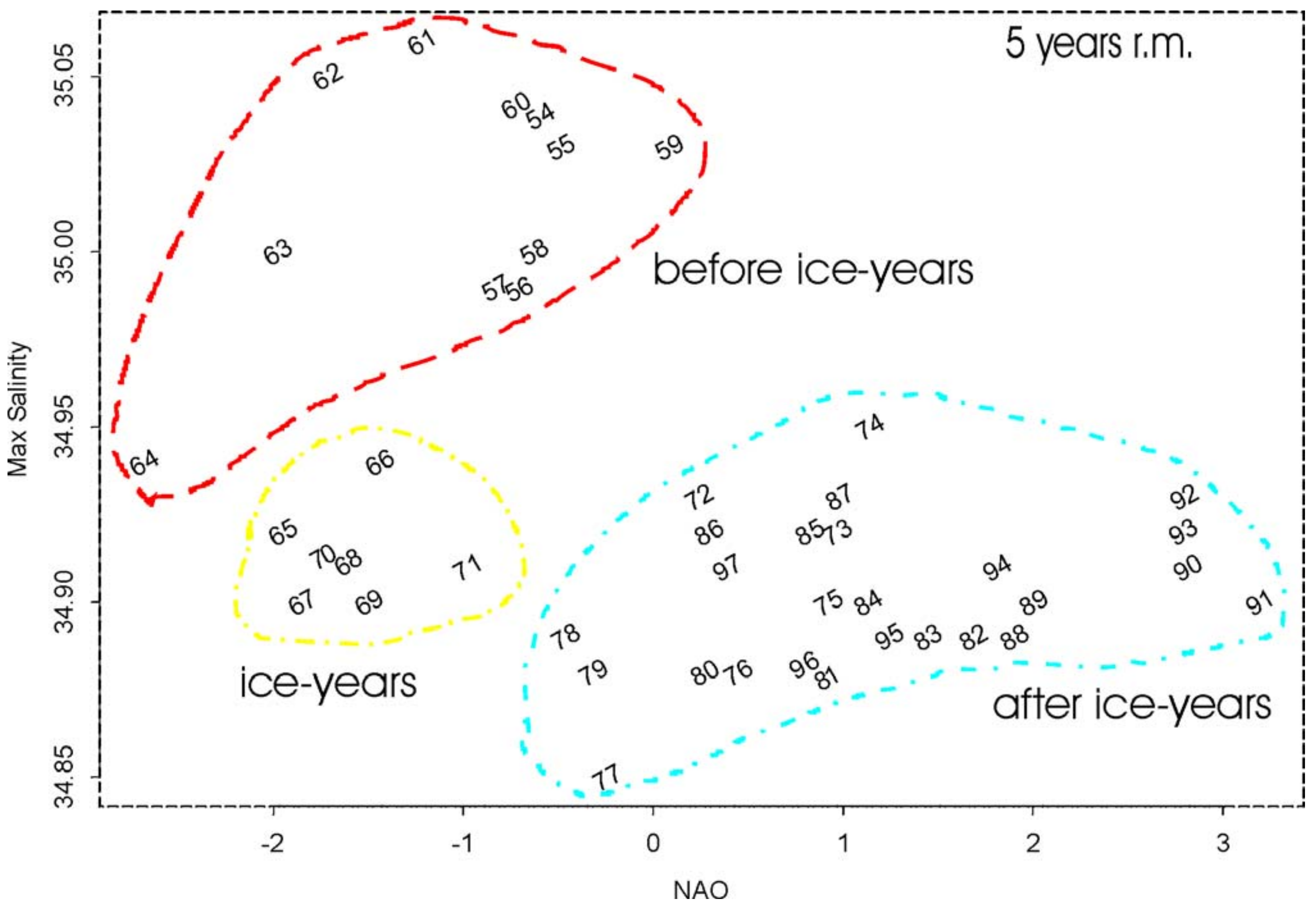
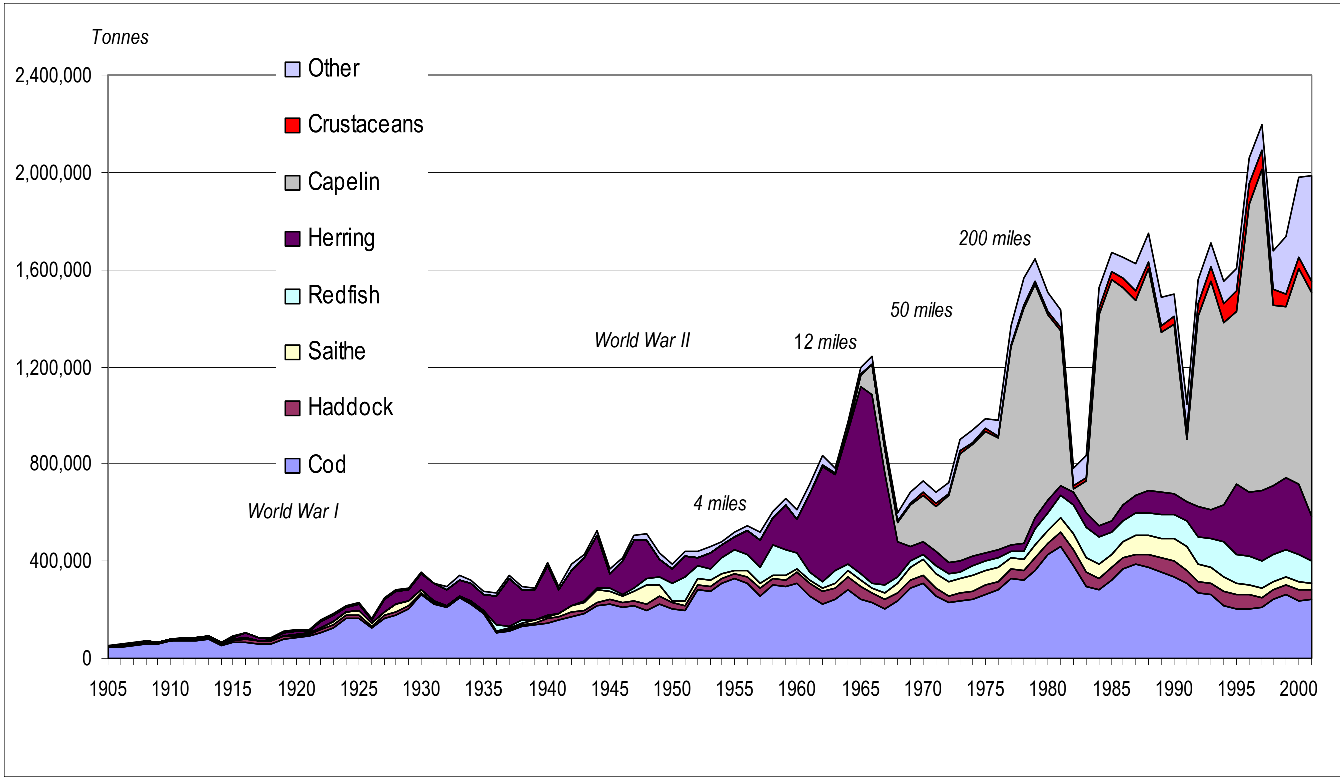



**Fig 6.** **Relationship between 5-year running means of maximum salinity in spring in the 0-300 m layer at Station Siglunes 3 and the 5-year running mean of the winter NAO index during the period 1952-1999. (Malmberg and Valdimarsson 2002).**

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