Growth variability in Atlantic cod (*Gadus morhua*) near its northern range of distribution

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Master thesis

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"To a person uninstructed in natural history, his country or seaside stroll is a walk through a gallery filled with wonderful works of art, nine-tenths of which have their faces turned to the wall; teach him something of natural history, and you place in his hands a catalogue of those who a worth turning around."

- Thomas H. Huxley

Preface & Acknowledgements

This master thesis marks the ending of my biology study at Aarhus University, and is a collaboration between Greenland Institute of Natural Resources and the Department of Bioscience, Aarhus University. The work presented in this master thesis was made possible with an archive of historical cod otoliths made accessible by Greenland Institute of Natural Resources. The project included a 3 month stay in Greenland where I had the opportunity to participate in field work performed on board Adolf Jensen. Therefore I would like thank the employees of Greenland Institute of Natural Resources, for making me feel welcome and always being helpful during my stay there.

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Contents

Dansk resumé

Torsken (*Gadus morhua*) har længe været en vigtig art for fiskeriet rundt omkring i verden. Den har ligeledes udgjort en stor del af fiskeriet ved de Grønlandske kyster igennem årtier, som dog har medført kollaps af bestandene. Viden omkring torskens vækstmønster er derfor meget vigtig med hensyn til god fiskerirådgivning. Variation i torskens vækstmønster er i dette projekt blevet undersøgt og holdt op mod variationer i temperatur og en række fysiske faktorer. Til dette formål blev der produceret en vækst kronologi fra 1973-2010 via "biological intercept back-calculation", baseret på otolither fra torsk fanget i NAFO område 1B ved den Grønlandske Vestkyst. Otolither fra torsk i aldrene 5-7 år blev brugt i denne undersøgelse og en vækst kronologi blev produceret for hver af de første fem vækst år i fiskenes liv. Derudover blev der også produceret en endokronologi ved at kombinere standardiserede residualer fra de fem vækst kronologier. Igennem den undersøgte tidsperiode varierede den gennemsnitlige havtemperatur mellem 0.48°C og 3.37°C, med en kold periode fra 1980-1996 hvor gennemsnits temperaturen var 1.15°C og en varm periode fra 1997-2008 hvor gennemsnits temperaturen var 2.4°C. Endokronologien var signifikant positivt korreleret med temperaturen i den kolde periode men ikke i den varme periode. Der blev fundet en signifikant negativ korrelation mellem endokronologien og den Arktiske Oscillation (AO) samt den Nordatlantiske Oscillation (NAO) gennem hele den undersøgte tidsperiode. Der blev dog ikke fundet nogen signifikant korrelation mellem temperatur og vækst i nogen af de fem undersøgte vækst år, men der var en aftagende styrke i korrelationen med højere alder. Væksten i alle fem vækst år var signifikant korreleret med AO og med NAO for vækst år 2 og 4. Resultaterne angående korrelation mellem temperatur og vækst er interessante i to sammenhænge. For det første indikere den positive korrelation at varmere havtemperaturer vil påvirke væksten hos torsk positiv ved disse nordige breddegrader. For det andet, indikerer den aftagende korrelations styrke med alderen at de tidlige livsstadier hos torsk er mere påvirket af svingninger i temperaturen end de ældre torsk. Dette er relevant med hensyn til rekrutteringen af torsk, da hurtigere vækst i de tidlige livsstadier vil betyde kortere tid tilbragt i disse sårbare stadier. At der ikke blev fundet nogen signifikant korrelation mellem temperatur og endokronologien i den varme periode i modsætning til den kolde periode, bliver interessant eftersom et kollaps af torskebestanden fandt sted i starten af 1990'serne. Det står ikke klart hvad der er årsagen til at den signifikante korrelation mellem temperatur og vækst forsvandt mellem den kolde og den varme periode, men en mulig faktor kan være at et højt fiskeritryk har selekteret langsomt voksende torsk. Den stærke korrelering mellem AO til alle fem vækst år samt til endokronologien er tegn på at vækstraten hos torsk er yderst påvirket af klimaet. Det står dog ikke klart hvilke underliggende faktorer der er ansvarlige for dette.

English summary

The Atlantic cod (*Gadus morhua*) has long been an important species to fisheries around the world. Likewise it was a big part of Greenlandic fisheries for decades, which ultimately lead to stock collapses. Knowledge about growth variability of cod therefore becomes of high importance in relation to fishery management. Variability in the growth patterns of Atlantic cod was investigated in relation to temperature and a variety of physical factors. A growth chronology from 1973-2010 was produced via biological intercept back-calculation, from otoliths originating from cod caught in NAFO area 1B in the waters of West Greenland. Otoliths from cod age 5-7 were used in this study, with a back-calculated growth chronology being produced for each of the first five growth years. Furthermore an endochronology combining all back-calculated growth years as standardized residuals was created. During the study period annual mean temperature fluctuated between 0.48°C and 3.37°C, including a cold period from 1980-1996 with an average temperature of 1.15°C and a warm period from 1997-2008 with an average temperature of 2.4°C. The endochronology was significantly positively correlated with mean temperature during the cold period, but not during the warm period. There was also a significant negative correlation between the endochronology and the Arctic Oscillation (AO) and the North Atlantic Oscillation (NAO) for the entire study period. During the entire study period there was no significant correlation between temperature and any of the first five growth years. However, there was a trend for declining correlation with age. Growth rate of all five growth years was strongly correlated with the AO and with the NAO for growth year 2 and 4. The results of correlation between temperature and growth are interesting in two respects. First of all the positive correlation indicates that a rise in ocean temperatures will increase growth rate of cod at these northern latitudes of their distribution. Second, the declining correlation with age indicates that early life stages of cod are more affected by variations in temperature. This has possible implications for recruitment of cod, as faster growth rate in early life stages would mean a shorter period of time in these very vulnerable stages of life. The lack of significant correlation between the endochronology and temperature in the warm period in contrast to the cold period becomes increasingly interesting, as a fishery collapse of the cod stocks took place in the early 1990s. Reasons for the disappearance of correlation between the cold and the warm period are unclear, but a possible factor could be selection of slow growing cod induced by fishing pressure. The strong correlation with AO for all five growth years and the endochronology shown in this study, suggest that climate affects the growth rate of cod in this area. However, the underlying factors responsible for this are not clear

Introduction

THIS STUDY

The Atlantic cod (*Gadus morhua*) is a very important fish to the Greenlandic fishery and it remains one of the most important fish on a global scale (Link & Garrison 2002). This makes an understanding of their growth patterns a subject of high importance, especially in the context of sustainable fishery management. The aim of this study is to investigate the growth patterns of Atlantic cod near the northern boundary of its distribution along the West Coast of Greenland. In particular the importance of temperature fluctuations on growth will be examined, but it will also be tested whether different physical or climatic factors affect their growth. However, it is important to keep in mind that growth is not affected by a singular parameter, but by a combination of environmental and human factors (Sinclair et al. 2002).

ATLANTIC COD

GLOBAL

The Atlantic cod is a teleost fish belonging to the family Gadidae. It is widely distributed in the Northern Atlantic. Its distribution ranges from the east coast of North America from Georges Bank to the Labrador Sea, along the Greenland east and west coast and the west European waters from the Celtic Sea to the Barents Sea (Drinkwater 2005). The relatively large area of distribution is possible because cod is capable of tolerating a wide range of temperatures from below -1°C to over 20°C. Their distribution also covers a large vertical scale as they are primarily caught from depths of 50-400 meters, although they are not restricted to these depths (Drinkwater 2005). Atlantic cod can reach ages of 20 years while growing to lengths of 130 cm and bodyweight of 25-35 kg, although they are much smaller when entering the fishable population (Fahay et al. 1999).

GREENLAND

Cod stocks at West Greenland are living at one of the northern boundaries of their distribution and are generally believed to be composed from three different origins, i.e. inshore stocks from the fjords, offshore stocks and cod originating from Icelandic waters (Buch et al. 1994). In fact it has been shown that the inshore and offshore cod stocks are genetically distinct stocks with limited connectivity (Pampoulie et al.

2011). These stocks are affected by both climate and fishery which influence many aspects of their life history. This includes recruitment (Stige et al. 2006) and growth rate (Conover & Munch 2002).

FISHERY & CLIMATE

The Atlantic cod has probably been present in the marine ecosystem of West Greenland for hundreds of years, but with great fluctuations in their abundance (Buch et al. 1994). Atlantic cod has been an important part of Greenlandic fishery since the 1920s, coinciding with a warming of the region brought along with warmer currents (Rätz et al. 1999; Hamilton et al. 2003; Drinkwater 2008). Atlantic cod has indeed been important not only to fishery but to culture, economics and ecology (Link & Garrison 2002). However, there have been collapses in the cod stock biomass in the early 1960s and again in the early 1990s (Riget & Engelstoft 1998). One reason for this was the rapid development in fishing technologies during the last century, including trawlers and sonar detection which permitted an increased human pressure on fish stocks (Lear 1993; Pauly et al. 2002). The critical effect fishing can have on fish stocks is well known, with the direct effect of fishing being reduced biomass and fish size of the targeted species (Shin et al. 2005; Shackell et al. 2012). Indirectly fishery can affect marine ecosystems by interference with inherent ecosystem control mechanisms, such as top-down control (Perry et al. 2010). Top-down control is the process in which predators keep the abundance of intermediate trophic levels in check, allowing lower trophic levels to prosper. An example of how fishery can interfere with this in West Greenland waters is the increase in northern shrimp (*Pandalus borealis*) abundance in the years following the 1990s cod stock collapse (Wieland 2005). Although it is generally accepted that the intensity of fishing carries a significant responsibility in stock collapse, it is also quite possible that environmental changes affected the stock biomass (Rätz et al. 1999, Pörtner et al. 2001).

Climate changes alone can have a huge impact on cod stocks, and if combined with strong fishing pressures it can result in a stock collapse (Beaugrand & Kirkby 2009). In the case of cod in West Greenland a decrease in water temperature is proposed to have strong negative effects on growth as they are living at the northern end of their distribution (Drinkwater 2005). Moreover, fishing pressure has been shown to amplify climate effects in marine ecosystems (Möllmann et al. 2008). With the evidence available on the effect of environment on cod stock productivity (Rätz et al. 1999; Pörtner et al. 2001), it becomes increasingly important to investigate ecosystem changes in the Arctic region in the presence of global warming. Ocean temperatures worldwide are believed to continue to rise and particularly the Arctic region is considered highly affected (Drinkwater 2005), as these areas with the largest increase in temperature also should experience the greatest responses (MacKenzie & Schiedek 2007). This expected rise in water temperature should affect the appetite of Atlantic cod and hence it's feeding rate (Jobling 1988), and ultimately result in a higher growth rate for cod in West Greenland assuming that prey abundances can sustain this (Drinkwater 2005).

GROWTH & FEEDING

ENERGY BUDGET

Energy intake serves purposes other than growth. Food ingested has to be allocated to serve functions of maintenance, growth and reproduction, in a way that allows for maximum lifetime production of offspring (Wotton 1998). The term energy allocation describes the balance between energy intake and the various outputs:

$C = G + E + R$

C = Total energy intake

G = Energy for somatic and reproductive growth

E = Energy lost via fecal matter or excretion

R = Energy for standard metabolism, active metabolism and food assimilation

Variations between these parameters cause fluctuations in growth. If C declines that would cause a decline in G and vice versa. However, if C remains constant while R increases this would also lead to a decline in G. Many different factors can affect energy allocation and hence available energy for growth. This includes genotype and external factors such as temperature, salinity and prey quality and availability. Two of the most important and most studied factors are temperature and food intake, and as temperature directly affects appetite, the two are closely interconnected (Jobling 1988).

TEMPERATURE

Contrary to birds and mammals fish have indeterminate growth, making them much more affected by the environment throughout their life span and more vulnerable to environmental changes (Campana & Thorrold 2001). Fish are poikilotherm animals, which mean that their body temperature is determined by that of its surroundings (Jobling 1993). Being poikilotherm, Atlantic cod receives a direct effect of temperature on growth physiology including its metabolism, feeding, food assimilation and excretion (Rätz et al. 1999; Pörtner & Knust 2007). Metabolism will increase with temperature, as will intake of food until temperature closes in on the tolerance limit, at which point food intake will decrease (Fig. 1a)(Jobling 1993). This is because the primary effect of an increase in temperature would be a loss of energy due to increased metabolism (Pörtner & Knust 2007), which must therefore be compensated for with increased food intake. The increased energy demand that comes with increased temperature, produces increased appetite, gastric evacuation and of course an increased energy intake (Jobling 1988). This creates a relationship between temperature and metabolism that result in a growth optimum, which is just below the temperature of maximum food intake (Fig. 1b)(Jobling 1993). It should be noted that growth could decline with rising temperature if food is limited (Sinclair et al. 2002). This becomes relevant in relation to temperature for growth optimum, as this temperature then will be lower when food is limited (Fig. 2)(Jobling 1993).

The effect of temperature on the growth of cod has been shown on numerous occasions. It is known that temperature positively affects length-at-age and weight-at-age (Jørgensen 1992; Brander 1995; Riget & Engeltoft 1998; Rätz et al. 1999). The effect on growth rate is the direct effect, but indirectly changes in temperature can also affect prey abundance and distribution (Jørgensen 1992; Riget & Engelstoft 1998). Temperature seems to not only influence the growth rate in a positive way, but better physical condition (Fulton's K) of Atlantic cod has been shown to be partly explainable by increasing temperature (Rätz & Lloret 2003). Indeed temperature affects multiple phases in the life history of cod. Age of maturity is known to decrease when temperature increases and time of spawning occurs earlier due to faster gonad development (Drinkwater 2005). The egg development is also faster as a result of warmer water temperature (Kjesbu 1989), which means a shorter period of extreme vulnerability to predation which is subsequently linked to recruitment and population growth.

PREY CHANGES

Feeding habits of cod is an intrinsic part of understanding its energy intake. The Atlantic cod is an opportunistic omnivore and its prey items tend to shift during its lifetime (Link & Garrison 2002). In the larval stage they feed on plankton, whereas younger cod feed mainly on crustaceans before a shift in diet towards becoming primarily piscivorous as they grow larger (Mehl 1989; Rose et al. 2000; Link & Garrison 2002). Among its prey items, capelin (*Mallotus villosus*) is important to Atlantic cod in Greenlandic waters, as it is to many predators in this ecosystem (Friis-Rødel & Kanneworff 2002). Capelin is known to be of particular importance to Atlantic cod, as their growth rates have been shown to relate to capelin abundance (Jørgensen 1992; Malmberg & Blindheim 1994). This could very well be caused by the fact that capelin is very lipid-rich and hence represent high quality food (Friis-Rødel & Kanneworff 2002; Hedeholm et al. 2011). It is known that not all prey items contain the same amount of nutritional value (Alverson et al. 1992), and therefore availability in quality prey might affect growth rate in Atlantic cod (Riget & Engelstoft 1998). This is referred to as the "junk food hypothesis", stating that when prey items of high nutritional value become scarce, they are replaced by prey of lesser nutritional value. This can become critical for growth not only in terms of lesser energy intake, but also an increased cost of digestion (Rosen & Trites 2000).

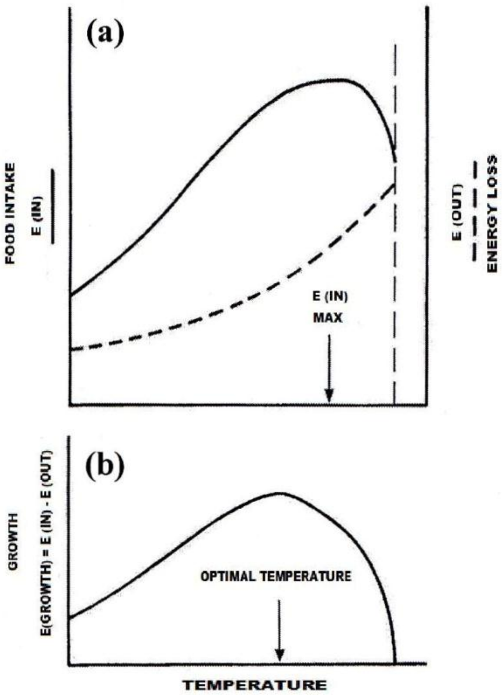

Figure 1. (a) The influence of temperature on food intake and metabolism, the dotted vertical line shows the maximum tolerable temperature. (b) The effect of temperature on growth, arrow indicates the optimal temperature for growth (Jobling 1993).

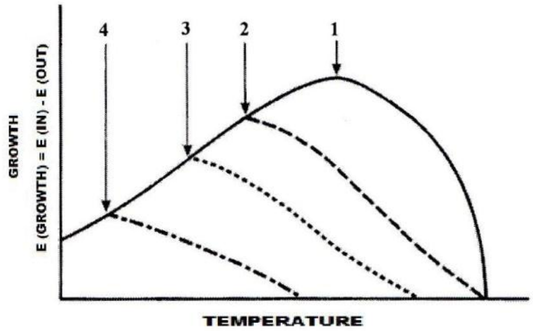

Figure 2. The effect of temperature on growth. Arrows indicate temperature optimum for growth at different food availabilities. 1: Unlimited food, 2: Some food limitation, 3: moderate food limitation, 4: High food limitation (Jobling 1993).

OTOLITHS

GENERAL

Both temperature and feeding habits has been shown to not only affect somatic growth but also growth of otoliths, which are calcified structures found in the inner ear of bony fishes (Otterlei et al. 2002; Campana 1982). Otoliths are present in three pairs in the inner ear of bony fishes, where they are part of a complex sensory system. This enables the fish to perceive direction, frequency and amplitude of sound, and also its static and dynamic position in the water column (Mosegaard & Morales-Nin 2000). Otoliths are composed of calcium carbonate, typically as aragonite and a protein matrix made of otoline. This protein matrix is accreted in cyclic layers along the otolith, which results in the visible growth increments (Fig. 3)(Mugiya 1987). The cyclic layers are present as dark and light zones (when viewed under reflected light), referred to as the hyaline and opaque zones respectively. It is believed that high protein content is responsible for formation of the opaque zones (Mosegaard & Morales-Nin 2000). Opaque zone formation is connected to periods of high metabolic rate, and hence should represent summer growth, whereas hyaline zone formation is connected to periods of low metabolic rate, which should be winter growth (Pilling et al. 2007).

SCIENTIFIC TOOL

Fish otoliths provide an excellent chronological tool. They are popular amongst fishery scientist due to the precision and clarity of the annual increments. Furthermore otoliths are easy to handle and prepare for examination (Campana & Thorrold 2001). The widths of the increments have been shown to depend on feeding frequency and metabolic rate, and to correlate with somatic growth which makes them a useable measurement for growth. Furthermore during starvation the increments deposited are narrower, indicating that unfavorable growth conditions are visible in otoliths (Campana 1982). Also temperature variations have been shown to affect the width of the opaque and hyaline zones (Pilling et al. 2007). Another advantage in the use of otoliths, are the fact that they do not degenerate once formed, not even in times of starvation (Campana & Thorrold 2001; Li et al. 2008). It has been argued that otolith growth is linked to metabolism and not to somatic growth (Wright 1991; Panfili & Tomas 2001). However Pilling et al. (2007) points out that otolith deposition is affected by a combination of many biotic and abiotic factors, such as feeding and environmental factors. These factors are all interconnected in the life history of a fish, thereby making metabolism, somatic and otolith growth interconnected.

For otoliths to be used as a tool for growth estimation, it is necessary to assume a linear relationship through time between fish and otolith length. The biological intercept back-calculation method is believed to produce very accurate growth estimates. Back-calculation is the estimation of previous fish size based on the dimensions of growth increments in calcified structures, in this case otoliths (Li et al. 2008). It incorporates a biological intercept which is the fish and otolith length corresponding to the moment that proportionality between fish and otolith growth begins (Campana 1990). The back-calculation model makes use of capture length of fish and otolith, and measurements of the increments themselves. The back-calculation growth model looks as follows:

$\Delta L_{t-1} = [(L_c - L_i) / O_c - O_i] * (O_t - O_{t-1})$

L_c = Fish length at capture (mm)

O_c= Otolith radius at capture (µm)

L_i = Fish length at biological intercept (mm)

O_i = Otolith radius at biological intercept (µm)

$O_t - O_{t-1}$= Measured growth increment from t-1 to t (µm)

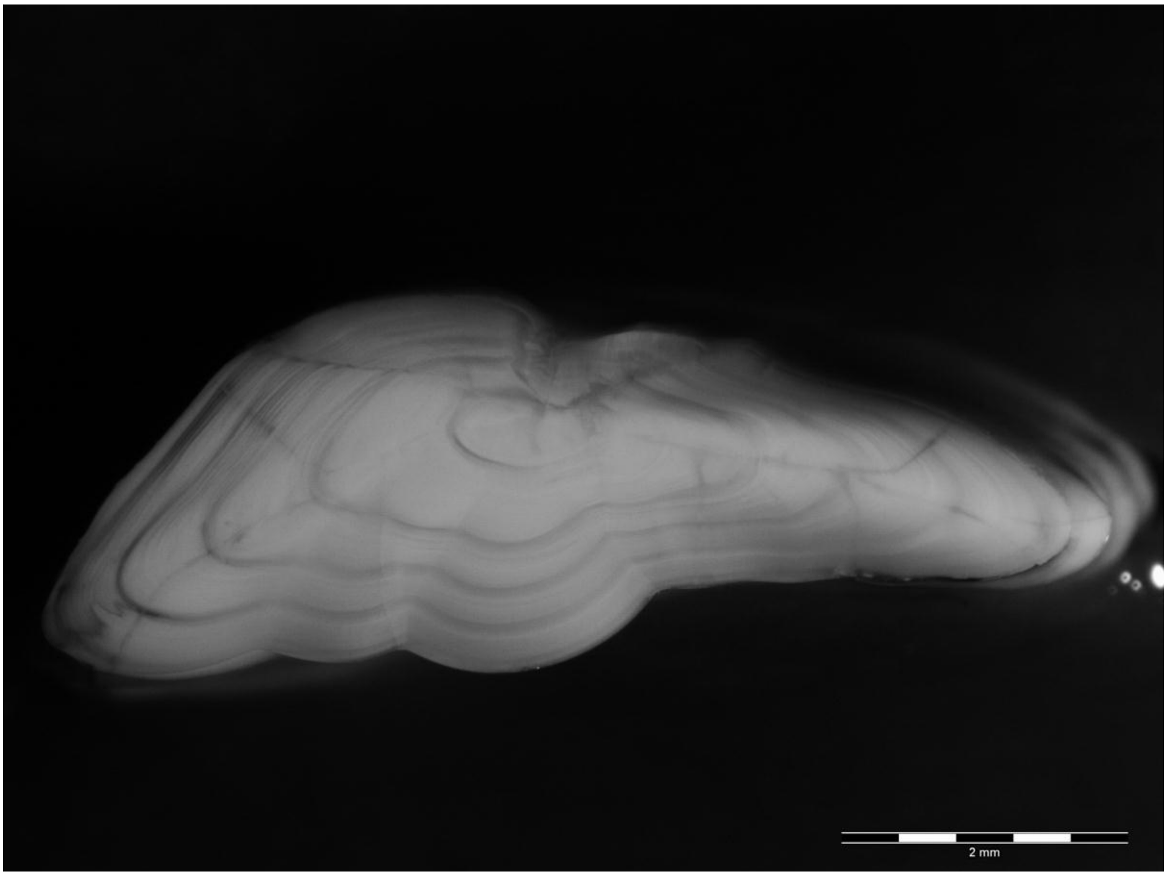

Figure 3. The cyclic layers forming the growth increments are clearly visible in this cod otolith.

PHYSICAL CONDITIONS

CLIMATE EFFECTS

The effects of climate on marine ecosystems are known to be complex, as climate variability consists of a wealth of different interconnected factors. These factors include variables such as sea surface temperature, wind speed, mixed layer depth and sea ice cover, which all influence the organism living in an ecosystem (Hurrel & Deser 2010). Hence an understanding of climate variability and the effect on ecosystems are important in the attempt to understand what drives and changes factors such as food chain structure, recruitment and in the case of this study, growth rate. A brief description of the most common climate and oceanographic indices in relation to West Greenland is given below.

NORTH ATLANTIC OSCILLATION

The North Atlantic Oscillation (NAO) is a measure of air pressure variations in the North Atlantic. More precisely it's the difference between the Azores high pressure and the Icelandic low pressure at sea-level (Hurrel 1995; Hamilton et al. 2003; Born & Mignot 2011). When the pressure difference is higher than normal it is associated with stronger than normal westerly winds across the Atlantic, which brings warm air over Europe, and subsequently stronger northerlies brings cold air over Greenland and the north-west Atlantic (Fromentin & Planque 1996; Stenseth et al. 2004). These pressure variations have had an upward trend since the 1960s, and have reached very high anomalies (Thompson & Wallace 1998; Langenberg 2000). However, in the last decade the NAO has again shown a declining trend (Sarafanov 2009). This is believed to have influenced some of the climatic changes registered in the Northern hemisphere (Hurrel and Van Loon 1997; Langenberg 2000). Amongst these changes the NAO affects sea and wind conditions in Greenlandic waters, and thereby the ocean ecosystem (Dickson et al. 1996; Vilhjálmsson 1997). It is known that sea and air temperature in West Greenland are affected by the NAO, even if it is not in a straight forward way (Hamilton et al. 2003).

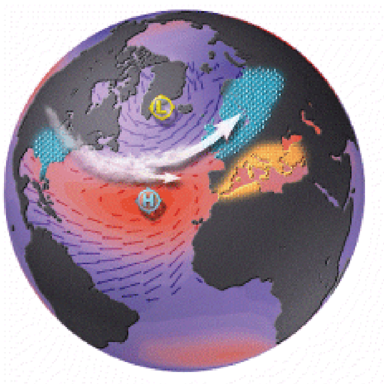

Figure 4. NAO during the positive phase, where strong westerlies bring warm maritime air in over Europe. From Ottersen et al. 2001.

ARCTIC OSCILLATION

The Arctic Oscillation (AO) is variability in sea-level air pressure over the arctic at latitudes above 20°N (Thompson & Wallace 1998). It is an oscillation between the north Pacific and the north Atlantic centered over the Arctic region (Visbeck et al. 2001) and is thought to be closely linked with the NAO (Cohen & Barlow 2005). The AO is characterized by a warm phase when air pressure is lower than normal and a cold phase when air pressure is higher than normal. These warm and cold phases affects climate in the northern hemisphere (Hodges 2000).

NORTH ATLANTIC SUBPOLAR GYRE

The North Atlantic Subpolar Gyre (SG) is a current of cold low-saline subartic water that moves in a counterclockwise pattern (Hátún et al. 2009). It stems from an extension of the Gulf Stream, which becomes the North Atlantic Current that carries water masses to the North Atlantic, and from there circulates west. The Greenlandic waters are located at the northern boundary of the SG, and it therefore seems plausible that variation in the SG could affect the Greenlandic marine environment (Stein 2005). It has previously been shown that variations in the SG can affect multiple trophic levels in an ecosystem by creating a "bottom-up" effect (Fig. 5)(Hátún et al. 2009). "Bottom up" effect refers to an ecosystem state in which nutrients and primary production control the ecosystem structure and abundance (Cury et al. 2008).

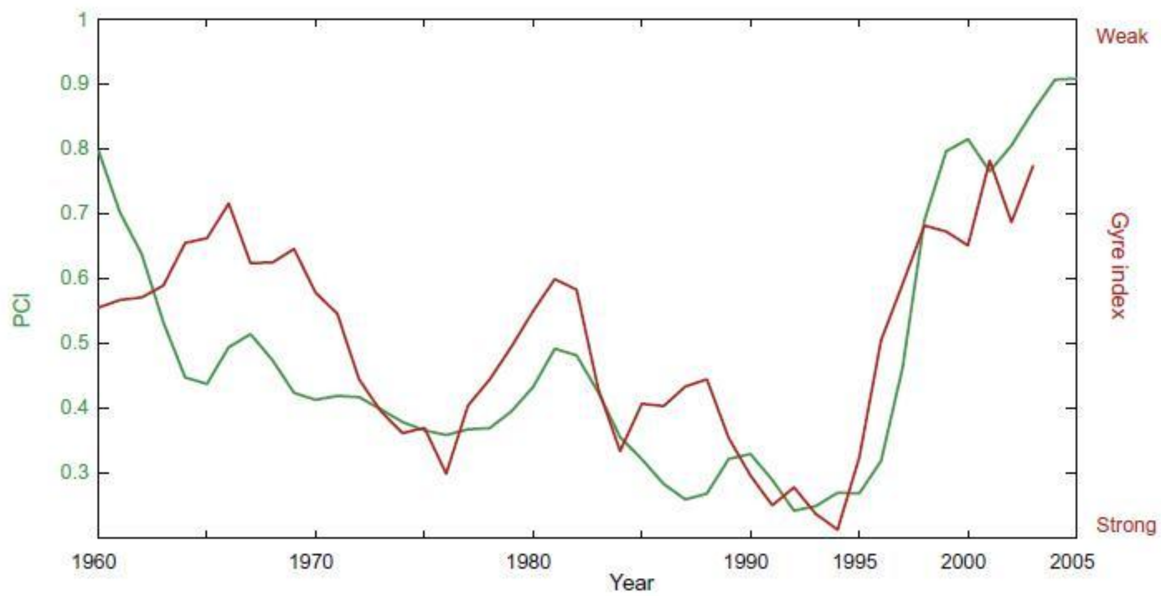

Figure 5. Relationship between a plankton color index (PCI) and the SG, illustrating the SG's potential for affecting an ecosystem through "bottom up" effects (Hátún et al. 2009).

ATLANTIC MULTIDECADEL OSCILLATION

The Atlantic Multidecadel Oscillation (AMO) is a mode of variability, which is measurable by sea surface temperatures in the North Atlantic. It was recognized in 1994 by Schlesinger and Ramankutty, and its cycle consists of warm and cold phases that are known to affect climate phenomenons such as rainfall (Enfield et al. 2001).

AIM OF STUDY

Growth variability in cod caught near Sisimiut, West Greenland, will be examined using a growth chronology produced via the biological intercept back-calculation model. Such a growth chronology will be produced for each of the first five growth years and in order to provide some insight into how climate affects the different age groups of cod. Further an endochronology will be produced based and standardized residuals of the back-calculated growth. This allows for all five back-calculated growth years to be comparable and one continuous growth chronology can be produced. These chronologies will then be tested for correlations with temperature and the physical factors described, in an attempt to shed light on what affects growth variability in Atlantic cod near its northern range of distribution.

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Manuscript

Growth variability in Atlantic cod (*Gadus morhua*) near its northern range of distribution

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ABSTRACT: Variability in the growth patterns of Atlantic cod (*Gadus morhua*) was investigated in relation to temperature and a variety of climatic factors. A growth chronology from 1973-2010 was produced by biological intercept back-calculation, from otoliths originating from cod caught in NAFO area 1B in the waters of West Greenland. Otoliths from cod age 5-7 were used in this study, with the back-calculated growth chronology being produced for each of the first five growth years. Furthermore an endochronology combining all back-calculated growth years as standardized residuals was created. . During the study period annual mean temperature fluctuated between 0.48°C and 3.37°C, including a cold period from 1980-1996 with an average temperature of 1.15°C and a warm period from 1997-2008 with an average temperature of 2.4°C.. The endochronology was significantly correlated with mean temperature during the cold period, but not during the warm period. There was also a significant correlation between the endochronology and the Arctic Oscillation (AO) and the North Atlantic Oscillation (NAO) for the entire study period. The age-group specific back-calculated growth was strongly correlated with the AO for all five growth years and with the NAO for growth year 2 and 4. During the entire study period there was no correlation between temperature and any of the first five growth years. However, there was a trend for declining correlation with age, indicating that early growth years could be more affected by temperature. The present study suggests that growth rate in cod is affected by large scale climate at these northern latitudes, but that the magnitude of the effect is age specific.

KEY WORDS: Atlantic cod, *Gadus morhua*, growth, temperature, Arctic oscillation, North Atlantic Oscillation

INTRODUCTION

Atlantic cod (*Gadus morhua*) is found in most marine shelf ecosystems in the North Atlantic, including West Greenland. Along the coast of West Greenland it is distributed from Cape Farewell 59° N in the south to the Disko bay 70° N in the north (Drinkwater 2005, ICES 2005, Fig. 1). Cod in West Greenland waters have been shown to consist of three different stock components: Inshore, offshore and an occasional influx from Iceland (Pampoulie et al. 2011). These stocks have been under severe fishing pressure which has resulted in stock collapses in the 1960s and 1990s (Riget & Engelstoft 1998). This has a potential effect on cod growth and size-at-age as fishing is a very size selective process (Law 2000; Conover & Munch 2002; Swain et al. 2007). In addition to the direct fishery induced changes, climate has been shown to affect cod stocks in different ways, especially via temperature fluctuations (Michaelsen et al. 1998; Drinkwater 2009). Such changes are becoming increasingly relevant with an estimated rise in temperature in the world oceans (Drinkwater 2005) and especially the confounding effects of fishery and climatic changes are highly relevant for all heavily fished stocks.

The effects of temperature on growth in Atlantic cod are well documented (Pedersen & Jobling 1989; Rätz et al 1999; Purchase & Brown 2001) and have been examined at multiple latitudes along Atlantic cod´s distribution (Taylor 1958; Brander 1995). Following an optimum growth curve (Jørgensen 1992), cod at the southern limit of distribution should experience a negative growth response with rising temperature, while cod at the northern limit should experience a positive relationship between growth and temperature (Drinkwater 2005). Indeed cod living near the edge of their thermal niche should be more sensitive to the effects of temperature (Beaugrand & Kirkby 2010). It is therefore expected that cod living near its northern distribution should experience an increase in growth rate with increasing temperature. Furthermore temperature is known to not affect all sizes equally. Studies have shown that optimal temperature for growth declines with increasing size for Atlantic cod (Björnsson et al 2001; Björnsson & Steinarsson 2002) and consequently increasing water temperatures should affect smaller size cod the most. In this study, age-classes will be studied rather than size-classes. However, any growth difference related to size should be visible through the studied age-classes.

Large scale climate indicators such as the North Atlantic Oscillation (NAO) and the Sub-polar Gyre (SG) position, affect marine ecosystems (Hátun et al. 2009; Hurrel & Deser 2010) and are being influenced by, or drive, climatic changes and should be considered when trying to understand growth variation.

The NAO affects ecosystems in the North Atlantic through a multitude of parameters such as sea surface temperature, wind patterns, mixed layer depth and sea ice cover (Hurrel & Deser 2010). The NAO has been shown to potentially affect cod stocks through “bottom up” effects, as a relationship between the NAO index and zooplankton has been demonstrated (Fromentin and Planque 1996). However, some studies link NAO to cod recruitment in a regional manner, with southern stocks responding negatively to a positive NAO, while northern stocks had higher recruitment (Stige et al. 2006). Brander (2005) showed that significant effect on recruitment only occurs when spawning stock biomass is low, while others argue that correlations vanish when time series are extended backwards (Solow 2002). The Arctic Oscillation (AO) is believed to be closely related to the NAO (Dickson et al. 1999; Cohen & Barlow 2005), as it is measurable by variations in sea level air pressure, in this case between the North Pacific and North Atlantic (Visbeck et al. 2001). Most studies of NAO effects on cod have been in relation to recruitment (Ottersen & stenseth 2001; Pörtner et al. 2001; Stige et al. 2006) but in this study we will be searching for effects on growth. With the close interconnection between the NAO and the AO, it seems reasonable that tests for climate effects on cod growth rate in West Greenland should take both oscillations into account.

The SG is a current of cold low-saline subartic water that moves in a counterclockwise pattern in the North Atlantic. It has been shown to affect marine ecosystems on multiple trophic levels through “bottom up” effects (Hátun et al 2009). “Bottom up” effects have previously been shown to affect recruitment in Atlantic cod via fluctuations in the plankton bloom, and hence impact on larval growth and survival in accordance with the match/mismatch hypothesis (Brander et al. 2001; Beaugrand et al. 2003). Recruitment and growth rate is thought to be tightly connected as higher growth rate means shorter period of time in the larval and juvenile stages. This means a shorter amount of time being spent in the most vulnerable life stages and hence more young cod can enter the fishable biomass (Sundby 2000). It therefore seems plausible that variations in the SG could affect productivity in West Greenland Atlantic cod.

Despite the collapse in cod production in West Greenland waters (Riget & Engelstoft 1998), the Atlantic cod is still an important fish to the fishery and it remains one of the most important fish on a global scale (Link & Garrison 2002). This makes an understanding of their growth patterns a subject of high importance. The aim of this study is to investigate the growth pattern of Atlantic cod near the northern boundary of its distribution along the West Coast of Greenland, more precisely in NAFO area 1B. This will be achieved by creating a growth chronology from 1973 to 2010 by means of biological intercept back-calculation based on otoliths. This time period includes a relatively cold period in the 1980’s leading up the fishery collapse, and a relatively warm period in the 2000’s. We hypothesize that Atlantic cod living at the high latitudes of West Greenland should experience an increased growth rate with increasing water temperature and that effects will be more pronounced in younger age-classes. Furthermore it will be tested whether large scale climate indicators are correlated to the growth rate of the different age-classes.

MATERIALS AND METHODS

OTOLITH COLLECTION

The cod otoliths used in this project have been made available by Greenland Institute of Natural Resources. They have been collected from the designated NAFO area 1B (Fig. 1), in a time period spanning from 1979 to 2011. Cod stocks at West Greenland are generally believed to be composed from three different origins, being inshore stocks from the fjords, offshore stocks and from cod originating from Icelandic waters (Buch et al. 1993; Pampoulie et al. 2011). Catches were primarily marked as being from Sisimiut or Sarfannguaq, meaning that most were caught inshore within the southern region of 1B. Furthermore the capture month most years were right after time of spawning, suggesting that the samples originate from local stocks. The otoliths were collected from both commercial and survey catches. Both sagittae had been removed and placed in paper envelopes. One of the otoliths had already been broken for age determination, but the remaining one was used for this study.

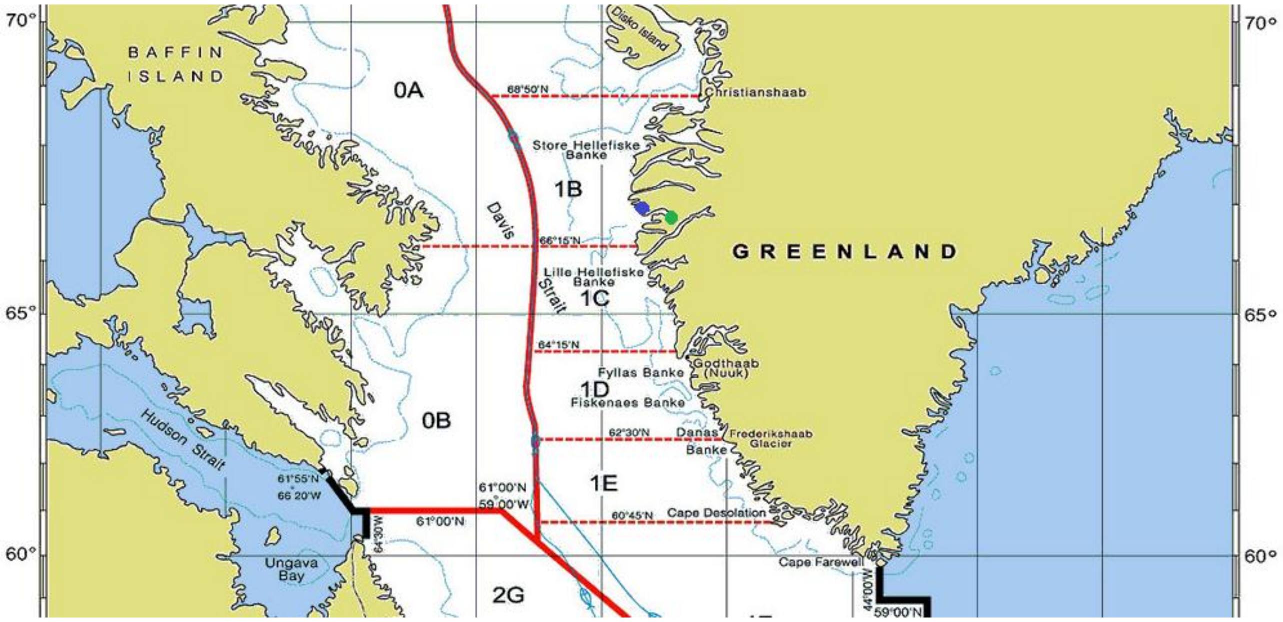


Figure 1. NAFO areas along the coast of West Greenland. Cod for this project were from area 1B. Blue marking is location of Sisimiut, green marking location of Sarfannguaq. Map modified from NOAA.

The sample design aimed at 50 otoliths pr. year from 5 year old cod, since sexual maturity is expected to be reached at that age, although this varies between populations and in response to fishing pressure (O'Brien et al. 1993; Fahay et al. 1999; ICES 2005). This turned out to be difficult due to large variation in yearly catches and cohort strength. To ensure sufficient sample size, as many otoliths age 4-9 as necessary were collected. Of these ages 5-7 ended up being used in the study. The amount of supplementary data (weight, gender etc.) varied between years, but length data was available for all samples, which was essential in later analyses (back-calculation). An overview of otolith data is seen in table 1.

Table 1. Data on otoliths used in this study. Month is designated by number (Jan=1, Feb=2…Dec=12).

Capture year	Capture month	Age 5	Age 6	Age 7	Male	Female	Gender unknown	Total
1979	5	24	14				38	38
1980	N/A	33	11	1			45	45
1982	11	46	1				47	47
1983	11		19	1			20	20
1984	8	23	5	3	5	9	17	31
1986	7	7	16	6			29	29
1987	7	15	8	8			31	31
1988	6	3					3	3
1989	7,9	37		2			39	39
1990	8,9	29	5				34	34
1991	N/A	19	4	4			27	27
1992	6	33	5	2			40	40
1993	6	35	21	13			69	69
1994	7	2					2	2
1995	7	11	3	1			15	15
1996	6	4					4	4
2002	6,7	20			10	8	2	20
2003	6	44	2				46	46
2004	6,7	17	11	2	2	6	22	30
2005	6,7	26	3	2	14	15	2	31
2006	7,8	15	2		7	10		17
2007	6	20	9	4			33	33
2008	N/A	18	4		8	14		22
2009	N/A	2	1		2	1		3
2010	4	12	29	5	38	8		46
2011	7	14	2		5	11		16

OTOLITH PREPARATION

Otoliths were examined externally to locate the point on the surface where the nucleus lies underneath. This point is a characteristic tap in the *Sulcus acusticus* (Jenke 2002), which is a groove going through the longest axis of the otolith. The point of the nucleus was then marked on each otolith before breaking it in half. It was cracked approximately 3 mm from the marked nucleus to allow room for grinding. Struers LaboPol-5 was used for the grinding process. All otoliths were ground with grain size 800 until about 1 mm from the nucleus, checking during the process in Stereomicroscope Leica MZ12.5. At this point the otoliths were burned over a bunsen burner, with an asbestos plate in between. This increased the clarity of the yearly increments. The otoliths were burned at very low heat to avoid shattering, and until they had a light brown color. The grinding process was finished with fine grinding, using grain size 1200 until the nucleus was reached.

For photo documentation an Olympus DP50-CU camera was fixed on Leica MZ12.5 stereomicroscope. All otoliths were photographed at 8 and 16 time magnifications. To further increase visibility of the growth rings, a thin layer of oil was applied to the smooth surface of the otolith. The 16 time magnification photo was used for the measurements.

OTOLITH MEASUREMENTS

Measurements of the increments were made in ImageJ 1.37v. To make the measurements as precise as possible, all photos were converted to black and white, which enhances the contrast between the dark hyaline zone and the light opaque zone. The hyaline zone represents winter growth and the opaque zone represents summer growth. Measurements were made from the outer point of the hyaline zone one growth year to the outer point of the hyaline zone the following growth year (Fig. 2). Each measurement was made perpendicular from one hyaline zone to the next. The increments were measured 3 times, and an average of these was used. The measuring area is illustrated in figure 2. During the measurement process each otolith was assigned a grade from 1-3, with 1 being measurements of the highest confidence and 3 the lowest confidence. Otoliths assigned grades 1 (N=623) and 2 (N=115) were used in the statistical analysis. No otoliths received grade 3.

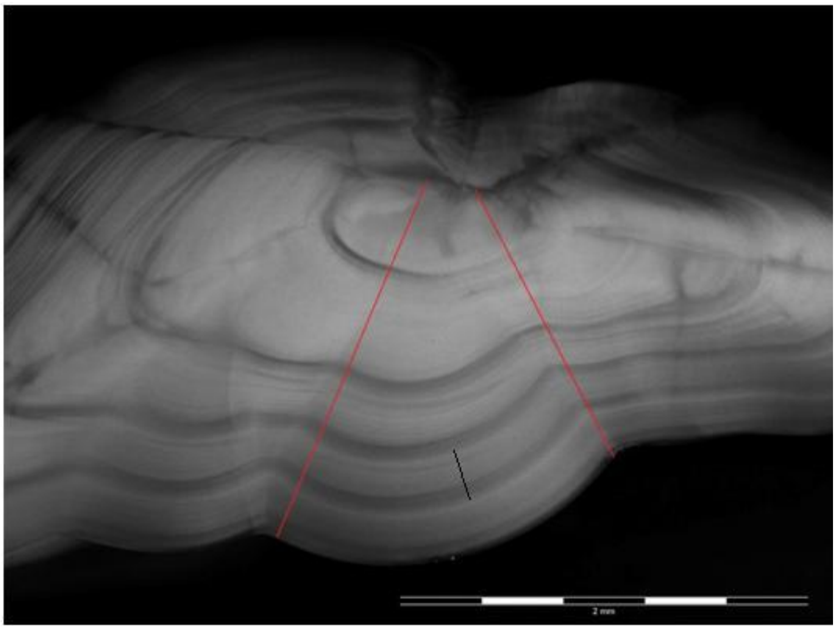


Figure 2. Measurements were made three different places within the red bars. The black line illustrates a measurement made for the 4th growth year.

DATA ANALYSIS

Annual growth was calculated using the "biological intercept back-calculation" method (Campana 1990). Biological intercept values used in this study are derived from *Poulsen* (2005), with a fish length of 26 mm and an otolith length of 316 um. Using these values growth was calculated as follows:

$\Delta L_{t-1} = [(L_c – L_i) / O_c – O_i] * (O_t – O_{t-1})$

L_c = Fish length at capture (mm)

O_c= Otolith radius at capture (um)

L_i = Fish length at biological intercept (26 mm)

O_i = Otolith radius at biological intercept (316 µm)

$O_t – O_{t-1}$= Measured growth increment from t-1 to t (µm)

With the back-calculation model the length increment of the fish in each growth year can be calculated and a population growth chronology can be produced for the whole period. However, due to years with fewer individuals, there were some gaps between 1973-1995 (Table 1). To produce a complete time series a chronology based on standardized residuals was also produced. These standardized residuals where derived from growth rates calculated with the back-calculation model using the following formula:

Standardized residual$_t$ = BC-growth$_t$ – Mean BC-growth$_t$ / Standard deviation of BC-growth$_t$

Standardized residuals were calculated for each year (t) from 1973-2010 and each growth year (1-5), and then put together as one chronology using the mean value for years that had more than one standardized residual. This technique produced a chronology from1973 to 2010 with only one empty year (1996).

CLIMATE DATA

Temperature data was derived from the ICES database (ICES 2012). Two different sets of temperature were used, both based on observations from a depth of 10-100 meters. Both temperature sets were based on inshore and offshore temperature. A combined inshore-offshore temperature dataset was necessary due to very few measurements inshore. Offshore and inshore temperature data was plotted, and showed a very strong correlation (Fig. 3), justifying a use of both data sets. Data from 1977 is not included as inshore temperature was composed of only 2 measurements. Temperature data were collected from 66.5 - 67°N and 52.2 – 57 °W. One temperature set was based on mean values for May, June, July and August, representing the growth period of cod (Jørgensen 1992). The second temperature set was based on mean values from the entire year. It was tested whether there was any difference between the inshore and the offshore temperature data set. There was no significant difference between the two data sets (Pearson correlation, r=0.79, df=23, P<0.001), and they were combined. Yearly mean temperature and growth period temperature (May-June-July-August) shows a high degree of overlap during the study period (Fig. 4) and will be referred to collectively as temperature.

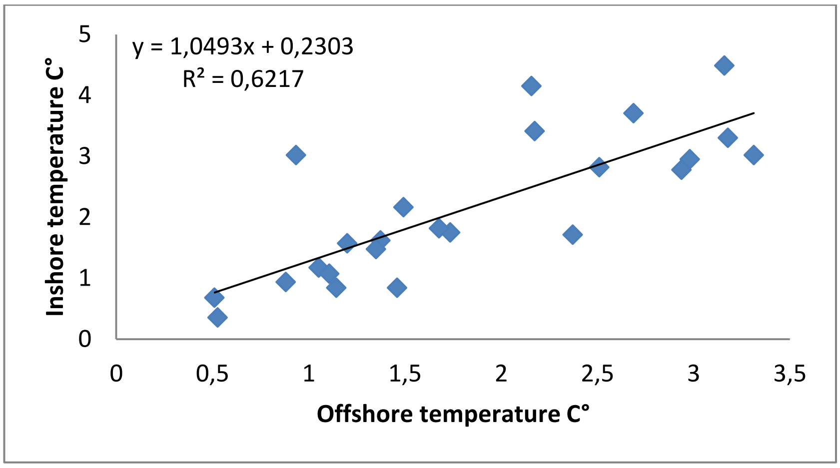


Figure 3. Inshore temperature as a function of offshore temperature, revealing a tight relationship between the two datasets.

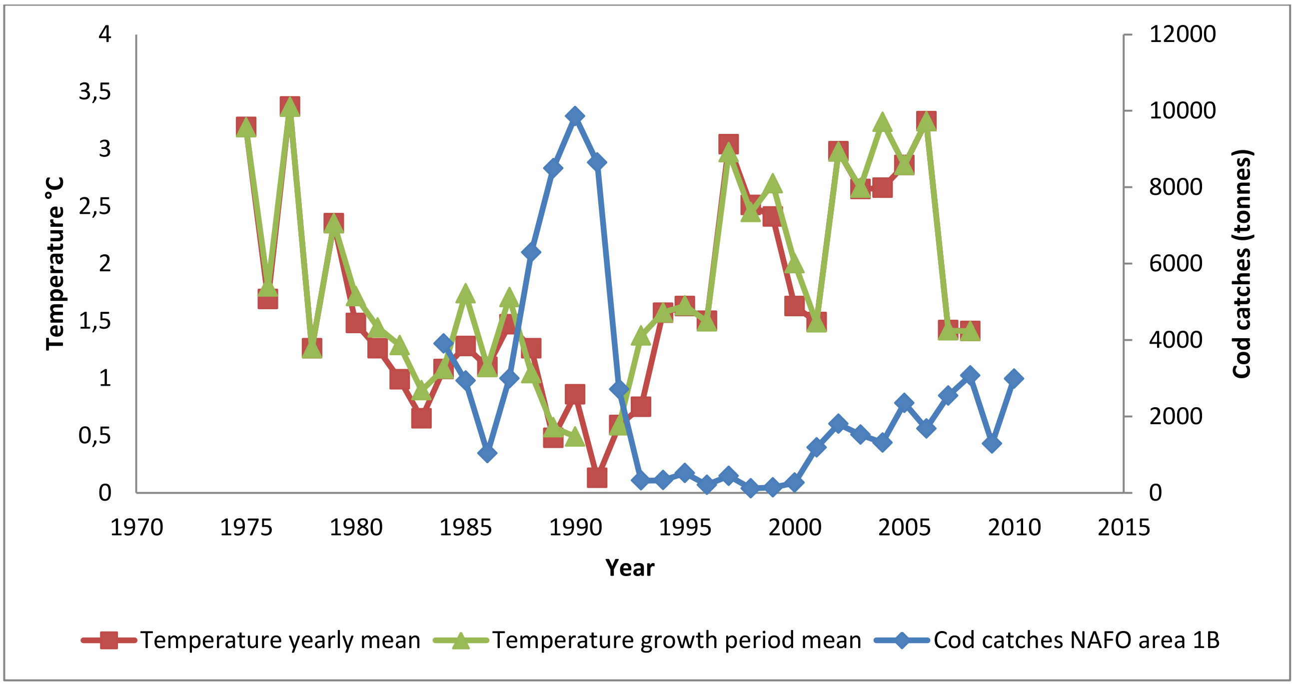


Figure 4. Water temperature at Sisimiut during the study period shows distinct patterns of warm and cold periods. Cod catches for NAFO area 1B is included in the figure to visualize how the rise in water temperature in the early 1990s coincided with the fishery collapse.

Physical factors which are being tested for correlation with growth in this study are shown in figure 5-7. Data on the NAO, AO and AMO were obtained from NOAA database (NOAA 2010). The NAO (Fig. 5) pattern shows that the winter NAO (DJF) follows the same trend, but with larger fluctuations than the yearly average. Both are used in the statistical analysis. Data on the SG was taken from Hatún et al 2005. Data on cod catches for NAFO area 1b was taken from ICES NWWG report 2011.

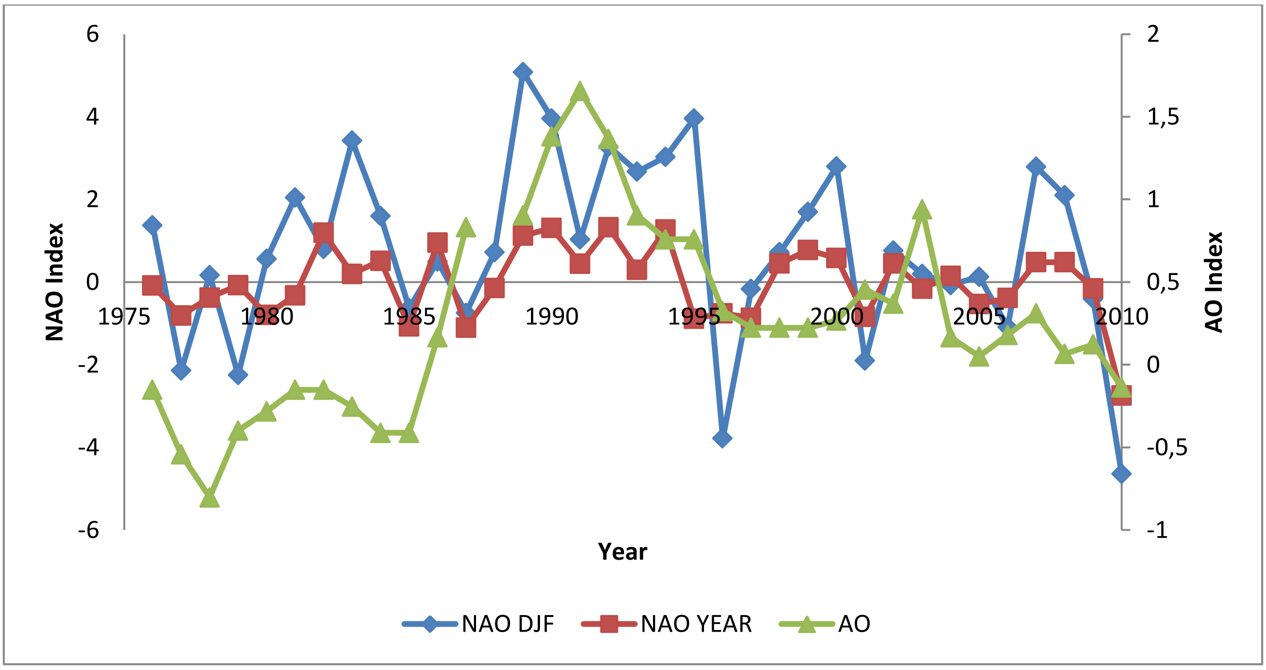


Figure 5. Variability of the closely related NAO and AO, both December-January-February (DJF) and yearly (YEAR) average of NAO is shown and used in the statistical analysis. AO data is yearly average.

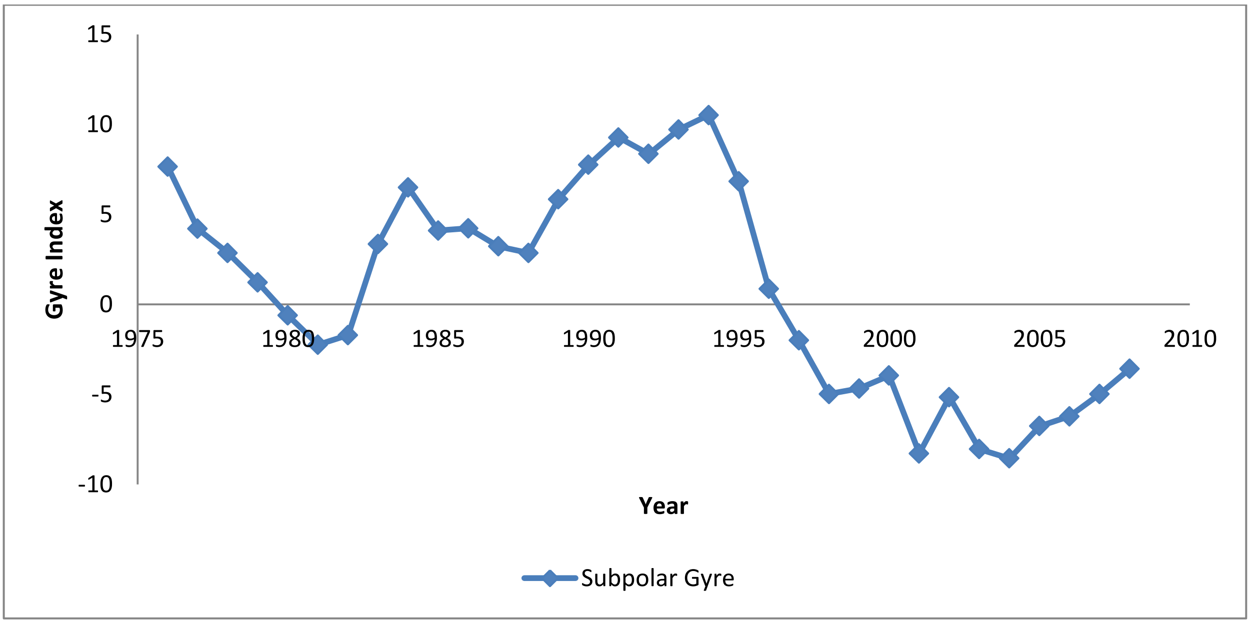


Figure 6. SG variability during the study period consists of both strong and weak gyre mode.

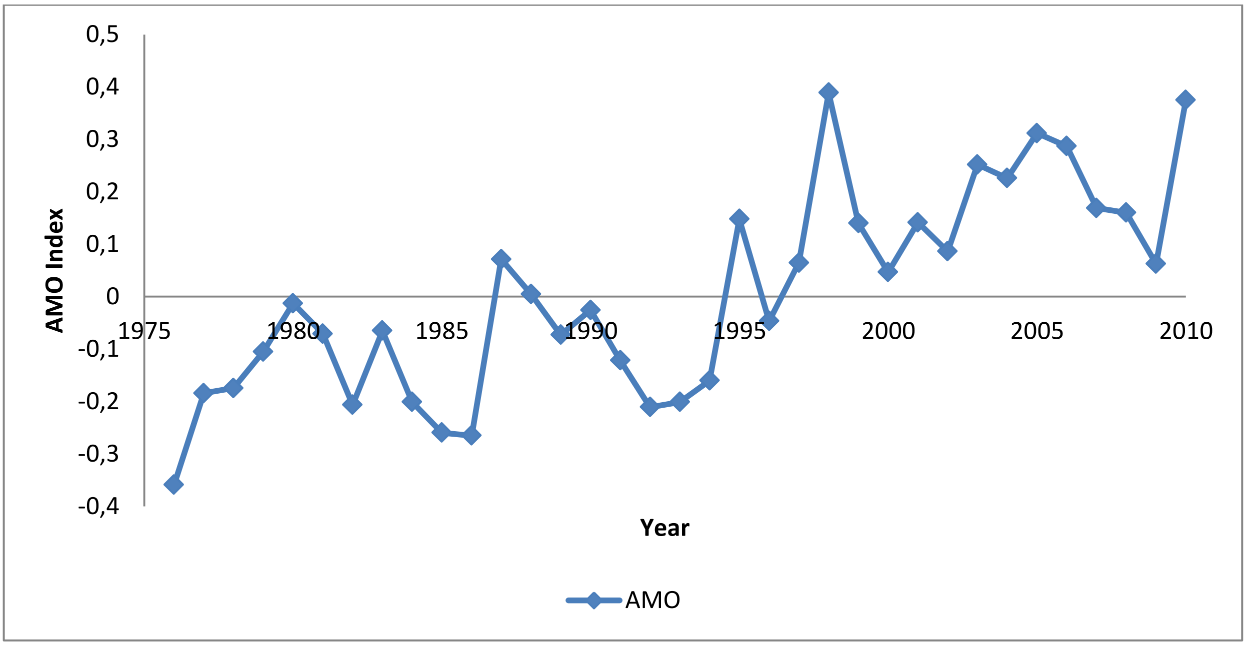


Figure 7. Variability in the AMO, which is based on sea surface temperatures in the North Atlantic, during the study period.

STATISTICAL ANALYSIS

ANCOVA was used to test for age group differences in the otolith size fish size relationship. T-test was used to examine differences in growth rate between sexes. The t-test based regime shift detection analysis STARS (Rodinov 2004) was used to check for regimes within the temperature timeseries. Pearson correlation was used to correlate climate and fish growth data.

RESULTS

GROWTH

Otolith radius was plotted against fish length for all age groups (5-7). This illustrates the size difference in otoliths and the overlap in otolith size between these age groups. There slope of otolith radius versus fish length was not significantly different between age groups (ANCOVA, $F_{2,767}$ = 1.98, P=0.14), but there was a small albeit significant difference in the effect of age group on otolith radius at a given fish length (ANCOVA, $F_{2,769}$ = 3.69, P=0.026). Age group 5 otoliths were 45 µm smaller than age group 7 otolith, while the difference between age group 6 and the two others was non-significant. The mean values for each capture year and each age group are presented in figure 9. There was a strong correlation between fish length and otolith size, which is important when using otoliths as a measure for growth (Pearson correlation, r=0.77, df=58, P<0.001). This suggests that otolith size is a useful proxy for growth in this study.

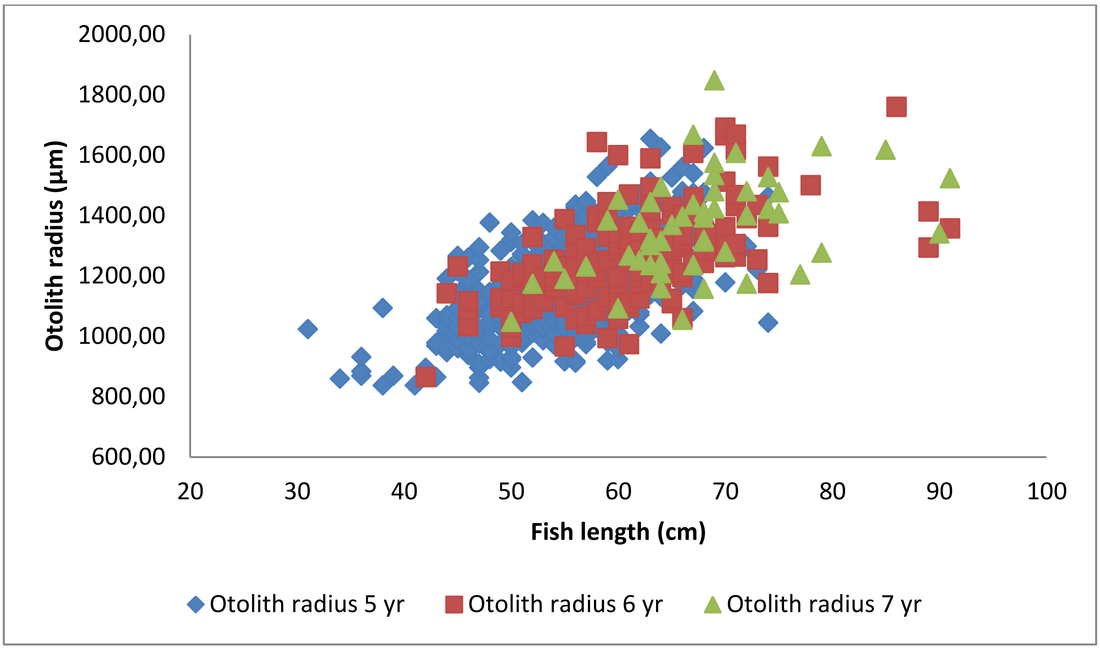


Figure 8. Individual otolith radius from all three age groups plotted against fish length.

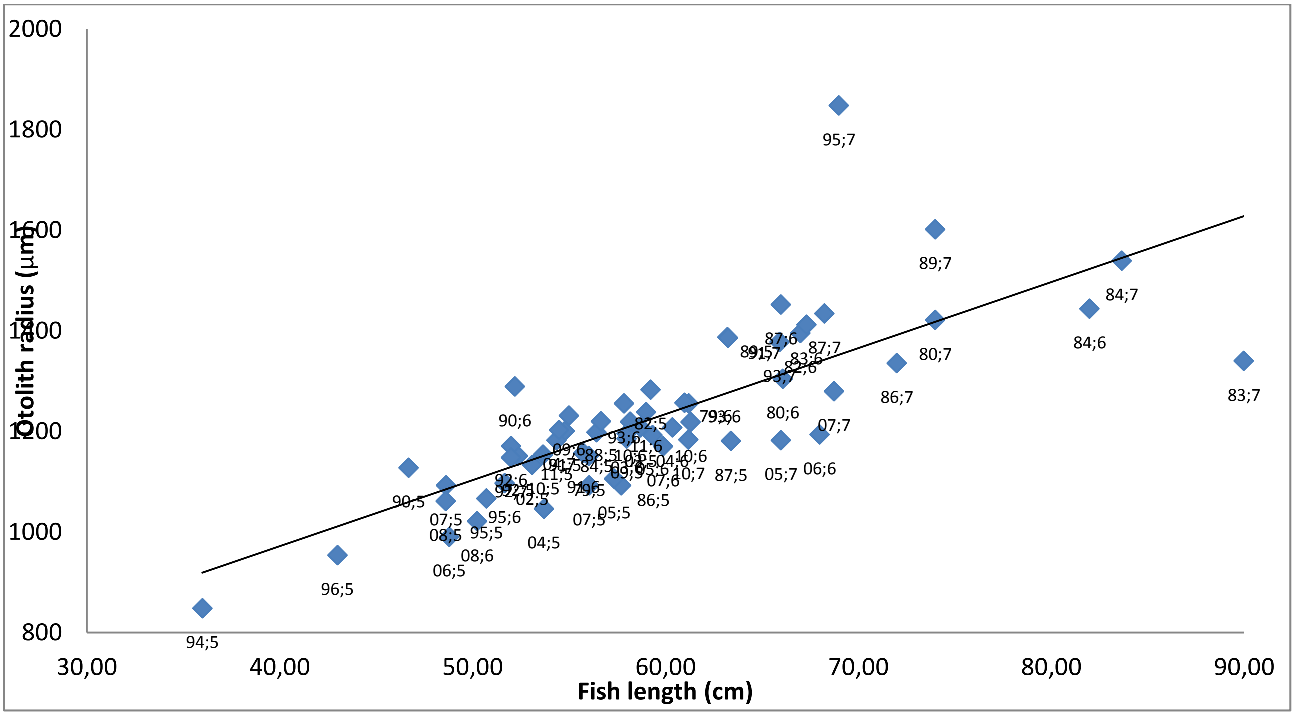


Figure 9. Otolith radius mean values from each capture year plotted against fish length. Markers represent capture year and age group.

To test for sex related growth differences, the back-calculated growth for the fifth growth year was compared between sexes. This age follows sexual maturity, where any differences should be most pronounced, but the growth pattern did not differ (T-test, $T_{(171)}$=0.835, P=0.41) and males and females were pooled in further analysis. Growth rates were highest in the first year of growth, with fish growing on average 193.4 ±16.7 (SD). The growth rate declined with age and in the oldest age examined in this study (5 years), the yearly mean somatic growth was reduced to 57.6 ±13.6 (SD).

Due to limited sampling, there were years without any available otoliths (1995-2000). To have a complete time series, standardized residuals for all growth years and ages were used to create one single growth chronology. This way, individuals of different ages could be compared, resulting in a time series with only one missing year (Endochronology, Fig. 11). The endochronology reveals clear patterns in growth rate of cod. The start of the study period from 1973-1985 is characterized by high growth rate, which corresponds to a period when temperature was high in the 1970s and became cold in 1980 (Fig. 4). The endochronology declines in the mid-1980s and growth rate remains at a low level until 1993, during a period in which temperature was at a low level (Fig. 4). From 1993 and onwards to 2001 growth pattern in the endochronology is fluctuating before a decline in growth rate lasting until 2009, which is during a period were temperature was at a high level overall (Fig. 4). The endochronology indicates a considerable increase in growth rate in 2010, however, in should be kept in mind that this point is solely based on the fifth growth year (Fig. 10).

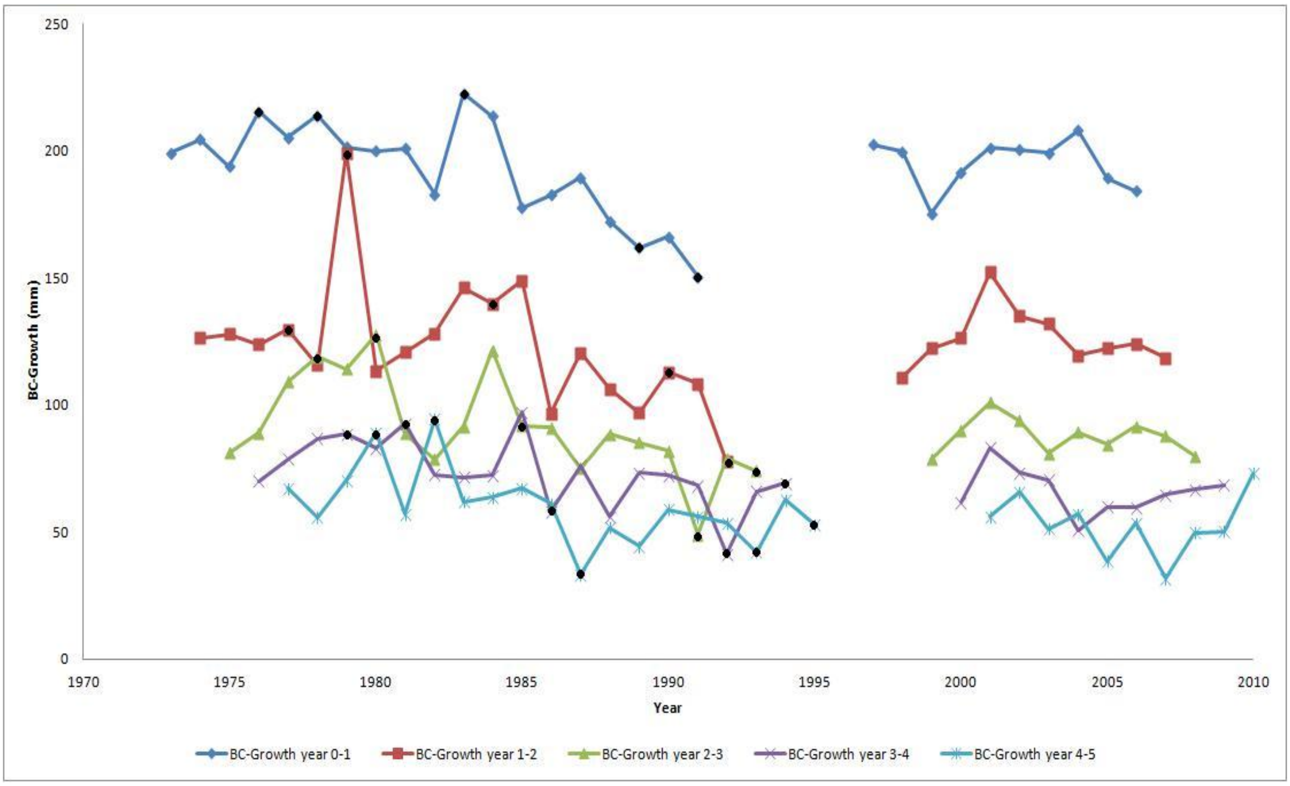


Figure 10. Mean growth of the first 5 growth years calculated with the biological intercept back-calculation model. Black markings indicate years with less than 6 individuals.

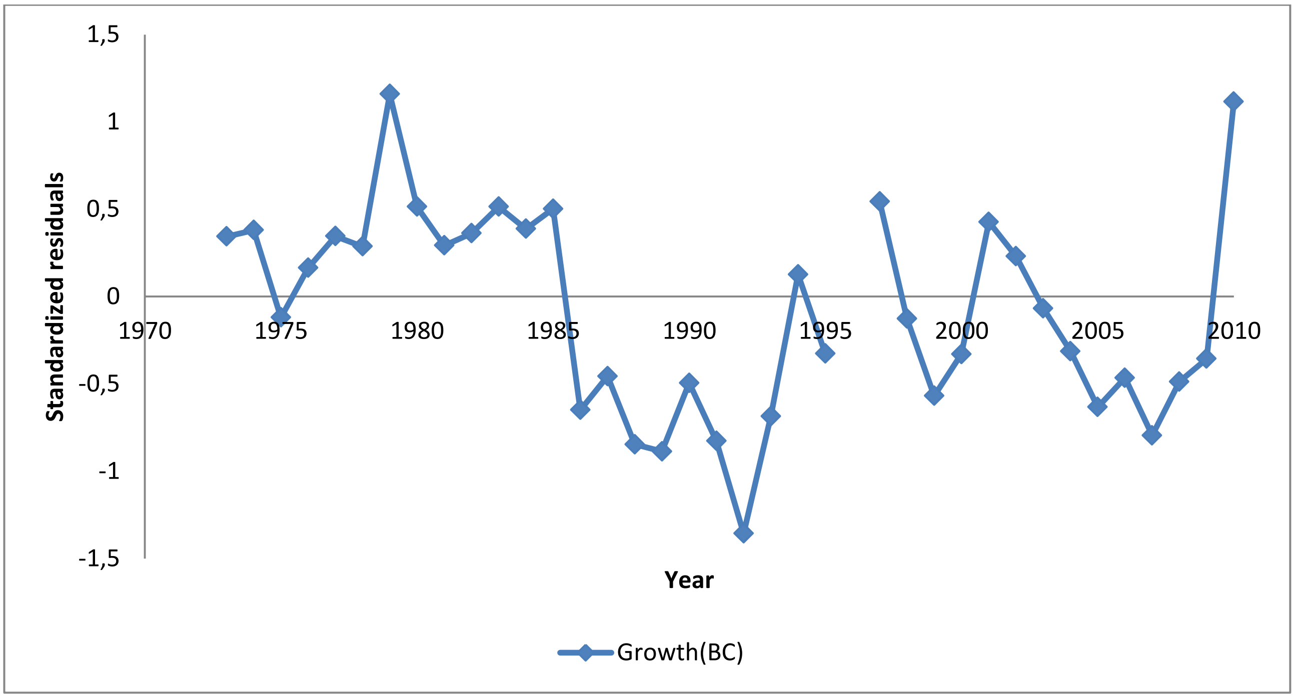


Figure 11. Endochronology. Yearly mean values of standardized growth residuals were used to create a chronology which makes use of all 5 growth years.

CLIMATIC FACTORS

Water temperature during the study period fluctuated (Fig. 4), with fairly high temperatures in the late 1970's before a drop in temperature in the early 1980's when the average temperature dropped from 2.35°C to 1.60°C. This low temperature regime lasted until the mid-1990s, at which point temperature again increased rapidly as average temperature went from 1.5°C to 3.0°C. STARS regime shift analysis identified two distinct periods, a cold period from 1980-1996 with an average temperature of 1.15°C and a warm period from 1997-2008 with an average temperature of 2.4°C. The rise in water temperature during the 1990's took place shortly after the fishery collapse (Fig. 4), making a potential growth response to higher temperature afterwards even more interesting.

Both the NAO and the AO have a relatively low index in the beginning of the study period (1975-1988), followed by a high index phase in middle of the study period before finishing off with a low index. This pattern of the NAO and the AO is the opposite of the temperature variations during this period. Both yearly NAO and DJF NAO was significantly negatively correlated with temperature (Pearson correlation, NAO yearly, $r=0.38$, $df=32$, $P=0.028$; NAO DJF, $r=0.50$, $df=32$, $P=0.003$). The AO was not correlated with temperature. The SG variability consist of strong and weak modes, both are represented during the period from 1976-2008 (Fig. 6). The SG was significantly negatively correlated with temperature (Pearson correlation, $r=0.61$, $df=32$, $P<0.001$), meaning that high gyre index results in cold water temperature for the region. The AMO shows an increasing trend during the period from 1976-2010 (Fig. 7), corresponding to the general increase in ocean temperatures as it is based on sea surface temperatures in the North Atlantic. The AMO was significantly positively correlated with temperature (Pearson correlation, r=0.54, df=32, P=0.001).

CORRELATIONS BETWEEN CLIMATE AND COD GROWTH

There was no correlation between the endochronology and temperature (table 2). However, there was a significant positive relationship between the endochronology and temperature during the cold period (1980-1995), but no correlation between the endochronology and temperature during the warm period (1997-2008)(table 2). If the growth rates at individual ages were considered separately there was a tendency for the relationship to be stronger at the youngest ages especially in the two first years of growth although still insignificant (Fig. 13). However, the general tendency was a declining impact of temperature on growth rate with age, as is illustrated in figure 13.

Table 2. Correlations between the endochronology and climatic factors. The cold period is 1980-1995 and the warm period 1997-2008. *=significant correlation. Temperature growth period refers to temperature date from May-June-July-August, whereas year refers to yearly average.

	Temperature (growth period)	**Temperature (year)**	**AO**	**NAO (year)**	**NAO (DJF)**	**AMO**	**GYRE**
Endochron.							
Pearson correlation	0.240	0.275	-0.666	-0.513	-0.545	-0.053	-0.132
P-value	0.186	0.122	0.000*	0.002*	0.001*	0.765	0.472
N	32	33	33	34	34	34	32
Endochron. Cold period							
Pearson correlation	0.525	0.449	-0.854	-0.342	-0.271	0.063	-0.512
P-value	0.044*	0.081	0.000*	0.195	0.310	0.818	0.043*
N	15	16	15	16	16	16	16
Endochron. Warm period							
Pearson correlation	0.134	0.218	-0.359	-0.523	-0.552	-0.343	0.044
P-value	0.678	0.497	0.252	0.081	0.063	0.276	0.893
N	12	12	12	12	12	12	12

The endochronology was significantly negatively correlated with both the NAO and the AO (table 2), meaning that when NAO and AO indexes were at a high level, growth rate of cod was at a low level and vice versa. There was no significant correlation between the endochronology and the SG or the AMO (table 2). The relationship between the endochronology and the AMO and the SG was also negative although not as strong. However, a significant negative relationship was found between the SG and the endochronology during the cold period (1980-1995)(table 2), indicating that high gyre index had an impact on growth when temperatures were low.

In respect to individual growth years, growth rates in all growth years were strongly correlated with the AO, as it significantly affected all five growth years (Fig. 13). This indicates that growth rate in all five growth years were affected by climate. There was a significant correlation to the NAO for growth year 2 and 4, with a tendency for growth year 1 and 3 (Fig. 13). These correlations between AO, NAO and growth rates were all negative just as for the endochronology, however, the relationship between AO and growth rate in the fifth growth year was positive (Fig. 13). Correlations with the different age groups are illustrated in figure 13, were the tendency for the NAO and the SG is a declining impact with age. Whereas impact on age groups seem fairly stable in regards to the AO and an increased impact with age is observed for the AMO.

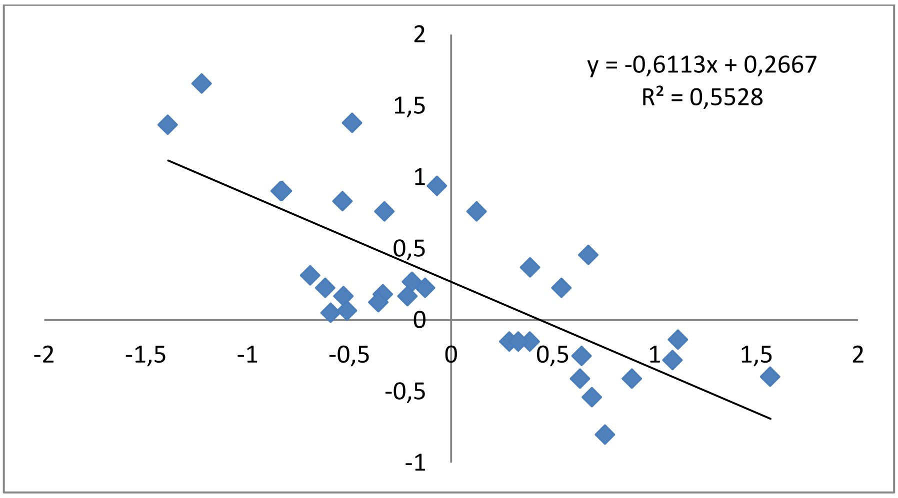
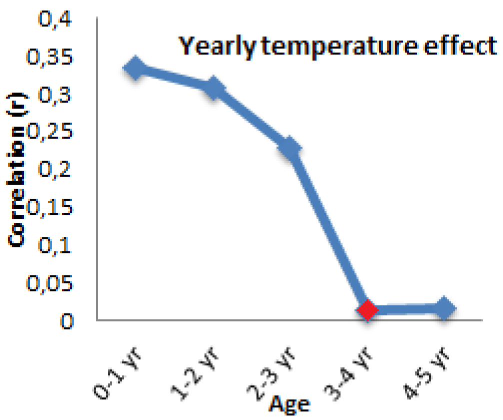
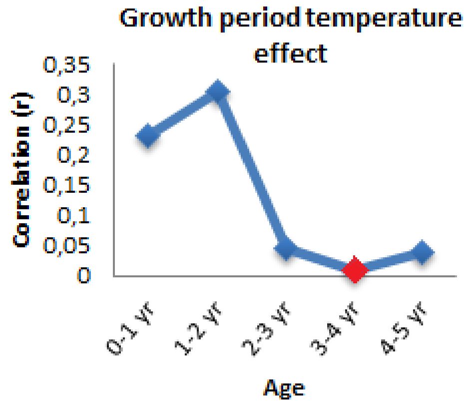
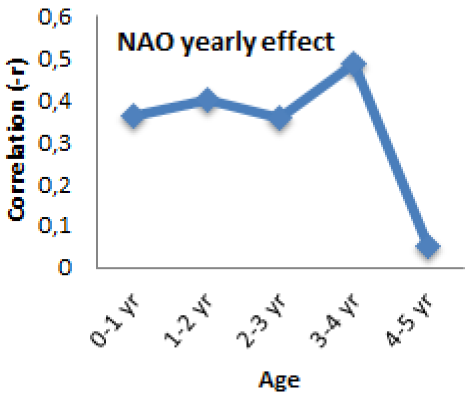
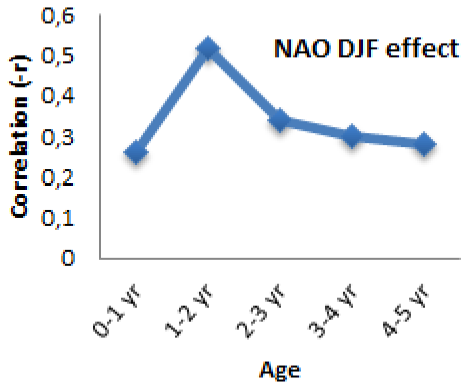


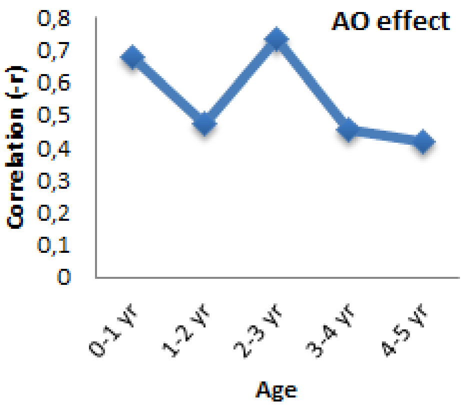
Figure 12. The relationship between the endochronology and the AO is strongly negative as illustrated by this scatter plot.

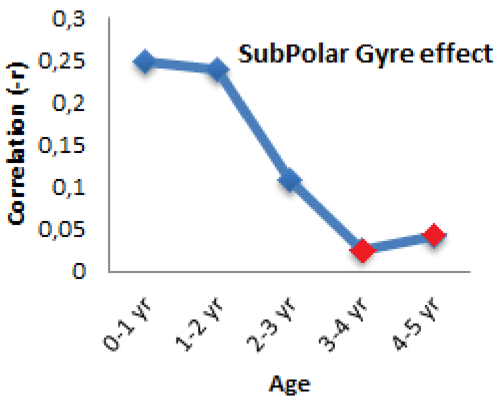












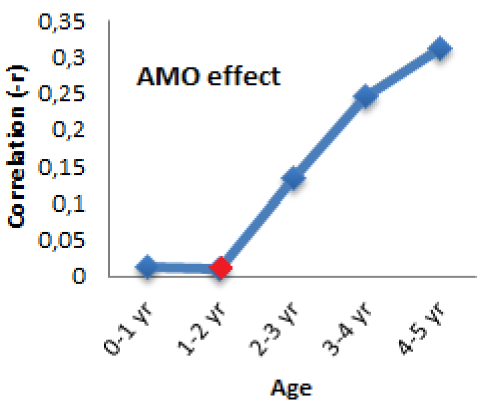


Figure 13: Pearson r values of the correlations between climate factors and growth of the different age groups. Significance at the 5% level is found at r = 0.38 and the 1% level is found at r = 0.48 (with df=25). An x-axis with –r indicates negative correlation. Red markings indicate opposite correlation of y-axis.

DISCUSSION

It has been hypothesized that the different life stages fish go through might be affected differently by climate, with the early life stages being more sensitive (Rijnsdorp et al. 2009). In this study there was no significant correlation between the overall growth pattern and temperature in any growth year, however, the correlation was positive during the first three growth years suggesting a positive impact of temperature on growth rate of young cod. The same result has been found for other growth chronologies on cod caught further south in West Greenland waters (64° N), were a positive relationship was likewise established between temperature and in this case growth rate between age 4-5 (Goncalves 2008, unpublished data). This suggests that cod near its northern geographical limits benefits positively from increasing temperatures. The positive relationship between growth and temperature disappears with age and in growth periods 3-4 and 4-5 the value is very close to zero. In line with the literature (Pörtner and Farrel 2008), these trends indicate that early life stages are more directly susceptible to environmental fluctuations. Ottersen et al. 2006 showed a stronger correlation between recruitment and sea temperature as the age-composition of the spawning component shifted towards younger ages. This illustrates what the effect of shifting temperature might be, if the fishery at the same time is at a level that could alter population demography. This is especially relevant in an area were the fishery is considered intense, and possibly concentrated on a local stock (Therkildsen et al. 2012).

The endochronology revealed a positive correlation between growth and temperature for the cold period, but no correlation for the warm period. It should be noted that as the endochronology makes use of all five growth years as standardized residuals, it might be the early growth years pulling the correlation. This positive relationship between growth and temperature for Atlantic cod is in accordance with other studies (Jørgensen 1992; Brander 1995) and was expected for cod at its northern distribution (Drinkwater 2005). This relationship suggests that cod at its northern distribution would be vulnerable to a drop in temperature. As ocean temperatures fluctuate (Figure 1), years with low temperatures will negatively affect growth rates in cod at this location. The lack of correlation between growth and temperature in the warm period becomes increasingly interesting as it takes place after the fishery collapse of the early 90s. Fishing is an extremely selective process, targeting larger individuals as these are more vulnerable to most fishing gears and represent greater value. Thus fishing introduces size modification to stocks of the targeted species (Shin et al. 2005; Swain et al. 2007). This size selection potentially removes fast-growing individuals while leaving behind slow-growing individuals (Conover & Munch 2002; Sinclair et al. 2002). Indeed fishing can apply selection pressure which causes evolution of phenotypic traits, such as length and weight (Law 2000; Swain et al. 2007). It is possible that size-selection in West Greenland waters during high fishing pressures has favored slow-growing cod, which then has been left behind to repopulate the stocks. This might partly explain the lack of correlation between growth and temperature during the warm period. However, many factors are obviously in play which can affect growth. A change in genetic composition in relation to growth is not proven in this case and therefore remains speculative.

Cod should increase its growth rate at the northern boundary of distribution with an increase in temperature (Pörtner et al. 2001; Drinkwater 2005). However, it is known that this not necessarily the case if food is limited, indeed growth can decline with increasing temperature if food is limited (Sinclair et al. 2002). The endochronology was not correlated to temperature in the warm period. One possible explanation for this could be the fact that growth only increases with temperature if adequate amount and quality of food is available (Sinclair et al. 2002). Quality of food refers to the "junk food" hypothesis, with prey of high energy content being replaced by prey of low energy content (Rosen & Trites 2000). Capelin (*Mallotus villosus*) represents high quality food with high energy content (Hedeholm et al. 2011) and is an important prey to Atlantic cod as it is too many marine animals in West Greenland (Fris-Rødel & Kanneworff 2002). Capelin is distributed along the coast of West Greenland from Upernavik to Cape Farewell, but with varying distribution inter-annually. Capelin landings have gone down since the late 1980's in West Greenland, but it should be noted that no reliable stock estimate has been made (Fris-Rødel & Kanneworff 2002). If capelin should make out a smaller portion of cod diet than previously, that could decrease the energy intake of the cod. Dwyer et al. (2010) showed that Greenland halibut (*Reinhardtius hippoglossoides*) could function as an ecosystem tracker through its diet, in the Northwest Atlantic. In their investigation of stomach content from 1978 to 2003, they discovered a change in diet from being dominated by capelin up until the early 1990s, to being dominated by shrimp (*Pandalus borealis*) and Cephalopoda since. It is known that biomass of shrimp have increased substantially in West Greenland since the mid-1990's (Wieland 2005). There is no stock data on capelin in NAFO area 1B or investigations of changes in cod diet, therefore the "junk food" hypothesis in this case remains an hypothesis. However, it is possible that lack of high quality food and a selection of slow-growing cod due to high fishing pressure are responsible for the lack of growth rate response with increasing temperature in this area.

Climatic effects on Atlantic cod stocks have been examined numerous times. Often the effects of climate have been investigated in relation to recruitment, using the NAO as a measure for climate variability (Ottersen & stenseth 2001; Pörtner et al. 2001; Stige et al. 2006). The NAO has through such studies been shown to be a strong climatic factor in the North Atlantic. In this study we achieved significant negative correlation between growth rate and yearly NAO for growth year 2 and 4, while there was significant negative correlation between growth rate and winter NAO for growth year 2 (Fig. 13). Further there was a correlation with the endochronology for both yearly and winter NAO (Table 2). This suggests that climate variability's measured by the NAO does affect cod stocks as northerly as Sisimiut, 68°N. However, even stronger negative correlation was discovered between growth rates and the AO, this correlation was significant for all five growth years (Fig. 13) and the endochronology (Table 2). This makes sense as the NAO and the AO are closely related (Cohen & Barlow 2005), with the NAO being measurable by sea level air pressure variations between Iceland and the Azores (Hamilton et al. 2003; Born & Mignot 2011), while the AO is pressure variations over the Arctic (Thompson & Wallace 1998). It therefore stands to reason that cod stocks at such northerly distribution as Sisimiut would be more affected by the AO than the NAO. It has been hypothesized the climate variability such as the NAO doesn't affect all cod stocks uniformly, and it has been shown that recruitment in Atlantic cod respond differently to the NAO depending on geographic location (Brander & Mohn 2004). In this study area relations ship between both NAO and AO to growth rate was negative. This corresponds well with the positive relationship established between temperature and growth, as both high NAO and AO index results in cold climate over the arctic region (Hodges 2000; Stenseth et al. 2004). However, it is important to keep in mind that these oscillations affect factors beyond temperature, such as wind speed, precipitation and sea ice cover (Dickson et al 1996; Hurrel & Deser 2009). The results in this study demonstrate a clear link between climate, measured by the AO, and growth rates in Atlantic cod, but the underlying factors are not clear.

No significant correlation was found between the SG and any of the five growth years. However, just as with the temperature data, the correlation weakened with age although the correlations weren't as strong as for the temperature correlations. The SG did achieve significant correlation with the endochronology for the cold period, but as for temperature, the correlation disappeared in the warm period. Based on these results the SG does not seem to affect the northern cod stocks in same magnitude as the AO or the NAO. However, it cannot be dismissed that these waters are influenced by the SG to some degree.

SUMMARY AND CONCLUSION

A positive, though not significant, relationship was established between growth and temperature during the study period from 1973-2010. This was expected for cod living near the lower temperature range of its distribution. This relationship means that the growth rate of cod will fluctuate as temperature fluctuates, with periods of low temperatures having a negative impact on growth rate. Further, a declining strength in the correlation with age was revealed, meaning that early life stages of cod are more affected by variations in temperature. This could have an impact on recruitment of cod, with periods of high temperatures leading to higher recruitment, as faster growth rates would mean less time spent in the vulnerable early life stages. This also means that periods of low temperatures could have a negative effect on recruitment in this area.

When temperature data was tested against the endochronology, a positive but not significant relationship was established again. Results became increasingly interesting when within the endochronology two temperature regimes were identified, a cold period from 1980-1995 and a warm period from 1997-2008. Correlation between temperature and the endochronology was much stronger and also significant during the cold period, whereas correlation became very weak and insignificant in the warm period (Table 2). The identified warm period follows the fishery collapse of the early 1990s, raising questions of why the correlation between growth rate and temperature disappeared from the cold period to the warm period. Reasons for this are not clear. However, it is hypothesized that selection of slow-growing cod during high fishing pressures, and possibly a change in diet could be responsible.

Growth rate in Atlantic cod living at these northern latitudes is shown to be strongly affected by climate (AO). Although a clear link between growth rate and the AO is demonstrated, the underlying factors are not clear. Further studies on this subject should aim at identifying the role of the underlying factors, to increase the knowledge of how climate affects growth rate in cod near its northern range of distribution.

The results presented here provide information useful for fishery management, as stronger correlation between temperature and growth rate for young cod has implications regarding recruitment. The disappearance of significant correlation between temperature and growth rate from the cold period to the warm period suggest that cod stocks needs sufficient time to recover following a fishery collapse. The strongest correlation to growth rate in this study was with the AO, which means that variations in this climate variable probably should be taken into account when planning fishery management for this region of cod distribution.

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