UNIVERSITY OF TROMSØ UIT

NORWEGIAN COLLEGE OF FISHERIES SCIENCE

Population dynamics of cod, *Gadus morhua*, in Porsangerfjord, Northern Norway

- Analysis of back-calculated length at age from otoliths in 1992 and 2009



Trine Holm Larsen

Master's Degree Thesis in Fisheries Science
Field of Study - Fisheries Biology
(60 credits)

August 2010

This thesis is a part of **EPIGRAPH**, a project initiated by the Institute of Marine Research (IMR, Havforskningsinstituttet). EPIGRAPH is an acronym for “**E**cological **P**rocesses and **I**mpacts **G**overning the **R**esilience and **A**lternations in the **P**orsangerfjord and the **H**ardangerfjord”

Photo/Illustrations:

Front page: Trine Holm Larsen. Left/right: otolith photographed from both sides. Middle: cross-cut otolith (25x magnified) in a stereomicroscope.

Other photos/illustrations: Trine Holm Larsen, if not credited anyone else.

ACKNOWLEDGEMENTS

Tromsø, August 16th 2010

YES!

First of all, I would like to thank my supervisors for guidance and reading and commenting through the thesis:

Prof. Torstein Pedersen

Faculty of Biosciences, Fisheries and Economics (BFE), Institute of Arctic and Marine Biology, University of Tromsø

Scientist Ulf Lindstrøm

Institute of Marine Research/Havforskningsinstituttet, Tromsø

Scientist Knut Sunnanå

Institute of Marine Research/Havforskningsinstituttet, Tromsø

A special thanks to Torstein for help with the statistical challenges, both with statistics in itself, and how to use MYSTAT to obtain figures, and I appreciate all the hairsplitting comments.

Thanks to Institute of Marine Research (Havforskningsinstituttet): Ivan Ahlqvist for support with collected data from 2009 cruises in Porsangerfjord. Per Ågotnes for age reading otoliths, and education in age reading of otoliths. Ole Thomas Albert and Frank Beuchel - tip of and help with installation of ImageJ. Thanks to everyone at R/V Johan Ruud on cruises in February, May and September 2009. Thanks to the technical department at BFE for making one extra modified U-shaped metal block for otolith cutting, and thanks to Rahman Mankettikkara and Hans Christian Eilertsen (BFE, Institute of Arctic and Marine Biology, University of Tromsø), for providing temperature data from Porsangerfjord. Thanks to Keith Brander (Danish Institute of Aquatic Resources Technical University of Denmark), for providing articles impossible to obtain on the Internet. I'll give my thanks to the librarians at the University Library in Tromsø for great service. Thanks to Hans Martin Sollien (Pibo Optik, Synsam) for fixing the stereomicroscope. I am grateful to all who have proofread and commented on the manuscript: Bjørn Tore Dragnes, Hilde S. Heitmann, Inger-Britt Falk-Petersen, Malcolm Jobling, Petter Holm and Sibylle Liso. Thanks to Leif Villinger for the drawing. My sincere gratitude to Helén Perzon for all her support.

R/V Johan Ruud in Honningsvåg, Porsangerfjord

PROLOGUE

A local historic homage to the «ancestors» of otoliths, the stockfish

By courtesy of Kine Hellebust

Tørrfesken si utvikling på rytme og rim

av Kine Hellebust

Fesk ved fesk ved fesk ved fesk
heng og heng og heng og heng
på hjell ved hjell ved hjell ved hjell
heng fesk ved fesk så tørr så tørr

For tørrfesk er ikkje den fesken som svøm,
den her han er open i buken.
Open i buken med smak som ein drøm,
smak som ein drøm i buken.

Den kjem ifrå havet skridande -
så våt og så glatt - glidande
frå snute til gatt - skridande.
Den gyter i havet - glidande -
milliardar av egg - stridande.
Og dei veit ikkje kor dei vil ende…

Torskeegg langs Lofotvegg.
Torskeegg får hakeskjegg og svøm,
og svøm. Dei svøm og svøm…
- Men dei veit ikkje kor dei vil ende!

Ei planktonreka så lita som så,
er livretten til desse torskeegg små
- skridande - glidanes…
Og dei anar` kje kor det vil ende!

I vintrar så mild med ein tre fire grader,
vi sløyer, skjer tunger, og hiv han på hjell.
Vi bind han i sporden, og heng han i rader,
litt vind og litt sol… Han blir heilt spesiell.

På hjellan der heng han om lag eit kvartal.
Då skrumpe den skrotten og blir minimal.
I alle de år har tørrfesken gjedd
oss rikdom, der han hang på geledd.

Og var det eit år utan klingande mynt,
så var han eit måltid - ja, meir enn til pynt!
Han smakte og ga oss den sunnaste mat.
Vi åt han begjærlig frå alle slags fat!

Men no er han klår til å yppe til strid,
og utfordre alle slags måltid:
For vi kan ha han i salatar,
med olje og oliven…
Litt grovsalt utpå kniven -
Det her blir optimalt!

Til pasta og purréar, og tørrfeskfrikasséar!
I stuing med litt fløte - mmm…
vi går eit praktfullt mål i møte!

Tørrfesk er meir enn det magre du ser!
Han æse i vatn - eit under som skjer!
Så nyt berre du, før du svelgje han ned,
og kjenn at han gir deg ein lysteleg fred!

For tørrfesken han er den ekte og reine -
Han blir snart den einaste eine!

CONTENT

ABSTRACT

The thesis investigates growth of Atlantic cod (*Gadus morhua*) caught in 1992 and 2009, in Porsangerfjord North-Norway, with use of back-calculated length at age based on cod otoliths. The cod population in Porsangerfjord ecosystem have experienced major changes in abundance during the last decades: a dramatic decline in the costal cod population, and environmental influences.

A back-calculation method estimating length at previous age was done on cod otoliths. The otoliths were embedded in black resin and transversely cut before photographed in a stereomicroscope. Growth zones in otoliths were measured and growth was back-calculated for previous length at age.

In the outer areas (A - B) adult cod, above 5 years of age, were longer at age in the second time period (1998 - 2009) than cod from the first time period (1980 - 1992). Adult cod grew faster in outer areas than in inner areas (C - D) in 1992. In outer area cod had better growth for 1 year old, and 5 - 7 year old, than in inner area (C) in 2009.

In conclusion, increasing sea temperature seem to play maybe the most important role in increased mean length at age for adult cod, above 5 years of age, caught in 2009, compared to cod caught in 1992. In addition, a shift from abundance of cod in inner areas with cold sea temperature in 1992, towards outer warmer areas in 2009 has probably also contributed to increased length at age for older cod.

KEYWORDS:

coastal cod,
back-calculating length at age,
otolith,
distribution,
Porsangerfjord

ABBREVIATIONS:

BFE	Faculty of Biosciences, Fisheries and Economics
CC	Coastal Cod
ICES	International Council for the Exploration of the Sea
IMR	Institute of Marine Research (Havforskningsinst.)
NEAC	North East Arctic Cod (or «skrei» in Norwegian)
uCC	uncertain Coastal Cod
uNEAC	uncertain North East Arctic Cod
UiT	University of Tromsø

1 INTRODUCTION

1.1 BACKGROUND

In the North Atlantic Ocean, Atlantic cod (*Gadus morhua*) probably has been a major top-predator on the continental shelves for centuries. The largest population, at present, is the North East Arctic Cod (NEAC) in the Barents Sea (Stransky et al., 2008). Over the last decades, most Atlantic cod populations, particularly in Canadian waters, have declined in size (Trippel, 1998; Christensen et al., 2003). Cod fisheries in most areas of the Canadian shelf has been restricted since the beginning of the 1990s (Brander, 2007). Overfishing is often regarded as the major cause of cod stocks decline (Hutchings, 2000; Worm and Myers, 2003), but questions arises concerning environmental effects and climatic fluctuations on the process (Ottersen et al., 2006; Brander, 2007). Since 1970, 14 of 15 stocks analysed by Brander (2007), have faced a decline, including the NEAC stock, but the decline in NEAC is much smaller than in the Canadian cod stocks.

1.1.1 Cod in Norway

In Norwegian waters north of ca 62°N there are two types of Atlantic cod, the migrating NEAC («skrei» in Norwegian) and the more stationary Norwegian coastal cod (Rollefsen, 1933; Svåsand et al., 2000; Pedersen et al., 2008a). The coastal cod (CC) populations north of 62°N have declined dramatically the past 20 years (Fig. 1). In contrast, the NEAC stock is in good shape due to sustainable fishery (Gjøsæter et al., 2010). The International Council for the Exploration of the Sea (ICES) has evaluated three populations of cod in Norwegian waters to have reduced reproductive ability with high risk of population collapse (Agnalt et al., 2009). Coastal cod north of 62°N (endangered), coastal cod in Skagerrak (near threatened) and North Sea cod (near threatened) are on the Red List of Threatened Species (ibid).

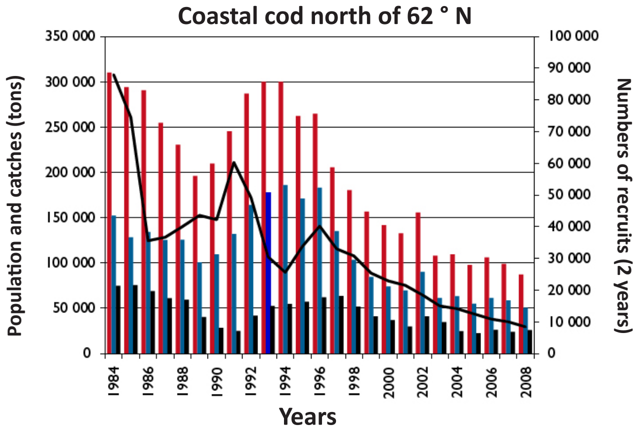


Figure 1. Coastal cod biomass (red), spawning biomass (dark blue), catch biomass (black) and number of recruits (black line), in the period 1984-2008. Figure taken from www.imr.no (Gjøsæter et al., 2010, page 153).

NEAC is one of the most important commercial fish stocks in the world (Vinje et al., 2003). Cod in high latitudes marine coastal ecosystem, especially in fjords, are regarded as one of the main top predators (Kanapathippillai et al., 1994). It is a generalist, exploiting both benthic and pelagic prey, but feeds mostly on fish as adult (Svåsand et al., 2000; Pethon, 2005). The diet varies much both in time and space among cod stocks. In the north of Norway, herring (*Clupea harengus*) and capelin (*Mallotus villosus*) are important prey for cod in the fjords (Kanapathippillai et al. 1994; Svåsand et al., 2000).

Adult NEAC migrate long distances from feeding area in the Barents Sea, to spawning areas along the Norwegian coast (Vinje et al., 2003; Otterå et al., 2006). Important spawning grounds are off the Møre coast, Lofoten and areas between Lofoten and Sørøy, Finnmark (Bergstad et al., 1987). Coastal cod reaches maturity at 3 - 6 years of age, spawns in the innermost parts of large fjords along the coast, and also in the same areas as the NEAC. In contrast to NEAC, the juveniles of CC settle at the bottom in shallow waters and stay in shallow areas until about two years of age (Løken et al., 1994; Berg and Pedersen, 2001; Pedersen and Pope, 2003a). In general, cod may reach 180 cm in length, whereas coastal cod above 80 cm are rare (Pethon, 2005). Cod can weigh as much as 55.6 kg and can reach 40 years of age (Pethon, 2005). Due to fishing, cod older than 15 years of age are rare (Gjøsæter et al., 2010). Adult NEAC spend most of their time in the Barents Sea, close to the polar front feeding during summer and autumn (Ottersen et al., 1998). CC live their whole life in more limited areas, such as the fjords. Egg and larvae of NEAC drift north along the Norwegian coast from the most important spawning areas in Lofoten and Vesterålen (Gjøsæter et al., 2010). In recent years (2000s) NEAC have reached maturity at mean age of about 6 - 7 years, in contrast to a mean age of 10.5 in the 1930s (Pedersen et al., 2009).

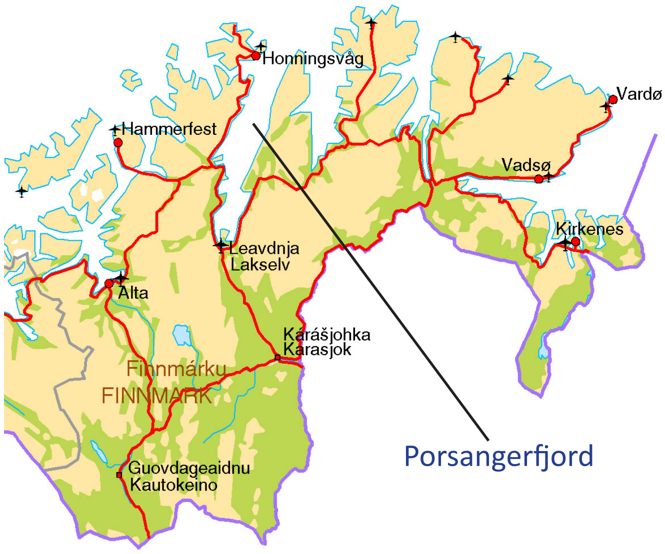


Figure 2. Map over Finnmark county with Porsangerfjord and adjacent areas (www.statkart.no, 2010.)

1.1.2 Cod in Porsangerfjorden

In Porsangerfjord (Fig. 2), situated in Finnmark (Norways northernmost county), the biomass of cod has declined dramatically in the past decades (Agnalt et al., 2009). The ecosystem in the fjord has undergone major changes in the last 40 - 50 years (ibid). Since the 1970 - 1980s large numbers of sea urchins (*Strongylocentrotus droebachiensis*) have grazed heavily on the kelp forest (*Laminaria hyperborea*) along the Norwegian coast, from Nordmøre and north across the Russian border (Sivertsen, 2006; Norderhaug and Christie, 2009). In Porsangerfjord, sea urchins have depleted large areas of kelp forests to barren grounds (Agnalt et al., 2009). Kelp forests are assumed to be important shelter and nursery habitat for young cod (Norderhaug and Christie, 2009).

According to Agnalt et al. (2009) the decline in the cod population in Porsangerfjord probably happened due to several factors e.g. more efficient fishing and the collapse in the Norwegian spring- spawning herring at the end of the 1960s.

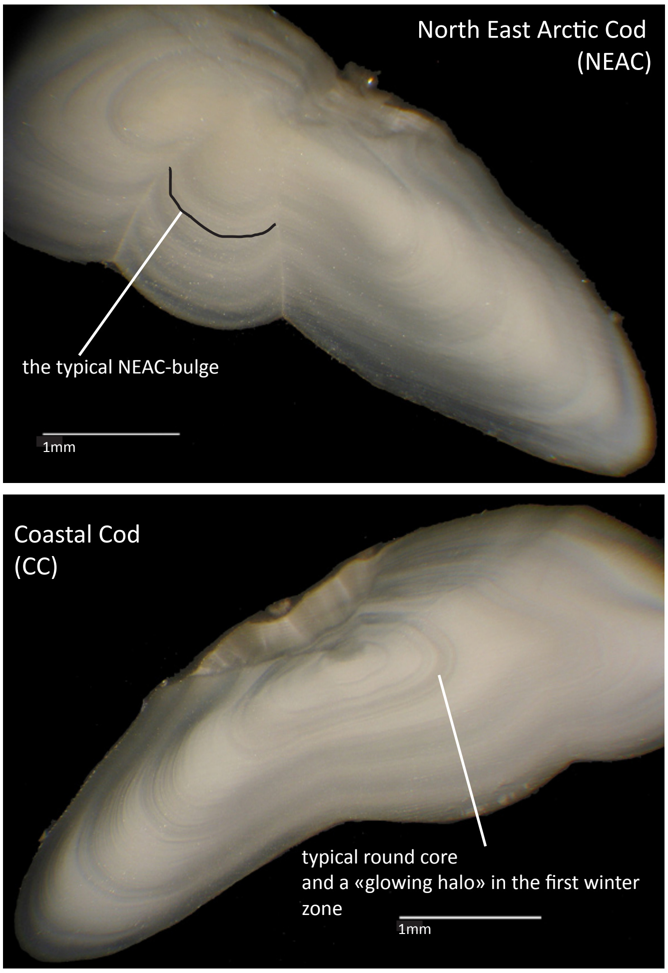


Figure 3. Photos of differences in otolith structure for NEAC (top) and CC (bottom). White bars represents 1mm of original otolith size. Both 4 years of age.

The situation worsened after a cold period with the collapse of the capelin population and massive harp seal (*Pagophilus groenlandicus*) invasions in 1986-1988. The cod population in Porsangerfjord has not yet recovered (ibid). Porsangerfjord serves as spawning ground for capelin. It is also a nursery area for the Norwegian spring- spawning herring (0 - 3 years) and North East Arctic cod (1 - 3 years). Further, northern shrimp (*Pandalus borealis*) are widespread in the fjord (Gjøsæter et al., 2010). Small colonies of grey seals (*Halichoerus grypus*) and common seals (*Phoca vitulina*) are also present in the fjord (Agnalt et al., 2009). Common seals are assumed to feed in the inner parts of the fjord, whereas grey seals use the outer part of the fjord (ibid).

1.2 OTOLITHS

Age and length at age of individual fish are important information for fishery science to estimate and predict population dynamics. The early method used to determine age of fish was to analyse fish scales, but from 1932 age-reading from otoliths was shown to be a better method (Rollefsen, 1933). Otoliths are calcareous structures and part of the hearing and balance systems (Álvarez et al., 2008). Otoliths are formed prior to hatching and grow parallel to the fish somatic growth (Fuiman and Werner, 2002). Most fish have three pairs of otoliths, and the biggest ones (sagitta) are often used for age determination (Álvarez et al., 2008). Otoliths are composed of calcium carbonate, aragonite and a protein: otolin (ibid).

1.2.1 Age determination

Two different zones can be distinguished in the cod otoliths from northern waters: one opaque (summer) and one hyaline (winter). When reading otoliths these two zones make up one year. The zones are made up of alternating layers of calcium carbonate and protein (Álvarez et al., 2008).

1.3 GROWTH AND USE OF OTOLITHS

Fish grow throughout their whole life and it is assumed that they have indefinite growth (Fuiman and Werner, 2002). Since growth may vary between years, seasons and year classes, growth phases will be reflected in the otolith pattern. The width of zones reflects somatic growth. Major transitions in life may be detected in the otolith e. g. hatching marks and metamorphosis in larval otoliths, and spawning zones in adult fish otoliths (ibid). For cod in the North Atlantic the hyaline winter zones in the otolith start forming in October-November (dark months of the year) and the opaque summer zones start forming in April-May when it is much light (Høie et al., 2009). The opaque zone is usually broader since it reflects the good feeding conditions and extensive growth during summer, while the winter zone is narrow due to less growth (Pedersen et al., 2009). The zone pattern may be reversed in other areas (Høie et al., 2009). The shape of an otolith is very species specific (Álvarez et al., 2008).

1.3.1 Cod types

As early as the 1930s Rollefsen (1933) discovered that the structure of the two first zones (growth zones) of the otolith had a different visual expression for cod living mainly along the coast and in the fjords, compared to cod living in the Barents Sea (Fig. 3). Otoliths from coastal cod differed in external form, relative width of the zones and structure in the otolith compared to the Barents Sea cod (Rollefsen 1933, 1934). This led to the classification of two main types of cod: costal cod (CC) and North East Arctic Cod (NEAC) which both are found in the North East Atlantic (Berg and Albert, 2003).

The first hyaline zone in NEAC otoliths is elongated and often has a bulge on one side (Fig. 3). In contrast, the first hyaline zone in CC otoliths is oval and often shines like a «halo» (Stransky et

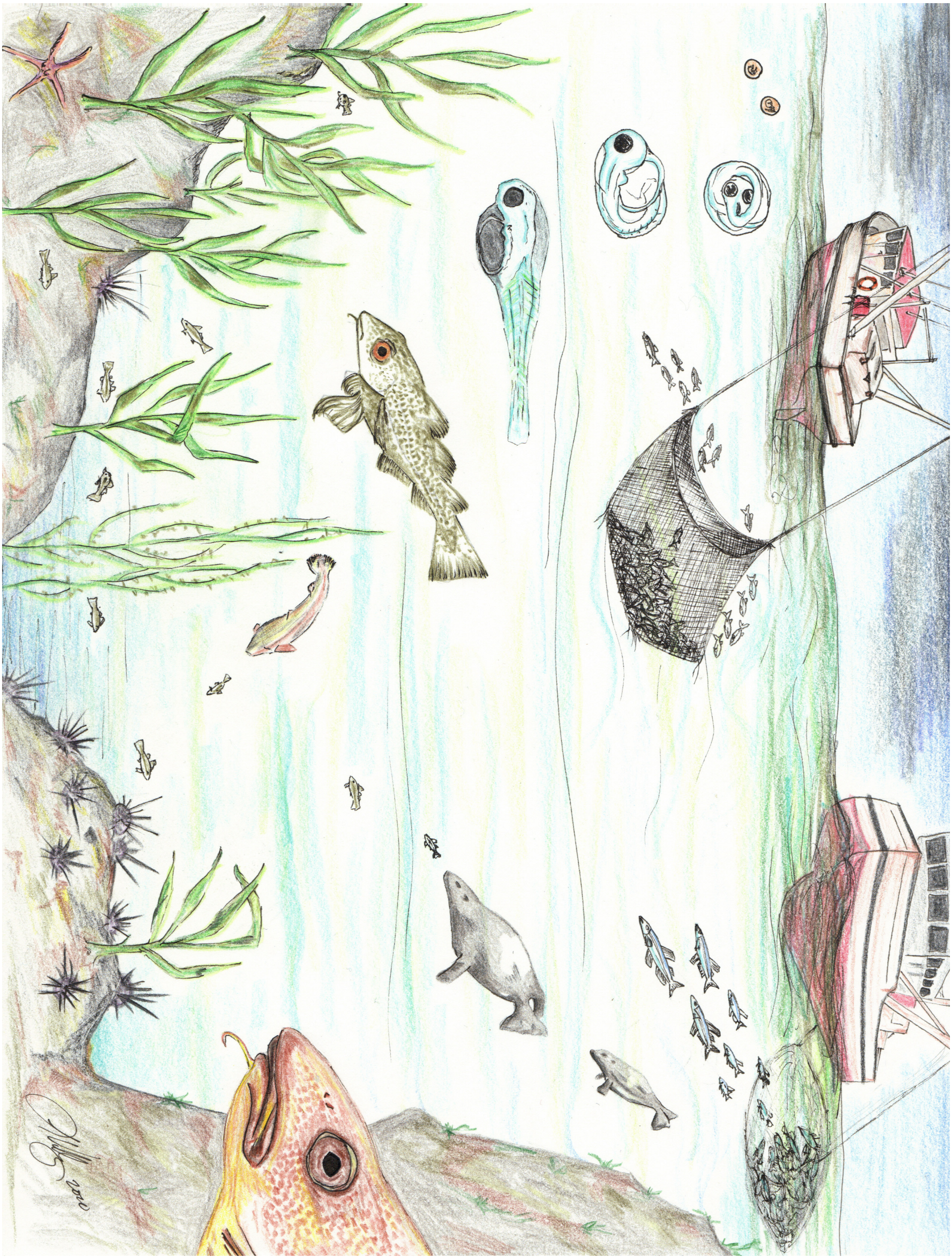


*Figure 4. A part of Porsangerfjord cod-ecosystem with main factors influencing the life of cod (*Gadus morhua*) the past decades, such as invasion of harp seals, fishing, heavily grazing on kelp forests (*Laminaria hyperborea*) from sea urchins (*Strongylocentrotus droebachiensis*), fishing and the fluctuating population of capelin (*Mallotus villosus*). In addition climate changes and temperature are important factors in the ecosystem. Drawing made by Leif Villinger for this thesis.*

al., 2008), and the second opaque zone are large compared to that of NEAC (Fig. 3). Offspring from CC and NEAC, experiencing similar conditions after hatching, do not show this difference in the otolith structure (Agnalt et al., 2009). The differences in otolith structure in CC and NEAC might indicate that the pattern in the otolith can act as a marker for body growth, and also indicate which environment young cod spend their first two years. This difference in otolith patterns appears to be consistent with results from genetic DNA analysis of cod (Berg and Albert, 2003).

1.3.2 Factors influencing growth

Several field studies and laboratory experiments have shown that temperature plays an important role for growth in fish (Jørgensen, 1992; Brander, 1995; Michalsen et al., 1998; Godø and Haug, 1999; Ottersen and Loeng, 2000; Sundby, 2000; Neat et al., 2008). For marine fish larvae, an important factor for good growth is temperature in combination with food availability and body size (Otterlei et al., 1999). Rapid growth is important, especially in the vulnerable larval stages, to reduce the risk of mortality (ibid). Growth is food dependent and growth rates of fish are density-dependent (Godø and Haug, 1999; Stige et al., 2006). In contrast to this view Brander (2007), suggest that density-dependent effects are of minor importance, and that density-dependent growth may occur if there are limited food resources, - but it is hard to prove.

1.4 OBJECTIVES AND APPROACH

To investigate if there has been changes in growth for cod in Porsangerfjord, in the light of the perceived alterations, otoliths from cod caught in 1992 and 2009 will be analysed for possible differences. For fish, length at age indicate individual growth per year.

Back-calculations of previous length at age for fish, with known length at capture, is a widely used method to estimate growth (e.g. Morita and Matsuishi, 2001; Li et al., 2008; Wilson et al., 2008). A proportional relationship between otolith growth and somatic growth is assumed (Morita and Matsuishi, 2001). This assumption is used in statistical models, called back-calculations, to calculate body length at previous age, prior to capture of fish. This method is useful for estimating individual fish growth and can be used to compare growth rates and fit growth curves (Li et al., 2008). The advantage of the back-calculation method is that, in contrast to an alternative approach, e. g. using relatively few tagged and recaptured fish, this method can be utilized on all individuals in a population (Li et al., 2008).

In Porsangerfjord, spatial differences in growth rate may be expected for cod between areas. Individuals experience different environmental conditions depending on for example age and age at maturity (Jakobsen, 1987). Growth patterns may differ between CC and NEAC (Berg and Pedersen, 2001; Berg and Albert, 2003). NEAC are highly migratory (Vinje et al., 2003), thus small differences between areas in growth pattern may be expected, whereas CC are more stationary and expected to reside in the fjord (Nøstvik and Pedersen, 1999; Pedersen et al., 2008a), this may result in spatial differences in growth rates between areas. Berg and Pedersen (2001) found that CC grew much faster in the outer warmer area than in the inner and colder areas of the Ullsfjord - Sørfjord system. Berg and Albert (2003) found similar differences for CC along the coast of north Norway; cod in colder water grow slower. The geographical distribution of the two types (CC, NEAC) may reveal insight into the causes of the perceived changes (Pedersen et al., 2009).

Due to the changes in Porsangerfjord ecosystem since ca 1980 (illustrated in Fig. 4) one may expect differences in growth patterns for fish caught in 1992 and 2009. A change in abundance is also expected as cod biomass has declined. Density-dependent growth may have occurred for cod caught in 1992, when more cod was present. Unfavourable nursery habitat for juveniles between the two sample years (lack of kelp), may lead to different growth pattern the first critical years (Fuiman and Werner, 2002). Fluctuations in food density may lead to changes in growth, both for young and adult cod, depending on environmental changes between the two sample years in, for example, temperature and predation.

Investigation of otolith pattern between year classes may reveal indications of environmental changes from year to year in Porsangerfjord. Environmental conditions like temperature, food availability and competition for prey, are regarded to have a major influence on the formation of growth increments in the otolith (Neat et al. 2008; Stransky et al., 2008). If environmental conditions change from year to year, it is expected that these differences would result in different otolith patterns depending on which environment cod experience from year to year. This may also induce different growth rates in different cohorts of cod (year classes).

Synchronisation in growth rates may be expected for age groups which stay in the same areas and/or experiences similar environmental conditions. Cod growth rates may differ depending on age, size and environmental conditions.

This thesis focus on the population dynamics of cod, especially growth of coastal cod (CC), in Porsangerfjord in the periods from 1980-1992 and 1998-2009. Otoliths from cod caught in Porsangerfjord were analysed and length at age was back-calculated to test specific hypotheses regarding spatial, temporal and year class and age effects on growth rates.

1.5 HYPOTHESES

To investigate possible differences in growth in the cod populations between areas, time-periods, year classes and age groups for CC and NEAC, the following null hypotheses were formulated and tested separately;

1. There is no spatial differences in growth patterns; back-calculated lengths at age of cod are equal in the inner part and outer part of Porsangerfjord.
2. There is no change in growth patterns between cod caught in 1992 and cod caught in 2009.
3. Growth patterns is equal for all year classes of cod.
4. There is no synchronisation of growth rates of various age groups.

2 MATERIALS AND METHODS

2.1 STUDY AREA

Porsangerfjord is 123 km long, 13-19 km wide and is Norway's fourth longest fjord (Fig. 5). In contrast to most Norwegian fjords, Porsangerfjord has no outer shallow sill. Mean depth in the outer part of the fjord ranges between 50 - 280 m, with a maximum of 310 m. There are some islands, Store Tamsøy being the biggest one. The inner part of the fjord is shallower with several islands. Austerbotn, a basin of 115 m depth in the south east of the fjord, consists of particularly cold water with elements of arctic fauna (Agnalt et al., 2009).

Porsangerfjord was divided in four areas: **A** (outer area), **B** (outer middle), **C** (inner middle) and **D** (inner area). An overview of all trawl hauls and the fjord areas is given in Fig. 5, and details of area and sampling depths in appendix. The same trawl stations were used both in 1992 and 2009, with some additional stations in 2009. Temperature stations marked **H** and **P** in Fig. 5 are from paper by Eilertsen and Skardhamar (2006) and refer to outer station Helnes (H, N 71°07.5; E 26°18.0, depth 205 m) and inner Porsanger (P, N 70°43.1 E; 25 °44.8, depth 210 m). In addition, temperature data (provided by Mankettikkara and Eilertsen, pers. com, UiT, BFE.) from two stations sampled in Porsangerfjord during 1980 - 2009 were used, both marked **T** in Fig. 5. They refer to outer area Porsangnes West (N 70°52.5; E 26°01.0, depth 150 m) and inner area Porsanger Inner West (N 70°21.0; E 25°14.9 depth 150 m). A bottom profile included in Fig. 5 shows the four areas roughly marked. From the bottom profile it is clear that the inner area (D) are by far the most shallow area (0 - 150 m), while the three others are quite similar and relatively deep (150 - 250 m).

2.2 SAMPLING OF COD

This thesis includes cod samples collected in Porsangerfjord in September 1992 (n = 282, 7 stations) and February (n = 94, 6 stations), May (n = 187, 8 stations) and August 2009 (n = 98, 7 stations). Research vessel R/V Johan Ruud was used to conduct surveys in Porsangerfjord both in 1992 and 2009 (Table 1). Age reading of otoliths from cod caught in 2009 was conducted by Institute of Marine Research (IMR).

Sagittal otoliths from 1992, including data on length at capture, age and type (CC or NEAC) collected by IMR was used in the study. At least one of the otoliths was broken due to previous age determination. Cod that were difficult to type were classified as uncertain CC or uncertain NEAC according to IMRs «Håndbok for prøvetaking av fisk og krepsdyr» (Mjanger et al., 2007). Included in the data files were information on date, depth, trawl speed, longitude, latitude, trawling equipment and trawling time. Otoliths from seven sta-

Table 1. Technical information of the bottom and pelagic trawl hauls in September 1992 and Feb., May and Aug. in 2009.

Trawl	1992	2009
Pelagic	**Harstad trawl**	**Harstad trawl**
Net size	10 fathoms	10 fathoms
Cod-end	8 mm net	8 mm net
Gear	-	buoys in Aug.
Distance	3.1 nm	3.1 nm
Speed	3.0 knots	3.0 knots
Bottom	**Campelen**	**Campelen**
Name	shrimp trawl	shrimp trawl
Meshes	1 400	1 400
Mesh size	35 mm	35 mm
Speed	1.8 - 2.7 knots	1.9 - 2.1 knots
Time	standard 30 min	standard 20 min
Distance	0.4 - 1.6 nm	0.6 - 0.7 nm
Depth	43 - 218 m	139 - 293 m
CTD	SeaBird SBE911+	SeaBird SBE911+

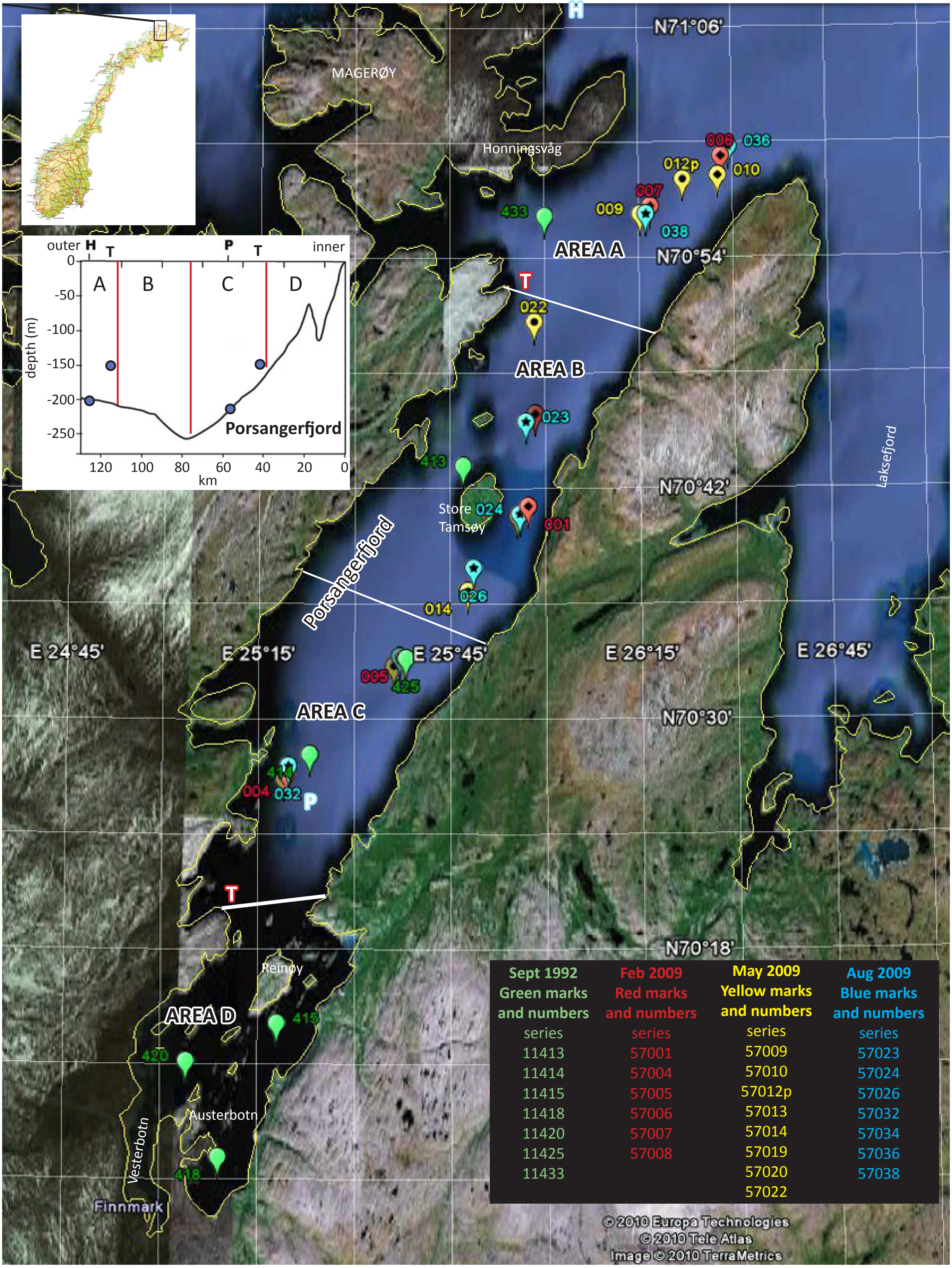


Figure 5. Trawl locations in Porsangerfjord with stations from Sept. 1992 (green marks and numbers) and stations in Feb., May and Aug. 2009 (red, yellow and blue marks and numbers). Only the last three numbers in the stations are shown. The letter p indicates pelagic trawl. T, H and P = indicate temperature stations used. Bottom profile (inserted) modified from Eilertsen and Skardhamar (2006). Stations plotted in Garmin, BlueChart Atlantic v6.5 and shown in Google Earth. More detailed area maps and sampling depths in appendix. Inserted map over Norway obtained from www.statkart.no, 2010.

tions (trawl hauls) from 1992 were included in this study (details in later paragraphs). Six fish caught in 1992 were double checked with original data on paper because measured weight/length did not fit with read age. Data from these six fish were corrected since it turned out that the punched data for length were incorrect.

A total of 21 stations (trawl hauls) from 2009, where cod was present, was used in this study. All cod were killed as soon as possible after catch. Fish longer than ca 20 cm were measured (total length) and weighed. Fish below ca 20 cm were frozen directly to preserve the stomach content for further analysis, but these fish were not included in the study. Both sagitta otoliths from cod caught in 2009 were removed (Fig. 6), and stored in marked paper envelopes.

2.3 LABORATORY WORK

Otoliths from February 2009 were broken transversely, and the zones were studied in a Leica, Wild M3C stereomicroscope, with a Wild Heerbrugg light source at 16x magnitude (Fig. 7). One year is read as one opaque (not transparent) summer zone plus one hyaline (transparent) winter zone (Fig. 8). In the stereomicroscope the different zones are shown as light/pale or dark, depending on whether the light is coming from underneath or above the otolith.

Length and width of all otolith pairs (left and right, totally approximately 1 300 otoliths), from 1992 and 2009 were measured with a Cocraft 0-150 mm digital caliper (Fig. 9). Broken otoliths were temporarily put together with adhesive tack-it pads to achieve the best possible accurate measurement (Fig. 9). For some cod, length or width of otoliths, or both, were impossible to measure because they were crystallized, broken in too many parts or otoliths were missing.

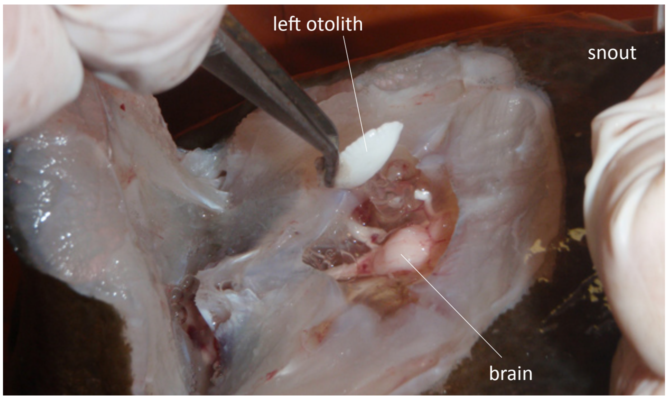


Figure 6. Removing otolith from cod head. Otoliths (sagitta) is located on each side of the brain.

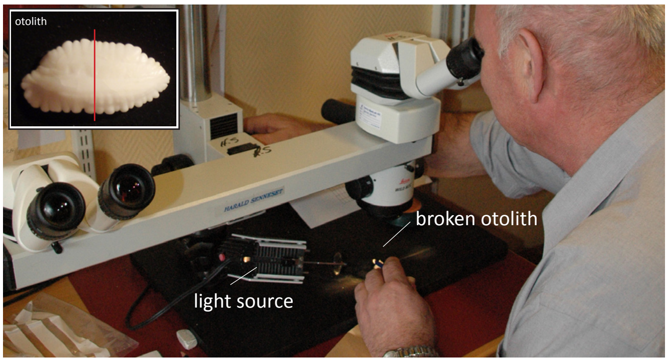


Figure 7. Age-reading otoliths from Feb. 2009 in Porsangerfjord. Inserted photo: red line showing the preferred breaking/cutting line for otoliths.

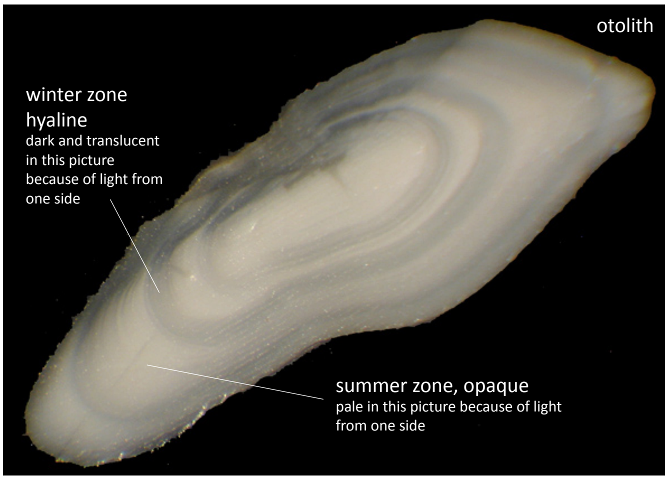


Figure 8. Cross-cut section of otolith (age 3 years, caught in Sept. 1992, area D) with hyaline and opaque zones. Light from above.

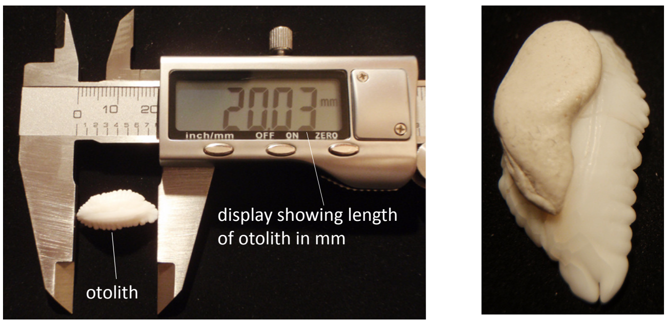


Figure 9. Measuring length of otolith with a digital caliper (left), and broken otolith with tack-it pad for easy measuring (right).

2.4 EMBEDDING AND SAWING

A total of 661 cod otoliths were embedded, 282 and 379 from 1992 and 2009, respectively. It was possible to back-calculate length at age on 618 cod (Table 2). Whole otoliths were preferred if possible. For fish with both otoliths broken, the largest of the two otolith parts was chosen. This was the case for most 1992 otoliths. When both otoliths were intact, an otolith was randomly chosen from the pair; the first otolith emerging from the storing envelope was embedded if it was not broken, had no missing parts or was not crystallized.

The embedding method was based on Jenke (2002) and modified to this study. Struers EpoFix Kit with clear resin and hardener was used as embedding material. Mixing was done according to the description included in the kit. To colour the resin two methods were tested. Medical coal tablets were crushed, grained and put in the mixture to get a black colour to contrast the otolith for better analysis. The first batch took several days to harden properly, so it was placed in a heating cabinet for 3 days to harden better. Most of these blocks were possible to saw, but some (n = 3) were too soft and therefore not used in the study. This was carried out with 48 otoliths. As an alternative, Lamp Black with natural pigments (natural carbon) was tested and used for the rest of the otoliths. This color was much easier to work with, and gave a good and hard otolith block.

After mixing the resin, one otolith from each fish was placed in ice cube moulds (Fig. 10 A) and fastened to the mould with Tack-It (Faber-Castell). To mark all the otolith blocks a paper strip with information of station number, fish number, otolith length and otolith width was placed in the mould after the resin was poured in (Fig. 10 B). Paper strips were used in the beginning, but to avoid the paper strip to separate from the block the rest of the paper strips were laminated to stand handling,

Table 2. Spatial and temporal distribution of cod sampled, collected from pelagic and bottom trawl hauls (stations), used in this thesis. Sorted by area.

Year/month	Stations	Area	Read	Back-calculated
1992, Sept.	trawl hauls		n	n
	11433	A	48	35
	11413	B	6	6
	11414	C	10	10
	11425	C	96	86
	11415	D	50	43
	11418	D	50	47
	11420	D	22	21
	Total 1992		**282**	**248**
2009, Feb.				
	57006	A	22	22
	57007	A	11	11
	57001	B	5	5
	57008	B	24	23
	57004	C	25	21
	57005	C	7	7
	Total		**94**	**89**
2009, May				
	57009	A	34	33
	57010	A	38	37
	57012	A	1	1
	57013	B	20	20
	57014	B	10	10
	57022	B	22	22
	57019	C	10	10
	57020	C	52	52
	Total		**187**	**185**
2009, Aug.				
	57036	A	11	11
	57038	A	16	15
	57023	B	4	4
	57024	B	13	12
	57026	B	11	11
	57032	C	15	15
	57034	C	28	28
	Total		**98**	**96**
	Total 2009		**379**	**370**
	TOTAL		**661**	**618**

and the later sawing process. After approximately 12 hours, the resin was hard, but to ensure that it was hard enough to be sawed, cutting was first performed 2-3 days later.

A Buehler IsoMet low speed saw (Fig. 10 C) with diamond blade (15HC No 11-4244) was used to cut the otolith block in two. With help of a 6 x 0.7 cm long and narrow metal extension taped to the digital caliper, the middle position of the otolith was found and marked with a white paint-marker pen (Edding 751) on the otolith block before cutting. The otolith block was fastened to the saw with an U-shaped metal block, with screws in both ends to manually tighten the otolith block to the metal block, which then was fastened with a screw to the saw (Fig. 10 D).

A few blocks (n = 6) containing half otoliths (1992 fish) were impossible to use after sawing. This as a result of missing the middle of the otolith with the saw, or because the piece of the otolith was too small or broken in the middle in such a way that the otolith was impossible to read or analyse after photographing.

2.5 IMAGE PREPARATION AND ANALYSIS

A Canon Camera (Mitutoyo Digimatic CD-15B) with a tube LM-Scope was connected to the stereomicroscope (Wild Heerbrugg 6 - 50x) for taking pictures of the zones (Fig. 11). A light source attached to the stereomicroscope was pointed to the otolith from above and from one of the sides to obtain the best possible contrast of the zones in the picture. Glycerol was used on the surface of the cut otolith block to make the hyaline zone more clear. The software ImageJ was used to set marks and measure each zone (free download from the Internet http://rsbweb.nih.gov/ij/download.html, 2010). Other picture adjustments, like down sizing, cropping and colour management were done in Photoshop (CS3). See appendix for details of plugins and use of ImageJ.

A total of ca 3 400 pictures were taken, and the best were picked out to be measured in ImageJ. Age reading from otoliths for cod caught in May

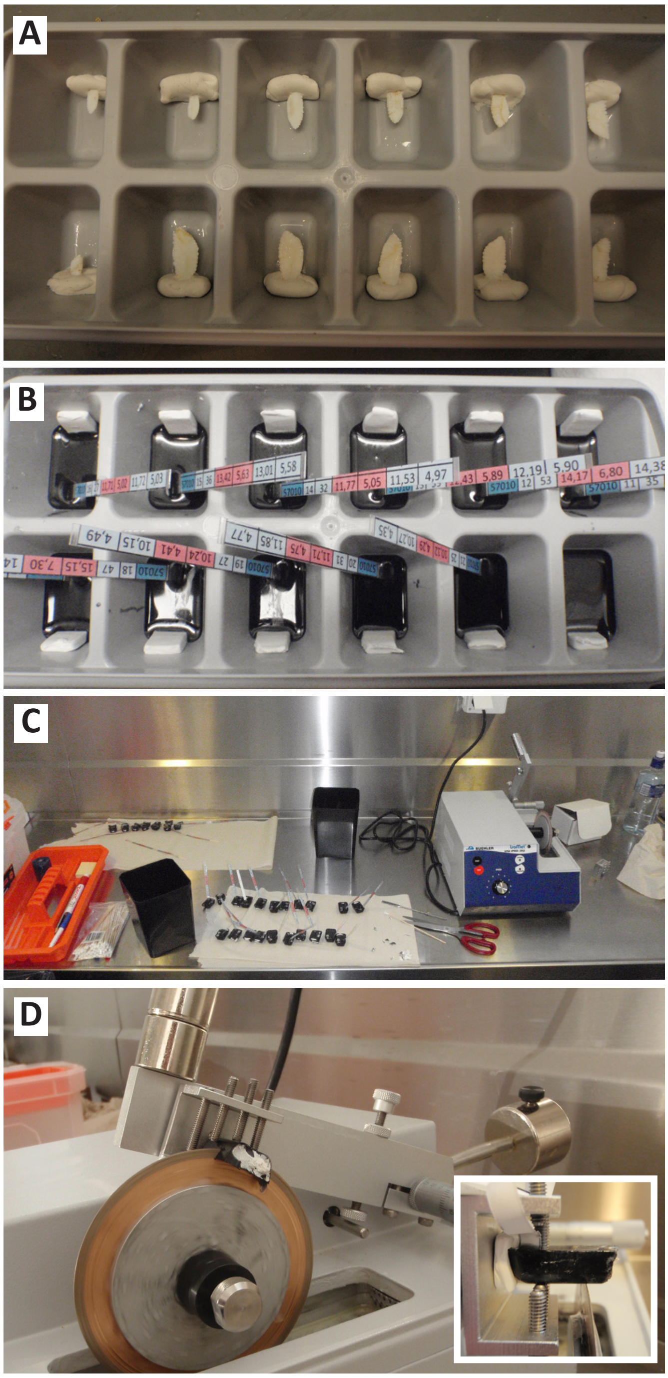


Figure 10. Embedding and sawing process;
A: *Otoliths in ice cube tray mould fastened with Tack-IT pads to the sides to ease removing the otolith block from the tray.*

B: *Mixed resin poured over the otoliths and with laminated paper strips with information about the individual otolith (trawling series, fish number, fish length, otolith width and length for both otoliths.*

C: *A Buehler IsoMet low speed saw (right) and embedded otolith blocks.*

D: *Two close-up pictures of sawing process with otolith block adjusted to the saw.*

and August 2009 was done at IMR from these pictures. Preferred picture magnification was 25x, but large otoliths were also photographed in 12x. For some otoliths, two pictures were taken; one picture containing the core/summer zone, with some including the next zone and the other picture containing the rest of the zones. For each magnification (12x and 25x) a scale factor giving pixels/mm were calculated from image of a ruler (Wild 310345). Totally 43 otoliths were excluded from zone marking due to causes mentioned earlier (wrong cut, too soft blocks). Most of these (n = 34), were hard to interpret regarding where to place the marks due to false zones (checks), or missing parts in the picture. In ImageJ marks in all otolith pictures were set as shown in Fig. 12. A start mark (red dot) is placed at the beginning of first opaque zone (core), then follows marks of outer margin of opaque zones (green dots). Last mark (blue dot) indicates the outer margin of the otolith. The x marks the half width of the first opaque zone and is the starting point of width measurements and the sum of distance 1, 2, 3 and 4 is the sum of cumulative otolith width.

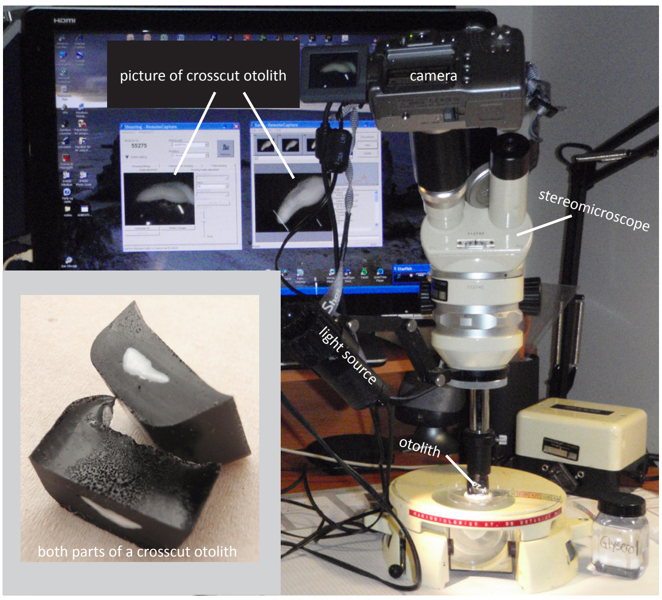


Figure 11. Stereomicroscope connected to the camera, and the camera connected to a computer for taking pictures of sawed embedded otoliths. Inserted photo: close up of cross-sectioned otolith.

There was no time to seek a second opinion from age reader experts, as wished. Instead, doubtful otoliths was discussed with supervisor Torstein Pedersen, and photographed otoliths which were difficult to mark, according to known read age, were not used. The main causes for rejection of otoliths were that many false zones or read age did not fit read age on photograph (especially for old cod caught in 1992).

2.6 CALCULATING GROWTH FROM MEASUREMENTS

A text file, generated in the program ImageJ, of zone measurements with x- and y- coordinates was copied into an spread sheet. A document in Excel was made for every station containing one sheet for every fish. In addition one sheet with original x- and y- coordinates belonging to the relevant station was made. A pre-made Excel sheet including the «Pythagorean theorem» (right-angled triangle) was used to calculate the distance between the x- and y- coordinates in otolith pictures (Fig. 12). Red lines in the picture show the two last sides of the right-angled triangle.

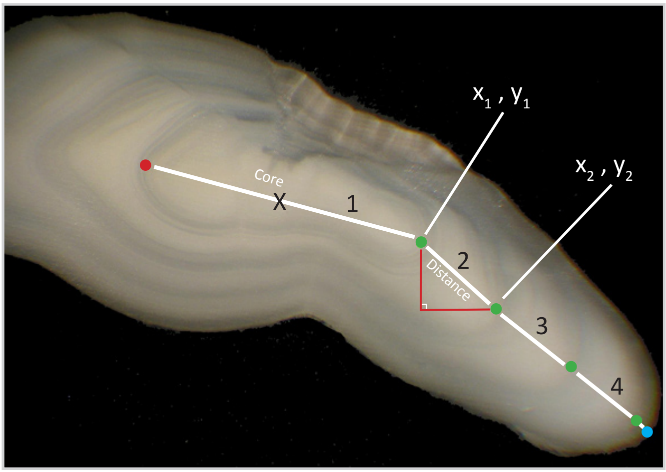


Figure 12. Cross-cut otolith picture with start mark (red), 1 - 4 zone (green) and last mark indicates the end of the otolith (blue). The X marks the half width of the first opaque zone and is the starting point of width measurements. The cumulative otolith width is the sum of the distance 1, 2, 3, 4 and out to outer margin of otolith (blue). This coastal cod is 4 years old, with a hyaline zone at the end (sampled in May 2009, area B). Marks are enlarged in this picture. Photo: 25x magnification.

Measured distance (pixels) =
$\sqrt{((x_1 - x_2)^2 + (y_1 - y_2)^2)}$ (1)

$x_1 - x_2$ are first and second measured point on x-axis, and $y_1 - y_2$ are first and second measured point on the y-axis. To obtain the real distance in mm:

Distance (mm) = Measured distance (pixels) / scale factor (pixels/mm) (2)

Half the distance of the core was used as measurement for the first opaque zone. Scale factor for 25x was 446.5 pix/mm and for 12x it was 209.5 pix/mm.

A definition of age and zone is required at this point. Zone 1 do not correspond to a full year of growth, but from until formation of the first hyaline zone, after approximately six months. The hyaline zone starts formation in October/November (Sandneseng, 2006), and lasts until about age 1, in April. Even if zone 1 not equals age 1, it will be referred to as age 1 in the sake of ease. For age 2 - 9, a year (age) equals one zone.

2.7 STATISTICS

MYSTAT (version 12, student version of SYSTAT) and Microsoft Office Excel 2007 was used for treatment and statistical analysis of the data. MYSTAT was obtained from the Internet (http://www.systat.com/MystatProducts.aspx, 2009). Standard statistical methods was used to test the hypotheses. Thus, normality and equal variance and heterogenety for length distribution within each age group was assumed. For all statistical tests, a probability level of 5 % indicates statistical significance.

Adjustment of age of fish sampled in different months was done by adding time for each month assuming a birth date (time of hatching) to be 1st of April for cod in Porsangerfjord, and then adding the number of months after 1st of April divided by 12. Additional time value after hatching was as follows for each month: $t_{Feb} = 0.83$, $t_{May} = 0.08$, $t_{Aug} = 0.33$ and $t_{Sept} = 0.42$.

To estimate length at age from the distance between the mark X, as described in Fig. 12, and outer margin of the opaque zones, a simple nonlinear body-proportional hypothesis (non-linear BPH) model was applied (Morita and Matsuishi, 2001). This corresponds to a general power relationship between fish length (L) and otolith size (x):

$$L_T = a * cum_T^b \quad (3)$$

where L_T is fish length at capture, cum_T is the sum of distances between the mark X (Fig. 12) and outer margin of first opaque otolith zone, to the outer margin of the otolith (distance 1, 2, 3, 4 and out to the end of the otolith, blue dot in Fig. 12). For back-calculation of length L_t at time t, it was assumed that:

$$L_t = a * cum_t^b \quad (4)$$

where cum_t is cumulative otolith distance along marks at outer margin of opaque zone, and *a* and *b* are constants, calculated by regression analysis in MYSTAT.

When dividing L_t (eq. 4) by L_T (eq. 3) and rearranging, the constant *a* (eq. 4) disappears. This gives:

$$L_t = L_T * (cum_t / cum_T)^b \quad (5)$$

To apply eq. 5 for back-calculating L_t from L_T, cum_t, cum_T, and *b* have to be known. To estimate *b* (see eq. 3), L_t and cum_T were ln-transformed and *b* estimated by linear regression:

$$\ln(L_T) = a_1 + b_1 * \ln(cum_T) \quad (6)$$

where $\ln(L_T)$ is the predicted log of body length. However, *b* may not be constant, since the relationship between fish length and otolith size may be influenced by growth rate and other biological factors (Campana, 1990). To investigate which variables that may affect the *b*-value in the back-calculating model (eq. 5), a multiple regression model for fish length with year, area and type as independent variables performed in MYSTAT including term for year, area, type and the interaction term year∗area.

$$\ln(L_T) = \text{year} + \text{type} + \text{area} + b_1\ln(\text{cum}_T) + b_2\ln(\text{cum}_T)*\text{year} + b_3\ln(\text{cum}_T)*\text{area} + b_4\ln(\text{cum}_T)*\text{type} + b_5\ln(\text{cum}_T)*\text{year}*\text{area} \quad (7)$$

where $\ln(L_T)$ is the logarithm of body length (cm), $b_{1\text{-}5}$ are regression coefficients, year is 1992 and 2009, type are CC, uCC, NEAC and uNEAC and area are A, B, C and D.

The full model was reduced by stepwise removement of variables that were not statistically significant ($P > 0.05$). At each step the term with highest P - value was removed until terms with $P < 0.05$ remained.

Regression with ANOVA assumes that the variance within and between groups is approximately equal (Løvås, 2004; Van Emden, 2008). A multiple regression model was used to test if year class and area affected back-calculated length at age (L_t).

$$L_t = c + d * \text{year class} + e * \text{area} \quad (8)$$

where L_t is mean back-calculated length at age, *c*, *d* and *e* are parameters to be estimated, and year class is the back-calculated year in the two periods investigated (1979-1992, and 1998-2009), and area is area A, B, C and D in Porsangerfjord. Separate regression models were estimated for each age group (1 - 9 years) and sampling years (1992 or 2009).

To investigate if growth rate of different year classes was synchronised, i. e. high or low growth rates occurred in the same years for several age groups, Pearson product-moment correlation coefficient of growth rates of two age groups from the same year, was estimated and it was tested whether it differed significantly from zero.

A Mann-Whitney (M - W) U Test was used to test temperature at the two temperature stations (Fig. 5, marked T) in Porsangerfjord for the whole time period 1980-2009. One station was in the outer area and one was in the inner area. Data from Porsangerfjord provided by Mankettikkara and Eilertsen (2010, pers. com., UiT, BFE).

3 RESULTS

3.1 DISTRIBUTION OF COD

Coastal cod (CC) dominated the cod catches in 1992 (n = 227, 81 %), and 2009 (n = 251, 67 %) (Table 3, Fig. 13). In 2009, no cod was caught in area D, which had the highest catch rates in 1992. Three- and six-year-old cod dominated in 1992, independent of type (Table 3). In 2009, five-year-old cod dominated followed by three-year-old cod. In 1992 and 2009, few individuals were older than 6 and 9 years (n<20 in each age interval) respectively. Old cod was caught in the inner area, C and D (Table 3).

The numerical contribution of NEAC in the trawl catches was low in both sampling years (total 6 %). Cod typed as uncertain CC and uncertain NEAC contributed with a total of 13 % in 1992 and a total of 27 % in 2009 (Table 3).

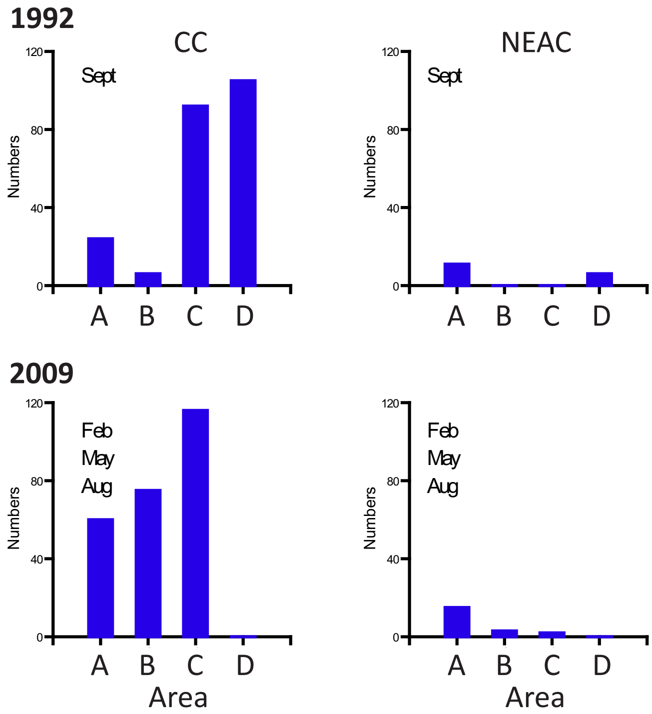


Figure 13. Number of cod caught in Porsangerfjord in Sept. 1992, and Feb., May and Aug. 2009. Cod sorted by year and area (A - D) for type CC (costal cod) and NEAC (North East Arctic cod). Classification of cod based on typing from otoliths.

Table 3. Number, type CC (Costal Cod), NEAC (North East Arctic Cod), uCC (uncertain Costal Cod) and uNEAC (uncertain North East Arctic Cod) and age (1 - 13 years) of cod caught in four areas (A - D) in Porsangerfjord, in Sept. 1992, and Feb., May and Aug. 2009. % is percent of total number of type or area for 1992 and 2009. More detailed tables are given in appendix.

A. By type.

TYPE	YEAR	1	2	3	4	5	6	7	8	9	10	11	13	Total	%
CC	**1992**	3	15	54	21	32	48	13	8	10	11	11	1	227	81
CC	**2009**	2	26	50	41	42	40	19	18	9	3	1	-	251	67
NEAC	**1992**	-	-	8	3	1	3	1	1	-	-	-	-	17	6
NEAC	**2009**	-	1	1	1	-	1	9	4	3	-	-	-	20	5
uCC	**1992**	-	-	12	2	1	2	-	-	-	1	-	-	18	6
uCC	**2009**	-	3	6	8	19	7	9	5	4	-	-	-	61	16
uNEAC	**1992**	-	-	7	5	4	3	-	-	-	-	-	-	19	7
uNEAC	**2009**	-	1	5	3	6	5	10	7	4	1	-	-	42	11
Total	**1992**	**3**	**15**	**81**	**31**	**38**	**56**	**14**	**9**	**10**	**12**	**11**	**1**	**281**	**43**
Total	**2009**	**2**	**31**	**62**	**53**	**67**	**53**	**47**	**34**	**20**	**4**	**1**	**-**	**374**	**57**
TOTAL		**5**	**46**	**143**	**84**	**105**	**109**	**61**	**43**	**30**	**16**	**12**	**1**	**655**	**100**

B. By area.

AREA	YEAR	1	2	3	4	5	6	7	8	9	10	11	13	Total	%
A	**1992**	1	3	13	13	6	10	1	1	-	-	-	-	48	17
A	**2009**	-	6	19	27	28	19	23	6	5	-	-	-	133	35
B	**1992**	-	-	5	1	-	-	-	-	-	-	-	-	6	2
B	**2009**	-	12	15	13	13	17	14	13	8	3	-	-	108	29
C	**1992**	-	5	35	7	17	18	8	3	6	2	4	-	105	37
C	**2009**	2	14	28	15	26	17	11	15	7	1	1	-	137	36
D	**1992**	2	7	28	10	15	28	5	5	4	10	7	1	122	43
D	**2009**	-	-	-	-	-	-	-	-	-	-	-	-	0	0
Total	**1992**	**3**	**15**	**81**	**31**	**38**	**56**	**14**	**9**	**10**	**12**	**11**	**1**	**281**	**43**
Total	**2009**	**2**	**32**	**62**	**55**	**67**	**53**	**48**	**34**	**20**	**4**	**1**	**-**	**378**	**57**
TOTAL		**5**	**47**	**143**	**86**	**105**	**109**	**62**	**43**	**30**	**16**	**12**	**1**	**659**	**100**

Cod caught in in area A 2009, were larger and older, than in 1992 (independent of type). In area C, cod from 2009 were larger at read age, but CC from 1992 were slightly older (Fig. 14). In area A, B and C, cod caught in 2009 reached lengths at about 70-90 cm at 7-8 years of age. In contrast, cod caught in 1992 did not exceed 70 cm in any of the areas. Area D is dominated by coastal cod, and many fish are 10-11 years old. The oldest cod, 13 years, was found in this area. Cod with uncertain typing (uCC and uNEAC) are not investigated further (except in regressions) to avoid biasing the result by including uncertainties.

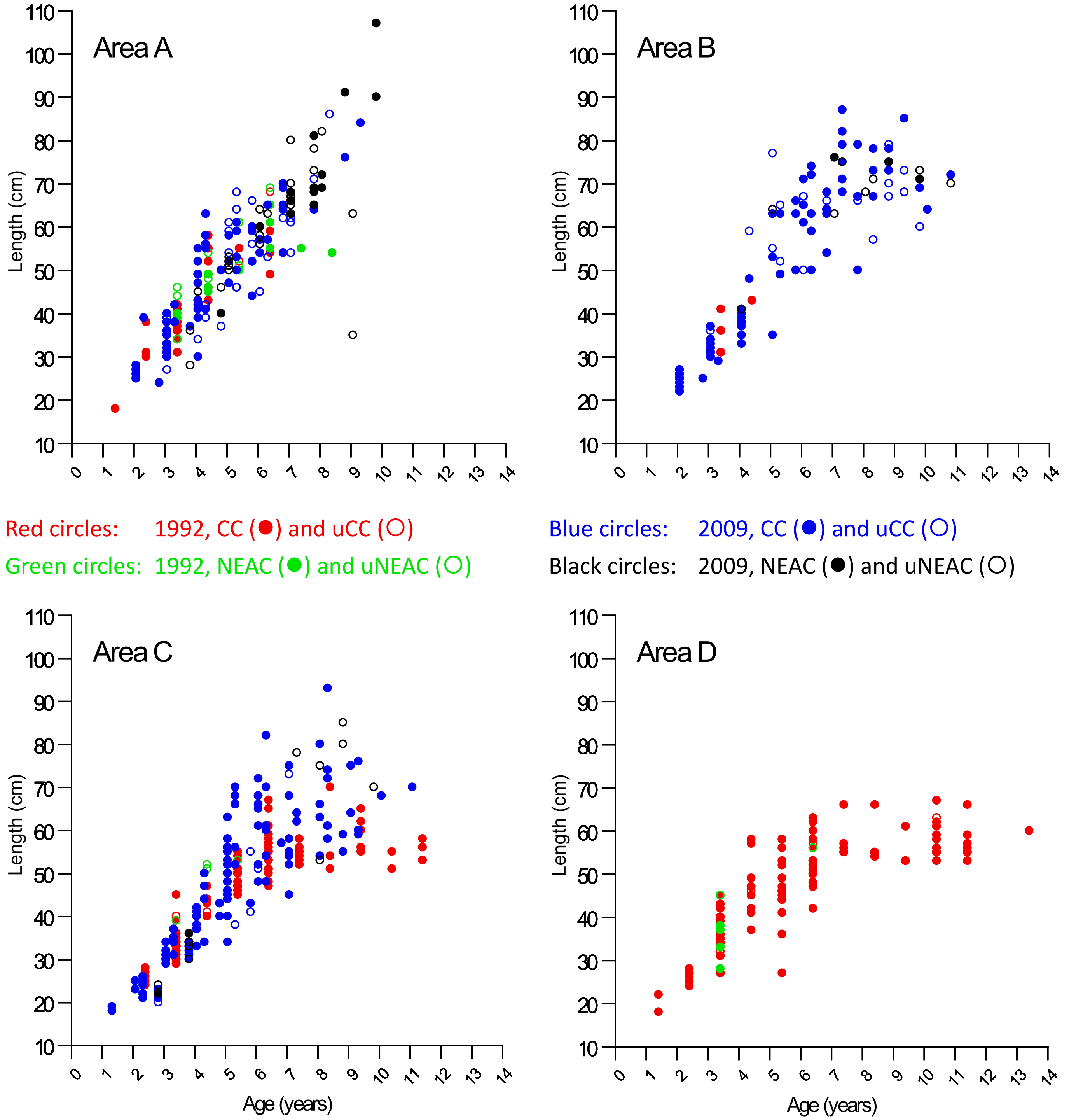


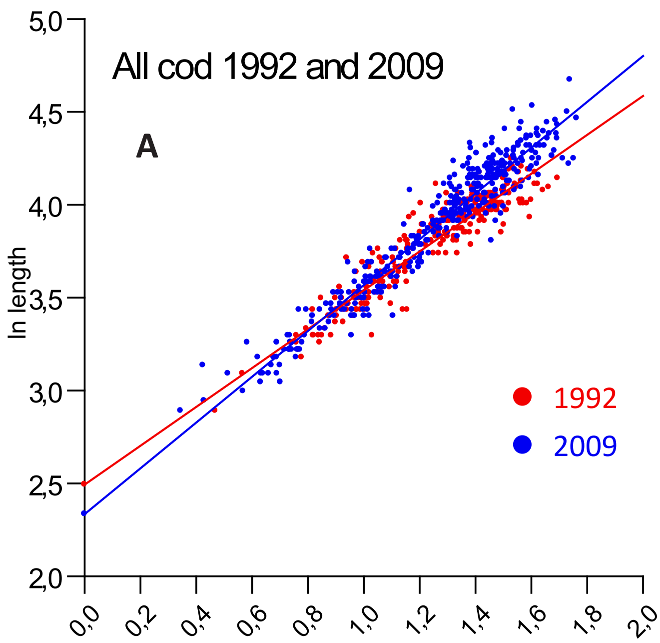
Figure 14. Measured length at age from otolith (adjusted for assumed hatching 1st of April) of cod type CC (Costal Cod), NEAC (North East Arctic Cod), uCC (uncertain Costal Cod) and uNEAC (uncertain North East Arctic Cod) in four areas (A - D), in September 1992, and February, May and August 2009.

3.2 OTOLITH - FISH SIZE RELATIONSHIP

It is important to find representative b-values to use in eq. 5 for back-calculation of length at age. Regressions with natural logarithm (ln) of fish length as a function of year, type, area and cumulative otolith width (cum_T) in eq. 7 were estimated to investigate which parameters effected the *b*-value in the back-calculating model (eq. 6). The complete eq. 7 was tested and the most insignificant parameters were removed step by step (Table 4). Case 289, an outlier, defined as an unusual high or low value by Quinn and Keough (2002), in the data set, was removed in all steps. Year and area affected the intercept, and year and area affected slope (*b*) significantly (Table 4). There was no significant effect on the slope for either type or year∗area.

Table 4. Regressions for ln (L) as a function of cumulative otolith width (cum) for year, type and area. P = p-value, $ln(cum_T)$ = natural logarithm of cumulative otolith width. P-values are shown for each step and the least significant term was removed in each step.

Effect	P-value				
	step 1	step 2	step 3	step 4	step 5
Year	0.001	0.001	0.001	0.001	0.001
Type	0.473	0.469	0.051	0.079	-
Area	0.032	0.033	0.034	0.022	0.006
$ln(cum_T)$	0.526	0.056	0.058	-	-
$ln(cum_T)$∗Year	0.243	0.001	0.001	0.001	0.001
$ln(cum_T)$∗Area	0.853	0.003	0.003	0.001	0.001
$ln(cum_T)$∗Type	0.751	0.746	-	-	-
$ln(cum_T)$∗Year∗Area	0.902	-	-	-	-



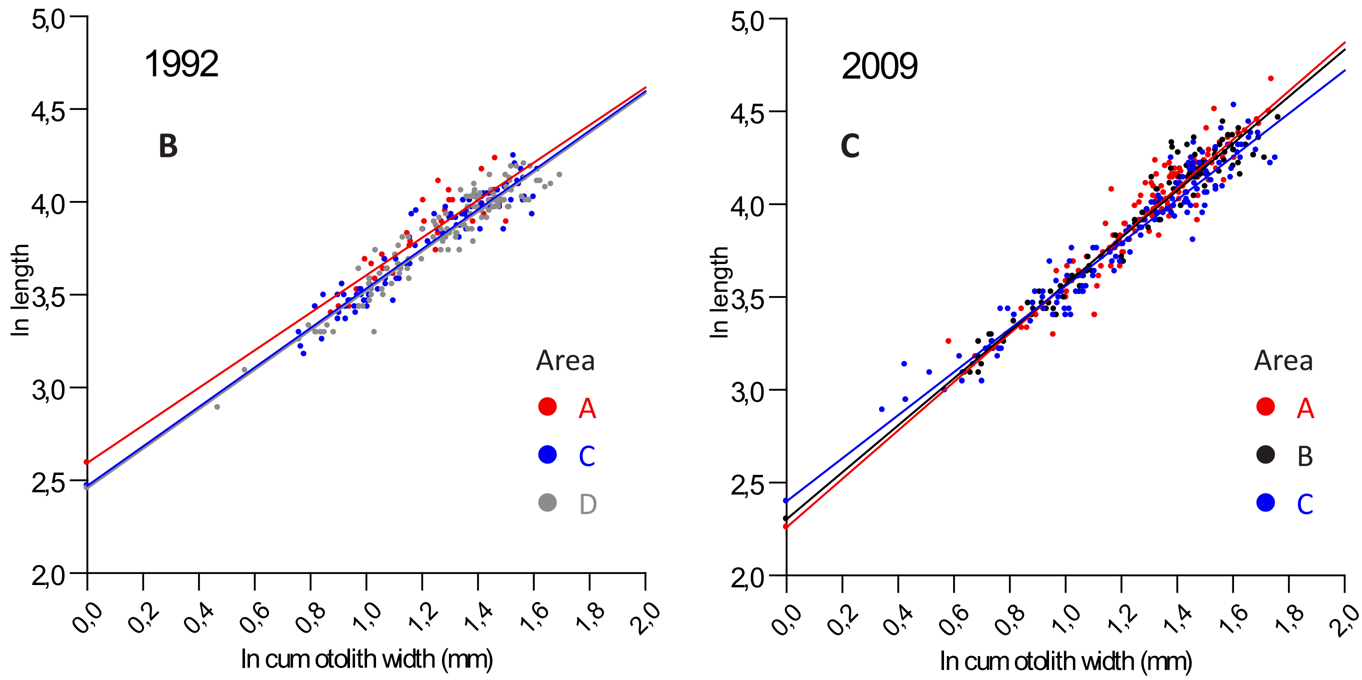


Figure 15. Ln transformed length as a function of ln cumulative otolith width in four areas (A - D) in 1992 and 2009. Panel A displays the year effect of 1992 and 2009, panel B displays the area effect in 1992 (no cod were caught in area B) and panel C displays the area effect in 2009 (no cod were caught in area D).

Since sampling year and area affected the *b*-value, separate regressions for $\ln(L_T) = a_1 + b_1 * \ln(cum_T)$ was estimated for each area and sampling year. Large CC from 2009, had smaller otolith width than cod caught in 1992 (Fig. 15, panel A). In 1992, cod in area A have smaller cumulative otolith width at fish length than cod in area C and D (Fig. 15, panel B). In 2009, cod with otolith width 1.0 > mm from area A and B have smaller otolith width at fish length than cod in area C (Fig. 15, panel C).

Since year and area affected the slope b, which is the exponent in the back-calculation model (eq. 6), separate *b*-values were estimated by linear regression (eq. 6) for each year and area. The constant *b* was estimated for sampling year and area (Fig. 16). Due to few cod in Area B in 1992, cod from Area B and C was pooled. The estimated *b*-values were significantly lower (no overlapping confidence interval) in 1992 (1.01 - 1.06) than in 2009 (1.2 - 1.3). Only area C in 2009 have a confidence interval overlapping with that of area A - D in 1992.

3.3 BACK-CALCULATED LENGTH AT AGE

Back-calculation was performed using year and area specific *b*-values. Uncertain typed cod (uCC and uNEAC) are not included in the figures or test. In addition, the 1989 year class, for example, was a strong year class and this may give a year class effect on mean back-calculated length at age (Fig. 17).

In area A, mean back-calculated length at age for cod caught in 1992 and 2009 (Fig. 17, top panels) reached the highest mean length at 50 - 65 cm for CC (Fig. 17, top left panel) and 80 - 90 cm for NEAC (Fig. 17, top right panel). CC in 1992 had higher length at age up to 4 years of age than in 2009, but after 5 years of age, CC from 2009 grew faster. From 5 years of age NEAC caught in 2009 have greater mean length at back-calculated age.

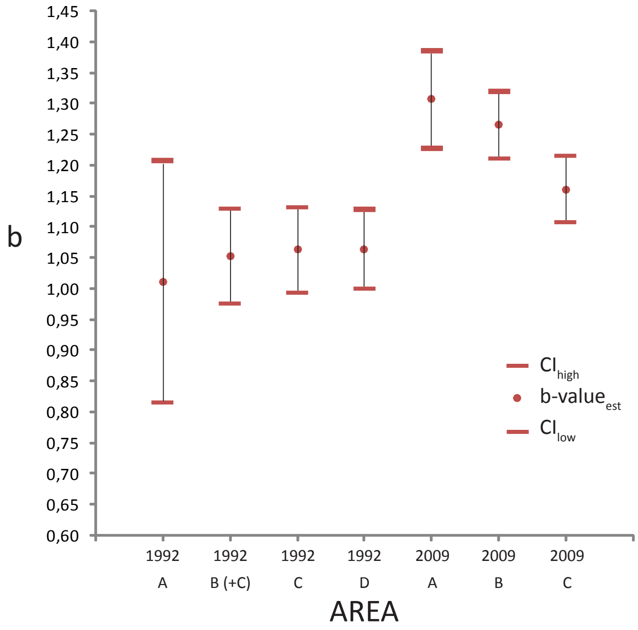
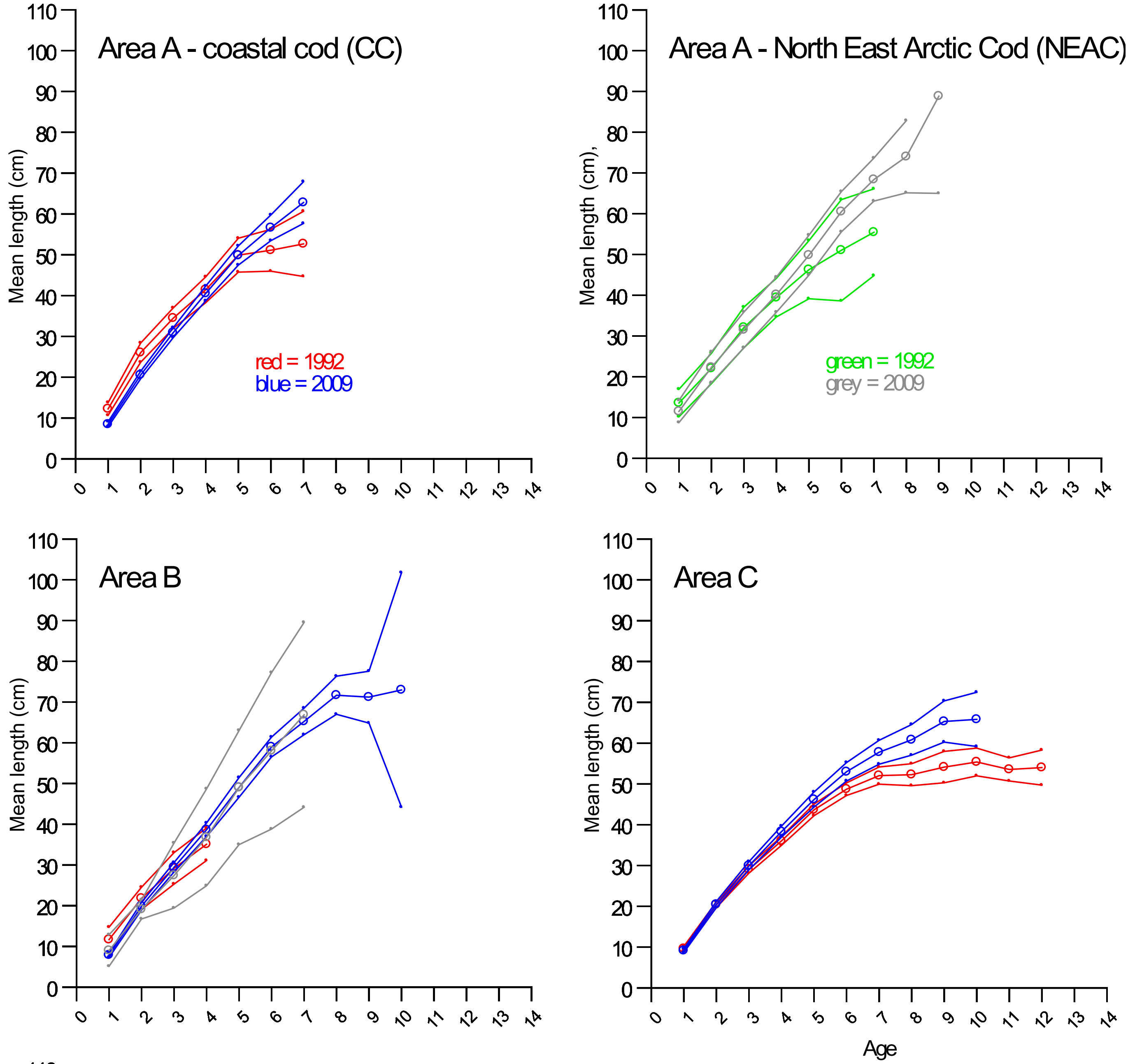


Figure 16. Estimated b-values (red dots) for back-calculating length at age for coastal cod and NEAC in area A - D in 1992 and 2009. All b-values are given with 95 % confidence interval (CI). Relation fish length = a ∗ *cumulative otolith width*^{b}.

In area B the situation is similar to that in area A; CC caught in 1992 mean length at age was higher until age 2, compared with CC caught in 2009, whereas at age 3 - 4 they display equal mean length at age (Fig. 17, middle left panel). NEAC from 2009 follow the same pattern as CC from 2009.

In area C, all CC caught in 1992 and 2009 have very similar mean length at age up to age 3 (Fig. 17, middle right panel). After this age, CC in 2009 display significantly (no overlapping confidence intervals) better length at age than CC in 1992. After age 5, the length at age in 1992 increase very slowly with a mean length at age of 7 years and older of about 53 cm, whereas fish caught in 2009 were 58 - 65 cm at age 7 and older.

In area D (Fig. 17, bottom panel), no cod was caught in 2009. In 1992, the NEAC were few and young (≤ 4 years) in this area. The growth pattern of CC in area D, in which they occurred in highest density, is similar to the growth pattern in area C.



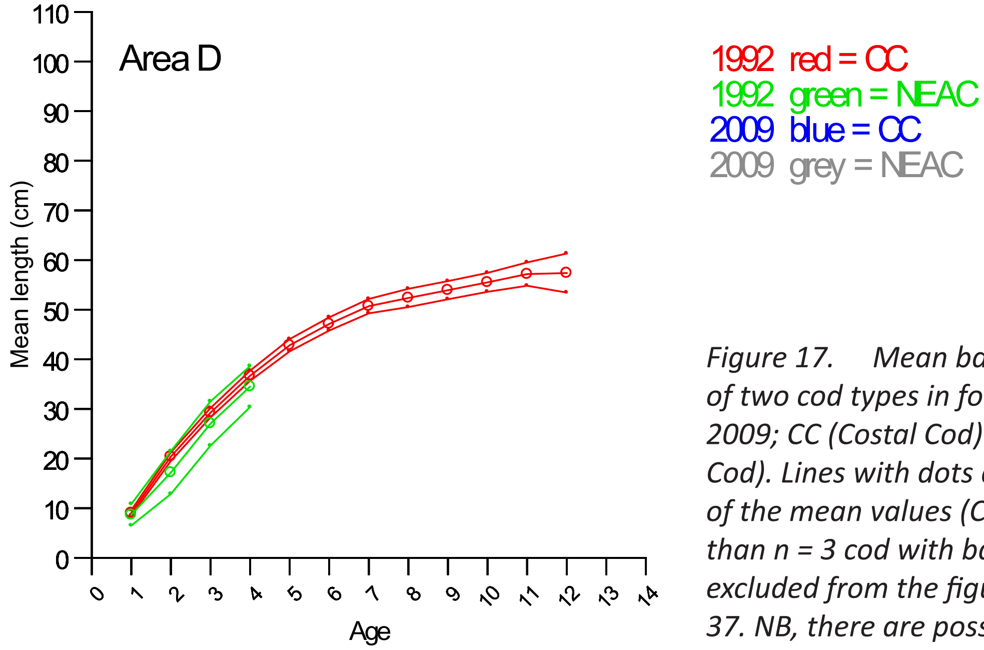


Figure 17. Mean back-calculated length at age of two cod types in four areas, A - D, in 1992 and 2009; CC (Costal Cod) and NEAC (North East Arctic Cod). Lines with dots are 95 % Confidence interval of the mean values (CI_{high} and CI_{low}). Age with less than n = 3 cod with back-calculated length are excluded from the figure. $N_{CC\ tot}$ = 478 and $N_{NEAC\ tot}$ = 37. NB, there are possibilities for year class effects for mean back-calculated length at age, e.g. year class 1989 was strong.

It was attempted to investigate whether back-calculated length at age for CC was affected by year class and areas for each age. In 1992, there was a significant year class and area effect for age 1 - 4, whereas for age group 5 - 9 there was only a year class effect (Table 5). In 2009, there was a significant year class effect for age 2 - 5, and there was a significant area effect for age groups 1 and 5 - 7. For CC, best growth was achieved for age group 2 staying in area A in 1992, whereas in 2009, best growth was achieved in area B for age group 7 and in area C for age group 1.

Area and year class explains more of the variation in growth in 1992 compared to 2009. The fitted models in 1992 explain similar proportions of the variance r^2 ($0.48 < r^2 < 0.60$), whereas in 2009 the models explain less of the variation (age 1 - 4: $0.28 < r^2 < 0.36$, and 5 - 9: $0.43 < r^2 < 0.72$).

Table 5. Regression analyses (eq. 8) for back-calculated length at age as a function of year class (Y.class) and area for age groups 1-9 in 1992 and 2009 with four levels of significance (P-values, see bottom of table) and, r^2 = percent of explanation, n = numbers. One model is estimated for each age.

1992					2009			
CC	P	P			P	P		
Age	Y.class	Area	r^2	n	Y.class	Area	r^2	n
1	***	*	0.60	206	NS	**	0.33	248
2	***	***	0.53	204	*	NS	0.28	242
3	***	**	0.48	192	*	NS	0.31	213
4	***	**	0.56	143	*	NS	0.36	168
5	***	NS	0.50	123	*	*	0.43	124
6	***	NS	0.59	96	NS	*	0.47	79
7	***	NS	0.63	49	NS	***	0.62	44
8	*	NS	0.54	38	NS	NS	0.49	27
9	**	NS	0.59	32	NS	NS	0.72	11

Level of significance:	0.0001	<*** p	< 0.001
	0.001	< ** p	< 0.01
	0.01	< * p	< 0.05
	0.05	< NS	< 1.0

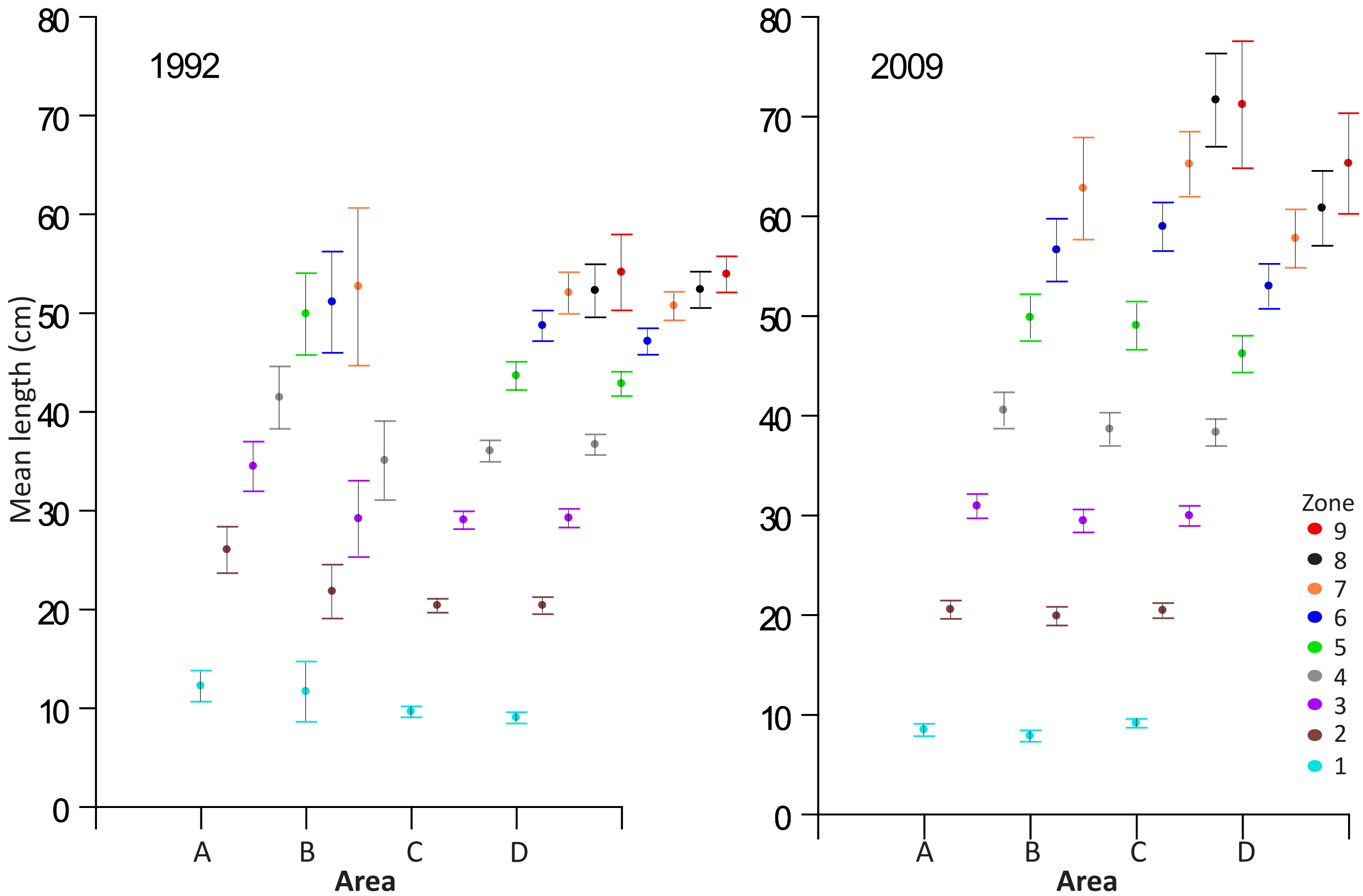


Figure 18. Mean back-calculated length (cm) at age for CC of age groups 1-9 in area A - D in 1992 (left panel) and 2009 (right panel). Mean estimates are given with a 95 % confidence interval. Samples with less than 3 fish are excluded. Points for each area are slightly displaced to prevent overlap.

In 1992, all cod but age group 7 (zone 1-6) in area A (Fig. 18) had higher length at age than in the other areas. The «length at age» pattern in area C and D are uniform, and annual length increments for zones 1-5 are much higher than for zones 6-9. Young cod achieve an annual increase in length at age of 10 cm, and the annual growth declines to 1-5 cm as the cod gets older. For CC, length at age of adult fish (age > 5) was higher in 2009 compared with 1992. In 2009, adult fish in area B grow faster compared with the other areas, whereas age 1 seems to grow better in area C. but this may be caused by area effect.

CC sampled in 1992 grew up in the time period 1980 - 1992, whereas CC sampled in 2009 grew up in the time period 1998 - 2009. Mean length (cm) at each year for the different year classes varies in the two periods as shown in Fig. 19. At age 4, for example, cod from year class 1981 reach a length at approximately 33 cm, while 4 year old from year class 1988 reach a mean length at 42 cm at age 4. A similar variability in growth pattern is also present in the last time period, where 4 year old cod from the 1998 year class have a minimum length at age of just above 30 cm, whereas year class 2003 at age 4 reach the maximum length at age at 42 cm. Additionally, old cod in the second

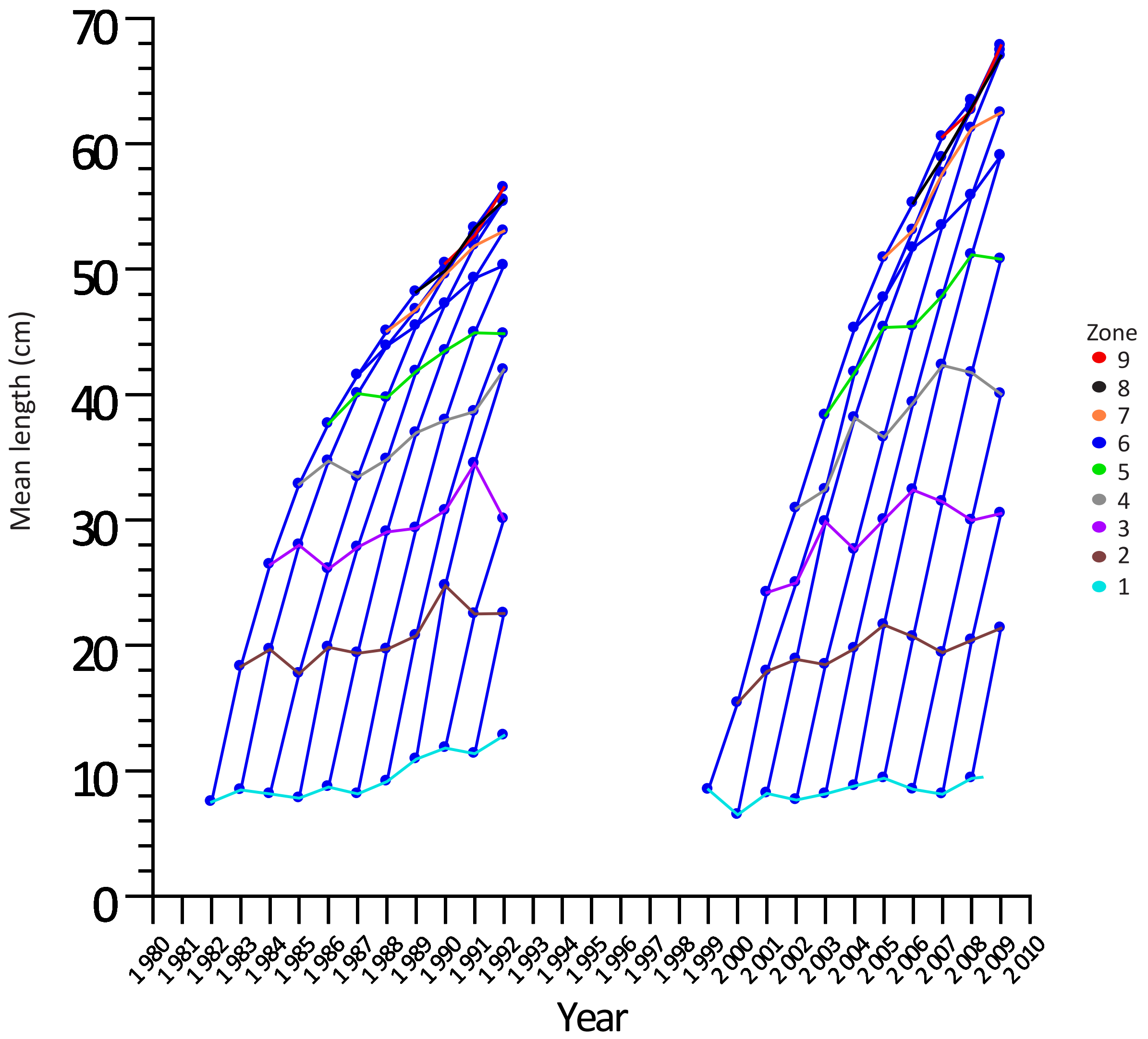


Figure 19. Mean back-calculated length (cm) of cod in each year class (year) sampled in 1992; corresponding to fish from year class 1981-1992 and in 2009; corresponding to fish from year class 1998-2009. Year class 1981 is one year of age in 1982. Blue «vertical» lines illustrates mean length at age for each year class: zone 1 - 9. «Horizontal» lines (different colours) show mean length at age for each cohort or age group, e. g. zone 1 (light blue) is age group 1.

time period (1998 - 2009) have generally better growth after age 5, compared with the first time period (1980 - 1992).

In both periods, 1980 - 1992 and 1998 - 2009, the annual growth rate for age 1 and 2 was well synchronised for CC (Fig. 20, left panel). The lowest growth rates was in 1999 for age 1 and 2. For age 3 - 10 (Fig. 20) the rates in the first time period appear to be quite synchronised in age 5 - 8, and age 9 - 10 have almost the same rate. In the 1998 - 2009 time period age 5 - 6 and 8 - 9 were well synchronised (Fig. 20, right panel). Generally, growth rate decreases by age in both periods (for age 1, 4 and 5 in the last time period, and age 3 in the first time period growth rates are in the same range between 7 and 10 cm per year). At age 3 in the last time period, there was a low growth rate in the beginning of the period (7 - 9 cm per year), but growth increased at this age to a maximum of 11 cm in 2002, and around 10 cm per year the rest of the period, except in 2003 where the rate was low. From age 4 - 5 growth rates in the last period are higher than in the first time period.

There were several significant correlations for growth rate between year class in the same year for CC (Table 6). Four of the correlations are illustrated in Fig. 21. The growth rate of CC of ages 1 and 2 in 1992 and 2009 are significantly positive correlated (Fig. 21, top left panel), and age 1 is significantly negative correlated to age 8 (Fig. 21, bottom left panel). At age 2 the growth rates are in the same range for 1992 and 2009. Growth rate for age 4 are significantly positive correlated to age 6 (Fig. 21, top right panel), and the growth rate of age group 6 is positive correlated to age group 8 (Fig. 21, bottom right panel).

For age 1 and 2 the growth ranges are overlapping in 1992 and 2009 (Fig. 21, top left panel), whereas the other (Fig. 21, top right panel, and both bottom panels) growth ranges are more separated between the two years. For cod caught in 2009, age 4, 6 and 8 display higher growth rates than cod caught in 1992, and growth rates for all correlations are quite close in range.

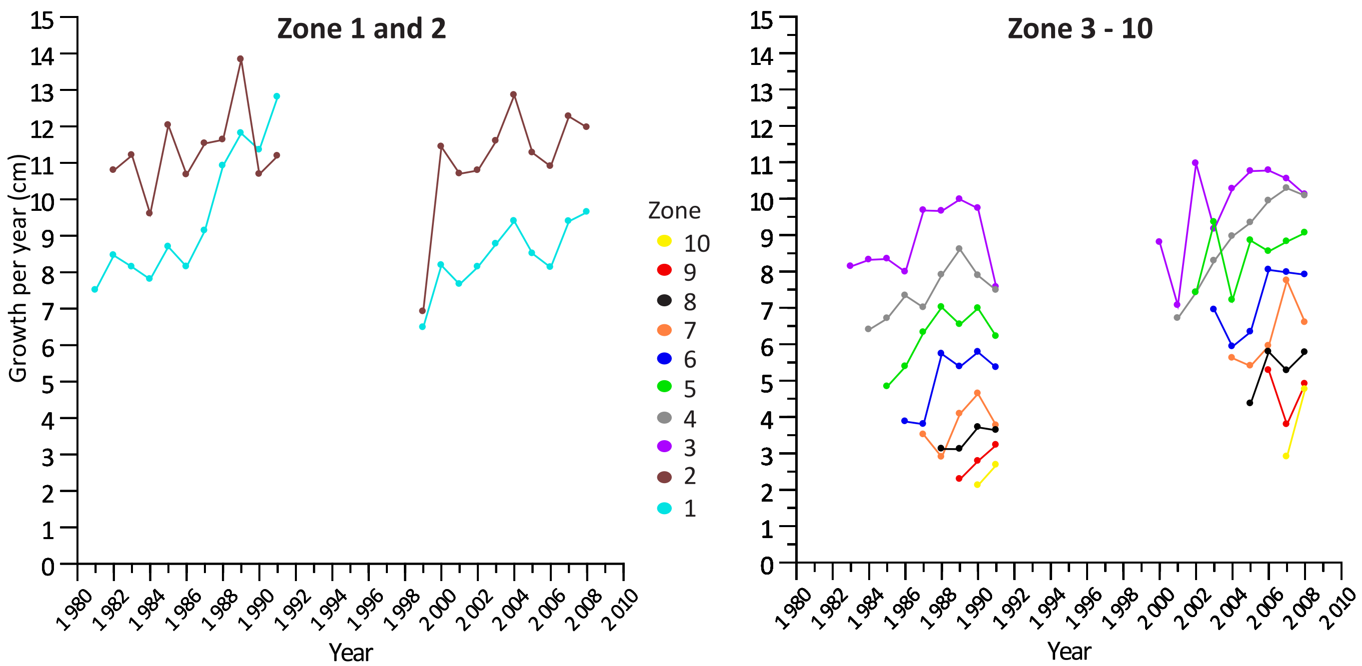


Figure 20. Mean back-calculated growth rate (cm) per year in time periods 1980-1992 and 1998-2009 for CC in Porsangerfjorden. Zones 1 and 2 (left panel) and zones 3-10 (right panel).

Table 6. Correlation coefficient (Pearson) for back-calculated mean growth rate (cm per year) of year classes and zones (1-10, zone = age) in the same year for coastal cod. Four levels of significance (p-values; see left side of table). All significant correlations marked in blue cells. Number of year classes of each zone measured is given by n. Negative correlations are shown in red. See also Fig. 21.

Level of significance:

0.0001 < *** p < 0.001
0.001 < ** p < 0.01
0.01 < * p < 0.05
0.05 < NS < 1.0

Zone	n	1	2	3	4	5	6	7	8	9
1	-									
2	20	0.57 **								
3	18	0.06	0.35							
4	16	0.12	0.46	0.70 **						
5	14	-0.23	-0.01	0.65 *	0.80 ***					
6	12	0.20	0.10	0.58 *	0.90 ***	0.88 ***				
7	10	-0.54	0.09	0.57	-	0.83 **	0.84 **			
8	8	-0.77 *	-0.22	0.51	0.88 **	0.86 **	0.96 ***	0.87 **		
9	6	-0.83 *	-0.40	0.42	0.72	0.82 *	0.87 *	0.63	0.95 **	
10	4	-0,55	0.62	0.31	0.66	0.70	0.68	0.47	0.83	0.98

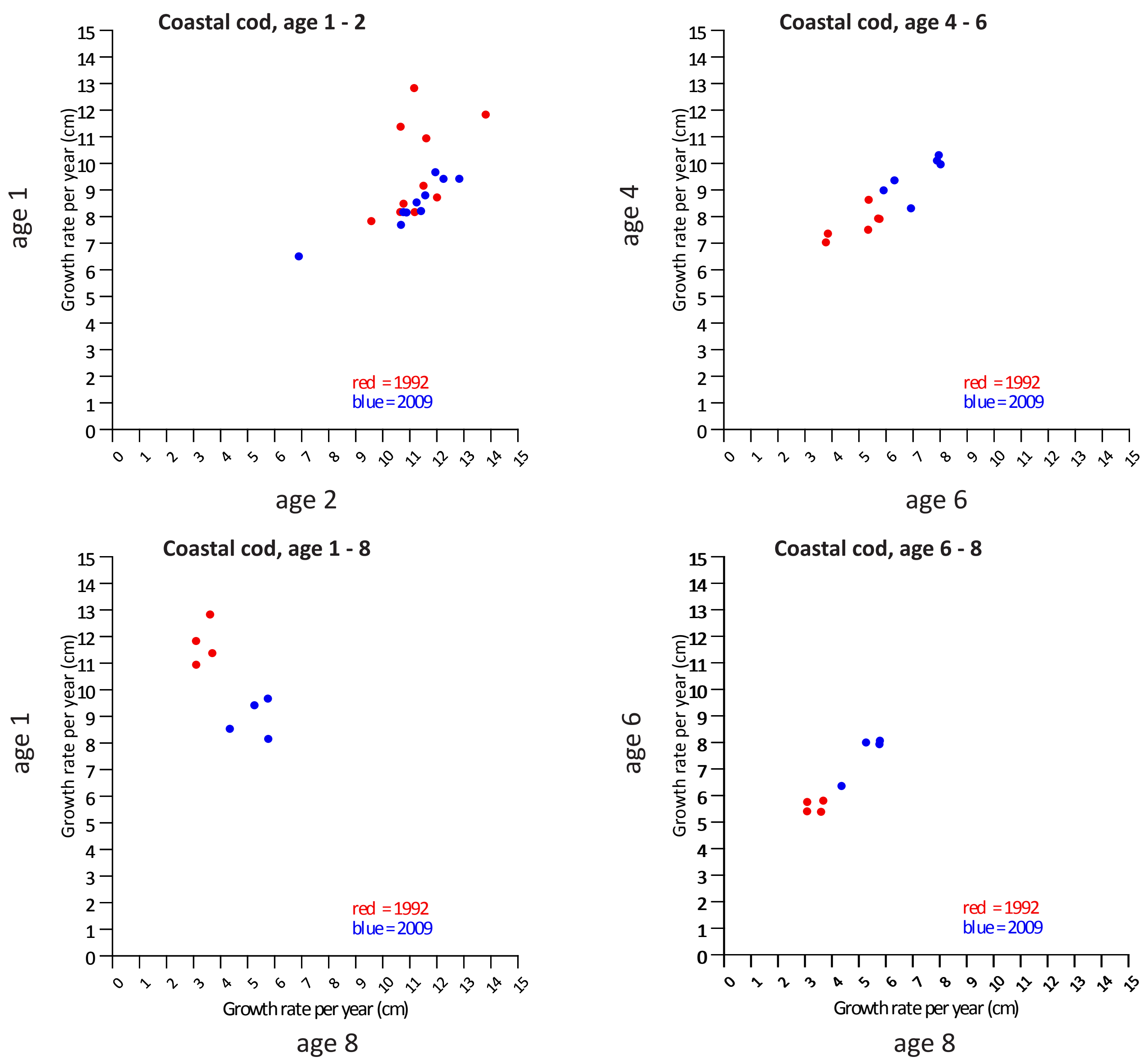


Figure 21. Relationship for back-calculated mean growth rate (cm per year) for different age groups in the same year for coastal cod. From Tab. 6; 1 vs 2 (positive, top left), 4 vs 6 (positive, top right) 1 vs 8 (negative, bottom left), 6 vs 8 (positive, bottom right).

3.4 TEMPERATURE

There was a significant difference for mean temperature (M - W test) for the whole time period between the inner station and the outer station in Porsangerfjord (Fig. 22). There were also significant difference (M - W test) in mean temperature for the inner station between the first time period (2.55 °C in 1980-1992) and second time period (4.09 °C in 1998-2009), and significant difference in mean temperature between outer station in first time period (4.44 °C in 1980-1992) and second time period (5.60 °C in 1998-2009).

For both stations, the mean temperature was lowest in the first time period. Mean temperature in the outer station was almost 2 °C higher than in the inner station in the first time period, and 1.5 °C higher in the second time period.

Through the year, mean temperature changes with the lowest temperature in March and highest in October, for both outer and inner station (Fig. 22). In outer station the mean temperature is warmer all year round, than in inner station. Outer station mean temperature range is from just above 3 °C and up to approximately 7 °C, and inner station mean temperature range is from approximately 0.5 °C and up to just above 6 °C.

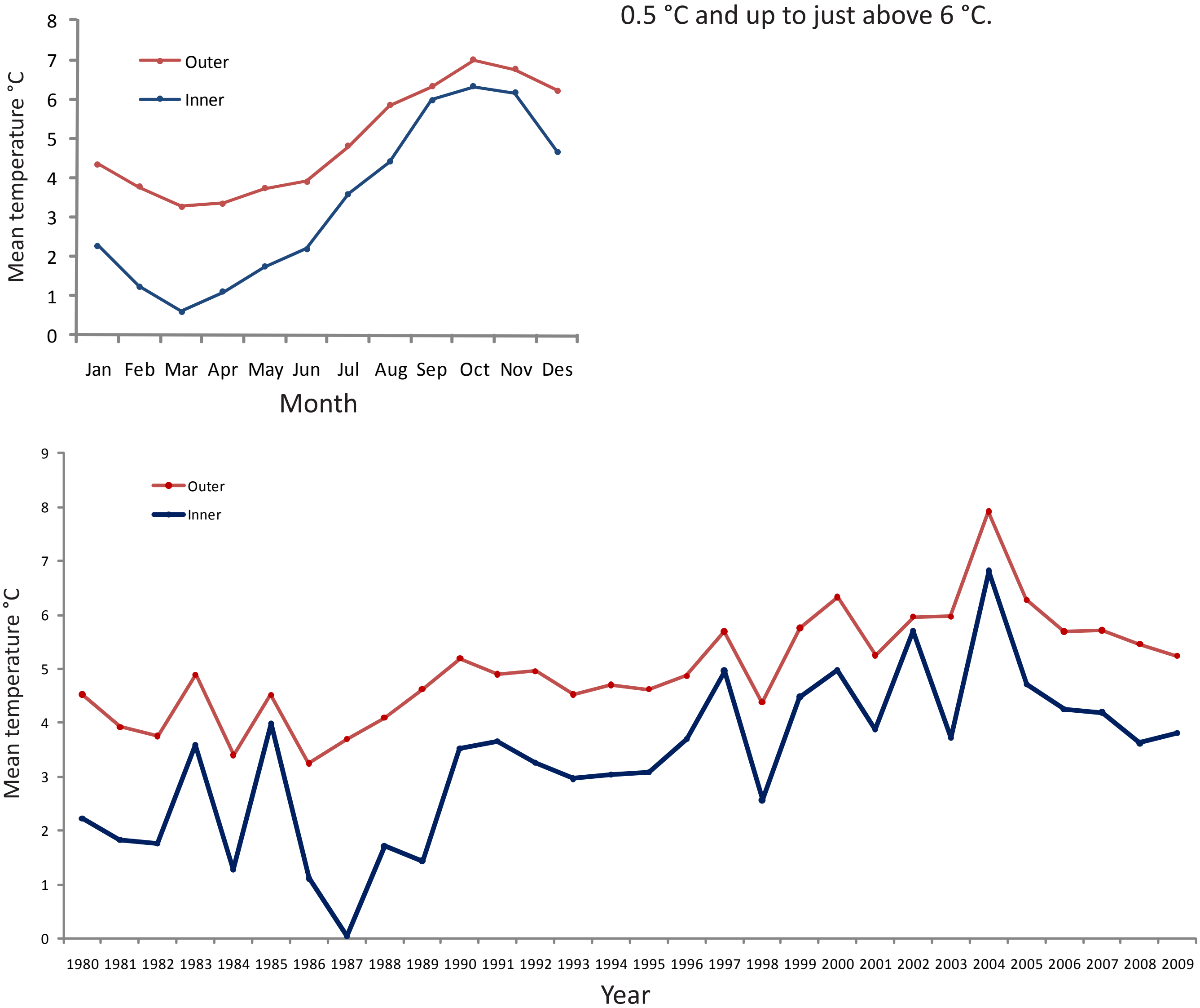


Figure 22. Mean temperature in Porsangerfjord at 150 m depth for one station in the inner part (Porsanger Inner West. Position: 70°21.0 N; 25°14.9 E) , and one in the outer part (Porsangnes West, position: 70°52.5 N; 26°01.0 E). See Fig. 5. Top panel shows mean temperature by month from 1980 - 2009 and bottom panel shows mean temperature from 1980 - 2009. Few measurements (n < 3) for year 1984, 1985, 1988, 1989, 1996 and 2004. (Data from Porsangerfjord provided by Mankettikkara and Eilertsen, 2010, pers. com., UiT, BFE.)

4 DISCUSSION

The first part of the discussion contains a list of major findings, followed by a chapter on sources of errors and evaluation of data. In the second part, each hypothesis will be discussed separately. The third part is a general overview considering factors influencing growth directly and indirectly in relations to the findings, and with future investigations and conclusive remarks at the end.

4.1 MAJOR FINDINGS

CC dominated the catches both in 1992 and 2009. The major findings are:

- No cod was caught in area D in 2009, in contrast to 1992 were cod (CC) was most abundant.
- In the outer areas (A - B) adult cod, above 5 years of age, were longer at age in the second time period (2000s) than cod from the first time period (1980s).
- Adult cod grew faster in the outer areas (A - B) than in the inner areas (C - D) in 1992.
- In the outer areas (A -B) cod had better growth for 1 year old, and 5 - 7 year old, than in the inner area (C) in 2009.
- Cod above age 4 had higher growth rate in 2009 than in 1992.
- All age groups had a strong year class effect in 1992. In contrast, there was a weaker year class effect only for age group 2-5 in 2009.
- Growth rates for 1-2 year old cod were well synchronised in both time periods.
- Good growth years for age groups 1 - 2 was not good growth years for adult fish in the same years.

4.2 SOURCES OF ERRORS

The process from catching cod to measuring the otolith zones consists of many stages, and during these different stages several factors may occur and bias the results. The most critical factors to obtain good results from back-calculations of previous length at age of cod in this thesis are (i) the selectivity of the trawl gear, (ii) ageing and typing of cod from the otoliths, and (iii) the accuracy of where the otoliths were cut and measuring zones from pictures.

(i) Trawling was not possible to conduct in some preferred locations, due to rocky bottom, bad weather or local fishing gear at the sites. In the western part of area A fishing gear was observed in 2009, and therefore trawling for cod in this area was limited, and had to be done further east. In an experiment of escapement of gadoid fish beneath a commercial bottom trawl conducted by Ingólfsson and Jørgensen (2006), cod escape rates were highly length-dependent, and L_{50} (length at 50 % escape, sigmoid curve) was estimated to 38.5 cm. Approximately 33 % of the cod available to the trawl escaped. Underwater video recordings and photographs also revealed that the trawl rockhopper gear collided with and run over fish, including cod (Ingólfsson and Jørgensen, 2006). Larger cod have better swimming capacity and may escape the trawl (Huse et al., 2000), but endurance declines with decreasing temperature, and in cold water (below 5° C) small fish with poor swimming ability may escape, while larger fish with better swimming ability may be herded into the trawl, and the opposite are likely to happen in water with higher temperature (He, 1991). Pedersen and Pope (2003b) found that for small cod, the trawl has higher selectivity, and for cod longer than 45 cm selectivity flatten out, and for larger cod this indicates a slight decrease in selectivity. There are especially few young cod (0-2 years of age) and > 8 years of age. Combined, all these factors may have excluded mostly young individuals important to the study. The back-calculating method compensate the lack of young cod since most cod used in the study are > 2 years of age, and therefore all contribute to the mean length at age, at age 1 and 2. The results are regarded valid.

(ii) Age reading of otoliths is a commonly used tool in fishery science, since it has a high potential for accuracy, and is a relatively fast and cheap method. Nevertheless, the method bears the risk of error. It is of greatest importance to use an experienced reader in order to be able to read age in otoliths correctly (Gjøsæter and Lønnhaug 1990). Some otoliths are easy to read, whereas others may have false zones or even a missing annulus (Fuiman and Werner, 2002). Cod caught in 2009 was age read by an expert on cod otoliths in Norway, who pointed out that cod from Porsangerfjord are difficult to age and type read (P. Ågotnes, 2010 pers. com., IMR, Bergen). Ageing and typing, on both broken and cut otoliths sampled in 1992 and 2009 in this study, was done by an experienced reader, whereas the measuring and cutting of the otoliths was done by the author, who is a novice in reading and measuring otoliths. Misinterpretation of age, too young or too old, could lead to over- or underestimation of length at age. Nevertheless, since age reading was done by an expert and questionable otoliths was removed, the result are regarded valid.

(iii) There are several methods of back-calculation of previous length at age in use. All methods have pitfalls, and errors are hard to avoid (see e.g. Campana, 1990; Li et al., 2008). One important factor, which can be crucial to the back-calculation is keeping the core of the otolith intact when cutting the otolith. The ideal cut is in the middle of the core. The core is the first summer zone, where the age-determination starts. Gjøsæter and Lønnhaug (1990) found that deviation of back-calculated length, assuming direct proportionality between fish length and otolith diameter, normally will be < 5 % if the cut of the otolith does not go through the core (tested on transversely broken otoliths and sagittally grounded). Further, Gjøsæter and Lønnhaug (1990) concluded that, even though this could give an underestimation of back-calculated length at age, it will be a satisfactory basis for the back-calculation of growth, if age reading are done by an experienced otolith reader. Taking this into account the back-calculating method used are regarded valid.

4.2.1 Evaluation of data

The data material is to a certain extent unbalanced with regards to numbers in each age group. Fish of age group 1 - 2 (zone 1 - 2) at catch, were poorly represented in the material, but with back-calculation of length at age all individuals analysed had data for length at zone 1 - 2. In contrast, for cod older than 8-9 years of age there were few cod otoliths for back-calculations of length at age. Trawling is not the best method for catching juveniles, so to obtain cod between 0 - 2 years of age other supplying catching methods (e. g. gill nets, long line and fine meshed plankton nets) could have been used more extensively in areas were trawling is impossible, also close to the shore. Few old cod may be explained by the intense fishing effort the past decades on fast growing mature cod (Jørgensen, 1990), or that they are more able to avoid the trawl than smaller cod (Huse et al., 2000). Further, differences in sampling time may bias the results of the two periods (1992 and 2009), comparison of the two time periods and between areas in Porsangerfjord.

To reduce bias, fish with uncertain typing (uCC and UNEAC) were not included in the hypothesis tests. Data with uncertainties can not provide good information about the population. Due to poor data material for age, years, areas or types, it is not easy to achieve statistical tests to verify differences. NEAC were poorly represented in the data material, so no conclusive statement regarding

NEAC are possible to give based on material from this study only.

All cod otoliths were at the start of the study expecting to manage the embedding and sawing process. All were prepared for the task (whole or half measured otolith), taking into account that some damage could occur to otoliths during processing. This strategy was chosen to secure a good study material, even if some otoliths were damaged in the process and had to be excluded.

4.3 SPATIAL VARIABILITY IN GROWTH (1)

4.3.1 Habitat

Cod in Porsangerfjord inhabit watermasses of low mean temperatures , 0 - 9 °C (Fig. 22). Growth rates increases with rising temperature until an optimum growth temperature is reached, assuming enough available prey (Jørgensen, 1992). Outer areas were warmest, and CC in outer areas show increased length at age, both for adult cod caught in 1992 and 2009, with especially good growth for adult cod in 2009. In 2009, adult cod had higher length at age in area B. In 2009, there are few old CC (age > 5 years) in inner area. In 1992, adult cod had slower growth and stayed in the innermost areas. Growth decreases after maturation (Berg and Pedersen, 2001), and this may indicate spawning in inner areas, and explain why adult cod seems to prefer inner areas in the first time period. Perhaps there were minor migrations among areas for adult cod in 1992.

Back-calculated length at age show faster growth in 1992 for CC in outer area (A - B) than in inner area (C - D) for fish 1 - 4 years of age. In contrast, faster growth are found for age 5 - 7 in outer area in 2009. This indicates a shift from favourable conditions in outer area for mostly young cod in the first time period (1980 - 1992), to the youngest and oldest in the second time period (1998 - 2009). Vinje et al. (2003) found similar spatial structures for cod in the Barents Sea at age 2 - 4, following the temperature gradient in the Barents Sea. The effect was decreasing with higher ability to migrate at older age. This suggest that cod seeks habitat with warmer temperature if possible.

4.3.2 Local stocks?

The results indicates that there has been a shift from abundance of cod in the inner areas towards the outer areas. A possible explanation may be that fish at different ages have access to various food sources and stay in other areas in the fjord. Old cod caught in 1992 seem to prefer the inner parts of the fjord where better growth is gained, while cod caught in 2009 gains better length at age in the outer parts of the fjord. It appears to be a shift from an abundant habitat for cod in the inner part and outward in Porsangerfjord from the 1980s to 2000s. It is known that a fish stock may consist of several local components (Kritzer and Sale, 2004). Cod in area C and D had very similar growth pattern in 1992, and may belong to the same component of sub-stock. If this was the situation in the inner area (D) of Porsangerfjord in 1992, a possible explanation may be that this local component has decreased, and moved outward in the fjord to area C. Another possible explanation may be that the innermost component has been depleted down.

In summary warmer sea temperature in the second time period and a shift to more abundance of cod in the outer areas in the last time period are the main reason for increased growth of adult cod in the last time period (1980 - 2009). The hypothesis of no differences in length at age in inner and outer part of Porsangerfjord is rejected on the basis that the findings are valid.

4.4 CHANGES IN GROWTH RATE BETWEEN YEARS (2)

4.4.1 Temperature

1981 was a relatively cold year (Fig. 22), generally there were cold periods before and in the 1980s, and warm periods from the 1990s (Fig. 23). According to Eilertsen and Skarehamar (2006) the cold temperature anomalies for station Porsanger were in periods 1980 - 1982; 1985 - 1988; 1993 and 1998 in Porsangerfjord. Warm periods were 1989 - 1992, 1994, 1997, 1999 - 2002. No warm or cold trends were identified due to data close to the means and small deviations (ibid).

Despite consistent decline of Porsangerfjord cod population, there was a strong year class in 1989 in Porsangerfjord (3 years when caught), with the largest length at age 1 in this study. This consist with the theory that warm years give strong year classes (Brander, 1994), and 1989 was a warm year (Fig. 22) and capelin was abundant in 1990-1992. Increasing water temperature in combination with increasing capelin ratio are positively related to growth in length of cod (Jørgensen, 1992). An indication of how important temperature is on growth, is demonstrated in an weight-at-age experiment, and shows that a 4 year old cod increases 29% per 1 °C increase (Brander, 1994).

4.4.2 Change in abundance

There are no trustworthy statistics on commercial cod landings in Porsangerfjord in the two time periods, 1981 - 1992 and 1998 - 2009, but acoustic surveys done by IMR started in 1996 (Fig. 23) estimated the cod biomass to 6 000 tons in 1995, and less than 1 000 tons in 2008 (K. Sunnanå, 2010, pers. com., IMR, Tromsø). It is expected that the biomass in 1992 were approximately the same as in 1995, but prior to this estimates there are no available estimations of cod biomass in Porsangerfjord. Decreased abundance for cod in the last time period may lead to better growth for the surviving cod in Porsangerfjord. Assum-

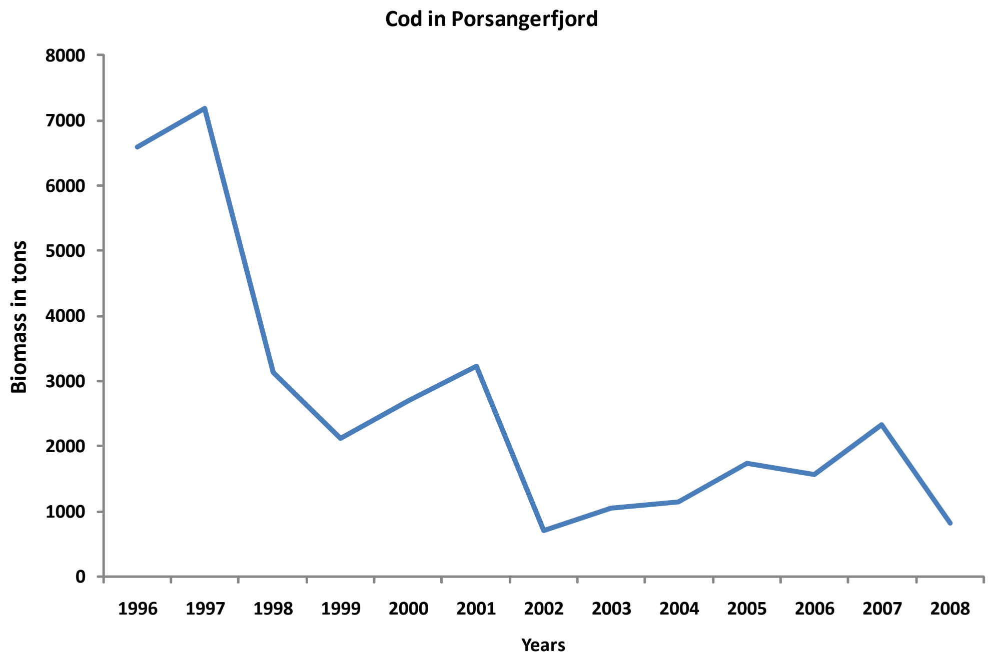


Figure 23. Estimated cod biomass (tons) 1996 - 2008 in Porsangerfjord from IMR acoustic surveys (K. Sunnanå, 2010, pers. com., IMR, Tromsø).

ing available prey, more prey are available for the remaining fish and food combined with increasing temperature indicates good conditions for growth (Jørgensen, 1992; Brander, 2007).

4.4.3 Density-dependent growth

A possible explanations for change in length at age may be density-dependent growth (Bax, 1998). For cod caught in 2009, old fish, above 5 years of age, had longer length at age than cod caught in 1992. There are also indications from the three 2009 cruises that food supply is good, due to the fact that there were much northern shrimp, capelin, herring and krill in the trawl hauls (T. Pedersen, pers. com., UiT, BFE), which are key species in the cod diet at high latitudes (Kanapathippillai et al., 1994).

Despite no estimates of cod biomass prior to 1995, one might not expect much higher estimates of cod than approximately on the 1996 level (Fig. 23), at least back until 1987. According to H. Sætrum (2010, pers. com., Sætrum fiskekjøp AS, Russenes) fish catches (all species included) in the 1987 - 1989 period decreased from normally 6 - 700 tons to under 100 tons a year. Assuming that the cod proportion in the catches were high, it indicates more fish in the fjord in the early 1980s. Due to the depleted cod biomass in Porsangerfjord, density-dependent growth is probably not a major issue, neither for cod living in the first time period (1980s) or the second time period (2000s), this consist with the statement from Brander (2007) addressing density-dependent growth only when food is limited. If density-dependent growth has affected growth, it probably would have been in the beginning of the 1980.

In summary warmer sea temperature and less density in the last time period may be the main reasons for increased growth of adult cod in the last time period (1980 - 2009). Hypothesis two states no change in growth patterns between cod caught in 1992 and 2009. The hypothesis is rejected, and the result are regarded reliable.

4.5 DIFFERENCES IN GROWTH PATTERN BETWEEN YEAR CLASSES (3)

The much large differences in length at age in between year classes sampled in 1992 compared to 2009 may indicate different temperature in the first time period and fluctuations in food availability. With less fish in the fjord in the last time period minor effects of density differences between years may have occurred. This consists with the temperature variability mentioned earlier.

In summary fluctuations in temperature and food may have caused differences in growth pattern between year classes. The hypothesis of equal otolith pattern between the two sampling years, 1992 and 2009, are rejected on the basis that the findings are valid.

4.6 TEMPORAL SYNCHRONISATION IN AGE GROUPS (4)

In the first period, the synchronisation in growth rates between age 1 - 2 indicates that cod during age 1 and 2 may inhabit the same area. Area C seems to provide good feeding conditions for young cod. Good growth year for cod at age 1 - 2 did not occur in the same years as good growth years for older fish. This may indicate different feeding habits at different ages, and possibly that cod are present in different areas at different ages. CC caught in 1992, had higher mean length age at age 2 in outer area, and CC caught in 2009 had higher mean length at age at age 1 in inner area. Areas with good feeding grounds may differ from year to year depending on temperature and available food. Adult cod caught in 2009 seems to inhabit outer deeper and warmer areas, and adult cod caught in 1992 seems to inhabit inner colder areas.

In summary this may indicate different feeding habits at different ages, and possibly that cod are present in different areas at different ages. The hypothesis of no synchronisation of growth rate are rejected on the basis that the findings are valid.

4.7 GENERAL DISCUSSION

So far factors influencing individual growth in cod has been discussed. There are other factors that may affect growth in the entire cod population biomass. In Porsangerfjord the estimated coastal cod biomass has declined dramatically (Fig. 23), despite the findings in this study showing increased mean length at age for adult cod in 2009, in contrast to 1992. So, why does the population biomass still seem to decline? The complete answer to this question is beyond the scope of this thesis, but some reflections may be in order.

4.7.1 Kelp and sea urchins

Survival of young cod imply rapid growth and shelter from predators. Kelp forests provide protection from predators and are important to the whole ecosystem with the variety in marine animals and plants. For most fish near the kelp forest the invertebrate fauna is an important food source (Norderhaug and Christie, 2009). A work by Hamilton and Konar, (2007) in south - central Alaska investigated interactions between kelp beds and fish communities, and found kelp important as habitat for several species of fish. This supports the importance of kelp forests to cod in Porsangerfjord. In Finnmark, grazing from sea urchins on kelp forests leaving areas as barren grounds may still be increasing (Sivertsen, 2006). Grazing is most severe in the inner parts of Porsangerfjord (T. Pedersen, 2010, pers. com, UiT, BFE).

In Porsangerfjord, were sea urchins have been removed from a sea bed area in October 2008, kelp forests have slowly recovered in the past year (Agnalt et al., 2009; Gjøsæter et al., 2010), and the area are now rich in kelp forest. Cod juveniles are seen in this rebuilt kelp forest area (Gjøsæter et al., 2010). This may indicate that if sea urchins are removed, the result probably will be better nursery habitat for juvenile cod, and may increase survival and hence better growth of juvenile cod. Temperature are probably also an important factor in the kelp-sea urchin ecology.

Kelp forests disappeared before the decline of coastal fish stocks (e.g. cod stocks), and this may be a possible cause for the decline in coastal fish stocks (Norderhaug and Christie, 2009), but a self-reinforcing process caused by over-fishing may have started with low predation on sea urchins from fish stocks, starting the loss of kelp forests, and then in turn loosing the nursery habitat (Norderhaug and Christie, 2009). The kelp-urchin process does not affect growth in cod directly, but the loss of kelp production will disturb the food chains in coastal ecosystems who rely on primary and secondary production export from kelp forests to ecosystems in shallow and deep water (Norderhaug and Christie, 2009). This may indicate an indirect slow growth in juvenile cod and consequently high mortality.

4.7.2 Seal invasions

The harp seal invasion along the Norwegian coast in 1986 - 1988 caused a huge impact on the cod population (Nilssen et al., 1992; Ugland et al., 1993). In Finnmark, cod and capelin dominated the seal diet. In 1987 harp seals consumed 41.000 ± 10.300 tons of cod off Norway (Ugland et al., 1993). For the 1985 cod year class, and the 1985 and 1986 year classes of saithe Ugland et al. (1993), estimated that totally 110 million individuals (± 25 mill. ind.) were consumed. In

Porsangerfjord, the findings of Ugland et al. (1993) indicates that the seal invasion probably have effected the coastal cod population extensively, since estimated cod biomass keeps declining (Fig. 23).

4.7.3 Capelin and herring

There was a shift from a cold temperature regime to a warm in 1989 in the Barents Sea (Kjesbu et al., 1998). Barents Sea capelin, an important prey for cod, were present in low numbers in 1986, and high in 1991 (Kjesbu et al., 1998). An increase in growth in zone 1 from year class 1989 - 1992 and is consistent with both a warm regime and much capelin available from 1991. Growth rates for cod increases with increasing temperature and enough available food (Jørgensen, 1992; Brander, 1994).

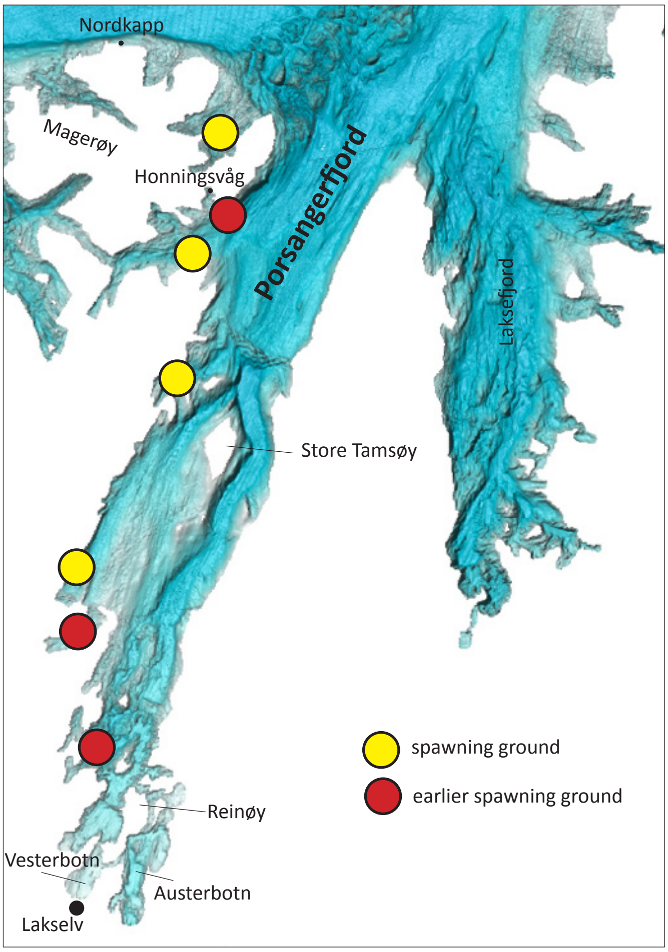


Figure 24. Spawning grounds in Porsangerfjord according to Maurstad and Sundet (1998). Map modified from Maurstad and Sundet (1998) and www.mareano.no.

In the early 1980s there was a relative cold temperature period which indicates slow/decreased growth, and this together with less capelin prey, and the extended harp seal predation on the cod population it is likely to influence the decline in the coastal cod population. Further, this decline in density may lead to increased growth for the remaining cod in the fjord.

There was almost no Norwegian spring-spawning herring in Norwegian waters from the mid 1960 until 1983 (Moksness and Øiestad, 1987), but this may not have effected the food resources of the cod population in dramatic ways in the two time periods studied.

4.7.4 «Top-down»

When top predators, like cod, decline in an ecosystem, the balance between predator and prey populations becomes disturbed (Frank et al., 2007). This may delay the recovery of the top predator, even if the ecosystem are in good health, because the prey species and predator then competes for food, or prey species feed on the early life stages, eggs and larvae, of the predator. This so called «top-down» situations is known for herring who eats cod eggs and larvae (Frank et al., 2007; Sundby and Nakken, 2008). If this is the situation in Porsangerfjord it could contribute to why the coastal cod population do not recover even other favourable factors, both biotic and abiotic are present in the fjord (e.g. food, shelter for young, optimal temperature and minimum fishing effort). In the area with no cod in 2009 (area D) there was much shrimp in the trawl hauls. This correspond to the acoustic biomass estimation of less than 1 000 tons of fish in Porsangerfjord, and relatively large catches of shrimp in 2009 cruises. This is also a typical situation in a top-down ecosystem (Frank et al., 2005).

4.7.5 Spawning and spawning grounds

Because of high fishing pressure over the last decades, cod mature earlier and the age of sexual maturation declines. This is not an advantage to the population due to poorer egg quality in first-time spawners and young adults (Trippel, 1998). Generally the average age at maturation for CC are 5 - 6 years at 40 - 50 cm lengths (Stransky et al., 2008). If the innermost component of cod in 1992 has been depleted down, this may consist with the reduction of spawning grounds in the inner part of Porsangerfjord (Fig. 24 Maurstad and Sundet, 1998).

The general discussion has looked at factors like harp seal invasions, kelp - sea urchin interactions, fishing, capelin fluctuations and a possible shift towards a top-down govern ecosystem in Porsangerfjord. These factors does not effect growth of individual cod, but may be influencing, and perhaps delaying the recovery of the coastal cod population in Porsangerfjord, in such a way that increasing the population biomass may be difficult in near future.

4.8 COASTAL COD IN THE FUTURE

Even if fishing play a minor role in the decline of coastal cod population, this is the only factor humans may influence in a short time perspective. ICES have since 2004, including 2010, for Norwegian CC recommended no quota north of 62°N (Gjøsæter et al., 2010). Regardless of ICES recommendation the quota for 2010 are 21 000 tons. One way to avoid high proportions of CC in catches may be no fishing in crucial areas in Porsangerfjord during a year or even a period of time so both young an adult fish survives. A main goal should be to keep old fish in the population, and a possible way to do this is by fine tuning selection in fishing gear, or, as suggested above, fishing rotation by area and year in Porsangerfjord. At this point in time it is hard to see rapid recovery of the CC population without drastic action. Total fishing stop in Porsangerfjord should be considered, in collaboration with local fishers, assuming the decline persist.

4.9 FUTURE INVESTIGATIONS

Maybe otolith reading in the future could be standardized from pictures, and maybe automatized with optical age reading. It should be possible to make the whole process more automatic, even if otoliths first had to be embedded in some form and transversely cut before photographing. More knowledge of where young cod spend their first years should be investigated, in aspect to see where in Porsangerfjord they stay in early years, and to what extend the kelp-urchin interactions influences life of young cod. In addition, the data material provides several possibilities for investigation, and further study should include dealing with maturity and spawning age. Data for spawning age is available for cod caught in 2009. For cod caught in 1992, such information could easily be obtained from the cross-cut otolith pictures. Estimating length at age from back-calculating is a time consuming method. There are also possibilities to do weight-at-age analysis.

4.10 CONCLUSION

In conclusion, increasing sea temperature seem to play maybe the most important role in increased mean length at age for adult cod caught in 2009, compared to cod caught in 1992. In addition, a shift from abundance of cod in inner areas with cold sea temperature in 1992, towards outer warmer areas in 2009 has probably also contributed to increased length at age for older cod.

5 REFERENCES

AGNALT, A.-L., BAKKETEIG, I. E., HAUG, T., KNUTSEN, J. A. & OPSTAD, I. (2009). Kyst og Havbruk 2009. In *Fisken og havet, særnummer 2-2009*. [in Norwegian]

ÁLVAREZ, A., MORALES-NIN, B., PALMER, M., TOMÁS, J. & SASTRE, J. (2008). A two-dimension otolith growth inverse model. *Journal of Fish Biology* **72,** 512-522.

BAX, N. J. (1998). The significance and prediction of predation in marine fisheries. *ICES Journal of Marine Science* **55,** 997-1030.

BERG, E. & ALBERT, O. T. (2003). Cod in fjords and coastal waters of North Norway: distribution and variation in length and maturity at age. *ICES Journal of Marine Science* **60,** 787-797.

BERG, E. & PEDERSEN, T. (2001). Variability in recruitment, growth and sexual maturity of coastal cod (*Gadus morhua* L.) in a fjord system in northern Norway. *Fisheries Research* **52,** 179-189.

BERGSTAD, O. A., JØRGENSEN, T. & DRAGESUND, O. (1987). Life history and ecology of the gadoid resources of the Barents Sea. *Fisheries Research* **5,** 119–161.

BRANDER, K. M. (1994). Patterns of distribution, spawning, and growth in North Atlantic cod: The utility of inter-regional comparisons. In *Cod and climate change - proceedings of a symposium, held in Reykjavik*, vol. 198, pp. 406-413.

BRANDER, K. M. (1995). The effect of temperature on growth of Atlantic cod (*Gadus morhua* L.). *ICES Journal of Marine Science* **52,** 1-10.

BRANDER, K. M. (2007). Food for thought The role of growth changes in the decline and recovery of North Atlantic cod stocks since 1970. *ICES Journal of Marine Science* **64,** 211-217.

CAMPANA, S. E. (1990). How reliable are growth back-calculations based on otoliths? *Canadian Journal of Fisheries and Aquatic Sciences* **47,** 2219–2227.

CHRISTENSEN, V., GUENETTE, S., HEYMANS, J. J., WALTERS, C. J., WATSON, R., ZELLER, D. & PAULY, D. (2003). Hundred-year decline of North Atlantic predatory fishes. *Fish and Fisheries* **4,** 1-24.

EILERTSEN, H. C. & SKARDHAMAR, J. (2006). Temperatures of north Norwegian fjords and coastal waters: Variability, significance of local processes and air–sea heat exchange. *Estuarine, Coastal and Shelf Science* **67,** 530-538.

FRANK, K. T., PETRIE, B., CHOI, J. S. & LEGGETT, W. C. (2005). Trophic cascades in a formerly cod-dominated ecosystem. *Science (New York, N.Y.)* **308,** 1621-3.

FRANK, K. T., PETRIE, B. & SHACKELL, N. L. (2007). The ups and downs of trophic control in continental shelf ecosystems. *Trends in ecology & evolution (Personal edition)* **22,** 236-42.

FUIMAN, L. A. & WERNER, R. G. (2002). *Fishery Science, The unique contributions of early life stages*, 1 edition. Blackwell Publishing.

GARMIN. (2009). BlueChart Atlantic 6.5. [Data program]

GJØSÆTER, H., HAUG, T., HAUGE, M., KARLSEN, Ø., KNUTSEN, J., RØTTINGEN, I., SKILBREI, O. & SUNNSET, B. H. (2010). Havforskningsrapporten 2010. *Fisken og havet, særnummer 1 - 2010*. [in Norwegian]

GJØSÆTER, J. & LØNNHAUG, K. (1990). Short Communication Back-calculation of growth from broken cod otoliths. *Fisheries Research (Netherlands)* **9,** 283-286.

GODØ, O. R. & HAUG, T. (1999). Growth Rate and Sexual Maturity in Cod (*Gadus morhua*) and Atlantic Halibut (*Hippoglossus hippoglossus*). *Journal of Northwest Atlantic Fisheries Science* **25,** 115-123.

HAMILTON, J. & KONAR, B. (2007). Implications of substrate complexity and kelp variability for south-central Alaskan nearshore fish communities. *Fishery Bulletin* **105(2),** 189-196.

HE, P. (1991). Swimming endurance of the Atlantic cod, *Gadus morhua* L., at low temperatures. *Fisheries Research* **12,** 65-73.

HUSE, I., LØKKEBORG, S. & SOLDAL, A. V. (2000). Relative selectivity in trawl, longline and gillnet fisheries for cod and haddock. *ICES Journal of Marine Science* **57,** 1271-1282.

HUTCHINGS, J. A. (2000). Collapse and recovery of marine fishes. *Nature* **406,** 882-885.

HØIE, H., MILLNER, R. S., MCCULLY, S., NEDREAAS, K. H., PILLING, G. M. & SKADAL, J. (2009). Latitudinal differences in the timing of otolith growth: A comparison between the Barents Sea and southern North Sea. *Fisheries Research* **96,** 319-322.

INGÓLFSSON, Ó. A. & JØRGENSEN, T. (2006). Escapement of gadoid fish beneath a commercial bottom trawl: Relevance to the overall trawl selectivity. *Fisheries Research* **79,** 303-312.

JAKOBSEN, T. (1987). Coastal cod in northern Norway. *Fisheries Research (Netherlands)* **5,** 223-234.

JENKE, J. (2002). A guide to good otolith cutting. *Fisheries Research* **141**.

JØRGENSEN, T. (1990). Long-term changes in age at sexual maturity of Northeast Arctic cod (*Gadus morhua* L.). *ICES Journal of Marine Science* **46,** 235.

JØRGENSEN, T. (1992). Long-term changes in growth of North-east Arctic cod (*Gadus morhua*) and some environmental influences. *ICES Journal of Marine Science* **49,** 263-277.

KANAPATHIPPILLAI, P., BERG, E., {DOS SANTOS}, J., GULLIKSEN, B. & PEDERSEN, T. (1994). The food consumption of cod, *Gadus morhua* L., in a high-latitude enhancement area. *Aquaculture and Fisheries Management.***,** 65-76.

KJESBU, O. S., WITTHAMES, P. R., SOLEMDAL, P. & WALKER, M. G. (1998). Temporal variations in the fecundity of Arcto-Norwegian cod (Gadus morhua) in response to natural changes in food and temperature. *Journal of Sea Research* **40,** 303-321.

KRITZER, J. P. & SALE, P. F. (2004). Metapopulation ecology in the sea: from Levins' model to marine ecology and fisheries science. *Fish and Fisheries* **5,** 131-140.

LI, L., HØIE, H., GEFFEN, A. J., HEEGAARD, E., SKADAL, J. & FOLKVORD, A. (2008). Back-calculation of previous fish size using individually tagged and marked Atlantic cod (*Gadus morhua*). *Canadian Journal of Fisheries and Aquatic Sciences* **65,** 2496-2508.

LØKEN, S., PEDERSEN, T. & BERG, E. (1994). Vertebrae numbers as an indicator for the recruitment mechanism of coastal cod of northern Norway. In *ICES marine science symposia. Copenhagen [ICES MAR. SCI. SYMP.]. 1994.*, pp. 510-519.

LØVÅS, G. G. (2004). *Statistikk for universiteter og høgskoler*, 2. utgave, 3. opplag 2008 edition. Universitetsforlaget. [in Norwegian]

MAURSTAD, A. & SUNDET, J. H. (1998). The invisible cod - fishermen's and scientists' knowledge. In *Commons in a cold climate. Coastal fisheries and reindeer pastoralism in North Norway: the co-management approach*, vol. 22. *Man and the biosphere series* (ed. S. Jentoft), pp. 167-184. Parthenon Publishing Group, Tromsø.

MICHALSEN, K., OTTERSEN, G. & NAKKEN, O. (1998). Growth of North-east Arctic cod (*Gadus morhua* L.) in relation to ambient temperature. *ICES Journal of Marine Science* **55,** 863-877.

MJANGER, H., HESTENES, K., OLSEN, E., SVENDSEN, B. V., WENNECK, T. D. L. & AANES, S. (2007). Håndbok for prøvetaking av fisk og krepsdyr (prosedyre for håndbok for prøvetaking av fisk og krepsdyr) [Handbook for sampling fish and crustacean]. Institute of Marine Research/ Havforskningsinstituttet. [in Norwegian]

MOKSNESS, E. & ØIESTAD, V. (1987). Interaction of Norwegian spring-spawning herring larvae (Clupea harengus) and Barents Sea capelin larvae (Mallotus villosus) in a mesocosm study. *ICES Journal of Marine Science* **44,** 32-42.

MORITA, K. & MATSUISHI, T. (2001). A new model of growth back-calculation incorporating age effect based on otoliths. *Canadian Journal of Fisheries and Aquatic Sciences* **58,** 1805–1811.

NEAT, F., WRIGHT, P. & FRYER, R. (2008). Temperature effects on otolith pattern formation in Atlantic cod Gadus morhua. *Journal of Fish Biology* **73,** 2527–2541.

NILSSEN, K. T., GROTNES, P. E. & HAUG, T. (1992). The effect of invading harp seals (*Phoca groenlundica*) on local coastal fish stocks of North Norway. *Fisheries Research (Netherlands)* **13,** 25-37.

NORDERHAUG, K. M. & CHRISTIE, H. C. (2009). Sea urchin grazing and kelp re-vegetation in the NE Atlantic. *Marine Biology Research* **5,** 515 - 528.

NØSTVIK, F. & PEDERSEN, T. (1999). Catching cod for tagging experiments. *Fisheries Research* **42,** 57–66.

OTTERLEI, E., NYHAMMER, G., FOLKVORD, A. & STEFANSSON, S. O. (1999). Temperature- and size-dependent growth of larval and early juvenile Atlantic cod (*Gadus morhua*): A comparative study of Norwegian coastal cod and northeast Arctic cod. *Canadian Journal of Fisheries and Aquatic Sciences* **56,** 2099-2111.

OTTERSEN, G., HJERMANN, D. O. & STENSETH, N. C. (2006). Changes in spawning stock structure strengthen the link between climate and recruitment in a heavily fished cod (*Gadus morhua*) stock. *Fisheries Oceanography* **15,** 230-243.

OTTERSEN, G. & LOENG, H. (2000). Covariability in early growth and year-class strength of Barents Sea cod, haddock, and herring: the environmental link. *ICES Journal of Marine Science* **57,** 339-348.

OTTERSEN, G., MICHALSEN, K. & NAKKEN, O. (1998). Ambient temperature and distribution of north-east Arctic cod. *ICES Journal of Marine Science* **55,** 67-85.

OTTERÅ, H., AGNALT, A.-L. & JØRSTAD, K. E. (2006). Differences in spawning time of captive Atlantic cod from four regions of Norway, kept under identical conditions. *ICES Journal of Marine Science* **63,** 216-223.

PEDERSEN, T., AMUNDSEN, C. & WICKLER, S. (2009). Hva forteller torskens øresteiner om fisket i middelalderen og nå? [What does cod ear stones (otoliths) tell about fishery in the Middle Ages and now?]. In *Ottar*, vol. 1. [in Norwegian]

PEDERSEN, T., CUVELIERS, E. L. & BERG, E. (2008a). Spatial Scales of Movement in Northeast Atlantic Coastal Cod. *Reviews in Fisheries Science* **16,** 348-356.

PEDERSEN, T. & POPE, J. G. (2003a). How may feeding data be integrated into a model for a Norwegian fjord population of cod (*Gadus morhua* L.)? *Scientia Marina* **67,** 155-169.

PEDERSEN, T. & POPE, J. G. (2003b). Sampling and a mortality model of a Norwegian fjord cod (*Gadus morhua* L.) population. *Fisheries Research* **63,** 1–20.

PETHON, P. (2005). *Aschehoughs store fiskebok, Norges fisker i farger*, 5 edition. H. Aschehoughs & Co (W. Nygaard) A/S. [in Norwegian]

QUINN, G. P. & KEOUGH, M. J. (2002). *Experimental Design and Data Analysis for Biologists*. Cambridge University Press, Cambridge.

ROLLEFSEN, G. (1933). The Otoliths of the Cod. *Fiskeridirektoratets skrifter* **IV**.

ROLLEFSEN, G. (1934). The cod otolith as a guide to race, sexual development and mortality. *Rapports et Procès-Verbaux des Réunions du Conseil International Pour l'Exploration de la Mer* **136,** 40–47.

SANDNESENG, E. (2006). Variation in abundance, diet, otolith zone patterns and black spot disease of 0-group coastal cod in northern Norway. Master thesis, University of Tromsø.

SIVERTSEN, K. (2006). Overgrazing of Kelp Beds Along the Coast of Norway. *Journal of Applied Phycology* **18,** 599-610.

STIGE, L. C., OTTERSEN, G., BRANDER, K. M., CHAN, K.-S. & STENSETH, N. C. (2006). Cod and climate: effect of the North Atlantic Oscillation on recruitment in the North Atlantic. *Marine Ecology Progress Series* **325,** 227-241.

STRANSKY, C., BAUMANN, H., FEVOLDEN, S.-E., HARBITZ, A., HØIE, H., NEDREAAS, K. H., SALBERG, A.-B. & SKARSTEIN, T. H. (2008). Separation of Norwegian coastal cod and Northeast Arctic cod by outer otolith shape analysis. *Fisheries Research* **90,** 26-35.

SUNDBY, S. (2000). Recruitment of Atlantic cod stocks in relation to temperature and advection of copepod populations. *Sarsia* **85,** 277-298.

SUNDBY, S. & NAKKEN, O. (2008). Spatial shifts in spawning habitats of Arcto-Norwegian cod related to multidecadal climate oscillations and climate change. *ICES Journal of Marine Science***,** 953-962.

SVÅSAND, T., KRISTIANSEN, T., PEDERSEN, T., SALVANES, A., ENGELSEN, R., NAEVDAL, G. & NØDTVEDT, M. (2000). The enhancement of cod stocks. *Fish and Fisheries* **1,** 173–205.

TRIPPEL, E. A. (1998). Egg Size and Viability and Seasonal Offspring Production of Young Atlantic Cod. *Transactions of the American Fisheries Society* **127,** 339-359.

UGLAND, K. I., JØDESTØL, K. A., ASPHOLM, P. E., KROYER, A. B. & JAKOBSEN, T. (1993). Fish consumption by invading harp seals off the Norwegian coast in 1987 and 1988. *ICES Journal of Marine Science* **50,** 27-38.

VAN EMDEN, H. F. (2008). *Statistics for Terrified Biologists*. Blackwell Publishing Ltd.

VINJE, F., HEINO, M., DIECKMANN, U., GODO, O. & MORK, J. (2003). Spatial structure in length at age of cod in the Barents Sea. *Journal of Fish Biology* **62,** 549–564.

WILSON, J. A., VIGLIOLA, L. & MEEKAN, M. G. (2008). The back-calculation of size and growth from otoliths: Validation and comparison of models at an individual level. *Journal of Experimental Marine Biology and Ecology*.

WORM, B. & MYERS, R. A. (2003). Meta-Analysis of Cod–Shrimp Interactions Reveals Top-Down Control in Oceanic Food Webs. *Ecology* **84,** 162-173.

References from Internet

http://rsbweb.nih.gov/ij/download.html. (2010). ImageJ.

www.Google.com. (2010). Google Earth.

www.imr.no. (2009). Institute of Marine Research. Havforskningsinstituttet.

www.mareano.no. (2009). Mareano. Institute of Marine Research/Havforskningsinstituttet.

www.statkart.no. (2010). Statkart. www.statkart.no/filestore/ny/pressesenter/webtjenester/Gratis_data/Norge5mill_utenramme.jpg.

www.systat.com/MystatProducts.aspx. (2009). MYSTAT, student version of SYSTAT.

6 APPENDIX

Table 1. Numbers of fish in each type, sorted on area and year.

1992	A	B	C	D	Tot
CC	24	6	92	105	227
NEAC	11	0	0	6	17
uCC	2	0	9	7	18
uNEAC	11	0	4	4	19
Total	**48**	**6**	**105**	**122**	**281**

2009	A	B	C	Tot
CC	60	75	116	251
NEAC	15	3	2	20
uCC	32	21	8	61
uNEAC	24	8	10	42
Total	**131**	**107**	**136**	**374**

Table 2. Total numbers of fish in each type, sorted on area.

92+09	A	B	C	D	Tot
CC	84	81	208	105	478
NEAC	26	3	2	6	37
uCC	34	21	17	7	79
uNEAC	35	8	14	4	61
Total	**179**	**113**	**241**	**122**	**655**

92+09	A	B	C	D	Tot
1992	48	6	106	122	282
2009	133	109	137	0	379
Total	**181**	**115**	**243**	**122**	**661**

Table 3. Total numbers of fish for each year, sorted on area.

1992	A	B	C	D	Tot
female	29	3	50	60	142
male	19	3	56	62	140
Total	**48**	**6**	**106**	**122**	**282**

Table 4. Numbers of fish in each sex, sorted on area.

2009	A	B	C	Tot
female	65	65	66	196
male	68	44	69	181
Total	**133**	**109**	**135**	**377**

How to install ImageJ Otolith plugin.

In addition to the program ImageJ two other downloads from the Internet are needed. First search for ObjectJ and download the file "objectJ_jar", and save it, i. e in the same folder as ImageJ program files are located in "explore" (no: utforsker i. e: C:program files/ImageJ.) Download and save "Otolith-7.zip" (number may increase) from http://simon.bio.uva.nl/Bergen/otolith. From this Internet site download and save the read me and video files as well. Print the read me file, which is useful when using the otolith-7 plugin. Watch the video. Do as follow to install:

1. Open ImageJ
2. Find the saved "objectj_" file, i. e. located in the plugins folder (this folder is in the ImageJ folder; use explore (norwegian: utforsker); right click on start button and find i. e: C: program files/ImageJ/Plugin/ objectj_).
3. Drag this file to the ImageJ program; i. e. in the grey area below the icons.
4. In ImageJ click on the menu "Plugins" and now the "ObjectJ" should appear on the list - click ObjectJ and then this will be a new menu in ImageJ
5. Locate the "Otolith-7.zip" folder, right click on the folder and unzip (no: pakk ut). A new folder will appear in the ImageJ folder in "Explore" (no: utforsker) i. e: C:program files/ImageJ/Otolith 7). In this folder two files are very important "otolith-7.ojj" and "Otolith 7".
6. These two files must be dragged to the folder where the images of otoliths are located.
7. Then drag the file "otolith-7.ojj" also to the ImageJ program i. e. in the grey area below the icons.
8. If all this has been successfully done the program is ready to be used. Press F4 to open the first picture in the image folder.
9. Use the video and read me file to see how the program works and the marking of the zones is done.
10. After closing the program step 4 and 7 has to be done to continue where the job was finished.

A - OUTER PART

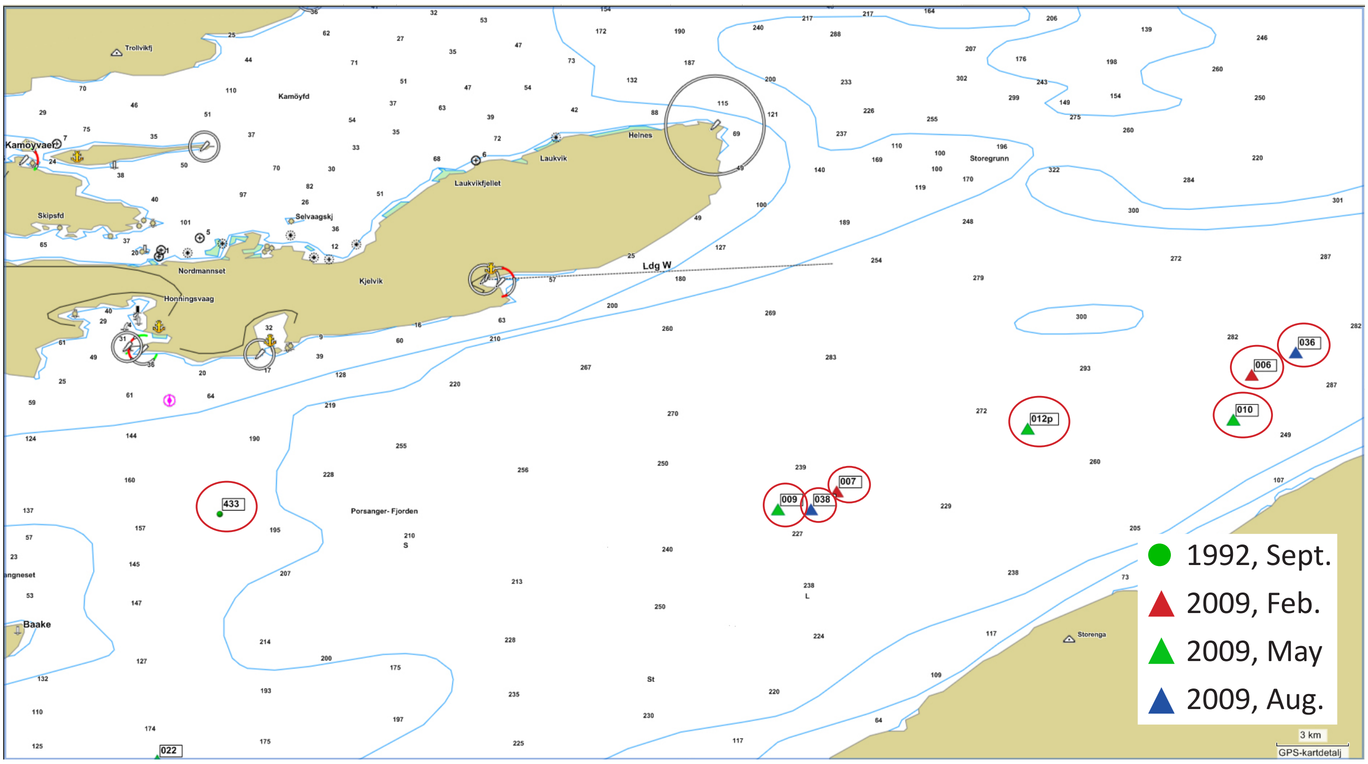


Figure 1. Trawl stations (hauls) in area A in Porsangerfjord. Stations plotted in Garmin, BlueChart Atlantic v6.5.

B - OUTER MIDDLE PART

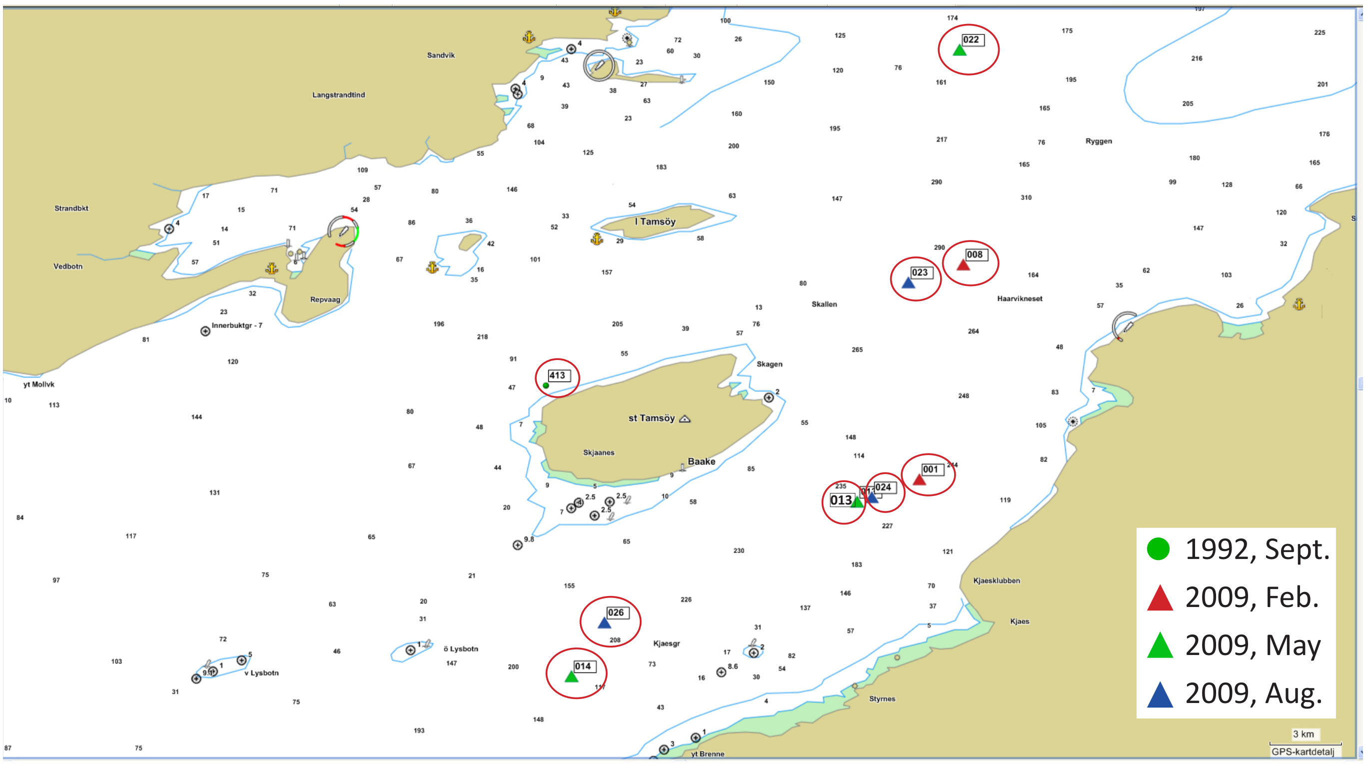


Figure 2. Trawl stations (hauls) in area B in Porsangerfjord. Stations plotted in Garmin, BlueChart Atlantic v6.5.

C - INNER MIDDLE PART

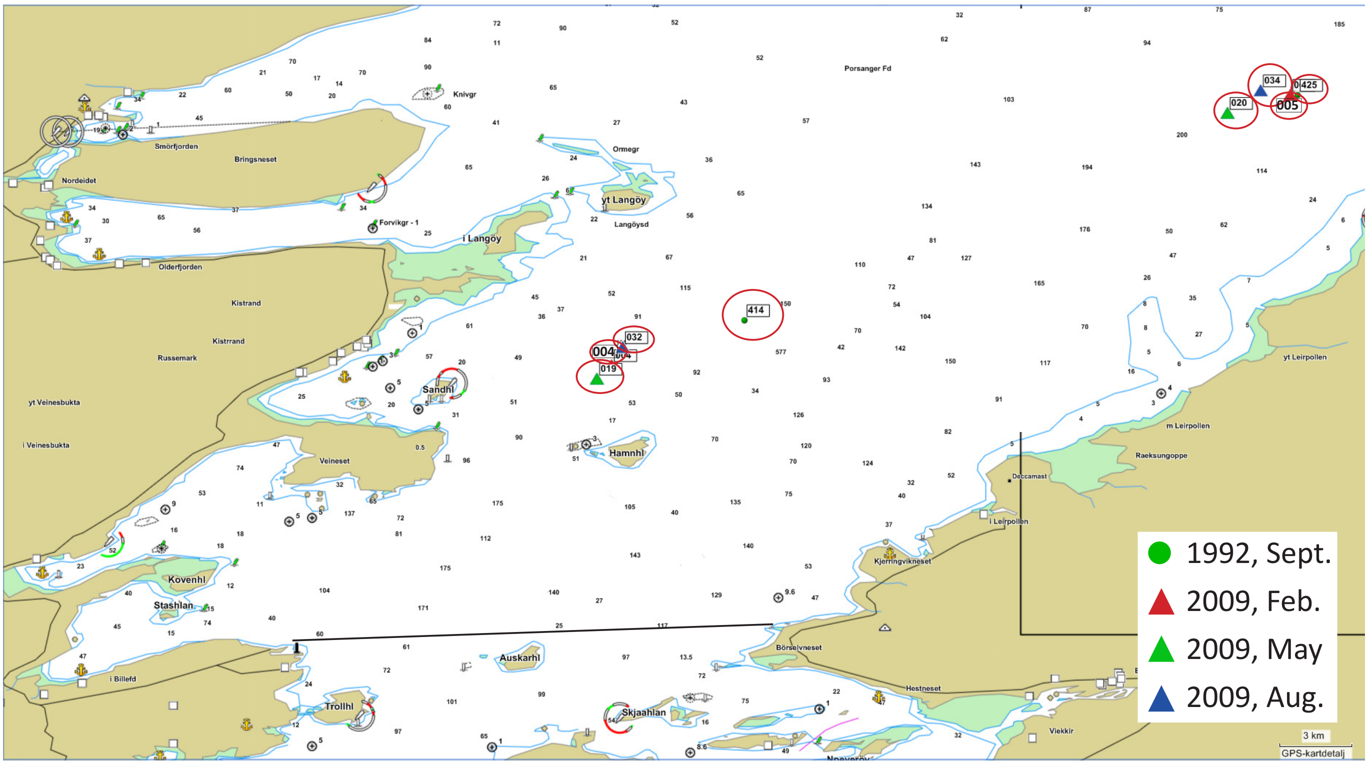


Figure 3. Trawl stations (hauls) in area C in Porsangerfjord. Stations plotted in Garmin, BlueChart Atlantic v6.5.

D - INNER PART

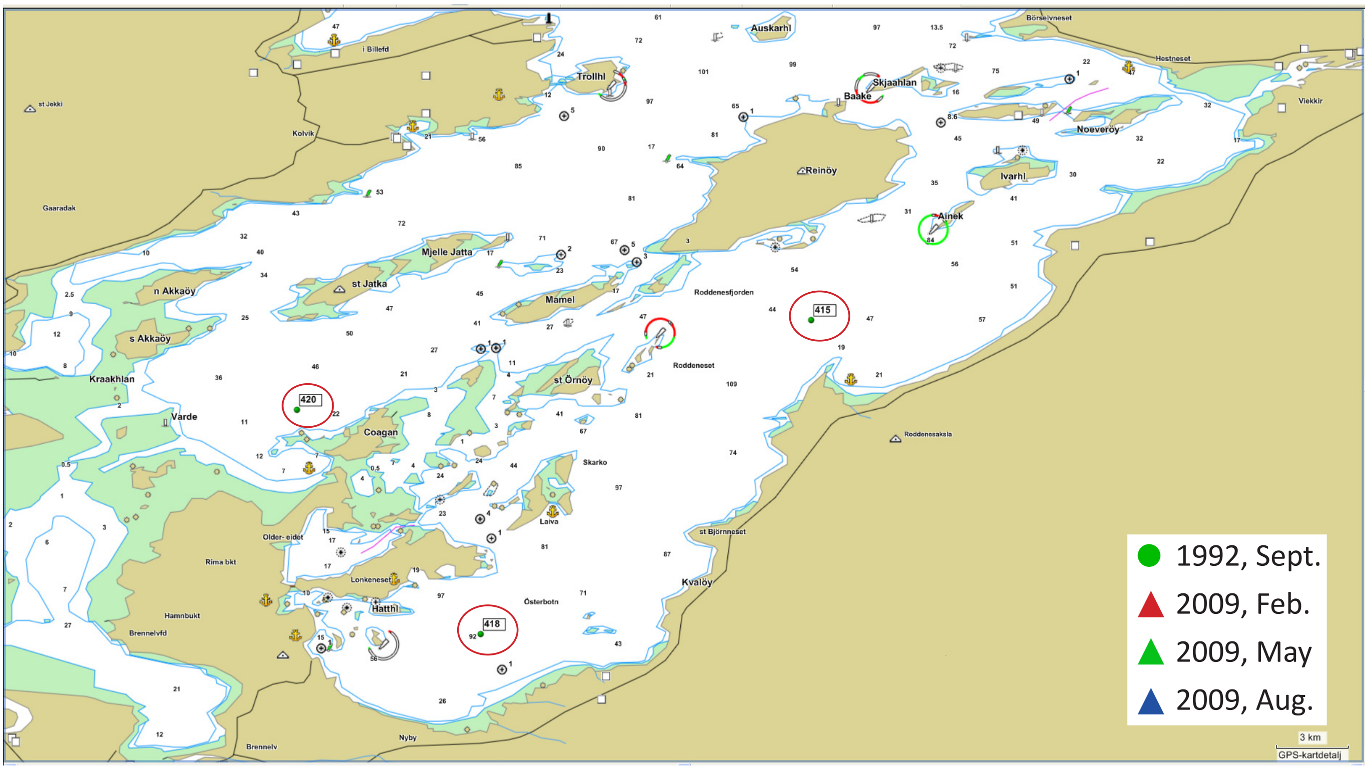


Figure 4. Trawl stations (hauls) in area D in Porsangerfjord. Stations plotted in Garmin, BlueChart Atlantic v6.5.

DEPTH MAP OF PORSANGERFJORD

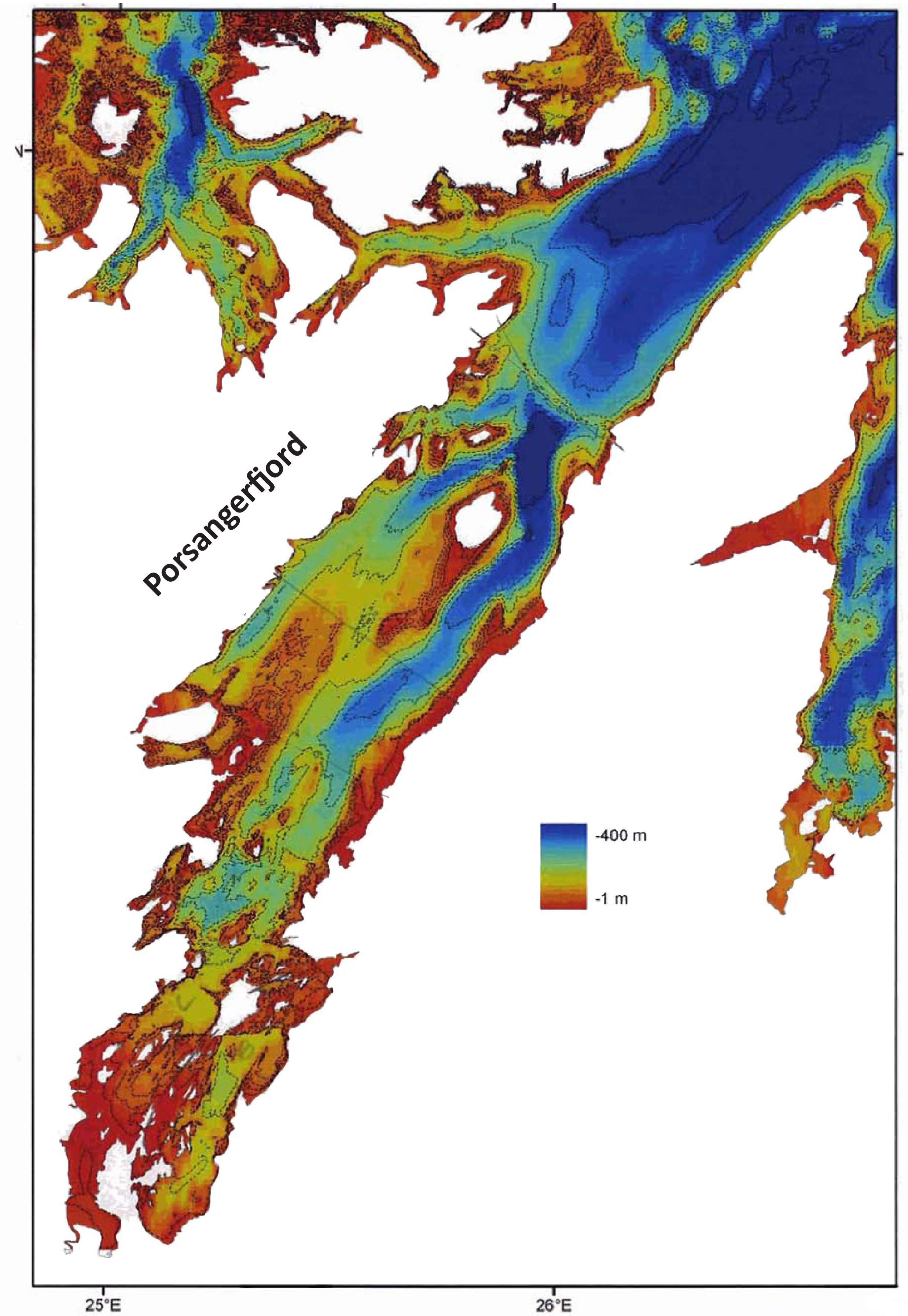


Figure 5. Map of depth Porsangerfjord with depth colouring. Made at by Trond Tangstad, IMR.

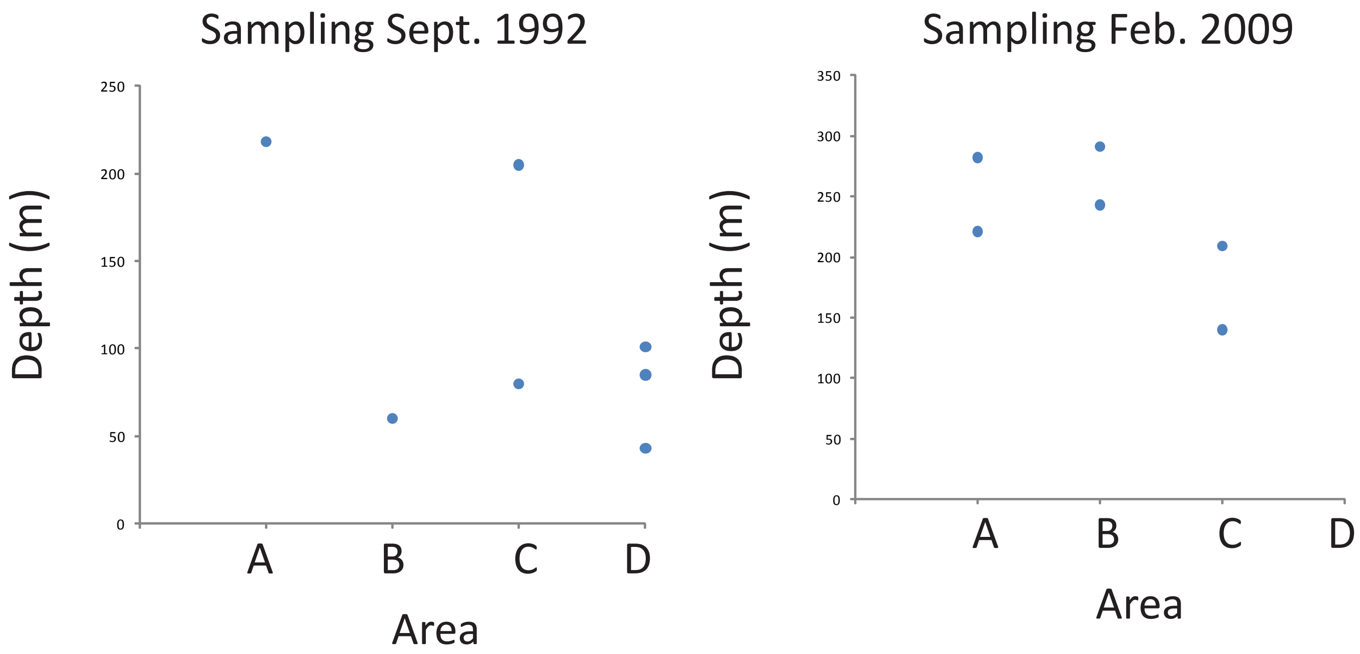


Figure 6. Sampling depths for trawl stations (hauls) in Porsangerfjord. Left in September 1992, and right in February 2009.

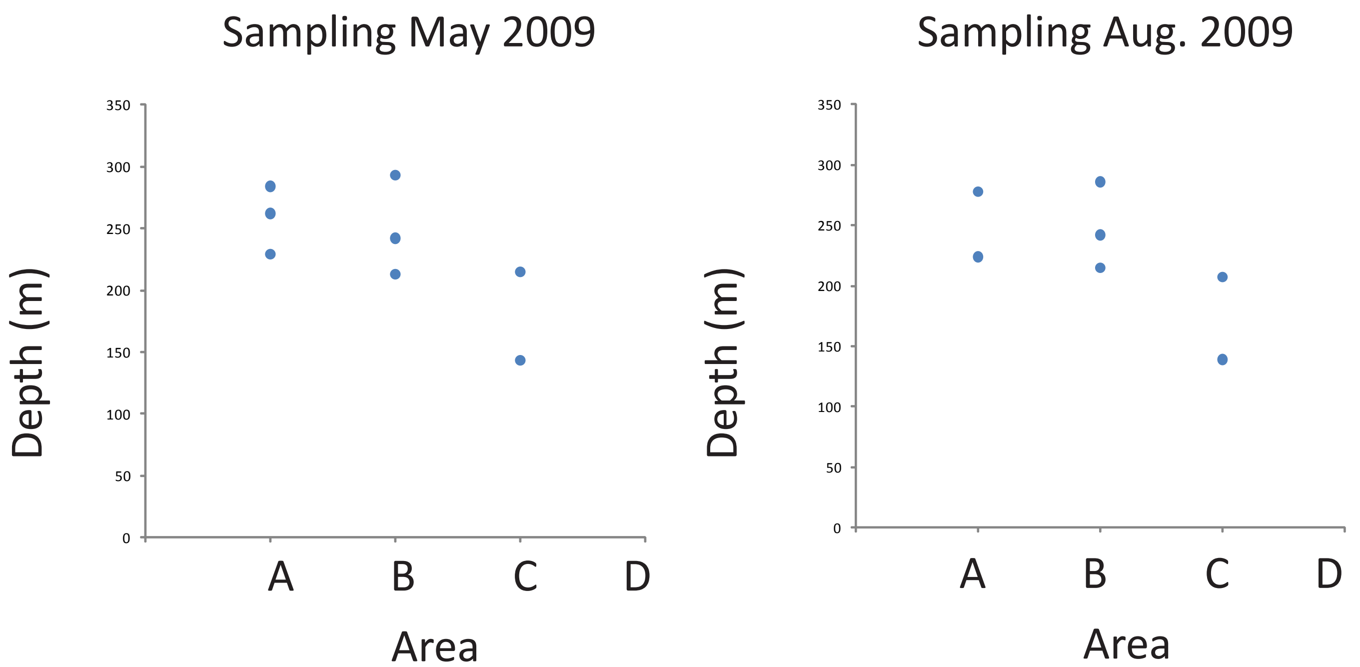


Figure 7. Sampling depths for trawl stations (hauls) in Porsangerfjord. Left in May 2009, and right in August 2009.

Table 5. Example of spread-sheet with data from some stations (trawl hauls) used in the study.

<u>Abbreviations:</u> Series = station (trawl haul), L = measured length (cm), Nr = fish number, W = measured weih (g), Sex: 1 = female; 2 = male, Age = read age from otolith, AAp = Age adjusted for birth 1st of April, Type = cod types from otolith, R = readable, A = Area, D = trawl depth, Year = sampling year, M = month, Y-C = year class, O_L = measured otolith length, O_B = measured otolith width, Z1-Z14 = measured otolith zone (mm); zone1 - zone 14 and cum = cumulative measured otolith zones (mm).

SERIES	L	Nr	W	SEX	AGE	AAp	TYPE	R	A	D	YEAR	M	Y-c	O_L	O_B	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Z14	cum
11413	31	1	240	1	3	3,42	CC	1	B	60	1992	9	1989	13,61	6,38	0,85	1,14	0,67	0,47											3,13
11413	31	2	300	1	3	3,42	CC	1	B	60	1992	9	1989	14,06	6,05	1,00	0,95	0,72	0,48	0,03										3,18
11413	36	3	350	1	3	3,42	CC	1	B	60	1992	9	1989	12,74	5,38	1,03	0,90	0,56	0,38											2,87
11413	36	4	400	2	3	3,42	CC	1	B	60	1992	9	1989	13,14	5,48	0,91	0,97	0,58	0,38											2,83
11413	41	5	630	2	3	3,42	CC	1	B	60	1992	9	1989	12,23	5,19	0,97	0,63	0,60	0,36											2,56
11413	43	6	730	2	4	4,42	CC	1	B	60	1992	9	1988	12,75	5,62	1,06	0,39	0,34	0,61	0,47										2,86
11414	61	1	2728	2	6	6,42	CC	1	C	80	1992	9	1986	17,58	8,15	0,91	0,95	0,67	0,45	0,72	0,58	0,39								4,68
11414	58	2	2025	1	7	7,42	CC	1	C	80	1992	9	1985	17,05	8,55	0,63	1,03	0,80	0,41	0,47	0,51	0,32	0,19							4,36
11414	67	3	2810	2	6	6,42	CC	1	C	80	1992	9	1986	16,49	8,91	0,97	0,70	1,05	0,59	0,52	0,39	0,42								4,64
11414	45	4	782	2	3	3,42	CC	1	C	80	1992	9	1989	14,29	6,68	1,22	0,94	0,63	0,39											3,18
11414	36	5	431	2	3	3,42	CC	1	C	80	1992	9	1989	12,87	5,91	1,05	0,72	0,60	0,54											2,92
11414	39	6	496	1	3	3,42	CC	1	C	80	1992	9	1989	13,55	6,00	0,86	0,87	0,92	0,54											3,18
11414	33	7	299	1	3	3,42	CC	1	C	80	1992	9	1989	12,21	4,91	0,97	0,72	0,42	0,35											2,46
11414	32	8	282	1	3	3,42	CC	1	C	80	1992	9	1989	11,90	5,27	0,98	0,79	0,74	0,48											3,00
11414	35	9	352	2	3	3,42	CC	1	C	80	1992	9	1989	12,12	5,37	1,13	0,57	0,63	0,42											2,75
11414	33	10	301	1	3	3,42	CC	1	C	80	1992	9	1989	12,48	5,31	0,73	0,76	0,63	0,57	0,06										2,75
11415	59	1	1990	1	10	10,42	CC	2	D	85	1992	9	1982	16,34	8,13	0,78	0,68	1,13	0,45	0,36	0,28	0,19	0,22	0,20	0,13	0,10				4,50
11415	56	2	1320	2	6	6,42	uNEAC	2	D	85	1992	9	1986	17,17	8,46	1,12	0,56	0,48	0,44	0,55	0,52	0,28								3,95
11415	66	3	2730	1	11	11,42	CC	1	D	85	1992	9	1981	18,56	8,86	0,57	1,35	0,59	0,51	0,35	0,22	0,28	0,28	0,18	0,18	0,25	0,15			4,90
11415	63	4	2520	1	6	6,42	CC	1	D	85	1992	9	1986	16,80	8,96	0,80	1,12	0,50	0,65	0,55	0,55	0,32								4,48
11415	56	5	1800	2	6	6,42	CC	1	D	85	1992	9	1986	17,12	7,79	0,78	0,70	0,47	0,66	0,88	0,39	0,13								4,01
11415	58	6	1900	2	10	10,42	CC	1	D	85	1992	9	1982	16,67	8,51	0,98	0,76	0,54	0,42	0,26	0,32	0,28	0,31	0,34	0,28	0,09				4,58
11415	57	7	1700	1	6	6,42	uCC	1	D	85	1992	9	1986	17,28	8,25															
11415	60	8	1860	2	13	13,42	CC	2	D	85	1992	9	1979	16,97	9,25	0,50	0,99	0,96	0,69	0,57	0,22	0,28	0,20	0,19	0,17	0,13	0,10	0,13	0,14	5,27
11415	56	9	1850	2	11	11,42	CC	1	D	85	1992	9	1981	15,50	8,30															
11415	36	10	380	2	3	3,42	uCC	1	D	85	1992	9	1989	13,34	5,84	1,19	0,61	1,04	0,34											3,17
11415	67	11	2310	1	10	10,42	CC	2	D	85	1992	9	1982	16,80	8,98	0,85	1,09	0,29	0,47	0,34	0,24	0,32	0,36	0,26	0,30	0,27				4,79
11415	25	12	120	1	2	2,42	CC	1	D	85	1992	9	1990	10,70	4,50															
11415	53	13	1280	2	9	9,42	CC	2	D	85	1992	9	1983	15,61	7,81	0,56	0,74	0,94	0,53	0,47	0,38	0,27	0,29	0,23	0,11					4,52
11415	35	14	470	1	3	3,42	CC	1	D	85	1992	9	1989	12,32	5,27	0,97	0,70	0,78	0,30											2,75
11415	24	15	120	1	2	2,42	CC	1	D	85	1992	9	1990	10,14	4,12															
11415	53	16	1560	2	11	11,42	CC	1	D	85	1992	9	1981	18,05	7,70	0,78	0,73	0,66	0,43	0,40	0,29	0,23	0,20	0,16	0,13	0,17	0,19			4,37
11415	46	17	930	2	5	5,42	CC	1	D	85	1992	9	1987	15,67	7,35	1,05	0,61	0,77	0,59	0,41	0,32									3,76
11415	53	18	1540	1	6	6,42	CC	1	D	85	1992	9	1986	16,96	7,72	0,78	1,07	0,63	0,58	0,50	0,44	0,28								4,29
11415	62	19	2360	1	6	6,42	CC	1	D	85	1992	9	1986	18,45	8,81	0,87	1,23	0,34	0,70	0,54	0,38	0,49								4,55
11415	50	20	1240	2	6	6,42	CC	1	D	85	1992	9	1986	17,08	7,77	0,64	0,73	1,15	0,71	0,47	0,38	0,13								4,19
11415	31	21	220	2	3	3,42	CC	1	D	85	1992	9	1989	11,48	5,14	1,15	0,51	0,49	0,53											2,69
11415	41	22	630	2	5	5,42	CC	1	D	85	1992	9	1987	14,52	6,82															
11415	53	23	1390	1	9	9,42	CC	1	D	85	1992	9	1983	17,31	8,04	0,70	0,82	0,59	0,60	0,47	0,40	0,30	0,31	0,25	0,11					4,54
11415	51	24	1240	1	6	6,42	CC	1	D	85	1992	9	1986	15,40	6,98	0,72	0,56	0,81	0,56	0,37	0,42	0,19								3,63
11415	57	25	1710	2	11	11,42	CC	1	D	85	1992	9	1981	16,14	8,02	0,51	0,92	0,67	0,41	0,37	0,27	0,24	0,26	0,13	0,15	0,19	0,17			4,29
11415	62	26	2390	2	10	10,42	CC	1	D	85	1992	9	1982	17,23	8,95	0,82	0,92	0,66	0,57	0,55	0,32	0,23	0,20	0,18	0,23	0,11				4,80
11415	55	27	1520	2	11	11,42	CC	1	D	85	1992	9	1981	16,64	8,23	1,01	0,54	0,76	0,44	0,29	0,21	0,21	0,13	0,12	0,14	0,14	0,09			4,06
11415	52	28	1370	2	6	6,42	CC	1	D	85	1992	9	1986	15,25	7,36	0,81	0,60	0,43	0,84	0,61	0,36	0,46								4,11
11415	52	29	1510	1	5	5,42	CC	1	D	85	1992	9	1987	16,14	7,31	0,69	1,22	0,92	0,63	0,40	0,20									4,07
11415	46	30	940	1	4	4,42	uCC	1	D	85	1992	9	1988	13,83	6,57															