Not to be cited without prior preference to the author

International Council for
Exploration of the Sea

ICES CM 2003/O:06
Transport of Eggs and larvae
Relevant to Cod Stocks of
The North Atlantic

The stock structure of Atlantic cod (*Gadus morhua*) in West Greenland waters: Implications of transport and migration

Marie Storr-Paulsen[1], Kai Wieland[1], Holger Hovgård[2] and Hans-Joachim Rätz[3]

[1]Greenland Institute of Natural Resources, PO Box 570, 3900 Nuuk, Greenland
[2]Danish Institute for Fisheries Research, Charlottenlund Slot, 3920 Charlottenlund, Denmark
[3]Federal Research Center, Institute for Sea Fisheries, Palmaille 9, 22767 Hamburg, Germany

Abstract

Atlantic cod in West Greenland water has shown large variations in abundance and distribution in the past decades. Strong year-classes gave good catches in both inshore and offshore areas in the late 1980s. Since then cod has been nearly absent in the offshore area and the inshore fishery remained at a low level, although a small increase in inshore landings is evident the last years. Links between the different stock components are not well understood, in particular it is not known to what extent strong year classes of Icelandic origin contribute to the biomass in the inshore areas or whether recruitment to the inshore components is solely due to local spawning.
The present study reviews survey information on the distribution of eggs, juveniles and adults as well as tagging experiments conducted in West Greenland inshore, coastal and offshore waters. Thereby, the importance of transport and migration for the recovery of a sustainable cod fishery in West Greenland waters is investigated.

Introduction

The Atlantic cod populations in West Greenland waters have shown large fluctuation in abundance and distribution in the last century. The West Greenland commercial cod fishery started in 1911 in local fjords where cod occurred regularly during summer and autumn (Horsted 2000). In the 1920s the offshore fishery developed and the importance of the inshore catches decreased. Landings increased during the next decades and peaked in the 1960s when annual catches between 350000 t and nearly 500000 t were landed, of which the inshore fishery accounted for 5-10%. Both spawning stock and temperature decreased in the same period, and in the late 1960s the stock collapsed (e.g. Buch et al. 1994). Due to single strong year classes (1973, 1984 and 1985), mainly of Icelandic origin, the abundance and landings of cod from offshore as well as from inshore areas increased in the late 1980s to an intermediate maximum of about 100000 t (ICES 2003). Thereafter, cod almost disappeared from the offshore waters off West Greenland. At present cod catches taken in fjord and coastal waters account for more than 90% of total the landings, however compared to earlier periods, the recent landings are negligible as they amount to 4000 t only (ICES 2003).

The first studies on the distribution of cod fry in Greenland waters were conducted in 1925 (Jensen 1926). Later on numerous ichthyolankton surveys were carried out until the mid 1980's. Reviewing this material, Wieland and Hovgård (2002) identified potential offshore spawning areas between 61° and 64°N in East Greenland between 62° and 66°N in West Greenland water (Fig. 1). However, little attention has so far been paid on a comparison of egg densities in offshore water with that in coastal and inshore waters.

Abundance of juvenile cod in offshore and inshore areas has been monitored annually by trawl and gillnet surveys since 1982 and 1985, respectively. These surveys provides abundance and biomass indices for assessment purposes (ICES 2003) but have yet not been used to study distribution patterns in detail.

From the first tagging experiments on cod carried out in West Greenland in the mid 1920s, some recaptures off Iceland were noticed (Hansen 1949). These experiments resumed after World War II in period 1946-1984 and again in 1989 and it became evident that especially cod tagged at Southwest Greenland undertook spawning migrations back to East Greenland and Iceland (Hovgård and Christensen 1990, Hovgård and Riget 1991).

The available information therefore indicates a complex stock structure of cod off West Greenland. The recruitment to the fisheries involves four different stock components with different spawning, larval drift and migration patterns:

1. A West Greenland offshore component spawning at the outer slope of various fishing banks.
2. Offspring from spawning areas located off southeast and East Greenland to West Greenland.
3. Cod of Icelandic origin, of which considerable numbers of larvae and pelagic 0-group stages in some years are transported to East and West Greenland.
4. A number of distinct local inshore populations for which spawning in separate fjord systems has been observed.

The present paper reviews information on egg abundance, distribution of juveniles and adults, as well as tagging experiments in order to study the significance of transport and migration for the cod stock complex in West Greenland inshore, coastal and offshore waters.

Materials and Methods

Ichthyoplankton surveys

The Danish and the Greenland Fisheries Institutes investigated the egg abundance and distribution in the Greenland inshore water in 46 years from 1925 to 1984. Prior to 1950, the ichtyplankton surveys were mainly limited to the inshore and coastal areas and the surveys were conducted in May to July. No strict sampling scheme was used and effort varied between areas and years. In the 1950s and

1960s the inshore sampling was intensified especially in the region of the Godthåbsfjord at 64˚15'N. Ring nets of 1 or 2 m diameter were used and towed with a ship velocity about 1.5 to 2 kn. All cod egg catches were adjusted to a standard tow of 30 min. and a net diameter of 2 m. Stramin nets with 1 mm mesh size were used in the majority of hauls while in the 1950s hauls with nylon netting were taken, but no significant difference in efficiency between the two different nettings was observed (Wieland and Hovgård 2002).

The area of the Godthåbsfjord (Fig. 2) was selected for a detailed analysis because sampling effort was concentrated there. In order to compare spawning intensity between inshore, coastal and offshore waters, egg catches were pooled into areas (Fig 2), each representing roughly an equal numbers of hauls. An egg-index was calculated, combining all samples taken in April and May weighted for the corresponding number of hauls and multiplied with the area (Table 1):

$$\text{Cod egg index} = M_{April} * N_{April} + M_{May} * N_{May} / (N_{April} + N_{May}) * A * 10^{-6}$$

Where M equals mean numbers of eggs, N is numbers of hauls and A is area in km^2.

Inshore gillnet surveys

Information on juvenile cod abundance and distribution in inshore waters were derived from a survey using gangs of gillnets with different mesh-sizes (16, 18, 24, 28 and 33 mm) which has been conducted annually since 1985 by the Greenland Institute of Natural Resources. The selectivity of the gillnets is adequate for ages 2 and 3, whereas only larger individuals of the 1-group are caught representatively (Hovgård 1992). Gillnets are placed at the bottom in the depth zones covering the ranges 0-5m, 5-10m, 10-15m to 15-20m. Three main areas have been target, NAFO Division 1B, 1D and 1F, but due to technical reasons the survey did not cover all areas in each year. The numbers of gillnet sets available for the present analysis is given in Table 2. Recruitment indices are expressed as number of fish from a given year class caught per 100 hr of net setting. The age compositions of each net setting were obtained by combining the length frequencies of the individual net catches with the relevant age-length key.

Offshore trawl surveys

Estimates of juvenile cod abundance and distribution were obtained from an annual groundfish surveys carried out by the German Federal Research Center's Institute of Sea Fisheries since 1982. The survey has primarily been designed for cod and covers the shelf and continental slope off East and West Greenland. The survey area of West Greenland comprises NAFO Divisions 1B to 1F and the area is divided into 4 geographical strata each subdivided into two depth ranges (< 200 m, 200-400 m). In the recent years, the survey area in the northern part of West Greenland has been reduced due to technical problems. Stations are allocated according to a stratified random strategy. The fishing gear used is a standardized 140-feet bottom trawl rigged with a heavy ground gear because of the rough bottom of the fishing grounds. The vertical net opening is 4 m and the standard towing time is 30 min at a speed of 4.5 knots. For the present study, cod densities at age (in number/km^2) were calculated from the total cod catch and the fished area, using year specific age-length-keys. The analysis focussed on year classes that were considered most likely to be of Icelandic origin.

Tagging experiments

Cod tagging experiments used for this paper were carried out from 1946- 1984 and in 1989.

From the first series of experiments a total of 13871 recaptures were reported of which 9415 (68 %) were returned with otoliths. Almost all tags (98 %) were fixated during summer (May to September) and tag returns were recorded by date and site.
Three subsets of data were excluded from the analysis 1) cod recaptured less than 1 year after tagged 2) with no detailed information on the recapture location and 3) cod marked outside West Greenland waters, i.e. NAFO Divisions 1A-F. This reduced the dataset to 6674 recaptures.
The second set of tagging experiments aimed on the 1984 year-class. This dataset is more limited as 3837 cod were tagged and 49 recaptures were reported during the following two years.
The present analysis was done in two ways: first without considering the age of the fish at recapture to achieve a maximum possible sample size, and secondly based on age. The latter was done in particular to account for age and size dependence of spawning migrations from West to East Greenland and further to Iceland.

Results

Egg distribution

Distribution of cod eggs in inshore and coastal waters off West Greenland for the years 1925-1984 identifies two major inshore spawning grounds: one in the southern part of NAFO Division 1B (Sisimiut area) and a second one in the northeastern part of NAFO Division 1D (Nuuk area / Godthåbsfjord). In 20% and 60% of all investigated years eggs were registered in these areas respectively. Besides, cod eggs were found in the coastal water in the northern part of NAFO Division 1B, in 1C, 1E. In Division 1F egg distribution were widely spread and extended into the fjords, but occurrence of eggs were only registered in 7% of all investigated years (Fig. 3).
A considerable proportion of all sampled cod egg have been registered in the Godthåbsfjord. In the bottom of the fjord system the small area of Kapisillit (~ 50 km^2), was by far the most important spawning ground in the inshore area. The far offshore area (~ 8200 km^2) had total egg abundance twice as high as in the Kapisillit area, but spread out over an area that is about 150 times larger (Fig. 1 and Table 2). This indicates that restricted spawning areas of the fjord system can be quite significant for the recruitment to the inshore and coastal waters, although not as productive as the larger offshore spawning grounds.

Distribution of juveniles and adults

Inshore waters

The inshore distribution of juvenile cod (age 2) reveals a very strong 1984-year class in all surveyed areas (Fig 4a). The strength of this year class is even more obvious as age 3 where abundance increased from a nearly non-existing level in 1986 to record high in 1987 (Fig. 4b). In the two northern survey areas (Divisions 1B and 1D) the 1987 and 1990 year classes are considered moderate, but since 1990 a decent year class has not been produced in Division 1D. This cannot be stated for NAFO Division 1B where last years age 2 recruitment index, the 2000-year class, was 2. highest in the time series. The 2000-year class could not be recalled as age 3 in this year gillnets survey. The southern survey area (Division 1F) only generates strong year classes when offshore recruitment is considered high (Fig. 4). The general picture is that in those years strong Icelandic year classes have entered West Greenland waters all inshore areas showed increased abundance of age 2 and 3, but in years with out input from Iceland the different inshore areas fluctuate without a common trend.

Offshore waters

In the West Greenland offshore waters the distribution and abundance of the strong 1984-year class were reflected, ass was the case in the inshore areas. Divided into age classes 2-6 it was evident that age class 2 had a wide distribution covering the main part of the survey area from NAFO Division 1B-1F. At age 3 the abundance were even larger, probably due to higher selectivity at the trawl. Densities were high west of Fiskenæsset (63º00'N), as well as around and north of the Nuuk area (64º15N'). Distribution of ages 2 and 3 also indicatet high abundances close to the inshore areas. At age 4 and 5 the largest densities were registered in NAFO Division 1D and northern part of 1E and at age 6 the main part of the age group were found in the southern areas in the region of Division 1F (Fig. 5).
The 1999-year class is the strongest observed since the 1984-85 year class, all though it only accounts to 5.5% of the 1984 year-class at age 2. A stock recruitment plot suggest that the 1999-year class is of Icelandic origin as it has obviously not been a product of West and East Greenlandic spawning stock biomass which was at a record low (Fig. 6). The distribution of this year class at age 2 and age 3 indicates a southern migration has all ready started at age 3, although the lower densities can make interpretations more uncertain.

Migration

Migration between fjord, coastal and bank waters
Migration behaviour differed between cod stocks from the fjords and from the banks. For the most part, cod were recaptured in the same area as tagged however, this was more pronounced for cod marked in the fjords (70 %) than for cod tagged at banks (51%) or close to the coast (23%). Cod tagged at the banks showed large migration behaviour between banks as 40% of cod marked at the banks were recaptured at another bank and in another NAFO Division than originally marked. Only a very small fraction of the cod marked at banks migrated into fjords or to coastal areas (1% and 3%, respectively) (table 3).
In order to analyse age-difference in migration, individuals were analysed from age 3-18. An equal large proportion of all age classes (age 4-18+) were recaptured in the same bank as tagged. The coastal migration and migration towards the fjords were largest in age group 5-8 and again at age 15+ (Fig. 9a).
The migration pattern for cod tagged in the fjord was somewhat different. A large fraction (70 %) was recaptured in the same fjord system as marked. Less than 0.1% was returned from a fjord system in another NAFO Division and 16% and 11% respectively were recaptured on the banks or of the coast.
All age groups tagged in fjords showed a large degree of stationary. The fraction migrating to the banks were greatest the first 10 years. At age 9 the largest migration rate of the fjords were recognised (Fig. 9b).
Compared to the fjord- and bank-tagged cod a smaller fraction (23%) of the cod tagged at the coast was recaptured in the same are as they were tagged. More than 40% were migrating towards the banks and 17% were migrating in the fjords. Behaviour like this would be expected if the cod marked in coastal waters were a mixture from the fjord and bank stock components. Cod marked at the coast showed the largest migration pattern towards the fjords at age 3-4. At age 5-7 the migration pattern were strongest towards the banks. At age 12+ the importance of migrations towards the fjords increased again. Through all age classes a small migration to other coast areas were evident. Only cod tagged at the coast showed a higher percentage of recaptures outside the tagging area than inside. This was especially true with the age classes 7-10 (Fig. 9c).

Alongshore migration offshore

Few marked cod were recaptured in NAFO division 1A. This could be due to the low fishery intensity in this northern division.

In 55% of the cases cod tagged at the banks were recaptured in the same NAFO division as they were marked. Cod tagged at banks in division 1B and 1C were returned from all divisions at the West coast of Greenland as well as from the East coast and Iceland. In division 1D cod were recaptured from all division except 1A, and the fraction of cod migrating to Iceland and East Greenland was higher. Cod tagged at banks in both division 1E and 1F were increasing recaptured at Iceland (40% and 20%, respectively). The overall trend for cod marked at the banks were large migration between banks in both a northern and southern direction and a larger part of the cod marked in the southern regions were migrating to East Greenland and Iceland (table 4a).

Cod tagged in fjords did not migrate as much between NAFO divisions as cod tagged on the banks and the one that did migrate were recaptured at a much narrower distance from tagging area location than cod tagged on the banks (table 4b).

Migration to Iceland

It could be expected that the fraction of recaptured cod in Icelandic water would increase with time between tagging and recapture. Indeed, the fraction of cod recaptured in Icelandic waters increased with time and peaked 5 years after tagging (table 5). No cod was recaptured at Iceland the same year as the tagging has been conducted.

To match the result of the tagging experiment from 1946-84 to the tagging experiment in 1989, the former dataset were reduced to contain cod marked at division 1D-1F and only from the size group 40– 65 cm (table 6). The result from the 1989 tagging showed a very high migration rate, as 47% of all recaptures were reported from Iceland (table 7). This migration rate was more than 30 times larger than in the period from 1946-84 supporting the theory that the 1984 year-class was indeed of Icelandic origin.

The average age of cod recaptured in Iceland was 9- 10 years and only 1 individual (age 6) younger than 7 years was registered in Icelandic waters (Fig. 9).

As would be expected, very few of the cod marked in the fjords were recaptured at Iceland (Fig. 8). A bit more unexpected, few of the cod tagged at the banks were recaptured in Iceland either. However, a considerable proportion (13%) of the cod marked along the coast were recaptured at Iceland, and 70 % of these individuals originated from Southwest Greenland. As for cod tagged at the banks and fjords, only cod between age 7 and 12 were recaptured at Iceland (Fig. 9).

Data from the first marking experiment in 1924-39 were reanalysed and compared to the later study. From this it was evident that a much larger fraction of the tagged cod in the early study were recaptured at Iceland, the youngest cod at age 6. Only few cod older than 13 years were recaptured in Iceland, but in the age-classes 7-11 more cod were recaptured in Iceland, than in Greenland waters.

Discussion

Egg distribution and recruitment

Historical observations confirm that spawning take place in several distinct fjord systems along the West coast of Greenland from 64˚N - to 67˚N (Fig. 3). Further to the south, only sporadic observations of egg have been registered (Hansen 1949, Engeltoft 1997). One exception is "Fiskenæsset" south of Nuuk at 63˚N where anecdotic information suggests the occurrence of a local stock, a theory supported by the very large/old fish caught in these fjords (quit a few fish landed are longer than 1 m, Storr-Paulsen pers. obs. 2003). Mature females have also been caught in more northern areas up to including Disko Bay at 69˚N, indicating possible spawning in these areas.

In the area around the Godthåbsfjord the main spawning area is in the shallow inlet of Kapisillit, the difference in density of eggs within the fjord clearly indicates the importance of that area (table 1). Even though it is beyond question that the area of Kapisillit is an important spawning ground, the significance is limited compared to the offshore production, which is more than twice as large. In 1963 the NORTHWESTLANT survey investigated cod egg abundance in a large area including West and East Greenland offshore waters as well as the western part of the spawning area at Iceland. An egg-index comparable to the one calculated for the Godthåbsfjord revealed much higher egg abundances off East Greenland and Iceland (Wieland and Hovgård 2002). The area at Kapisillit only produced 0.8 and 1.3% of the egg production calculated for East Greenland and Iceland, respectively. The inshore egg production is dense but as the area is much more restricted the total production is of limited importance compared to the large offshore spawning grounds. This confirms the high importance of the spawning grounds at East Greenland and Iceland as suggested by Wieland and Hovgård (2002).

Distribution of juveniles

Data from the gillnet survey and offshore trawl survey revels a strong 1984- year class. The common trend in age 2 abundance of the 1984- year class in fjords as well as at the banks indicates that the increase in biomass partly was caused by migration of fry of Icelandic origin to the banks and fjords. Tagging experiment confirmed that a large fraction of the 1984-year class tagged at West Greenland migrated to Iceland. This result is confirmed by the stock recruitment plot indicating that the spawning stock in East and West Greenland could not alone explain the large abundance of age 2 cod in 1986 (Fig. 6). However, as cod were only tagged in coastal areas and at the bank in 1989, and spawning stock biomass is not measured inshore, it cannot be verified that the increase in cod abundance inshore were caused by migration. An increase in water temperature these years could give favourable conditions for the reproduction and early life stage development of the inshore stock (Buch et al. 1994, Riget and Engelstoft 1998).

The 1999-yearclass is believed to be of Icelandic origin as well, as a very small spawning stock in West and East Greenland have produced the largest abundance of recruits since the 1985-year class.

Migration within West Greenland waters

The tagging experiments suggest high geographical stationarity for the fjord cod population. Some migration to coastal areas is evident and the tagging data give no conclusive evidence of return migration to the same fjord. The data revealed that <1% of the cod marked in the fjord were recaptured in fjords from other NAFO divisions. This is supported by the gillnet survey conducted in three different parts of West Greenland where only cod believed to be of Icelandic origin is reflected in all investigation areas. The 1993 and 2000 year-class is only apparent in the fjords around Sisimiut NAFO division 1B (Fig. 4). These findings suggest that we have highly separate fjord populations with low interference between fjords in West Greenland waters, which receives occasional input from West Greenland offshore areas and Iceland.

Spawning migration to East Greenland and Icelandic waters

The high migration rate to Iceland observed from the 1924-39 tagging experiment can be an artefact from the higher effort in Icelandic water. In the last 30 years only three year-classes of Icelandic origin were important to the Greenland cod population, i.e. the 1973, 1984 and 1985 year class. This indicates that although the larvae transport from Iceland is an important component to Greenland stock, it is not to be counted on as an annually event. A westerly migration of mature cod rarely occurs as Icelandic tagging experiments show immigration rate at 0.03 outside Icelandic fishing grounds (Schopka 1993, Rätz 1994).

Homing migration is believed to be connected to first spawning (Jones 1968, Rätz 1994, Secor 2002). In the first tagging experiment (1924-39) the earliest migration towards Iceland were registered at age 6 and in the latter experiment (1946-84) at age 7. This is a rather late first spawning compared to the maturity found today for Greenland offshore cod. In the years 1960-83 50% maturity was found at age 6 to 7, but has become earlier and more variable thereafter (Wieland and Storr-Paulsen 2003). From the tagging conducted in 1989 we have no information on age classes but we know that a record high spawning stock biomass in 1989 produced a very low level off recruits two years latter (Fig. 6). In 1990 the spawning stock in West and East Greenland were only 15% of the biomass in 1989. This indicates that the 1984-year class were homing at age 5. Survey results from 2002 state that 88% of the stock was mature at age 3 (Rätz 2003). This earlier maturation could be caused by the warm period we have experienced the last 8-10 years or be a function of a high fishing mortality giving an advanced to fish maturing faster. If the hypothesis of earlier maturations today holds true we would expect a homing migration at a much younger age, than was seen 20 years ago when the 1984- year class were homing. The distribution of age 2 and age 3 of the 1999-year class could indicate that a homing migration to Iceland has already started.

Reference

Buch, E., Horsted, S.A., and Hovgård, H. 1994. Fluctuations in the occurrence of cod in Greenland waters and their possible causes. ICES Mar. Sci. Symp. 198: 158-174.

Engelstoft, J.J. 1997. Indenskærs torsk ved Vest Grønland. Grønlands Naturinstitut, Teknisk rapport nr. 6, 22 p.

Hansen, P.M. 1949. Studies on the biology of the cod in Greenland waters. Rapp. P.-v. Réun. Cons. int. Explor. Mer 123: 1-77.

Horsted, S.A. 2000. A review of the cod fisheries at Greenland, 1910-1995. J.Northw.Atl.Fish.Sci. 28: 1-112.

Hovgård, H. and Christensen, S. 1990. Population structure and migration patterns of Atlantic cod at West Greenland waters based on tagging experiments from 1946 to 1964. NAFO Sci. Coun. Studies 14: 45-50.

Hovgård, H. and Riget, F. 1991. Preliminary results from cod tagging off West Greenland, 1989. NAFO SCR Doc. 91/63.

ICES CM 2003/ACFM: 24. Report of the North Western Working Group.

Jensen, A.S. 1926. Investigations of the "Dana" in West Greenland waters, 1925. Rapp. P.-v- Reun. Cons. Int. Explor. Mer. 39: 85-102.

Jones, H. F. R. 1968. Fish Migration. Fisheries Laboratory, Lowestoft. Publisher: Edward Arnold, London.

Riget, F. and Engelstoft, J. 1998. Size-at-age of cod (*Gadus morhua*) off West Greenland, 1952-92. NAFO Sci. Coun. Studies 31: 1-12.

Rätz, H.-J. 1994. Assessment of migration of Atlantic cod (*Gadus morhua*) between the stocks of West and East Greenland in 1984-86 by means of otolith typing. NAFO Sci. Coun. Studies 16: 7-18.

Rätz, H-J. 2003. Groundfish Survey Results for Cod off Greenland (offshore component) 1982-2002. Working document 3, ICES North Western Working Group 2003.

Secor, D.H. 2002. Historical roots of the migration triangle. ICES Marine Science Symposia. 215: 060-000.

Schopka, S.A. 1993: The Greenland cod (*Gadus morhua*) at Iceland 1941-1990 and their impact on assessments. NAFO Sci. Coun. Studies 18: 81-85.

Wieland, K. and Hovgård, H. 2002. Distribution and drift of Atlantic cod (*Gadus morhua*) eggs and larvae in Greenland waters. J. Northw. Atl. Fish. Sci. 30: 61-76.

Wieland, K. and Storr-Paulsen, M. 2003 Atlantic cod in Greenland waters. Working document presented to the ICES Cod and Climate Change working group meeting, May 2003, New Bedford, May 2003.

Table 1. Data basis for index of cod egg abundance from ichthyoplankton surveys in the Godthåbsfjord. Mean number of cod eggs per 30 min standard tow in April and May respectively, area size, numbers of hauls in April and May, and index of egg abundance (see Figure 2 for area limits).

Area	Area Size Km^2	No. hauls April	No. hauls May	Mean no. Egg/ April	Mean no. Egg/May	Cod egg Index
Kapisillit	51	18	17	90895	27960	3.08
Umanak	325	18	19	2098	6776	1.46
S.E. Fjord	132	13	21	1010	3349	0.32
Western Fjord	1541	6	10	680	592	0.96
Nuuk	112	17	29	46	77	0.01
Coastline	1087	10	15	19	90	0.01
Near Offshore	8735	15	16	44	41	0.37
Far offshore	8188	15	17	1572	203	6.92

Table 2. Number of valid hauls in the gillnet survey. Three main target area have been investigated; the fjord system around Sisimiut in NAFO division 1B, the fjords around Nuuk in NAFO division 1D and the inshore area at Qaqortoq in division 1F.

Division	1B	1D	1F	Total
1985	3	38	27	68
1986	26	22	23	71
1987	24	27	26	77
1988	21	24	24	69
1989	28	19	32	79
1990	18	21	18	57
1991	23	24	20	67
1992	27	29	23	79
1993	23	25	19	67
1994	20	29	17	66
1995	24	21	20	65
1996	26	25	-	51
1997	20	23	-	43
1998	24	26	22	72
1999	-	24	-	24
2000	-	27	20	47
2001	-	-	-	-
2002	21	20	-	41
2003	33	27	-	60

Table 3. Number and proportion (in brackets) of recaptures by area of cod tagged at West Greenland in the period 1946-1984. 8920 cod were used for this analysis. A cod marked and recaptured at a bank indicates that the recapture area is an other bank, if the recaptured is label “same area” then it is the same bank. Numbers indicate the actual numbers of recaptures and the number in parentheses indicates the frequency. Only fish recaptured min. 1 year after tagging are included.

	Recaptured					
Marked	Bank	Fjord	Coast	Same area	Iceland	Total
Bank	1454(0.40)	37(0.01)	105(0.03)	1854(**0.51**)	197(0.05)	3647
Fjord	334(0.16)	10(0.00)	229(0.11)	1501(**0.70**)	58(0.03)	2132
Coast	1305(0.42)	546(0.17)	83(0.03)	812(**0.23**)	395(0.13)	3141

Table 4a and **b**; Number and proportion (in brackets) of recaptures by area of cod tagged at West Greenland during the period 1946-1984.The table indicate the latitudinal migration pattern of cod tagged at the bank (**a**) and in the fjord (**b**). A total of 1929 and 1831 were recaptured at the bank and fjords respectively. Only cod tagged min 1 year are included.

Marked	Recaptured at West Greenland in NAFO divisions								
Bank (**a**)	NAFO 1A	NAFO 1B	NAFO 1C	NAFO 1D	NAFO 1E	NAFO 1F	East G.	Iceland	Total
NAFO 1A	0(**0.00**)	1(1.00)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	1
NAFO 1B	2(0.00)	358(**0.56**)	98(0.16)	97(0.16)	41(0.07)	6(0.01)	10(0.02)	11(0.02)	623
NAFO 1C	1(0.00)	54(0.11)	214(**0.43**)	149(0.30)	34(0.07)	10(0.02)	14(0.03)	19(0.04)	495
NAFO 1D	0(0.00)	34(0.05)	53(0.08)	459(**0.65**)	51(0.07)	21(0.03)	33(0.05)	53(0.08)	704
NAFO 1E	0(0.00)	0(0.00)	2(0.03)	13(0.17)	19(**0.25**)	3(0.04)	8(0.11)	31(0.41)	76
NAFO 1F	0(0.00)	0(0.00)	0(0.00)	2(0.07)	0(0.00)	20(**0.67**)	2(0.07)	6(0.2)	30

Marked	Recaptured at West Greenland in NAFO divisions								
Fjord (**b**)	NAFO 1A	NAFO 1B	NAFO 1C	NAFO 1D	NAFO 1E	NAFO 1F	East G.	Iceland	Total
NAFO 1A	1(**0.20**)	1(0.20)	1(0.20)	2(0.40)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	5
NAFO 1B	0(0.00)	62(**0.79**)	10(0.13)	4(0.05)	2(0.03)	0(0.00)	0(0.00)	1(0.01)	79
NAFO 1C	0(0.00)	5(0.06)	67(**0.86**)	6(0.08)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	78
NAFO 1D	0(0.00)	12(0.01)	31(0.02)	1335(**0.93**)	9(0.01)	15(0.01)	9(0.01)	27(0.02)	1438
NAFO 1E	0(0.00)	0(0.00)	0(0.00)	0(0.00)	27(**0.90**)	3(0.10)	0(0.00)	0(0.00)	30
NAFO 1F	0(0.00)	2(0.01)	1(0.01)	2(0.01)	1(0.01)	184(**0.92**)	4(0.02)	7(0.04)	201

Table 5. Results of cod tagging experiments off West Greenland during 1946-1984. The table shows the numbers of recaptures in West Greenland, East Greenland and Iceland in relation to the time lag between tagging and recapture. The number indicates the absolute numbers of cod recaptured; the number in brackets shows the proportion.

Return year	West G.	East G.	Iceland	Total
0	3438	7	0(0.00)	3445
1	4360	81	121(0.03)	4441
2	1849	71	169(0.08)	1920
3	969	41	133(0.12)	1010
4	397	24	87(0.17)	421
5	184	18	46(0.19)	202
6	57	5	10(0.14)	62
7	33	3	2(0.05)	36
8	21	1	1(0.04)	22
9	5	0	0(0.00)	5
10+	3	0	0(0.00)	3

Table 6. Reduced results of cod tagging experiments off West Greenland to resemble the experiment in 1989. Only cod between 40 and 65 cm tagging length were included and from NAFO division 1D-1F.

Return	Recaptured			
year	West G.	East G.	Island	Total
0	1016	1	0(0.00)	1017
1	1042	13	7(0.01)	1062
2	512	18	31(0.06)	561

Table 7. Tagging experiment conducted in 1989. 3836 cod were marked in NAFO division 1D-1F in the length group 40-65 cm. Recaptures the following two years are available.

Return	Recaptured			
year	West G.	East G.	Island	Total
0	15	0	0(0.00)	15
1	22	3	14(0.56)	25
2	0	0	9(1.00)	9

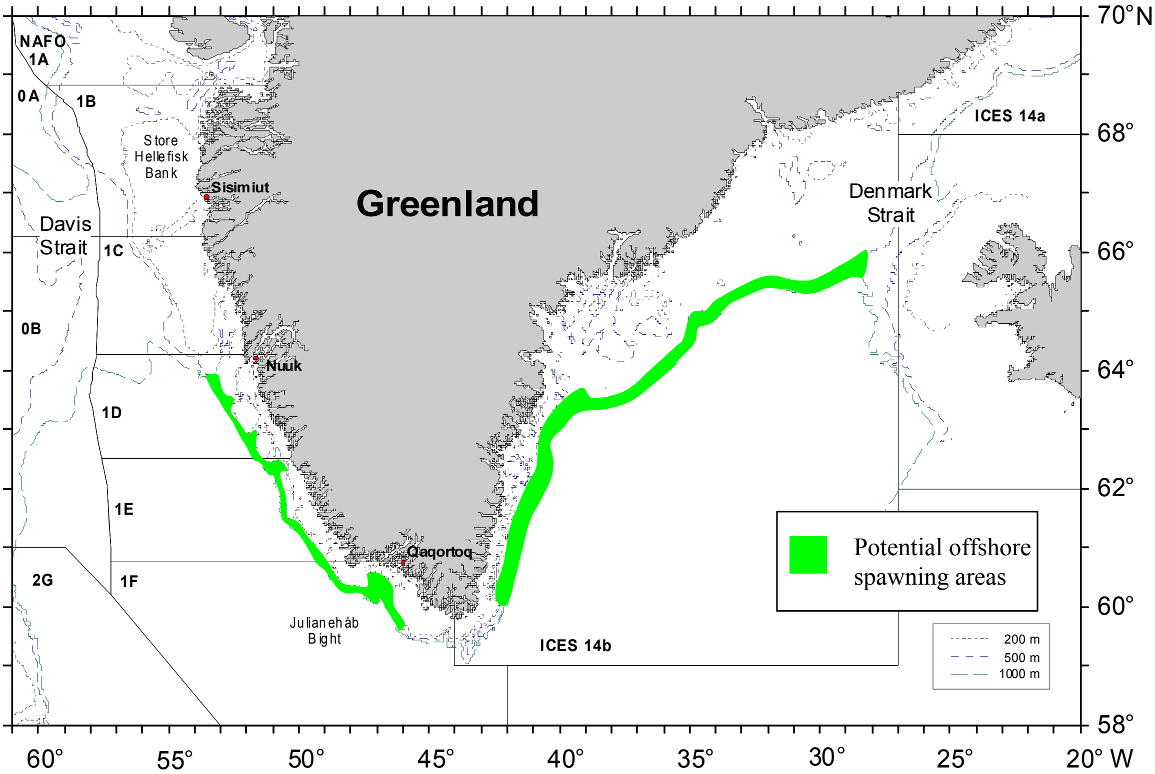


Fig. 1. Potential offshore spawning areas of Atlantic cod at West and East Greenland. Modified after Wieland and Hovgård 2002.

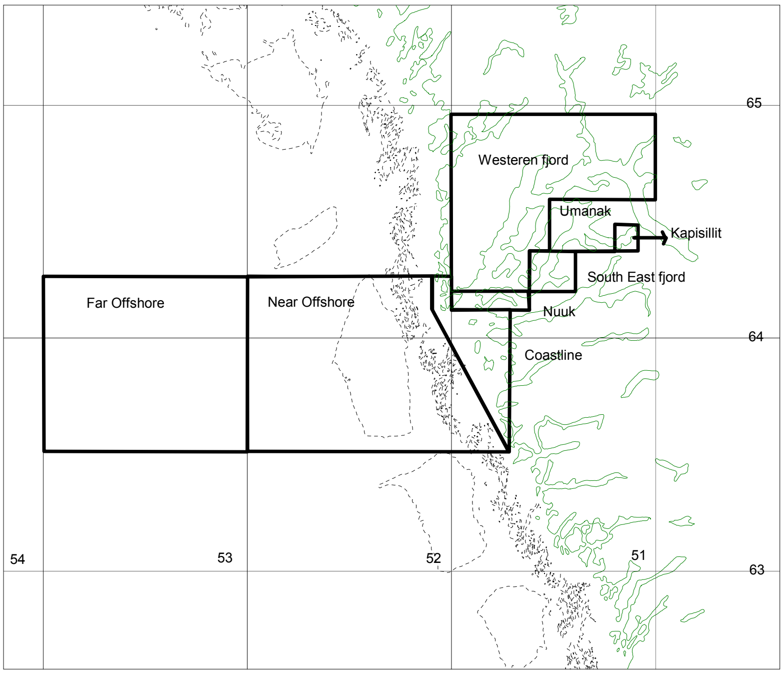


Fig. 2. Map of the area around the Godthåbsfjord. Areas used for comparison of egg abundance in inshore, coastal and offshore waters.

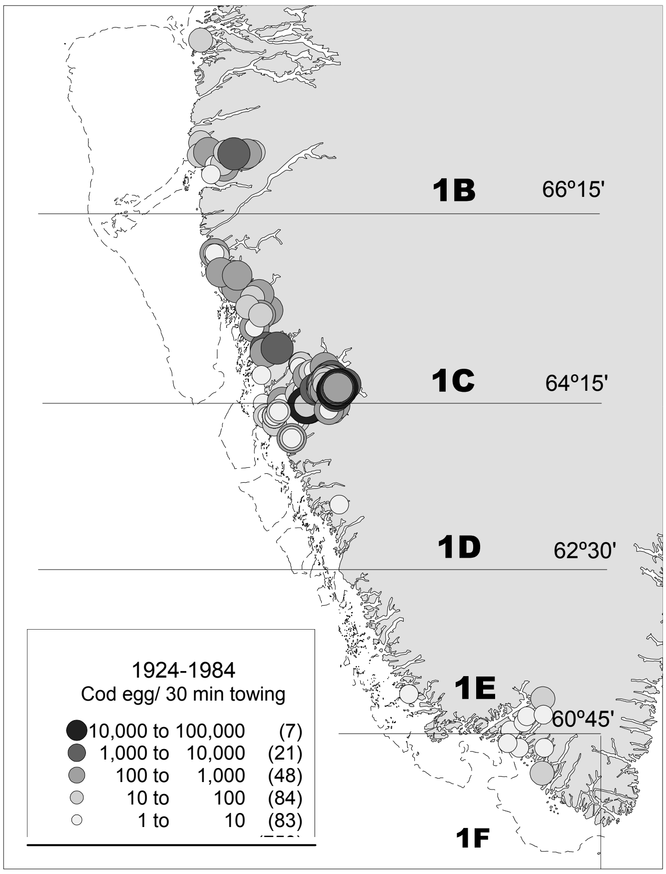
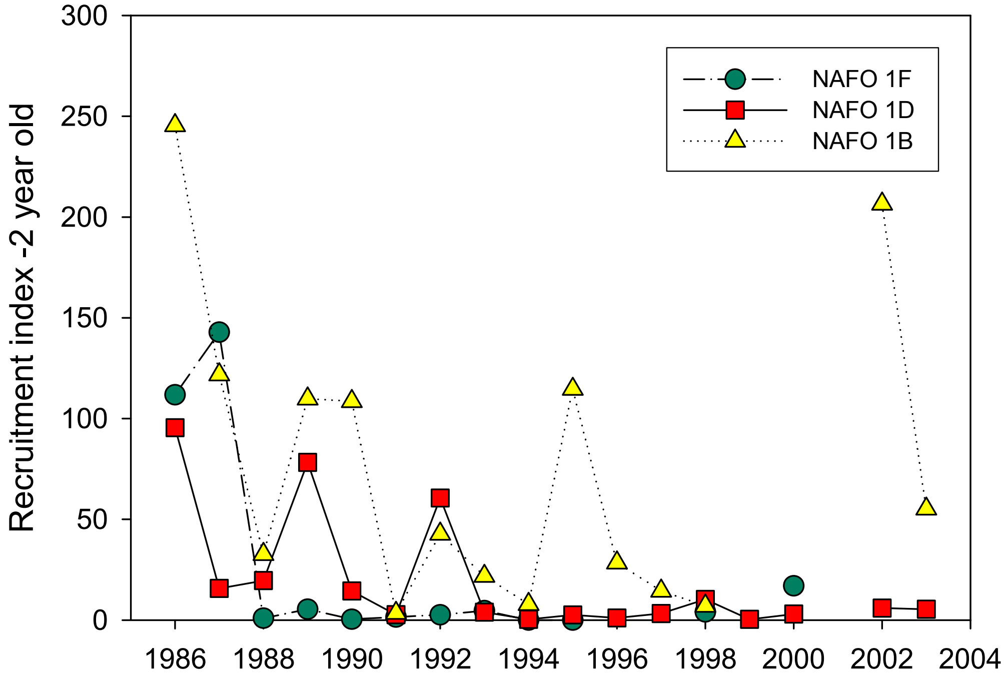


Fig. 3. Inshore density of cod eggs per 30 min haul, 1925- 1984.



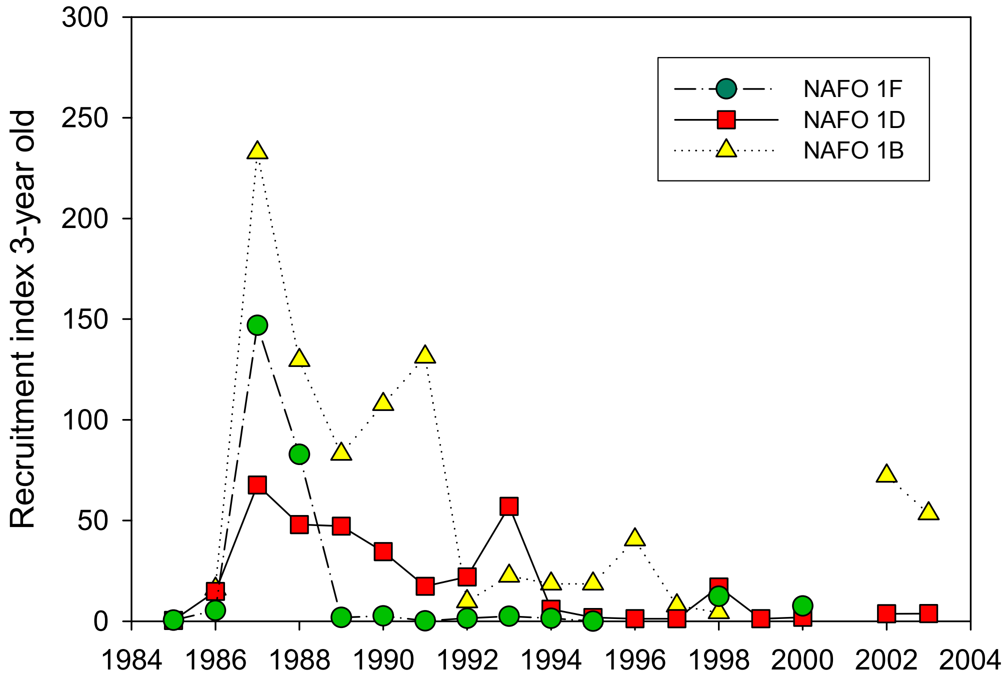


Fig. 4a and **b.** Time series of recruitment at age 2 and age 3 for West Greenland inshore cod. NAFO Division 1B, 1D and 1F.

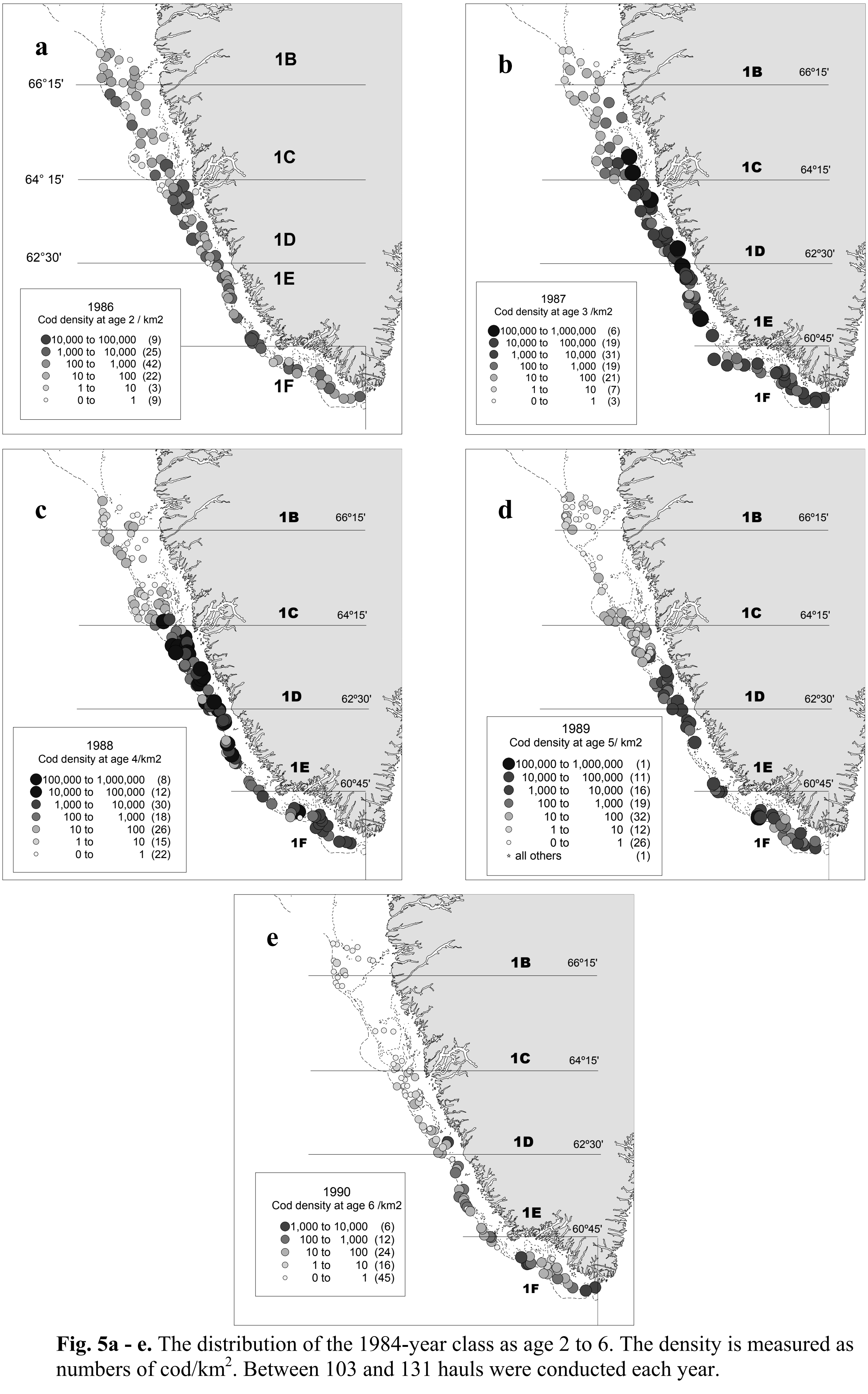


Fig. 5a - e. The distribution of the 1984-year class as age 2 to 6. The density is measured as numbers of cod/km^2. Between 103 and 131 hauls were conducted each year.

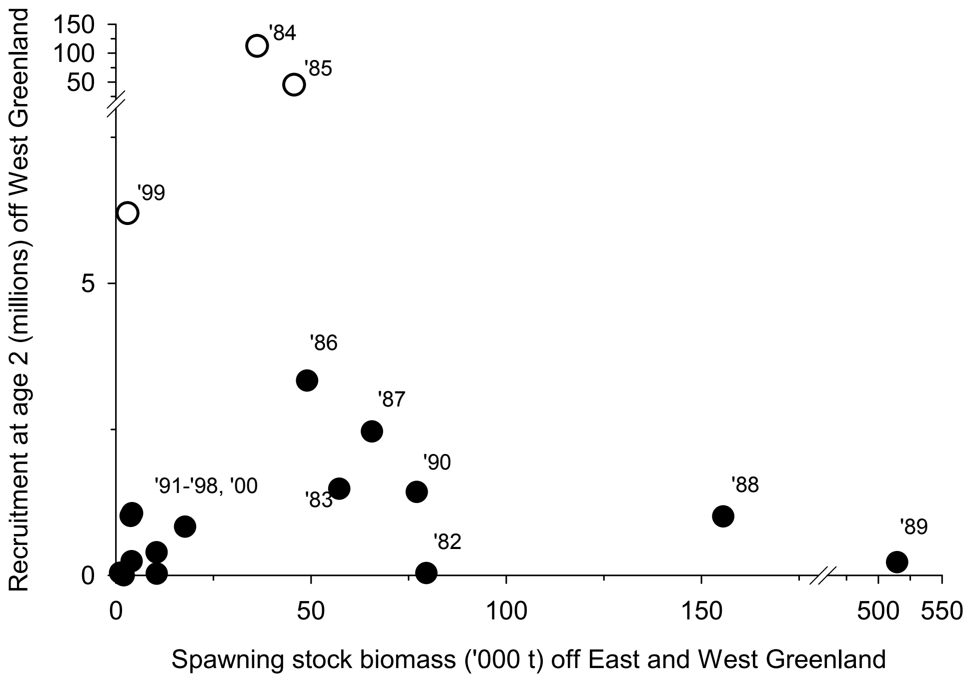
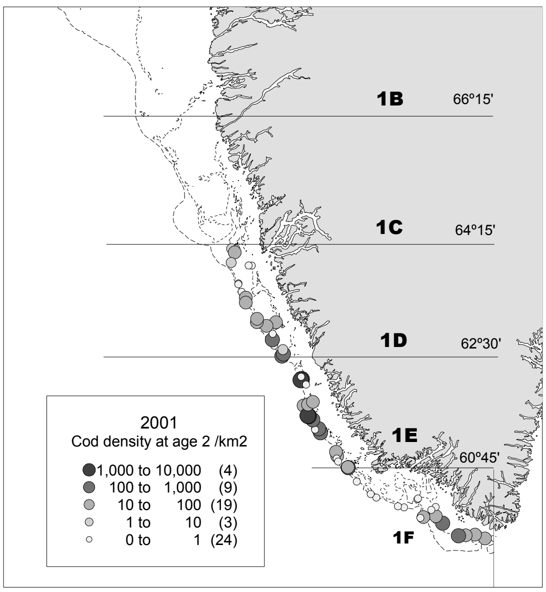


Fig. 6. Survey estimates of recruitment at age 2 at West Greenland in relation to spawning stock biomass off West and East Greenland combined. Open circles indicates year-classes assumed to be mainly of Icelandic origin. Modified after Wieland and Storr-Paulsen (2002).



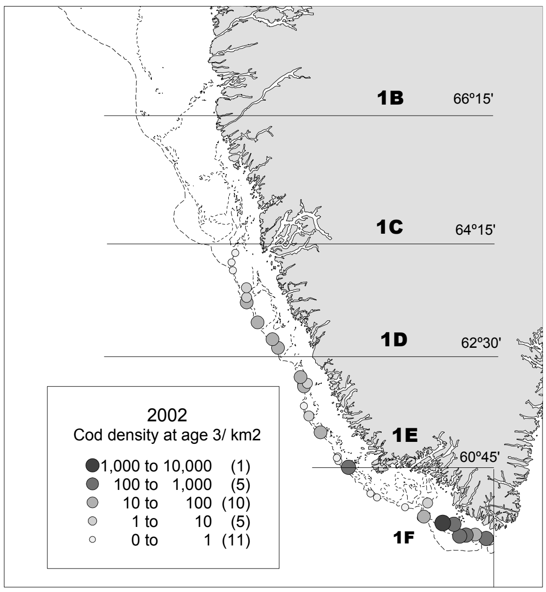


Fig 7a and **b**. Density distribution of the 1999-year class as age 2 in 2001 and age 3 in 2002. 59 hauls were conducted in 2001 and 32 in 2002.

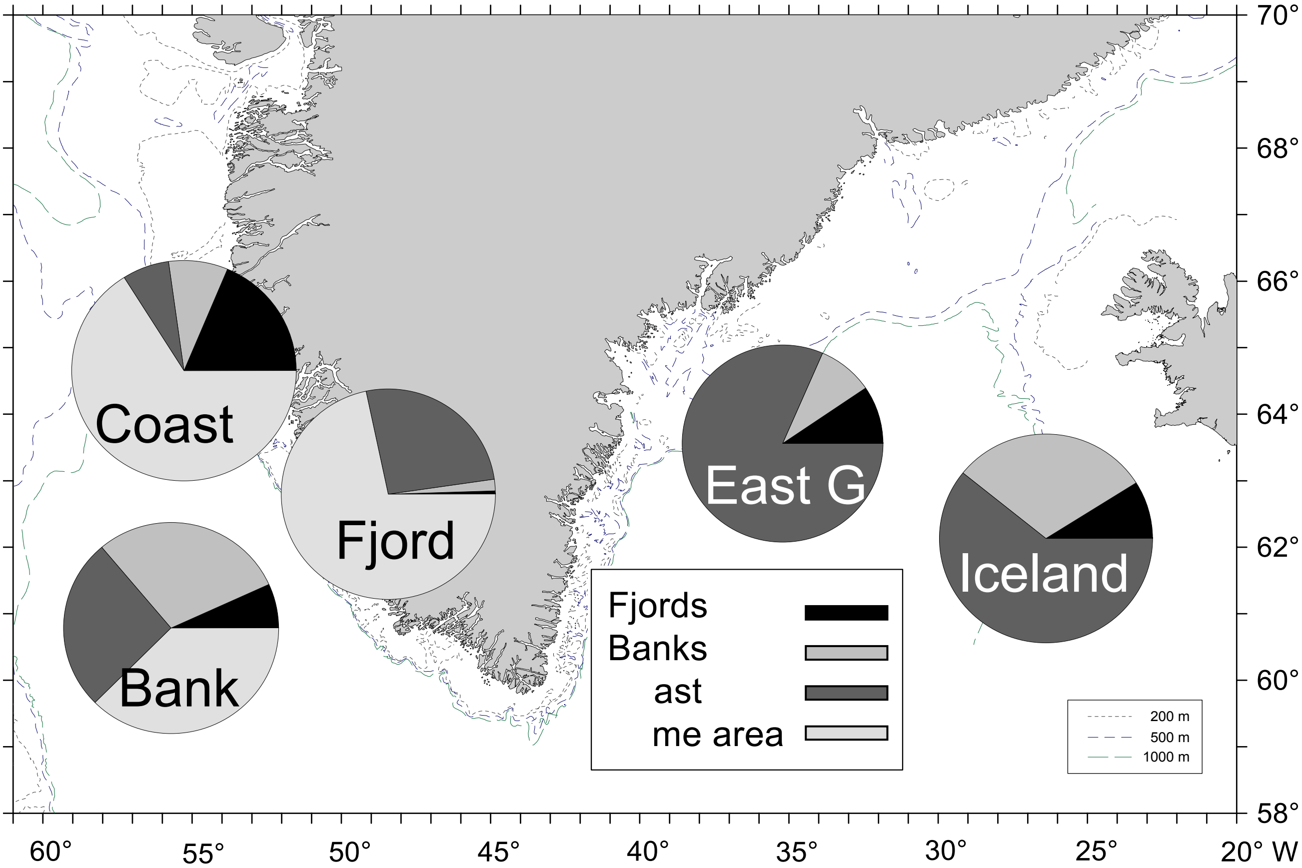


Fig. 8. Recaptures of cod tagged in West Greenland. Only data considered with at least one year between tagging and recapture.

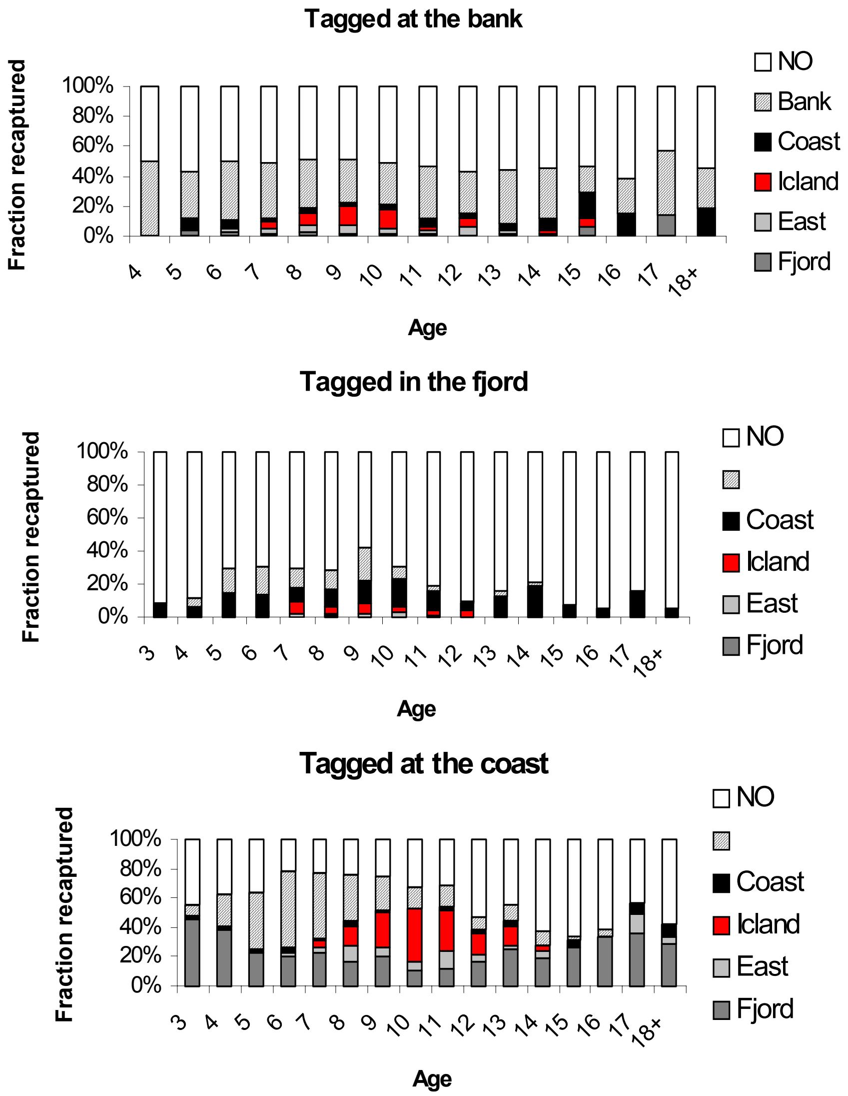


Fig.9a-c. Migration pattern of cod tagged at the bank (a), fjords (b) and coastal areas(c) by age class. No = recaptured in the same area as tagged. The tagging was conducted from 1946- 1984.

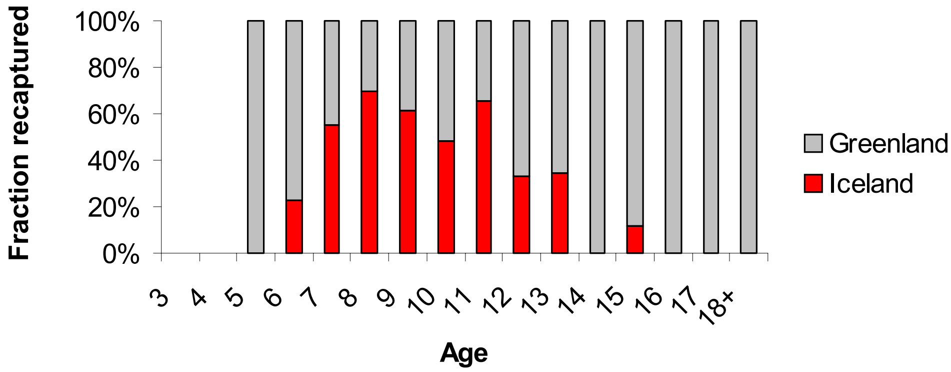


Fig. 10. Recaptures of cod by age, tagged in West Greenland water. 551 recaptures were reported. Data from Hansen (1949).

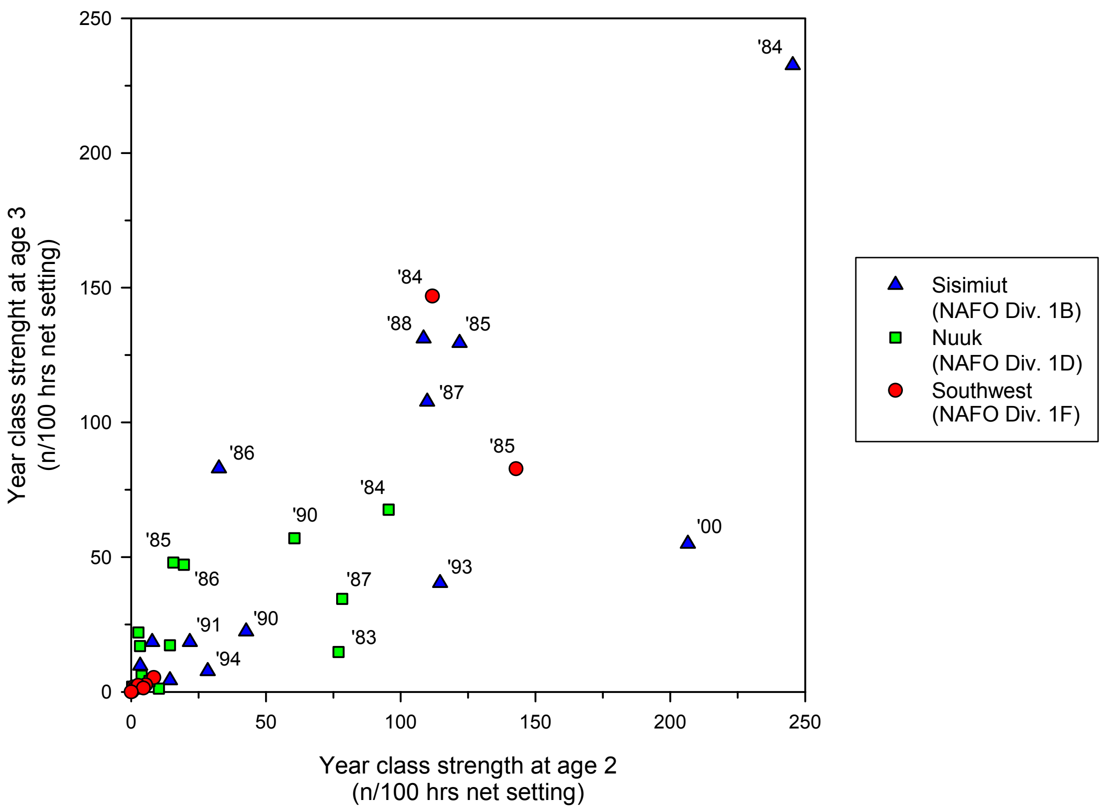


Fig. 11. Comparison of survey indices of West Greenland inshore cod for age 2 in a given year and age 3 in the succeeding year. Modified after Wieland and Storr-Paulsen (2002).