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Stock structure of Atlantic cod (*Gadus morhua*) in West Greenland waters: implications of transport and migration

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Atlantic cod in West Greenland waters have varied greatly in abundance and distribution in the past decades. Strong year classes yielded good catches inshore and offshore in the late 1980s, but since then cod have been nearly absent offshore and the inshore fishery has been depressed, though there has been a small increase inshore over the past few years. Different components contribute to the Greenland cod stock, and re-analysed tagging experiments indicate that migration behaviour differs between them. Inshore cod are sedentary, with almost no migration between different fjord systems. In contrast, there are many cases of alongshore migration of cod tagged on the offshore fishing banks. Further, observations have been made of occasional migrations from offshore to inshore, notably so in years of good recruitment originating from Icelandic waters.

Keywords: Atlantic cod, Greenland, homing, migration, spawning area, stock structure, tagging.

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Introduction

The abundance and distribution of Atlantic cod (*Gadus morhua*) populations in West Greenland waters fluctuated during the 20th century. The West Greenland commercial cod fishery started in 1911 in local fjords, where cod were caught regularly during summer and autumn (Horsted, 2000). In the 1920s the offshore fishery developed, and the importance of inshore catches decreased. Landings increased during the next few decades, then peaked in the 1960s with annual catches of some 350 000–500 000 t, of which the inshore fishery accounted for 5–10%. Spawning stock and sea temperature then decreased, and in the late 1960s the stock collapsed (Buch *et al.*, 1994). Subsequently, a few strong year classes (1973, 1984, 1985), mainly of Icelandic origin, stimulated increases in both abundance and landings offshore and inshore, so that by the late 1980s, there was a secondary peak in annual landings of some 100 000 t (ICES, 2003). Thereafter, cod almost disappeared from the offshore waters off West Greenland. Now, the cod catches made in fjords and coastal waters account for more than 90% of the total landings off Greenland, which, compared with earlier periods, are very low, just 5500 t in 2003 (ICES, 2004).

Early studies on the distribution of cod fry in Greenland waters were conducted in 1925 (Jensen, 1926), and numerous ichthyoplankton surveys have been carried out since then, at least until the mid-1980s. Reviewing this material, Wieland and Hovgård (2002) identified potential offshore spawning areas between 60 and 66°N in waters of both East and West Greenland (Figure 1). However, little attention has thus far been paid to comparing egg densities offshore with those in coastal and inshore waters. Further, abundance of juvenile cod offshore and inshore has been monitored annually by trawl and gillnet surveys since 1982 and 1985, respectively. The latter surveys provide abundance and biomass indices for assessment purposes (ICES, 2003), but have not yet been used to study distribution patterns in detail.

From the first tagging experiments of cod in West Greenland in the mid-1920s, some recaptures were made off Iceland (Hansen, 1949). Tag-recapture experiments

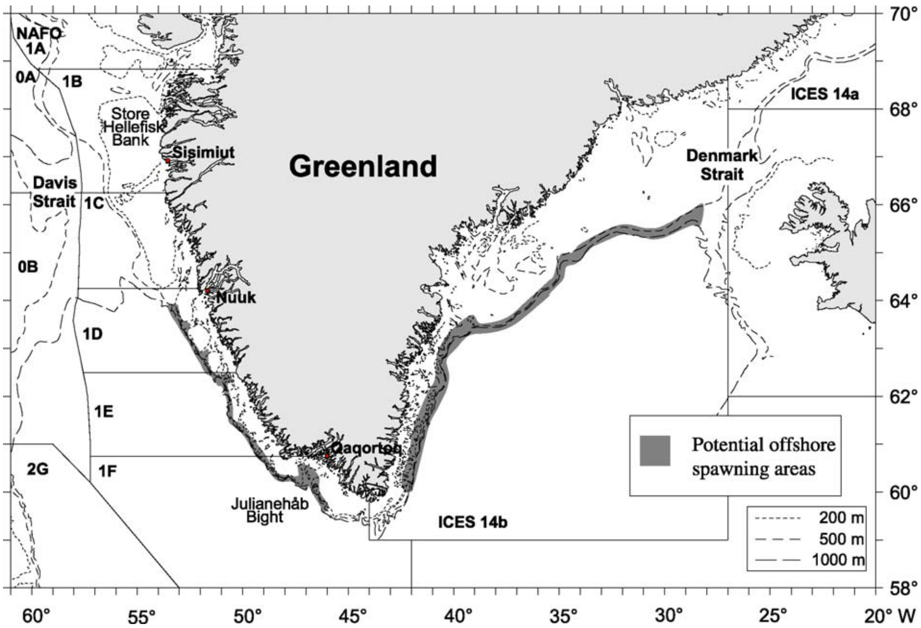

Figure 1. Potential offshore spawning areas of cod off East and West Greenland (modified after Wieland and Hovgård, 2002).

resumed after World War II in the period 1946−1984, and again in 1989. The results of those experiments, which have been reported in a fragmentary manner so far, indicate that cod tagged off Southwest Greenland (specifically) undertook spawning migrations back to East Greenland and Iceland (Hovgård and Christensen, 1990; Hovgård and Riget, 1991). However, any possible links between different stock components are not well understood, and it is not known to what extent strong year classes of Icelandic origin contribute to the inshore cod biomass, or whether recruitment to the inshore component is solely attributable to local spawning.

The present study reviews survey information on the distribution of eggs, juveniles, and adults, and tagging experiments conducted in West Greenland inshore, coastal, and offshore waters. Links between the different stock components and the importance of transport and migration in generating a sustainable recovery of the cod stock in West Greenland waters is investigated.

Material and methods

Ichthyoplankton surveys

The Danish and Greenland Fisheries Institutes investigated egg abundance and distribution in West Greenland waters in 46 of the years between 1925 and 1984, but prior to 1950, those ichthyoplankton surveys were mainly inshore and coastal. All surveys were conducted between May and July, but no strict sampling scheme was used, and the effort varied between areas and years. Then, in the 1950s and 1960s, inshore sampling was intensified, especially in the region of the Godthåbsfjord (64°15′N). Ring nets of diameter 1 or 2 m were towed at a speed of 1.5−2 knots. All catches of cod eggs were adjusted to a standard tow of 30 min, and a net diameter of 2 m. Stramin nets with 1-mm mesh were used for most hauls, though during the 1950s, hauls with nylon netting were made; no significant difference in efficiency between the two was observed (Wieland and Hovgård, 2002).

The area of the Godthåbsfjord was selected for 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 (Figure 2), each representing roughly an equal number of hauls. Indices of area-specific egg abundance (E) were calculated, combining all samples taken in April or May, weighted by the number of hauls, and multiplied by the area:

$$E = \frac{N_{April} * n_{April} + N_{May} * n_{May}}{n_{April} * n_{May}} * A * 10^{-6}$$

where N is the mean number of cod eggs per standard tow, n the number of hauls, and A is the area in km^2.

Inshore gillnet surveys

Information on juvenile cod abundance and distribution inshore was derived from gillnet surveys conducted annually from 1985 by the Greenland Institute of Natural Resources. Three main fjord systems were targeted in NAFO Divisions

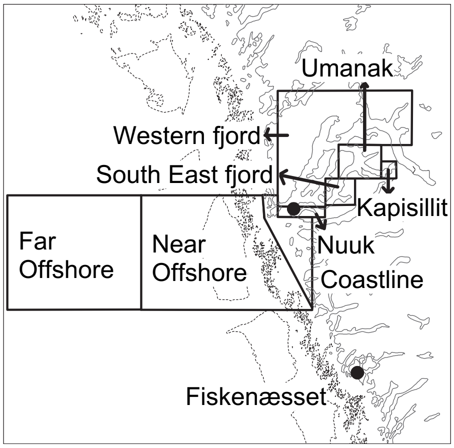

Figure 2. The Godthåbsfjord and adjacent coastal and offshore waters in the vicinity of Nuuk (areas used for the calculation of egg abundance indices are shown).

1B (Sisimiut), 1D (Nuuk), and 1F (Qaqortoq), but for technical reasons the survey did not cover all areas each year, and effort differed between years (24−79 hauls per year). Bottom gillnets, which contain sections of different mesh size (16, 18, 24, 28, and 33 mm bar width), were deployed in the depth zones 0−5, 5−10, 10−15, and 15−20 m. The selectivity of gillnets is adequate for ages 2 and 3, but cod aged 1 and 4+ are not well represented in their catches (Nygaard and Pedersen, 1991; Hovgård, 1996). Age compositions of each net-set are obtained by combining the length frequencies of the individual net catches with year- and area-specific age-length keys, and abundance indices are expressed as number of fish caught per 100 h of net-set.

Offshore trawl surveys

Estimates of cod abundance and distribution offshore were obtained from the results of an annual groundfish survey carried out by the German Federal Research Centre's Institute of Sea Fisheries from 1982. That survey was designed specifically for cod, and it covers the shelf and continental slope off East and West Greenland. The survey area of West Greenland consists of NAFO Divisions 1B−1F, and the area is divided into four geographical strata, each subdivided into two depth ranges (<200, and 200−400 m). Recently, the survey area in the northern sector of West Greenland has been restricted, for technical reasons. Stations are allocated according to a stratified random design. The fishing gear used is a standardized 140-ft bottom trawl rigged with heavy ground gear, owing to the rough nature of the seabed. The vertical net opening is 4 m, and the standard tow is 30 min at 4.5 knots. Cod densities at age (number km^{-2}) were calculated from the total catch of cod and the fished area, using year-specific age-length keys. Cod younger than 3 years are not sampled efficiently by the trawl, but despite this, the 2-group was included in the present analysis because year-class strength at that age closely correlates with that of age 3 cod a year later (ICES, 2004), indicating that the catchability of the 2-group does not vary between years.

Centres of gravity (C_G) of the age-specific distributions were calculated as the mean latitude and longitude weighted for density:

$$C_G = \begin{cases} \dfrac{\sum_i u_i * z_i}{\sum_i z_i} \\ \dfrac{\sum_i v_i * z_i}{\sum_i z_i} \end{cases}$$

where z_i is the observed density, and u_i and v_i denote longitude and latitude, respectively.

Tagging experiments

The cod tagging experiments reviewed and re-analysed for this study were carried out in the years 1946−1984 and 1989−1990.

In the first series of experiments, 84 651 cod were tagged in West Greenland waters, and 13 871 were recaptured (16%). Tagging was conducted mainly during summer (May−September), fewer than 0.5% of the total being tagged earlier than this. May−September should, according to Fowler and Stobo (1999), be the optimal time for tagging cod, because tagging done then should not influence recovery rate. Tagging area covered several fjord systems (∼30%), the main offshore fishing banks (∼30%), and coastal waters (∼40%) between the fishing banks and the coast in NAFO Divisions 1A−1F. Data were excluded from further analysis if recoveries were <1 year after release, or there was no detailed information on recapture location. This reduced the data set to 8665 recaptures; otoliths were obtained from 6029 of those fish recaptured.

In the second experiment conducted in 1989−1990, 3836 cod were tagged in coast and bank areas of NAFO Divisions 1D−1F. From the total of 49 recaptures, 12 tags were returned the same year as tagging took place. The length of the cod tagged ranged from 40 to 65 cm, and were mainly the 1984 year class.

The present analysis was done in two ways: first, without considering the age of the fish at recapture, the time at liberty after tagging was used to describe general migration patterns with a maximum possible sample size; second, for single age groups separately, to account for age- and size-dependence of spawning migrations.

Results

Egg distribution

The distribution of cod eggs in inshore and coastal waters off West Greenland for the years 1925−1984 (Figure 3) identifies two major inshore spawning grounds: one in the

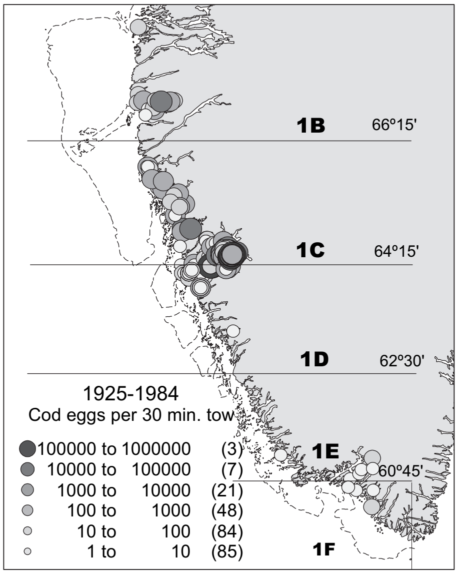

Figure 3. Average density of cod eggs in West Greenland inshore waters, 1925–1984.

southern part of NAFO Division 1B (Sisimiut area), and a second in the northeastern part of Division 1D (Nuuk area/Godthåbsfjord). In these areas for all investigated years, respectively 20% and 60% of cod eggs were recorded. Cod eggs were also found in coastal waters in the northern part of Division 1B, as well as at a few places in Divisions 1C and 1E, but in relatively low numbers. In Division 1F, cod egg distribution was broad and extended into the fjords (Figure 3), but the eggs occurred only in 7% of the years investigated.

The small area of Kapisillit (approximately 50 km^2), at the bottom of the fjord system around Nuuk (Figure 2), was by far the most important spawning ground of the inshore areas investigated. Total egg abundance offshore (an area of some 8200 km^2) was twice as high as in the Kapisillit area, but it was spread over an area about 150 times larger (Table 1). This indicates that restricted spawning areas of the fjord system can be significant for the recruitment of cod to inshore and coastal waters, although not as productive as the larger offshore spawning grounds.

Abundance and distribution of juveniles and adults

Inshore, abundance indices of age 2 cod from the gillnet surveys revealed a very strong 1984 year class in all areas surveyed (Figure 4a). The strength of that year class is even more obvious at age 3, as abundance increased from nearly zero in 1986 to a record high in 1987 (Figure 4b). In the two northern survey areas (NAFO Divisions 1B and 1D), the 1987 and 1990 year classes are considered moderate, but since 1990 there has been no strong year class in Division 1D. In contrast, the 2000 year class appeared to be stronger than average at age 2 in Division 1B. However, after a strong showing as 2-year-old cod in 2002, the second highest value in the time-series, it fell to just moderate level at age 3 in 2003 (Figure 4). Juvenile cod abundance was comparatively low in the southern survey area (Division 1F), except for a few single years in the late 1980s (Figure 4).

Offshore (off West Greenland), an exceptionally strong year class was recorded at age 2 in 1986 (Figure 5a) and at age 3 in 1987 (Figure 5b). Another strong year class followed a year later. Thereafter, recruitment was depressed for many years, before juvenile cod abundance increased again in 2001 (Figure 5). The strength of the 1999 year class amounted, however, to just 5.5% and 0.4% of that of the 1984 year class at ages 2 and 3, respectively. All of the three year classes, 1984, 1985, and 1999, emerged from moderate or even very low levels of cod spawning stock biomass off West and East Greenland (ICES, 2003), suggesting that a substantial portion of the recruits originated from spawning outside Greenland offshore waters.

The offshore 1984 year class was found at ages 2 and 3 from the southern tip of Greenland (Cap Farewell) to about 66°30′N (NAFO Division 1B), but densities were highest

Table 1. Cod egg abundance (mean number of cod eggs per 30 min standard tow) in the Godthåbsfjord and adjacent regions (see Figure 2 for region definitions).

Region	Area (km^2)	Number of hauls in April	Number of hauls in May	Mean number of eggs in April	Mean number of eggs in May	Cod egg index
Kapisillit	51	18	17	90 895	27 960	3.08
Umanak	325	18	19	2 098	6 776	1.46
Southeastern fjord	132	13	21	1 010	3 349	0.32
Western fjord	1541	6	10	680	592	0.96
Nuuk	112	17	29	46	77	0.01
Coastline	1 087	10	15	19	90	0.01
Near offshore	8 735	15	16	44	41	0.37
Far offshore	8 188	15	17	1 572	203	6.92

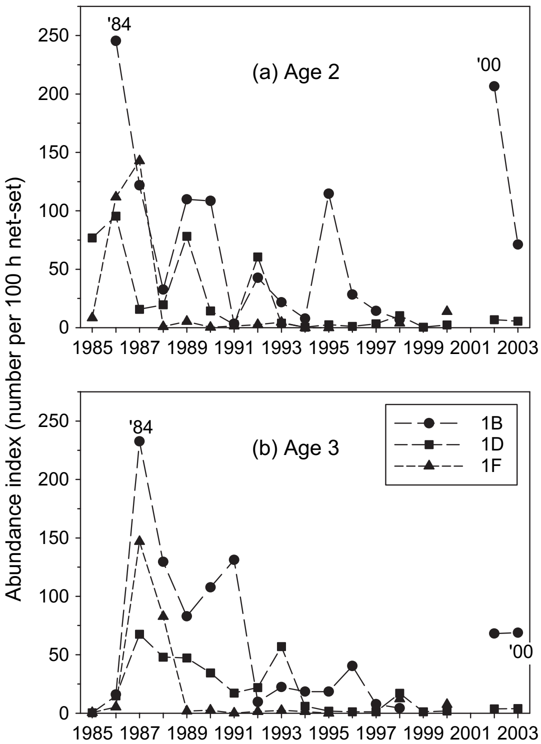

Figure 4. Gillnet survey abundance indices for juvenile cod, (a) age 2 and (b) age 3, in West Greenland inshore waters (NAFO Divisions 1B, 1D, and 1F). Numbers in figure denotes year classes.

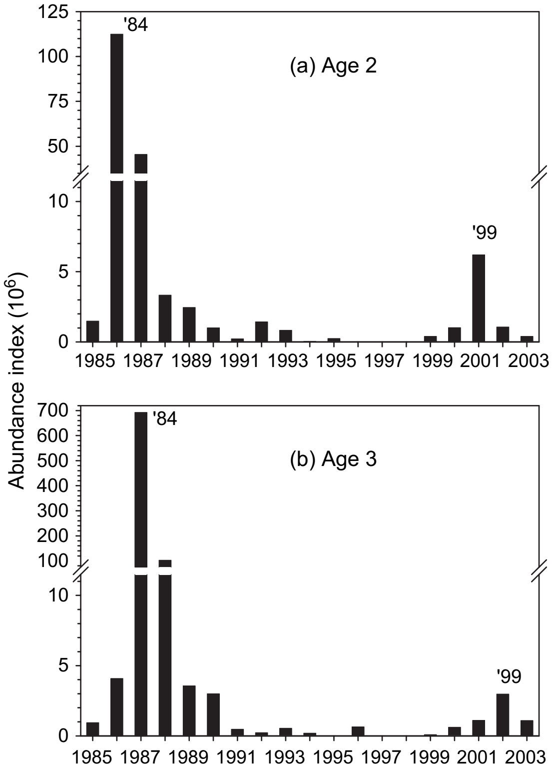

Figure 5. Trawl survey abundance indices for juvenile cod, (a) age 2 and (b) age 3, in West Greenland offshore waters (NAFO Divisions 1B–1F). Numbers in figure denotes year classes.

between the offshore fishing banks and the coast in Divisions 1C and 1D (Figure 6a, b). At age 4, cod densities were greatest in Division 1D and in the northern part of Division 1E (Figure 6c). At ages 5 and 6, cod concentrated in the southernmost area, i.e. Divisions 1E and 1F (Figure 6d, e). The distribution of the 1985 year class was similar to that of the 1984 year class. In contrast, the 1999 year class was most abundant at age 2 in Division 1E, and by age 3 was found almost exclusively in the southernmost part of Division 1F (Figure 7a, b). The 1984 and 1985 year classes centred at about 62°30′N at age 2, and moved gradually southwards with age (4+), whereas the centre of the distribution of the 1999 year class was located at about 61°45′N at age 2, and at about 60°N at age 3.

Spearman rank order correlation analysis indicated that the changes in inshore cod abundance at age 2 in NAFO Division 1F occurred independently from those in Divisions 1D and 1B, but that they were significantly correlated to abundance offshore, i.e. Divisions 1B–1F ($r_s = 0.62$, $p < 0.05$, $n = 13$). Even closer correlations were found between age 2 offshore abundance and the inshore abundance indices for Divisions 1D ($r_s = 0.74$, $p < 0.001$, $n = 18$) and 1B ($r_s = 0.74$, $p < 0.01$, $n = 15$). At age 3, correlation between inshore and offshore abundance was significant only for Division 1B ($r_s = 0.71$, $p < 0.01$, $n = 15$), but not for Divisions 1D and 1F.

Migration

Between fjords, coastal, and offshore bank waters

A χ^2 test indicated significantly different migration behaviour ($p < 0.01$, $\chi^2_{10} = 2135$) between cod tagged in the fjords, at the offshore banks, and in coastal waters in the years 1946–1984 (Table 2). The migration pattern between fjord-tagged cod and recaptures in other fjords, East Greenland, and Iceland was much smaller than would have

Table 2. Cod tagging experiments off West Greenland conducted from 1946 to 1984: number of recaptured cod by area ("Same as tagged" denotes recapture in exactly the same area as tagged, i.e. same fishing bank, fjord system, or NAFO division).

	Tagged		
Recaptured	Fjord	Coast	Bank
Same as tagged	1 503	808	1 853
Fjord	9	545	35
Coast	225	80	105
Bank	294	1 118	1 277
East Greenland	17	145	82
Iceland	45	349	175

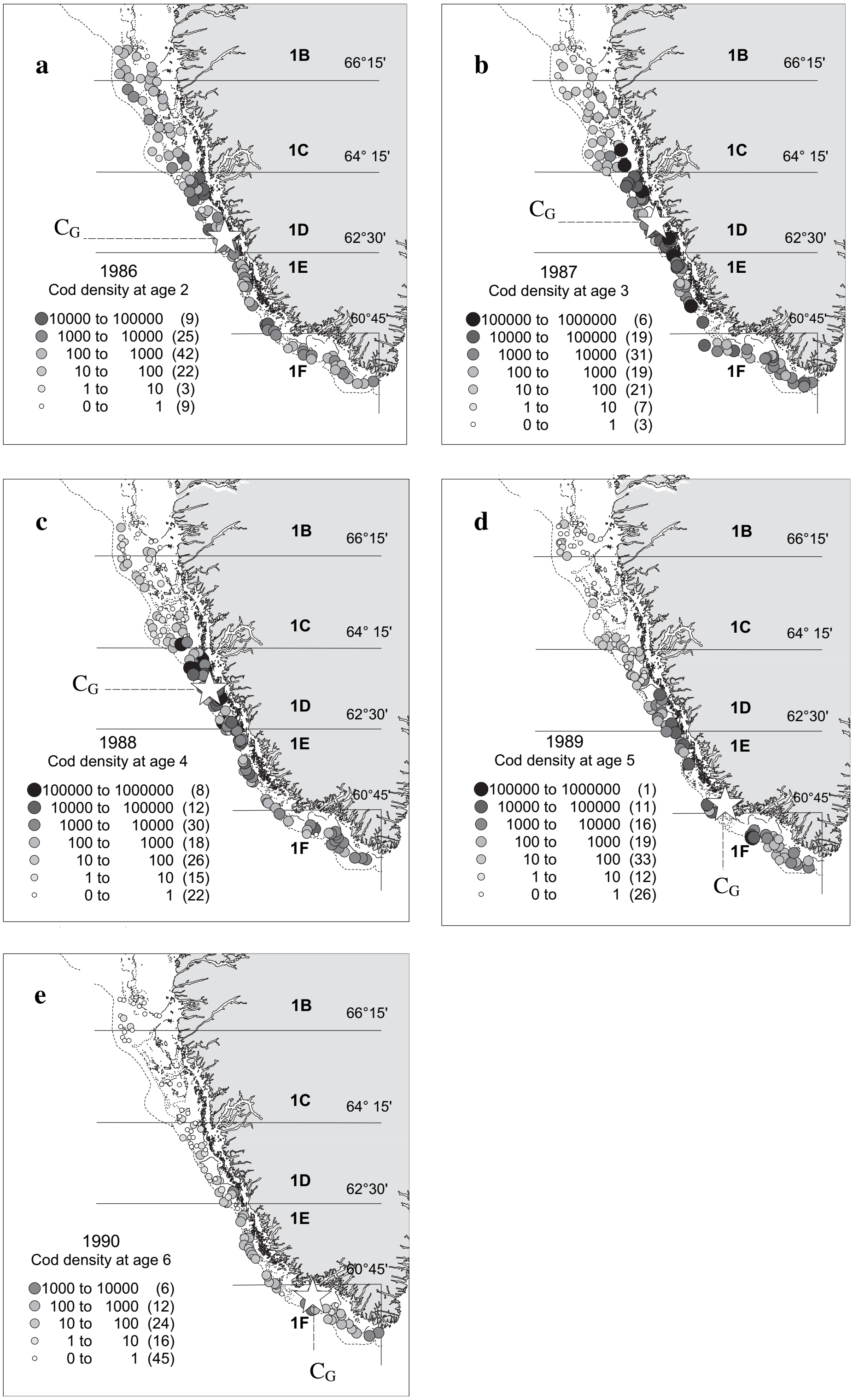

Figure 6. Changes in the distribution of the 1984 year class of cod in West Greenland offshore waters in the period 1986–1990, at ages 2–6. Cod density is given in number km^{-2}. The centre of gravity (C_G) is marked with a white star. Between 103 and 131 hauls were conducted each year. Numbers in parenthesis indicate the number of tows.

been expected according to the χ^2-test. Further, the fjord-tagged cod showed a greater-than-expected migration towards the coast, as well as a high degree of sedentary existence. The migration pattern from cod tagged at the banks differed from that expected, mostly in terms of the minimal rate of migration towards the fjords. Cod tagged in coastal waters migrated more than would have been expected to the fjords and to Iceland, and were caught less than expected in the same area as tagged. Four migration patterns accounted for 60% of the total χ^2: (i) the minimal migration from the bank to the fjords; (ii) the generally sedentary existence of the fjord-tagged cod; (iii) the extensive migration from coastal areas to fjords; (iv) the limited sedentary behaviour of coast-tagged cod.

A χ^2 test also confirmed the age-specific difference in the migration pattern for all three areas ($p < 0.01$; $\chi^2_{60} = 121.8$ (bank), $\chi^2_{60} = 200.6$ (fjord), and $\chi^2_{60} = 737.1$ (coast)). The most pronounced age-specific migration was for cod recaptured in Iceland, where cod from all three tagging areas showed the same pattern. At ages 3–6, fewer cod were recaptured in Icelandic waters than would have been expected, but at ages 7+ the picture changed, and more cod than expected were recaptured there (Figure 8). Moreover, recaptures in East Greenland waters indicated a less than expected migration until ages 5–7, but thereafter the migration rate was higher than expected. Fjord-tagged cod migrated more than expected towards the banks at ages 5–9 (Figure 8a). Coast-tagged cod aged 3–4 migrated more than expected towards the fjords, but there was a subsequent shift towards the offshore banks in cod aged 5–8 (Figure 8b).

Towards East Greenland and Iceland

In all, 15% of the recaptures of the cod tagged along the coast of West Greenland in the period 1946–1984 were returned from East Greenland and Iceland, whereas cod tagged in the fjords or at the banks did not show such a large-scale migration (Table 2). Of the returns from East Greenland and Iceland, 70% originated from cod tagged off southwest Greenland (NAFO Divisions 1E and 1F). The fraction of cod recaptured in East Greenland and Icelandic waters increased with time at liberty, and peaked five years after tagging (Table 3). The average age of cod tagged off Greenland and recaptured in Icelandic waters was 9–10 years, only one fish younger than 7 years being recaptured there.

Similar to the first series of tagging experiments, no recaptures were reported from East Greenland or Iceland in the first year after release in 1989 (Table 4). Returns from Iceland, however, increased to 56% and 100% of the total recaptures in the following two years, respectively, indicating that the migration rate of the 1984 year class was considerably greater than the average for the year classes born in the period 1946–1984.

Table 3. Cod tagging experiments off West Greenland conducted from 1946 to 1984: number of recaptures at West Greenland, East Greenland, and Iceland in relation to the time at liberty after tagging.

Time at liberty	West Greenland	East Greenland	Iceland	Recaptures off Iceland (%)
1	3 084	34	92	3
2	1 296	39	119	8
3	654	26	88	11
4	267	14	62	18
5	119	9	31	20
6	42	4	4	8
7	33	1	1	5
8	19	1	1	5
9	3	0	0	0
10+	2	0	0	0

Discussion

Egg production and recruitment

Historical observations confirm spawning in several distinct fjord systems along the western coast of Greenland from 64 to 67°N. Farther south, cod eggs have only been observed sporadically (Hansen, 1949; Engelstoft, 1997). Mature females have been caught in northern areas, including Disko Bay (69°N), indicating sporadic spawning there too. However, inshore spawning has been observed most regularly in the vicinity of Nuuk, i.e. Godthåbsfjord and Fiskenæsset, where in recent years mature cod have been found (Storr-Paulsen, pers. obs.). The large number of cod eggs reported for the shallow inlet of Kapisillit in the Godthåbsfjord indicates that local spawning there is significant for the inshore stock. However, the inshore spawning areas are not very large spatially, so the total egg production is low compared with the potential contribution from the much larger offshore spawning grounds (Wieland and Hovgård, 2002). In the present situation, and with virtually no offshore spawning stock (ICES, 2004), it appears unlikely that inshore spawning can have a significant effect on recruitment in coastal and offshore waters. However, the local importance of Kapisillit as an inshore spawning area should be noted for management purposes.

Table 4. Cod tagging experiment conducted in 1989: number of recaptures in West Greenland, East Greenland, and Iceland in relation to the time at liberty after tagging.

Time at liberty	West Greenland	East Greenland	Iceland	Recaptures off Iceland (%)
0	15	0	0	0
1	22	3	14	56
2	0	0	9	100

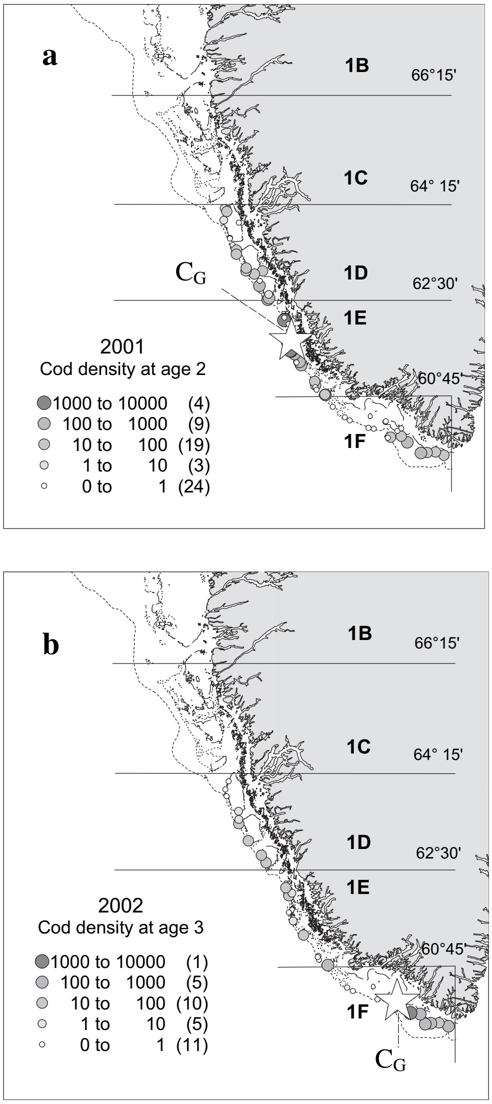

Figure 7. Changes in the distribution of the 1999 year class of cod in West Greenland offshore waters in 2001 and 2002 at (a) age 2 and (b) age 3. Cod density is given in number km^{-2}. The centre of gravity (C_G) is marked with a white star. In all, 59 hauls were conducted in 2001, and 32 in 2002. Numbers in parenthesis indicate the number of tows.

Abundance of juveniles, and migration within West Greenland waters

The tagging experiments suggest a high degree of sedentary behaviour for the fjord populations, because only very few cod tagged in specific fjords were recaptured in another fjord. Some migration along the coast is evident, but the tagging data gave no conclusive indication of return migrations to the same fjord. A comparable study along the Norwegian coast concluded that different cod stocks with shared feeding grounds showed great variability in migration, coastal cod staying put for most of their life, but mature northeast Artic cod migrating long distances (Godø, 1995). Moreover, Canadian studies suggest that different components of a cod stock can maintain their integrity even if they are feeding in the same rather small area of <20 km (Campana *et al.*, 1999). This result confirms our hypothesis that, although the Greenland fjord and offshore bank cod sometimes share feeding grounds, they can maintain their integrity.

The similarity in the trends of age 2 cod abundance inshore and offshore during the 1980s and 1990s suggests, however, that the increased biomass inshore was to some extent the consequence of transport or migration of early juveniles from the offshore banks or coastal waters into the fjords. Alternatively, increased water temperature may have produced favourable conditions for reproduction and survival of early life history stages of the inshore stock (Buch *et al.*, 1994; Riget and Engelstoft, 1998). Inshore abundance indices for cod aged 2 and 3 derived from gillnet surveys may be overestimating the fishery potential inshore if immigration of juveniles into the fjords is substantial, and if these fish move gradually offshore when they mature. This suggestion, however, cannot be verified, because the tagging experiments focused on larger fish caught with handlines, rather than on early juveniles, and spawning stock biomass is not measured inshore. Further, recent data on egg abundance there are not available.

Migration to East Greenland and Icelandic waters

Cod were identified in East and Southwest Greenland waters in the early 1920s, and then they spread gradually northwards along the coast of West Greenland during the 1930s, when the water temperature was unusually warm (Jensen, 1939). Based on tagging conducted between 1924 and 1939, Hansen (1949) reported that cod started to migrate back to Iceland at age 6, and that more 7–11-year-old recaptures were recorded from Icelandic than from Greenland waters. That statement supports the finding of age-specific migration towards East Greenland and Iceland observed in the tagging studies re-analysed here.

It is generally believed that migration back to the original spawning grounds is related to the age at maturity (Rätz, 1994; Secor, 2002). The age at 50% maturity was 6–7 in the years 1960–1983, but it has become more variable and younger since then (ICES, 2003). Earlier maturation may explain the different distribution patterns of the 1984, 1985, and 1999 year classes at West Greenland. The distribution pattern and the results of tagging in 1989 indicate that the homing migration began at age 5 during the mid-1980s, and perhaps even at age 3 in the late 1990s. These observations support the results of Canadian studies in 1997, which suggest that cod begin to migrate away from the area where they live as juveniles at an age of 5 years, and that post-spawning migrations of large cod are more extensive than

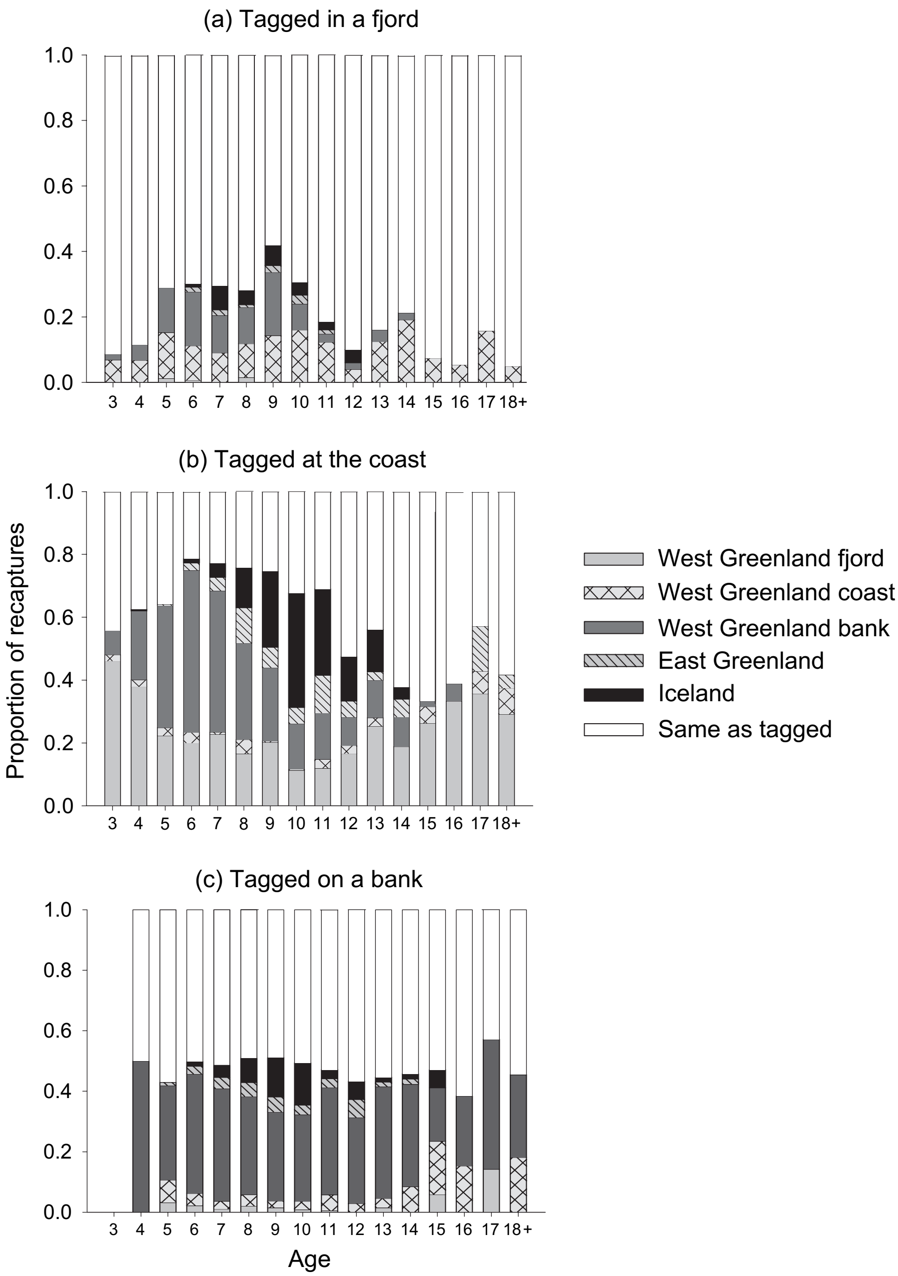

Figure 8. Age-specific locations of recapture of cod by area of tagging, (a) in a fjord, (b) in coastal waters, (c) on an offshore bank.

those of smaller fish (Lawson and Rose, 2000). The earlier age at maturity in the late 1990s could be related to increases in water temperature measured over the past 6–7 years (Stein, 2004). It should, however, be kept in mind that conventional tagging data do not provide irrevocable evidence of a homing migration, because a fish tagged off Greenland and recaptured in Icelandic waters may have been of Greenland origin.

The proportion of recaptures from East Greenland and Icelandic waters of cod marked off West Greenland was considerably higher during the 1989 tagging experiments than in the period 1946–1984. Two factors have to be considered here. First, the existence of a self-sustaining spawning stock offshore of West Greenland in the 1950s and 1960s (Buch *et al.*, 1994) was likely responsible for the limited migration of cod tagged in coastal waters and on the offshore banks then. Second, the number of recaptures of the 1984 year class could be biased towards Icelandic waters because of the low fishing effort in West Greenland offshore waters subsequent to the collapse of the stock there in the early 1990s (Horsted, 2000).

Stock structure, and links between components

The available information indicates that cod stock structure in West Greenland waters is complex. Recruitment to the fisheries can involve four different stock components, with different spawning, larval drift, and migration patterns: (i) an offshore component spawning over the outer slope of various fishing banks off West Greenland; (ii) an offshore component from spawning areas located off Southeast and East Greenland; (iii) an Icelandic component, of which considerable numbers of larvae and pelagic 0-group stages are sometimes transported to East and West Greenland; (iv) a number of distinct local inshore populations, which spawn in separate fjord systems.

The two components originating from spawning offshore of East and West Greenland have virtually disappeared for at least 15 years. Cod tagged in Icelandic waters rarely migrate towards Greenland (Schopka, 1993; Rätz, 1994), but transport of pelagic stages of cod from spawning grounds between Southwest Iceland and East Greenland has occurred occasionally during the past 30 years, e.g. in 1973, 1984, and 1985 (Buch *et al.*, 1994). As with earlier assessments of Icelandic cod (Shepherd and Pope, 1993; Schopka, 1993, 1994), the results of the present study confirm the belief that year classes of Icelandic origin migrate from West to East Greenland and back to Iceland when they mature. Considering the very small spawning stock biomass off East and West Greenland in the late 1990s, it is highly likely that the 1999 year class was also of Icelandic origin. The fjord components appear to retain their virtual integrity from each other, though they may receive occasional input from West Greenland offshore areas, when strong year classes of Icelandic origin are present. Tagging has indicated that the different stock components mix mainly in coastal waters, but genetic studies are needed to support this theory. It is, however, unlikely that inshore spawning, which is of great importance locally, can provide sufficient recruits for the coastal and offshore cod stocks to recover, so larval drift from Iceland is likely crucial for any short-term recovery of the cod stock offshore of West Greenland.

The current findings could have implications for managing the Greenland inshore cod fishery, which is now the most important cod fishery in Greenland waters, with a catch in 2003 of 5500 t (ICES, 2004). For now the inshore cod stock is managed as a unit, but this assumption is questionable. According to Templeman (1983), a stock is a group of fish whose spawning is spatially or temporally isolated from other stocks, and which shows particular distribution and migratory patterns. That definition does not appear to apply to Greenland's inshore cod stock, given the findings presented here.

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