NAFO Sci. Coun. Studies, 14: 45-50

Population Structure and Migration Patterns of Atlantic Cod (*Gadus morhua*) in West Greenland Waters Based on Tagging Experiments from 1946 to 1964

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Abstract

Population structure and migration patterns of Atlantic cod (*Gadus morhua*) in West Greenland waters is evaluated on the basis of tagging experiments from 1946 to 1964. It is suggested that the stock is composed of well segregated populations, where the inshore populations largely are stationary whereas the offshore populations perform regular seasonal migrations with homings to the areas where they were tagged.

Introduction

In West Greenland waters periods of high abundance of cod have alternated with periods of scarcity to the extent that sometimes they were thought to be absent (Hansen, 1949). Around 1920, high abundance of cod gave rise to a large fishery. Tagging experiments carried out since the 1920s have shown large scale migrations of cod from West Greenland to Iceland (Hansen *et al.*, 1935; Hansen, 1949; Anon., MS 1971) and this has been confirmed by studies of the pattern of parasitic infections in the areas (Platt, 1976).

The more local migrations within the West Greenland area have not attracted much attention and have only been superficially analyzed before. In this paper these migrations are described on the basis of tag returns from experiments carried out off West Greenland between 1946 and 1964.

Materials and Methods

Cod have been tagged regularly at West Greenland (NAFO Subarea 1, Fig. 1) since the late-1920s. The annual number tagged was highest in the period 1946-64 and this period is also characterized by the widest geographical coverage and the highest rates of tag returns. Therefore, tagging experiments from 1946 to 1964 were selected for analysis. During this period 57,928 cod were tagged of which 9,407 recaptures have been reported. The numbers tagged by NAFO Division in relation to the general site habitat is given in Table 1, and the numbers of annual taggings are shown in Fig. 2.

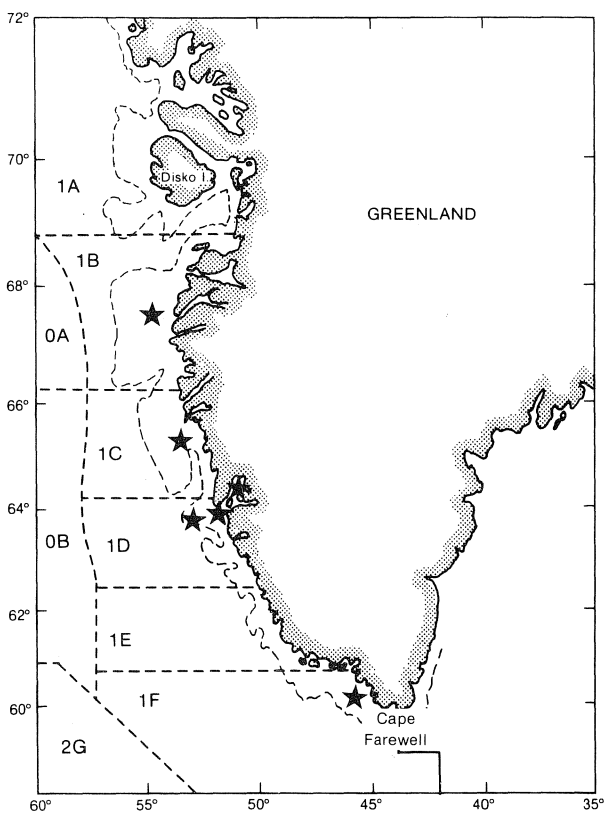

Fig. 1. Map of Greenland showing the NAFO Divisions and the six most important tagging areas (★).

Cod used for tagging were caught by various gear, with jigs being the most important (73% of the total). Only those classified as being in excellent condition

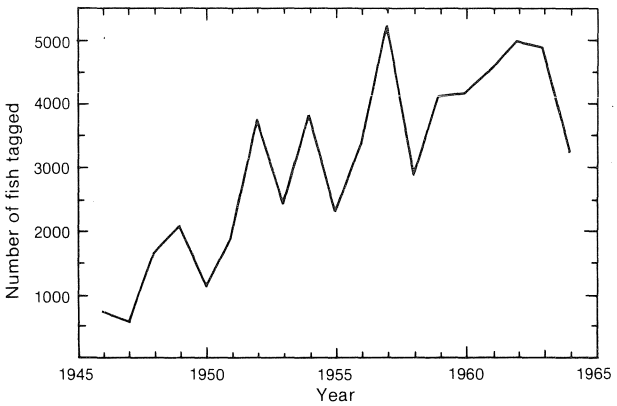

Fig. 2. Annual numbers of cod tagged off West Greenland, 1946-64.

TABLE 1. Numbers of cod tagged and recaptured from 1946 to 1964 and numbers of recaptures used in the analysis by division and habitat.

Div.	Habitat	No. tagged	No. returned	No. of returns used in analysis
	fjord	285	13	8
1A	coast	859	76	45
	bank	158	4	4
	fjord	880	148	48
1B	coast	3,116	300	97
	bank	7,245	1,406	1,055
	fjord	346	110	91
1C	coast	1,932	407	235
	bank	5,479	1,063	805
	fjord	6,336	1,324	890
1D	coast	6,449	1,058	692
	bank	8,466	1,620	1,111
	fjord	572	33	24
1E	coast	905	98	44
	bank	635	118	64
	fjord	2,421	283	154
1F	coast	11,844	1,350	802
	bank	0	—	—
Total		57,928	9,407	6,169

were tagged. Cod larger than 50 cm were mostly tagged with Petersen discs and smaller ones were most often tagged with Nocathene tags. Almost all taggings (98%) were made during summer (May to September, Fig. 3).

Tag returns were recorded by date and site of catch. Otoliths were returned with tags in 6,247 cases or 66% of the recaptures. Ages of returns without otoliths were derived from the overall age-length relationship of the returned otoliths.

Only cod returned at age 5 or older were included in the analysis. Three subsets of data were excluded from the analysis: (1) returns from outside West Greenland; (2) same year returns, which usually contained little information on migration; and (3) age 3 or younger

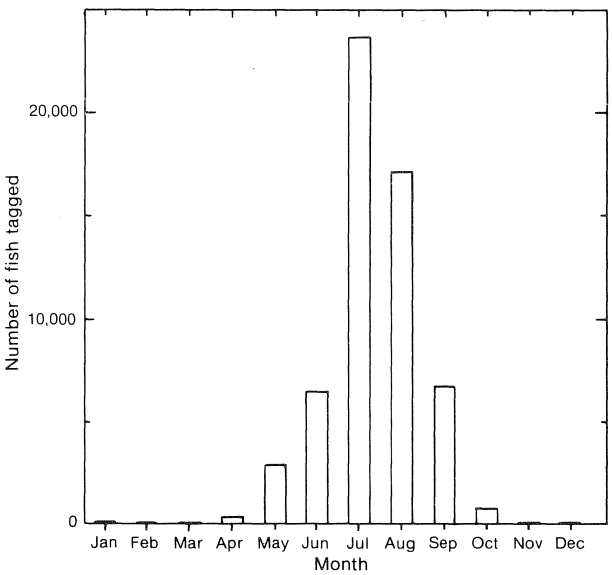

Fig. 3. Numbers of cod tagged off West Greenland, 1946-64, by month.

cod, as these were only tagged inshore and the returns were few. In total, 6,169 returns were included in the analysis (Table 1).

Although 6,169 recaptures were available, the numbers were insufficient for a full analysis of the migration behaviour which included variations between years and fish age. For example, if nine year-classes were considered over the 19 years studied in 18 geographic areas for durations of 50 months, a total of about 150,000 recapture combinations exist. Consequently a considerable aggregation of data was necessary. The data were aggregated over years and age in order to allow an analysis of the overall seasonal and geographic pattern of returns dependent on tagging locations, Even with this aggregation, high numbers of recoveries were only available for six tagging areas, namely the banks of Div. 1B, 1C and 1D, the coastal areas of Div. 1D and 1F and the fjords of Div. 1D (Table 1).

Results

In all divisions except one, the majority of recaptures were returned from the same division where the fish were tagged (Table 2). The only exception was in Div. 1A where the cod fishery was relatively small and few recaptures were therefore expected.

The seasonal distribution of recaptures were compiled for the six most important tagging habitats (Table 3). Returns reported mostly during summer reflect the seasonality of the fisheries in the 1946-64 period. The geographic distribution of returns from successive summers after the tagging year shows that most

TABLE 2. Distribution of tag returns by tagging division.

Return division	Tagging division 1A	1B	1C	1D	1E	1F
1A	10	2	3	1	0	0
1B	23	723	113	109	1	15
1C	6	161	583	183	2	16
1D	13	227	326	2,125	30	51
1E	3	60	71	182	82	51
1F	1	13	19	51	10	777
NK[a]	1	14	16	42	7	46
Total	57	1,200	1,131	2,693	132	956
% returns in tagging division	18	60	52	79	62	81

[a] Division not known

returns were from within the tagging division and that the geographic distribution changed only marginally over the years (Fig. 4).

The distribution of returns from adjacent habitats within the same division was assessed for Div. 1D (Table 4), where largest numbers of cod were tagged in the three habitats labelled as the banks, the coasts and the fjords. The majority (83%) of the returns from the fjord taggings were taken within the fjords and only 7% of the returns were taken outside Div. 1D. Similarly, from the bank taggings few returns occurred in the adjacent coast and fjord areas (3%), however, a relatively large proportion (28%) was taken outside Div. 1D. Returns from the coastal taggings, on the other hand, were relatively evenly distributed in all three habitats as well as areas outside Div. 1D.

In general, more tags were returned to the south of the tagging area during the first half of the year and more to the north in the second half of the year (Table 3). This trend is shown in more detail in Fig. 5, where the midpoints of the recapture distribution in every 2 month period are plotted against time after tagging (midpoints were calculated by weighting recaptures from Div. 1A to 1F by values of 6 to 1, respectively). A northward movement of the return midpoints were seen during late spring followed by a southward movement during the late autumn, and this pattern was repeated in successive years. There were, however, differences seen between tagging habitats with larger amplitudes in the north-south oscillations for offshore bank tagged cod compared to coastal and fjord tagged cod. The return midpoints of the offshore taggings were all centered around Div. 1D in winter, whereas in the summer the midpoints differed with northern tagged cod being returned further north.

TABLE 3. Distribution of returns by 2-month periods and return division for selected areas. Values are given in percent. (N = total number, NK = area not known.)

Month	Return division 1A	1B	1C	1D	1E	1F	NK	N
Tagging area = Div. 1B (bank)								
Jan-Feb	0	7	62	13	16	2	0	45
Mar-Apr	0	5	33	26	31	5	0	39
May-Jun	0	23	21	43	11	2	+	312
Jul-Aug	+	88	5	6	0	+	1	561
Sep-Oct	0	84	5	5	0	5	2	64
Nov-Dec	0	53	16	21	0	0	11	19
NK	0	33	20	13	0	0	33	15
Tagging area = Div. 1C (bank)								
Jan-Feb	0	0	54	20	9	14	3	34
Mar-Apr	0	0	44	22	17	9	9	23
May-Jun	0	2	30	50	16	2	1	303
Jul-Aug	+	18	54	26	+	0	1	337
Sep-Oct	1	11	70	14	1	0	2	83
Nov-Dec	0	20	60	10	0	10	0	10
NK	0	7	36	43	0	0	14	14
Tagging area = Div. 1D (bank)								
Jan-Feb	0	0	8	33	33	13	13	24
Mar-Apr	0	0	13	38	34	13	3	32
May-Jun	0	1	10	68	18	2	1	454
Jul-Aug	0	11	8	79	2	+	+	455
Sep-Oct	0	10	9	78	1	2	0	100
Nov-Dec	0	12	0	59	6	18	6	17
NK	0	7	7	31	7	0	48	29
Tagging area = Div. 1D (fjord)								
Jan-Feb	0	0	4	96	0	0	0	56
Mar-Apr	0	0	+	100	0	0	0	206
May-Jun	0	0	4	94	2	+	+	481
Jul-Aug	0	22	6	66	0	6	0	68
Sep-Oct	0	4	7	86	0	4	0	28
Nov-Dec	0	0	4	86	0	7	4	28
NK	4	4	4	70	4	9	4	23
Tagging area = Div. 1D (coast)								
Jan-Feb	0	4	18	43	21	7	7	28
Mar-Apr	0	0	4	76	18	1	1	84
May-Jun	0	2	8	74	11	4	1	294
Jul-Aug	0	10	9	76	3	1	1	140
Sep-Oct	0	3	9	86	0	0	1	96
Nov-Dec	0	0	8	81	8	0	3	36
NK	0	7	0	64	0	0	29	14
Tagging area = Div. 1F (coast)								
Jan-Feb	0	0	4	0	2	83	11	46
Mar-Apr	0	0	2	9	4	73	13	56
May-Jun	0	1	1	11	13	72	3	233
Jul-Aug	0	3	3	5	1	87	1	257
Sep-Oct	0	3	1	4	6	85	1	108
Nov-Dec	0	0	2	2	6	86	5	65
NK	0	3	0	0	5	51	41	37

Discussion

Fish migrations as inferred from the return pattern of tags is influenced by the distribution of fishing effort and the reporting rates of different fleets. Effort distribution and reporting efficiency by area and season were not available for West Greenland during the 1946-64 period and the return patterns could therefore not be corrected. In spite of this, some basic aspects of stock structure and migration pattern could be

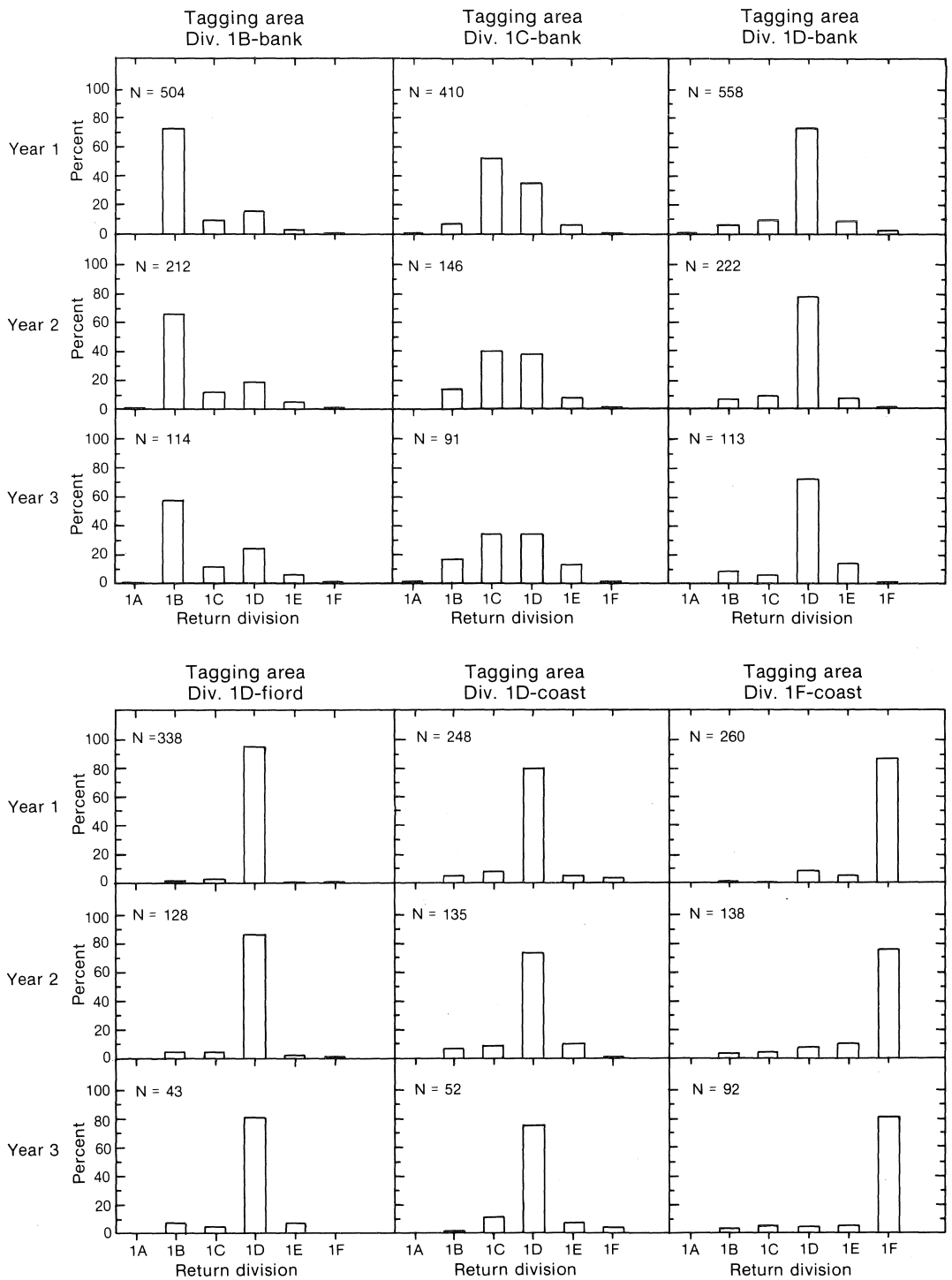

Fig. 4. Distribution of tag returns (N) reported during summer (May–September) in year 1 to year 3 after the tagging year.

deduced from the observed return distribution.

It was noted that the distribution of returns depended on where the cod were tagged and this indicated that different cod populations did not mix randomly. If random mixing had occurred, similar return distributions should be expected for all tagging experiments irrespective of where the cod were tagged, as the return patterns should simply reflect the spatial distribution of the fisheries.

Most returns were taken within the area of tagging (Tables 2–4) and most returns during successive summers (the period of tagging and also highest

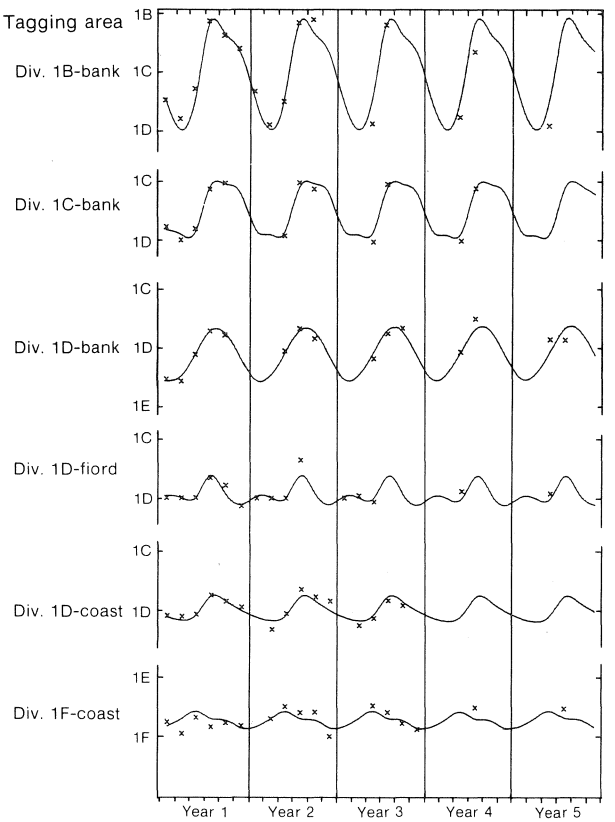

Fig. 5. Seasonal average pattern of returns plotted over successive years, calculated as mean northern latitude from Table 3. Points (x) show the observed geographic midpoints of 2-month periods. Only points based on at least 10 returns are plotted.

numbers of returns) also showed they remained within the tagging area (Fig. 4). This suggests that the cod populations, to a great extent, are segregated and either remain in the tagging areas or return to these areas in summer time.

When comparing the return pattern from adjacent fjord, coast and bank taggings in Div. 1D, only a small proportion of the cod tagged in the fjords were returned from outside that area. Also only a few tagged on the banks were found in the fjords, while those tagged in the intermediate coastal area were found distributed in all these areas (Table 4). Similar results can be extracted from cod taggings in the same areas from the period 1924-39 (Table 5). These findings suggest the existence of well segregated fjord and bank populations of cod in Div. 1D and that the coastal area is a mixing zone for these populations. Other evidence also support the existence of segregated inshore populations: (1) spawning in several fjords are known (Hansen, 1949); (2) inshore cod populations have been distinguished from nearby offshore populations on the basis of parasitic infections (Boje, MS 1987); and (3) otolith types, which are distinct from the typical West Greenland Bank type, are often seen in samples from inshore areas.

TABLE 4. Distribution of returns from taggings in Div. 1D during 1946-64.

Tagging area	Div. 1D Fjord	Div. 1D Coast	Div. 1D Bank	NK[a]	Outside Div. 1D	Total
1D fjord	728	37	48	7	70	890
1D coast	165	131	212	15	169	692
1D bank	13	18	750	1	329	1,111

[a] Area within Div. 1D not reported.

TABLE 5. Distribution of returns from taggings in Div. 1D during the period 1924-39 (data from Hansen, 1949).

Tagging area	Return area 1D fjord	1D coast	1D bank	Outside 1D
1D fjord	106	9	4	11
1D coast	6	10	0	3
1D bank	0	0	31	5

TABLE 6. Distribution of tag returns from Norwegian offshore taggings in Div. 1B during 1953-56 (data from Rasmussen, 1957).

Month	Return position (deg. northern latitude) 61°	62°	63°	64°	65°	66°	67°	68°	69°
May	2	7	6	8	—	—	—	—	—
Jun	—	17	20	20	12	6	—	1	—
Jul	—	1	6	3	2	6	9	3	1
Aug	—	—	1	1	1	29	24	2	2
Sep	—	—	—	—	—	16	24	2	2
Oct	—	1	—	1	—	2	1	1	—

The experiments further suggest that the inshore cod do not move much, whereas the offshore populations undertake seasonal north-south migrations (Fig. 5). Similar migrations for offshore cod is reported by Rasmussen (1957) on basis of Norwegian taggings from the banks in Div. 1B (Table 6). The apparent southward movement of the stock during winter can also be a result of an artifact of the winter fishery, for example if for some reason the fishery has been hindered in the northern areas. The ice chart information (Anon., 1976), however, does not indicate that the ice conditions in general restrict the access to the more northern areas during winter. On the other hand, a southward winter migration makes sense because extensive spawning takes place off the banks of Div. 1D and 1E during spring. The reverse northward summer migration could be a feeding migration, as assumed by Meyer (1962). If this is the case, the different distributions of returns from the summer periods (Fig. 4-5) suggest that different offshore populations home to different feeding areas during summers.

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