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Migration Patterns of Cod (Gadus morhua) in West Greenland Waters

by

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Abstract : The migration pattern of cod (Gadus morhua) in West Greenland waters is evaluated on the basis of tag return distributions from extensive tagging programs during the years 1946 to 64. Tag returns from the summer period were largely concentrated within the tagging area and these trends were stable over successive years. In late autumn offshore tagged cod moved southward and during early summer they returned north to the area where they were previously tagged. Inshore cod, in contrast showed little seasonal migrations and little mixing between fiord and bank populations were found.

1. Introduction

Cod occurrence in West Greenland waters has been of a periodic character. In the 19th century two short cod periods are known (Hansen, 1949). In this century cod returned to West Greenland around 1920 where it gave rise to a large fishery. It is assumed that the repopulation of the West Greenland area was caused by a migration of cod from Iceland.

In the 30'ies it was observed from tag returns that a substantial migration of cod from Greenland to Iceland took place and later tagging experiments (Hansen, 1949, Anon., 1971) as well as interpretations of parasitic infection patterns (Platt, 1976) have confirmed these findings. Although the exact magnitude of this migration is difficult to evaluate due to problems connected to the interpretation of tagging experiments a broad conception of the main pattern has been established (Harden Jones, 1968). Much less attention has been paid to cod migrations within the West Greenland area. Hansen (1949) concluded that cod in general was quite stationary and showed no regular migrations, whereas Rasmussen (1957) found a distinct seasonal migration cycle.

In this paper cod migrations within the West Greenland area will be evaluated on the basis of extensive tagging experiments carried out since 1946.

2 Materials and methods

Taggings

In the period 1946-84 396 tagging experiments have been carried out in West Greenland. A total number of 81,581 cod has been tagged and 12,892 have been reported recaptured.

The cod used for tagging have been caught by a variety of gears, with pound-net and jigs being most frequently used (table 1). Only cod classified as in excellent condition were tagged. Different tags have been used over the years. Prior to 1970 large cod (> 50 cm) were usually tagged with white or black Petersen discs most often attached to the gill cover. The smaller cod (< 50 cm) were usually tagged with Nocatene tags attached below the first dorsal fin. Since 1970 almost all taggings were made with T-tags. A summary of the importance of the major tag types is given in table 2.

The annual number tagged varies considerably but in general the numbers were highest in the 50'ies and 60'ies (fig 1). Almost all tagging experiments have been carried out during summer with 98 percent of the taggings made between May and September (Fig 2).

The experimental sites has been grouped by NAFO division (1A-1F) and into three areas : fiords, coast and banks (table 3). The highest numbers have been tagged on the banks of div 1B, 1C and 1D, in the coast of Div. 1D and 1F and inside the fiords of Div. 1D.

Tag returns

Tag returns have been recorded by year and date, site of catch, nationality of vessel and gears. Otolith of recaptured cod have been returned with the tags in 9015 cases, corresponding to a recovery of 70 % of total reported recaptures. The recaptures returned without otoliths have subsequently been given an age in accordance with the age-length key determined.

Variations in tag return rates

The amount of tags returned is known to depend on a range of factors; some related to the taggings (e.g. tagging mortality) and some related to the recapture (e.g. effort and reporting efficiency). Variation in these factors will all show up in the tag return rates (ratio of returns to tags). An evaluation of the variations in return rates are made below, in an attempt to reveal some overall trends in return patterns.

The effective number tagged has been defined as the number tagged minus the recaptures in the tagging year in order to reduce effects of varying tag returns within the tagging year. The tag return rate is then calculated as

$$\text{tag return rate} = \frac{\text{Recaptures after tagging year}}{\text{Effective number tagged}}$$

The tag return rate depends on the gear used for catching cod for tagging (table 4). The rate is high for jig, poundnet, mixtures of gears and gears not known (9-20 %) and low for longline, trawl and beach seine (2-6 %). The low values for trawl and longline can be attributed to high tagging mortality. The reason for low return rate from beach seine is probably that this gear mainly catches small cod (2-3 years old) and that the cod therefore are decimated due to

natural mortality before they are fully recruited to the fisheries at age 4-5.

In the evaluation of the overall return patterns, taggings from trawl, line and beach seine were excluded to avoid effects of unbalanced distributions of taggings by these rather 'uneffecient' gears. Recaptures and effective number tagged for the remaining gears were pooled by division, area and 5-year period. On these aggregated data the tag return rate was calculated and analyzed by the ANOVA model :

$$\text{tag return rate} = \text{Div}(i) + \text{Area}(j) + \text{Period}(k) + \text{noise}$$

where (i) signifies the 6 NAFO divisions, (j) the fiord, coast and bank area and (k) the eight 5-year periods. All factors, i.e. division, a Area and time periods are significant (table 5).

Most interesting is the marked reduction in the tag return rate from high levels in the period 1945-65 to low levels after 1965 (fig. 3). As no data indicates any reduction in fishing mortality since the mid 60'ies this implies that the reportings of recaptures deteriorated from 1965 to 1970. In this period major changes occurred in the fisheries of West Greenland with a decline in total catch from 360.000 tons (1965) to 113.000 tones (1970) and large segments of the international fleets vanished during these years.

Considerable differencies in return rates are also seen between divisions, with low rates from taggings in Div. 1F and notably in 1A (table 5). Also, taggings from fiords generally gives higher return rates than taggings from the coast and banks. As return rates are dependent on both effort and reporting efficiency, of which little information is available on a disaggregated geographical scale these findings are difficult to interpret. However, the low returns from Div. 1A might with some certainty be attributed to the rather limited cod fishery in this area.

Selection of data

In the evaluation of the migration pattern of the West Greenland cod only data from the period 1946-64 has been used, thereby avoiding all effects connected to the dramatic changes in the fisheries which occurred in the late 60'ies. However, as the 1946-64 period was charaterized by large numbers tagged as well as a high reporting rates considerable information is available from this period alone.

Recaptures from outside the West Greenland area have also been ignored in the present study. These returns will be analysed and reported at a later time.

All recaptures of fish of an age of 3 years and younger when tagged have further more been omitted, as preliminary work indicated that small fish were only effeciently taken by the inshore gears and this could bias the overall trends.

Finally, recaptures within the tagging year have not been used.

In total 57.703 tagged cod (71% of the total tagged) and 6262 returns (49 % of total returns) are included in the analysis (table 6).

Principles of analysis

In spite of the several thousands of recaptures, considerable aggregation of data is necessary (just consider having 9 age groups during 19 years in 18 geographical areas - totalling 3000 experimental units - followed over 50 months - totalling 150.000 recapture combinations).

For this reason all years and ages are combined. For the tag returns only the following information is therefore used in the analysis :

- a) Tagging site by division and area.
- b) Recapture site by division and area.
- c) Recapture time, in months after tagging.

In effect this is to follow the fate of average cod (age 5-13+) tagged in an average year in the period 1946-64, dependent on where it was tagged.

Obviously migration of small and large cod could be expected to differ and some considerations will therefore be given to the age effect.

Even with this relatively rough aggregation of data, sufficient information is only available for six tagging sites, i.e. Div. 1B, 1C, 1D banks, Div. 1D and 1F coastal and Div. 1D fiord (table 6).

This paper, therefore, concentrates on tag returns from these tagging sites. Their location are shown on fig. 4.

3. Results

Overall trends in recapture distribution

The majority of recaptures (overall average 71%) was found in the division where the fish were tagged (table 7). The only exception is division 1A where little cod fishery takes place and where few recaptures therefore are made.

The seasonal distribution of recaptures has been compiled for the six largest tagging sites (table 8). In general the highest number of recaptures are taken during the summer period. This reflects the fishery pattern of the 40'ies and 50'ies where the overwhelming part of the fishery took place in the summer period.

Distribution of returns during summer

As the majority of taggings was made during May to September (fig. 2) the tag distribution in successive summer periods can give information on the degree of stationarity or the returning tendencies of the cod. The distribution of tag returns in three successive summer periods (May to September) after the tagging year for the most important tagging sites are shown in fig. 5.

For all tagging sites the highest number of recaptures are taken within the tagging division and this pattern remains stable over the years. An increase in the scatter of the distributions with time can be observed, although this trend seems insignificant. Also the proportion caught within the tagging division is generally higher for the coastal and fiord tagging sites compared to the banks.

Seasonal distribution of tag returns

In general tags are returned to the south during the first half of the year and more to the north in the second half of the year (table 8). Also a wider scatter in the geographical pattern is observed for bank taggings compared to the inshore taggings.

In order to illustrate the trends in seasonal distributions more clearly the mean recapture position per 2-month period has been calculated by giving recaptures in div. 1A to 1F values of 6,5,4,3,2,1 respectively (in essence this is to express the recaptures by their mass midpoint). The midpoints of the actual distribution of recaptures per 2-month intervals have been computed in the same way for the first 5 years after tagging and are compared to the average pattern in fig. 6. Although important information on the scatter is lost when regarding the mass midpoint of the distribution only, three overall trends in the seasonal pattern of the geographical distribution can be extracted :

- a) There is a general seasonal pattern in the recovery positions with northward movement during late spring and southward movement during late fall.
- b) This pattern is consistently found over the years after tagging, i.e. there are no traceable tendencies for a change in distribution with time after tagging.
- c) There are significant differences in the amplitude of the tag movements with larger oscillations for offshore tagged fish compared to coastal and fiord tagged fish, and larger oscillation for fish tagged northerly than southerly.

Return distribution within division 1D

In Division 1D large number of taggings have been made in the fiords, at the coastal area and on the banks. This division was therefore selected for an investigation of tag intermingling between areas. Tag returns from this division is given by tagging and recapture areas in fig. 7.

For all three areas the main proportion of the recovered tags appeared in Div. 1D (94, 77 and 73 % for fiord, coast and bank taggings respectively). However, the returns from Div. 1D were unevenly distributed on the areas. For the fiord and bank taggings the vast majority of returns were taken within the very same area as where the fish were tagged (90 and 96 % of the returns from 1D was taken within the tagging area for fiord and bank, respectively). Returns from the coastal taggings were on the other hand evenly distributed between the three areas.

Age effect on the return pattern

In the above sections the recapture distribution has been described on an aggregation of fish from age 5 and older. As the migratory patterns could be expected to change with maturity and hence age, serious errors might arise in the data interpretations when not considering age effects.

The age effect is evaluated by comparing the proportions of the tag returns taken within the tagging division for different ages in the

first year after tagging (Fig. 8). Should large difference in migratory behaviour exists, trends in this proportion would be expected. No clear trends are detectable.

4. Discussion

Overall pattern in return distribution

The present results generally indicate a high degree of non-mixing of different cod populations in the West Greenland area with an overall proportion of 71 % of recaptures taken within the same division as where the fish were tagged.

From previous reportings of recapture distributions, covering the period 1924-39 (Hansen, 1949) it is possible to compile information on recapture distributions (table 9). In that period 82% of the recaptures were taken within the division of tagging. However, as recoveries from the tagging year are included in Hansen returns, little differences in overall 'stationarity' between the two periods can be expected.

Recaptures in successive summer periods

An evaluation of the recapture distribution in the summer period, the season of tagging as well as the season with highest fishing effort, showed highest returns within the tagging divisions and that recapture distribution changed only marginally over a period of 3 years following tag releases.

Recapture distribution, of course, reflects stock distribution only imperfectly as variations in fishery efforts and reporting efficiencies will bias results. If comparing the return patterns of the three bank taggings (fig. 6) one might for instance infer that effort/reporting efficiency were highest in division 1D. However, these effects are not able to distort the general return pattern with highest return rates from the tagging division found in all six tagging areas investigated.

It therefore seems safe to conclude that the cod populations examined are either quite stationary or that they to a large extent return to the same divisions during successive summers.

Inshore - offshore migrations

An evaluation on interrelations between populations in neighbour areas, ie. fiord, coast and bank in division 1D moreover showed a high level of stationarity within the same division with a majority of returns from bank and fiord taggings being recovered in the tagging area (fig. 7). Returns from the coastal taggings were on the other hand quite evenly distributed. A simple interpretation of these findings is the existence of two sub-populations - one in the fiord and one on the banks - and that cod from both populations are mixing in the coastal area. A similar pattern can be extracted from the 1924-39 taggings (loc. cited) although the numbers of returns from that period are rather low (table 10).

Seasonal migrations

A clear difference in the seasonal distribution of returns from offshore and inshore tagged cod can be noted from table 8 and fig 7, with inshore cod showing quite limited migrations. Offshore cod, on

the other hand, are migrating southward during late fall and returning north late in spring. A similar pattern is found in Norwegian tagging experiments from 1953-56 (Rasmussen, 1957) (table 11).

Now tag return patterns depend on the distribution of efforts and one can fear that the seasonal pattern found reveals more about the distribution of the effort than of the stock. As the winter fishery usually (also in later years) takes place quite southernly there is really no way in which this can be evaluated from tagging data. Of course, one might argue that fleets will follow the stock movements the best they can, and in that case tag return positions should reflect stock movements quite well

Fishery independent information on stock distribution is only available for the period since 1982 where Germany (FR) have conducted annual surveys for cod during November. In this period the stock has been concentrated from division 1C and southward. At least this stock distribution is not in contrast to what could be predicted on the basis of the earlier taggings.

5. Conclusions

In summary, this study on cod migrations suggests that the cod stock in West Greenland can be described as a complex of inshore and offshore populations.

The inshore populations are quite stationary with little migrations out of their areas.

The migration pattern of the offshore populations are more difficult to interpret. Two hypotheses which are in line with the present findings can be proposed:

I) If accepting the return patterns from the winter/spring period as a good index of stock movement the offshore populations shows regular migrations from a southern overwintering area to northern areas in summer and autumn. To a large extent different offshore populations return to the areas where they were tagged.

II) The offshore stock components are a mixture of stationary and migrating populations. The migrating populations dispersees randomly and some of these fish are caught to the south during winter/spring. The stationary populations stays within the tagging area and hence accounts for the high return rates found in the tagging area in successive summer periods.

Finally it must be stressed that migrations out of the West Greenland area (mainly to Iceland) concurrently takes place. This migration overlays the within-Greenland migrations and is known to affect various populations differently, e.g. southern tagged cod are more likely to be recaptured in Iceland than cod tagged more to the north. An analysis of this migration will be presented at a later time.

6. Methodological effects caused by non-mixing

It has been noted by Poulsen (1957) and Horsted (1963, 1965) that

the number of tag returns per 1000 tons of cod caught was very different between fleets. These differences could be related to the way of fishing, as high returns occurred in the small scale fisheries (dorys and greenlanders) where tags could easily be detected and to the reporting procedures applied by different nations. On this findings and on the assumption of an evenly distribution of tagged cod in the population in the calendar year after tagging it was possible to calculate the reporting efficiency of the different fleets.

It is quite certain that Horsted's and Poulsen's conclusions are still valid. However, if a considerable degree of stationarity or non-mixing exists the calculated fleet values should be reanalysed. In a non-mixing situation the number of tag returns per 1000 tonnes will depend both on the reporting rates of different fleets and on the tag density in the area. It is most likely that the tag density have been very different between areas. For instance, in the 1946 to 64 period most taggings have been made within the inshore areas which roughly comprises only a third of the total potential area available for cod (Hovgård et al, MS 1988).

7. References

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Table 1 : Number of cod tagged 1946-84 by gears used for catching fish to be tagged.

Gear	Jig	Pound net	Beach seine	Trawl	Long line	Mix-ture	NK
Nos.	51.580	16.215	6.960	449	52	4.848	1477

Table 2 : Number of cod tagged, 1946-84, by tag type.

Tag	Petersen white	Petersen black	Nochathene	T-tags	Lea	Double tagging
Nos.	25.122	25.140	22.301	7.540	1.315	152

Table 3 : Number of cod tagged, 1946-84, by Division and area.

Area Div.	Fjord	Coast	Bank	Total
1A	285	912	158	1.355
1B	1.304	3.535	9.140	13.979
1C	346	2.555	6.607	9.508
1D	17.227	9.041	9.215	35.483
1E	648	1.649	1.192	3.489
1F	2.901	14.518	348	17.767
Total	22.711	32.210	26.660	81.581

Table 4 : Tag return rates by gears used for catching fish for tagging. Effective numbers tagged are numbers tagged minus recaptures in the tagging year. Numbers of recaptures are recaptures minus the recaptures within the tagging year.

Gear	Jig	Pound Net	Beach seine	Trawl	Long line	Mix-ture	NK
Ef. Nos. tagged	49.406	14.019	6.852	444	52	4.763	1.434
Nos. of recapt.	6.571	1.221	407	9	3	598	281
Return rate (%)	13.3	8.7	5.9	2.0	5.8	12.6	19.6

Table 5 : Results from ANOVA of tag return on time period, division and area. For model see text.

ANOVA statistics

Source of variation	Df.	SS	F	P(F > F(oba))
Period	7	.177	11.06	<.0001
Area	2	.014	3.16	.499
Division	5	.054	4.76	.001
Residual	59	.135		

ANOVA estimates

R2=0.66

<u>Period</u>	<u>Division</u>	<u>Area</u>
45-50	0.110	1A 0.021
50-55	0.139	1B 0.107
55-60	0.186	1C 0.130
60-65	0.135	1D 0.104
65-70	0.065	1E 0.112
70-75	0.041	1F 0.061
75-80	0.040	
80-85	-0.003	

Table 6 : Numbers of tagged and recaptured cod, 1946-64, by division and area. Recaptures from the tagging year or from cod of an age of 3 or younger when tagged are excluded.

Tagging site	Nos. tagged	Nos. returned
<u>Div. and area</u>		
fiord	285	8
1A coast	859	41
bank	158	4
fiord	822	50
1B coast	3116	96
bank	7045	1071
fiord	346	93
1C coast	1922	235
bank	5479	829
fiord	6336	890
1D coast	6449	708
bank	8466	1131
fiord	572	24
1E coast	905	43
bank	635	66
fiord	2406	157
coast	11844	816
bank	0	-
<u>Total</u>	<u>57703</u>	<u>6262</u>

Table 7 : Distribution of tag returns by tagging and return divisions. The numbers returns are slightly smaller than the values in table 6 as some returns could not be accurately positioned on divisions.

Tagging div.	1A	1B	1C	1D	1E	1F
1A	10	2	3	0	0	0
1B	21	717	113	109	1	15
1C	6	160	582	182	2	16
1D	11	226	324	2121	30	51
1E	3	60	71	180	80	51
1F	1	13	18	50	10	774

Pct. returns in tagging div.	19	61	52	80	65	85
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Tagging site: div. 1B - bank

Division	1A	1B	1C	1D	1E	1F	N
1- 2	0	7	62	13	16	2	45
3- 4	0	5	33	26	31	5	39
5- 6	0	23	21	44	11	2	309
7- 8	+	88	5	6	0	+	556
9-10	0	86	5	5	0	5	63
11-12	0	59	18	24	0	0	17

Tagging site: div. 1D - fiord

Division	1A	1B	1C	1D	1E	1F	N
1- 2	0	0	4	96	0	0	56
3- 4	0	0	+	100	0	0	206
5- 6	0	0	4	94	2	+	480
7- 8	0	22	6	66	0	6	67
9-10	0	4	7	86	0	4	28
11-12	0	0	4	89	0	7	27

Tagging site: div. 1C - bank

Division	1A	1B	1C	1D	1E	1F	N
1- 2	0	0	56	21	9	15	34
3- 4	0	0	48	24	19	10	21
5- 6	0	2	30	50	16	2	301
7- 8	+	18	55	27	+	0	333
9-10	1	11	72	15	1	0	81
11-12	0	20	60	10	0	10	10

Tagging site: div. 1D - coast

Division	1A	1B	1C	1D	1E	1F	N
1- 2	0	4	19	46	23	8	26
3- 4	0	0	4	77	18	1	83
5- 6	0	2	8	75	11	4	291
7- 8	0	10	9	77	3	1	139
9-10	0	3	9	87	0	0	95
11-12	0	0	9	83	9	0	35

Tagging site: div. 1D - bank

Division	1A	1B	1C	1D	1E	1F	N
1- 2	0	0	10	38	38	14	21
3- 4	0	0	13	39	35	13	31
5- 6	0	1	10	69	18	2	448
7- 8	0	11	8	80	2	+	453
9-10	0	10	9	78	1	2	100
11-12	0	13	0	63	6	19	16

Tagging site: div. 1F - coast

Division	1A	1B	1C	1D	1E	1F	N
1- 2	0	0	5	0	2	93	41
3- 4	0	0	2	10	4	84	49
5- 6	0	1	1	11	13	73	246
7- 8	0	3	3	5	1	88	254
9-10	0	3	1	4	7	86	107
11-12	0	0	2	2	6	90	62

Table 8 : Distribution of returns from six selected tagging sites by season (2-month periods) and return division. Values are given in percent to facilitate comparisons, with N indicating total number returned. Month codes 1-2 indicates January-February etc.

Table 9: Percent return within tagging areas and sample size from tagging experiments during 1924-39 (Data from Hansen, 1949).

Tagging area	%return in tagging area	tot. nos. of returns
Div 1A	.75	36
1B	.86	126
1C	.75	128
1D ex. fiord	.84	50
1D fiord	.82	130
1E	.38	13
1F	.92	128
Average	.82	Sum 611

Table 10 : Return distributions from taggings in div. 1D in the period 1924-39. (data from hansen, 1949).

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

Table 11 : Distribution of tag returns from Norwegian off shore taggings in div. 1B. during 1953-56. Data from Rasmussen, 1957.

Month	Northern latitude									
	61	62	63	64	65	66	67	68	69	70
May	2	7	6	8	-	-	-	-	-	-
June	-	17	20	20	12	6	-	1	-	-
July	-	1	6	3	2	6	9	3	1	-
August	-	-	1	1	1	29	24	2	2	-
September	-	-	-	-	-	16	24	2	2	-
October	-	1	-	1	-	2	1	1	-	-

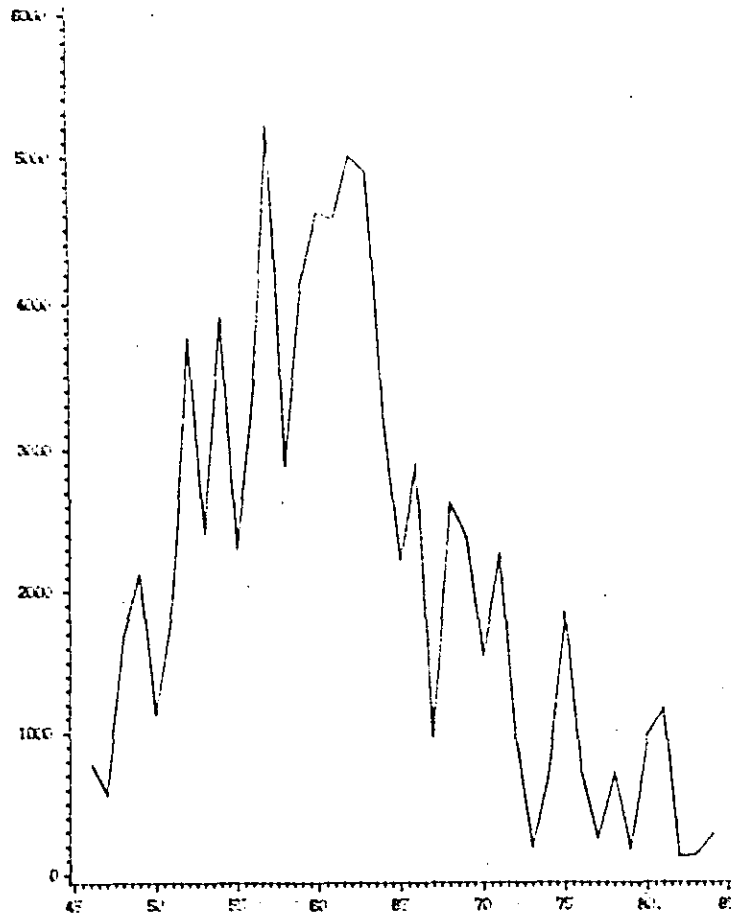


Fig. 1 : Numbers of cod tagged in West Greenland per year, 1946-64

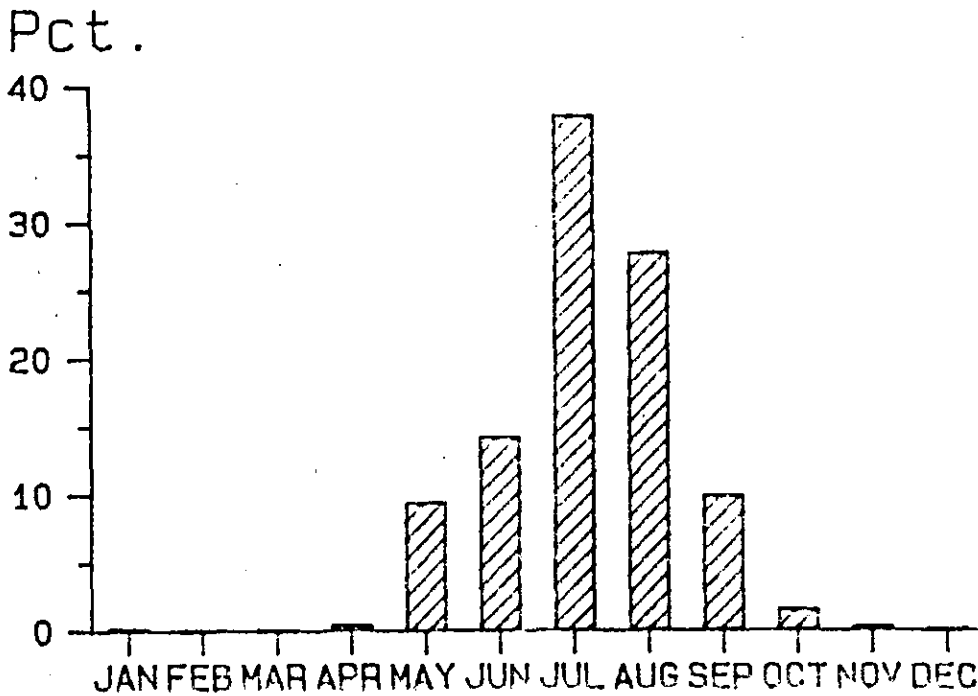


Fig. 2 : Tagging by month in West Greenland, 1946-84

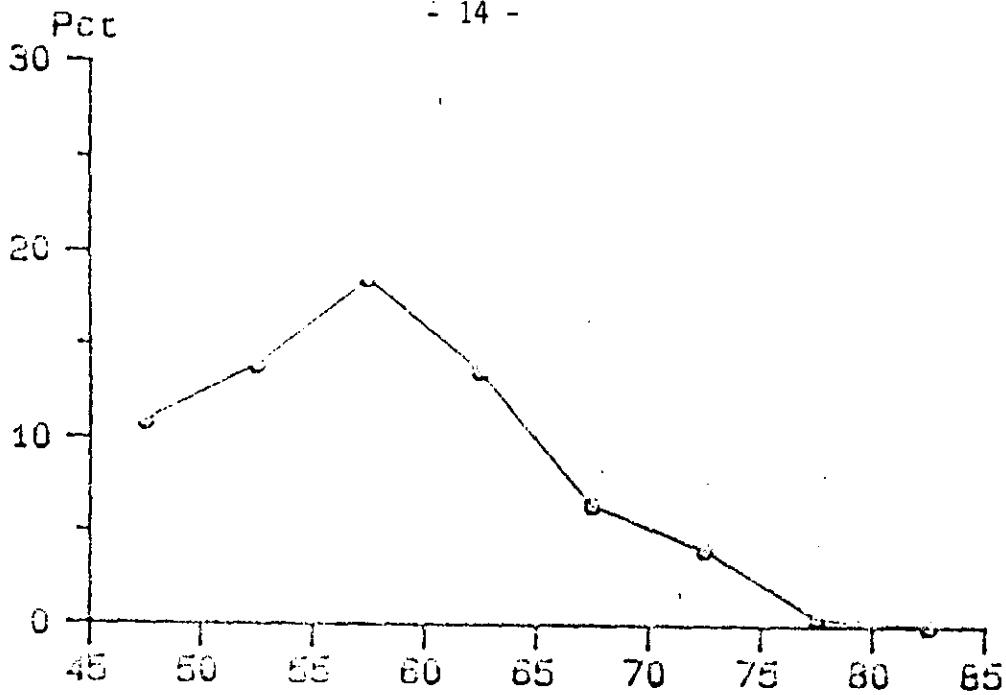


Fig. 3 : Tag return rate by 5 years periods as estimated in the ANOVA given in table 6.

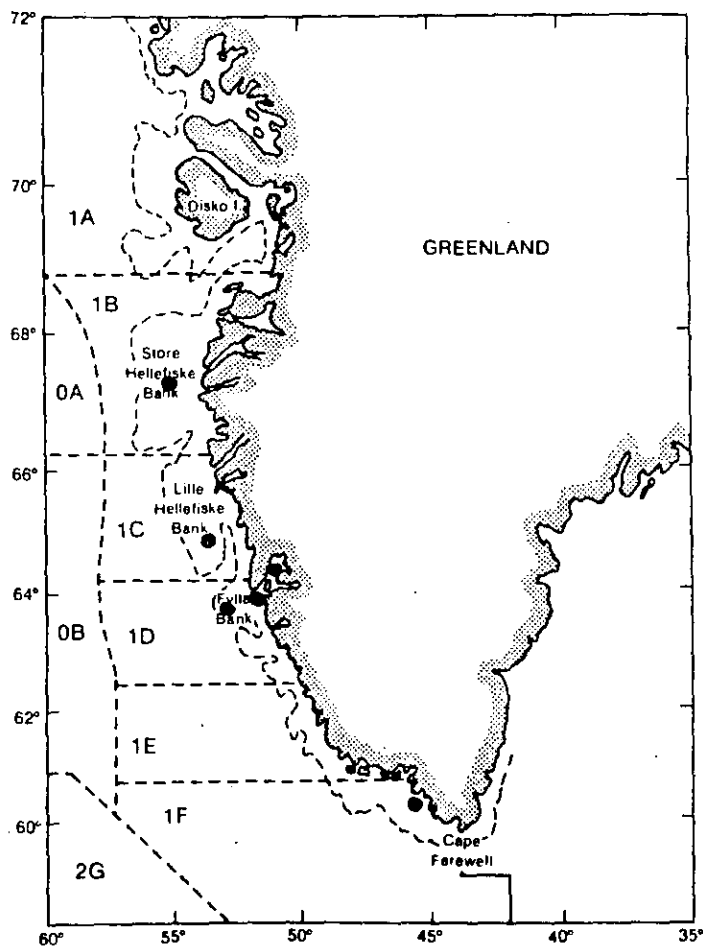


Fig. 4 : Map of West Greenland showing the NAFO divisions. The six major tagging sites are shown by • .

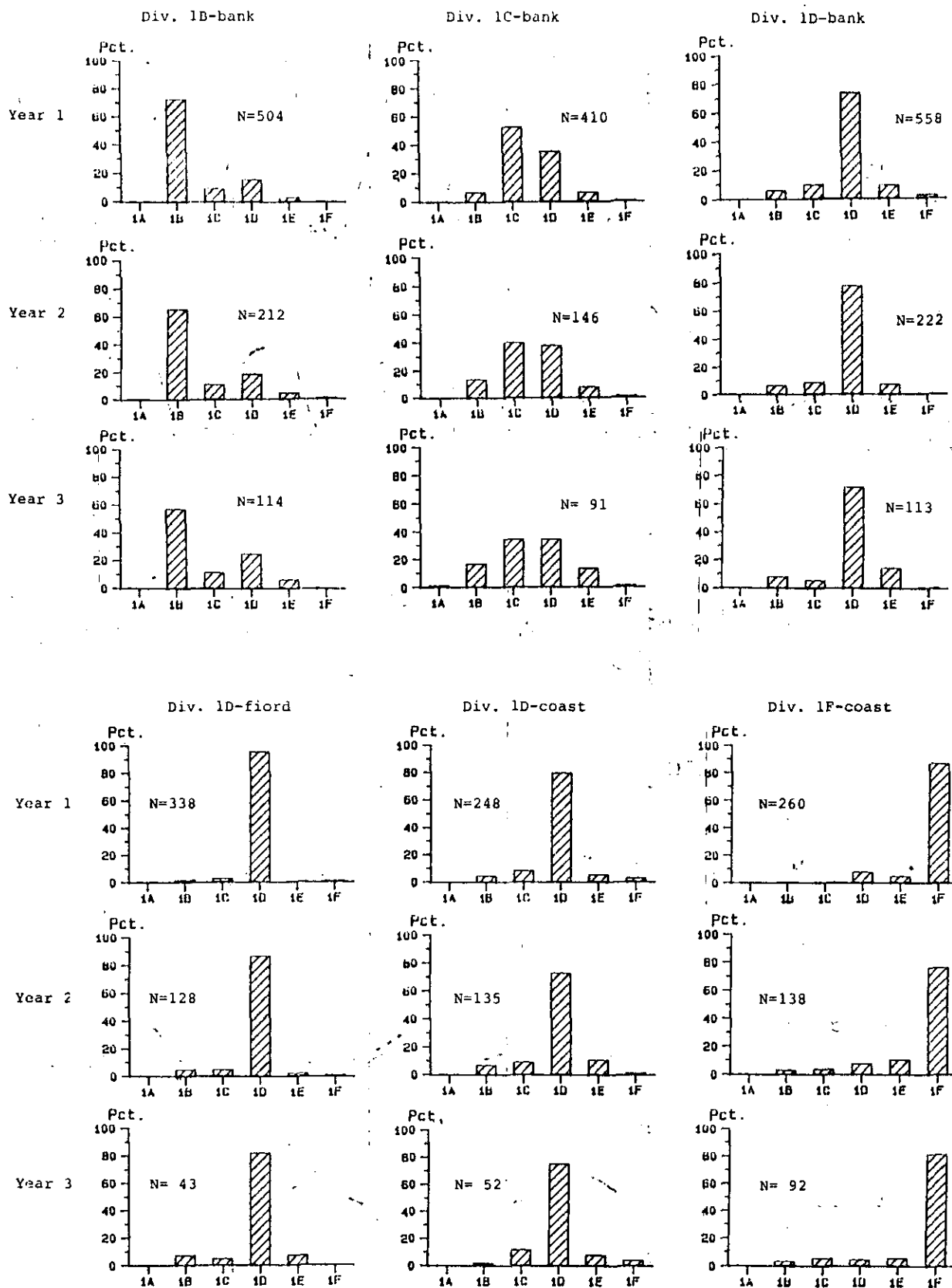


Fig. 5 : Distribution of returns from the period May-September in three successive years after tagging for the six major tagging sites.

Tagging
site

Recapture
Division

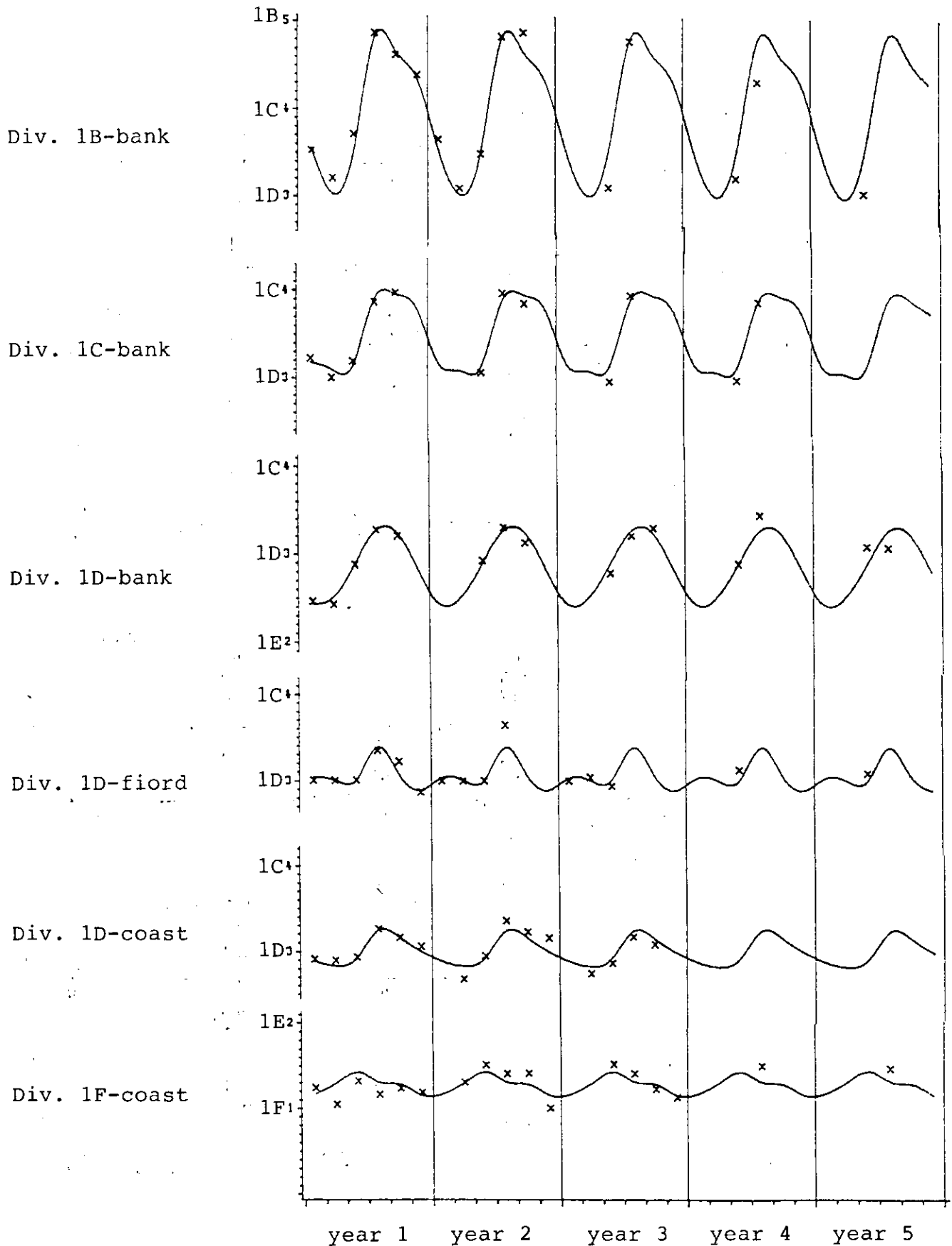
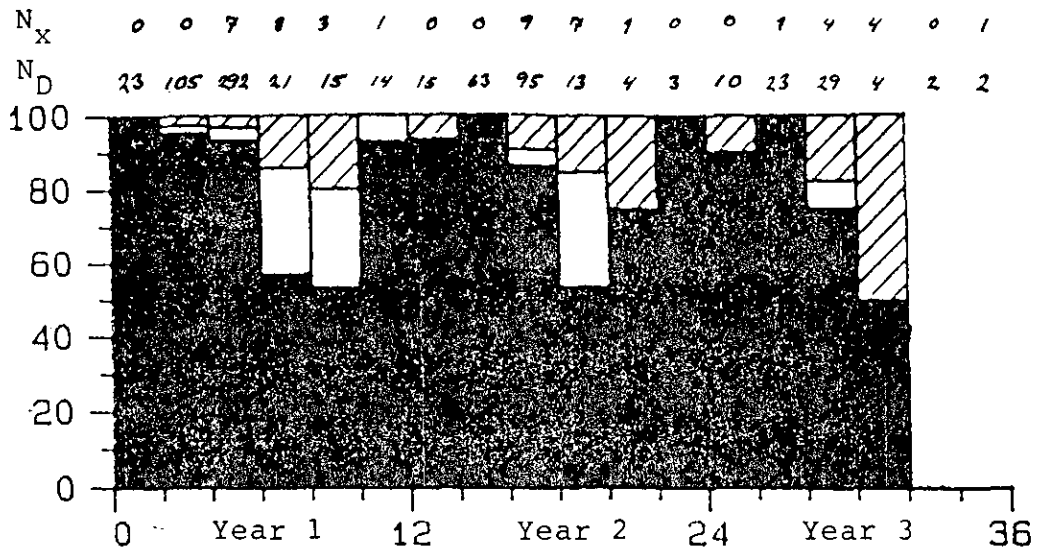


Fig. 6 : Distribution of the mass-midpoints of tag returns versus season (see text). The full lines shows the average seasonal distribution found in table 8, repeated over successive years. Points (x) shows midpoints of actual returns. Only points based on at least 10 observations are shown.

Area : Fiord

Return totals
year 1-3

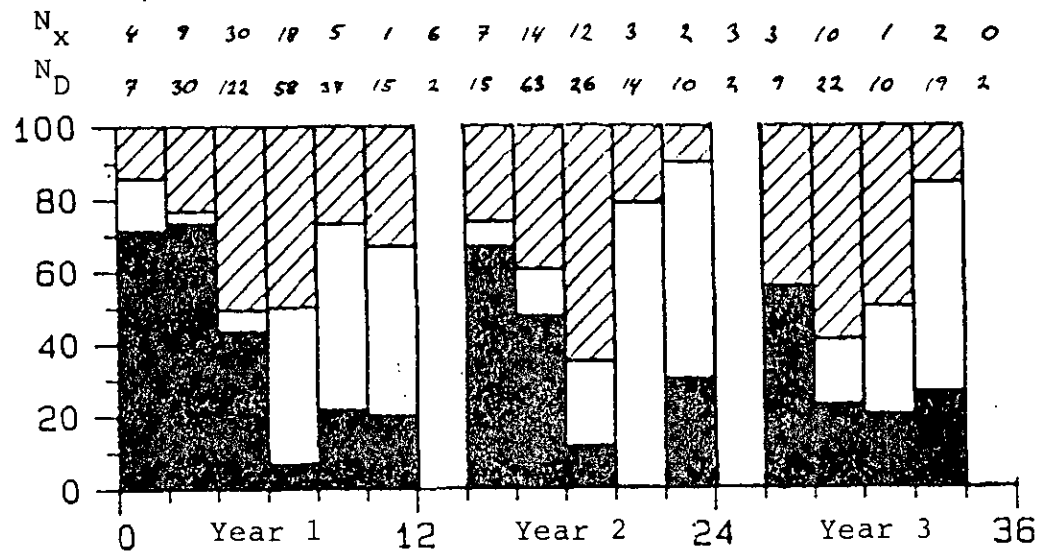
1D-fiord	657
-coast	36
-bank	40
Oth. Div.	46
Total	779



Area : Coast

Return totals
year 1-3 :

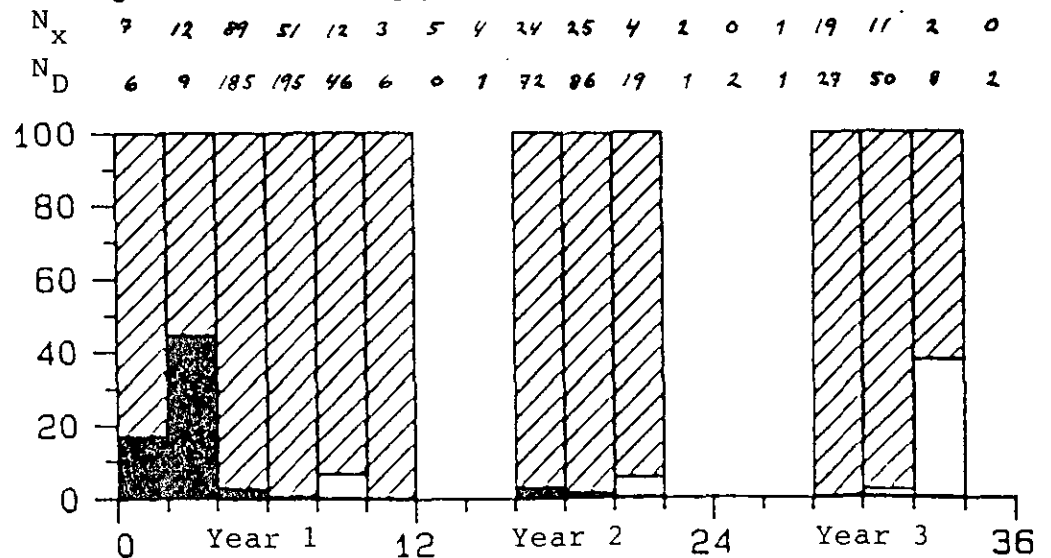
1D-fiord	161
-coast	112
-bank	190
Oth. Div.	140
Total	603



Area : Bank

Return totals
Year 1-3

1D-fiord	13
-coast	14
-bank	689
Oth. Div.	271
Total	987



Legend : Returns from Fiord, Coast, Bank

Fig. 7 : Distribution of tag returns by return area and month for three tagging areas within division 1D. Histograms show pct. distribution ; $N(D)$ indicates number returned within 1D and $N(x)$ concurrent returns outside division 1D. Pct. distribution are not given when numbers of returns are less than 2 (!). Tables at left sums up totals.

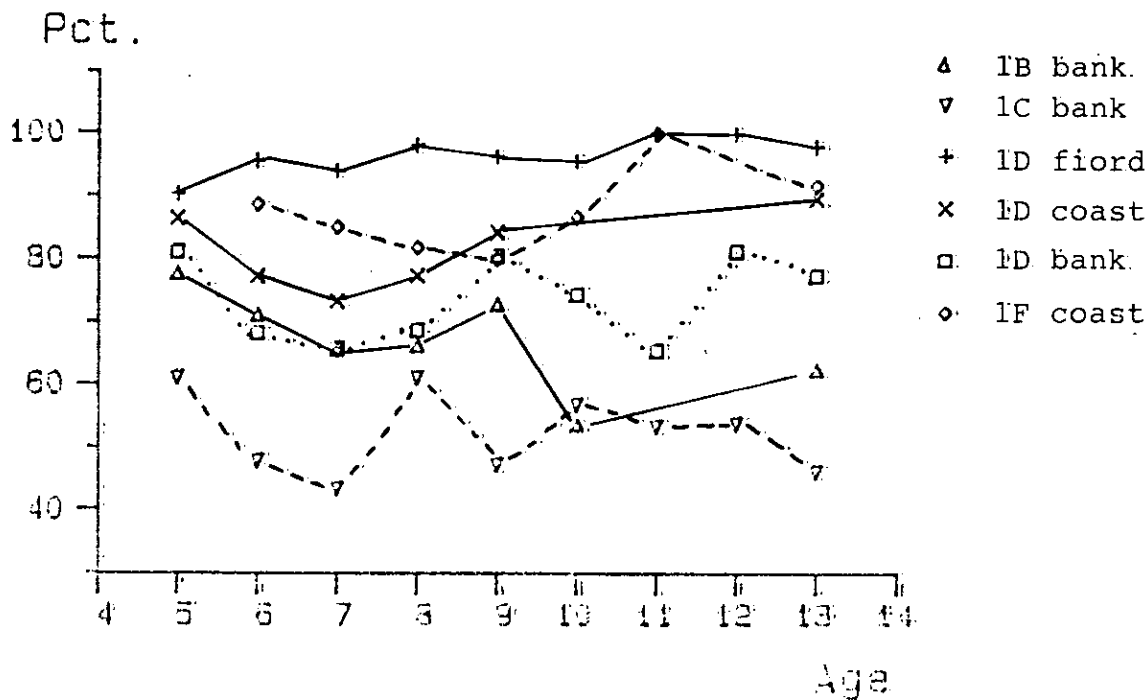


Fig. 8 : Percent recaptures taken within the tagging division in the first year after tagging. Only pct's based on at least 20 observations shown.