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**THE MIGRATION OF COASTAL COD (*Gadus morhua* L.) TAGGED IN A FJORD  
OF WESTERN NORWAY**

by

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## ABSTRACT

This study is part of a research program investigating the possibility of enhancing the production of coastal cod via a large scale release of pond produced fish in Masfjorden, a fjord of western Norway. An analysis of parts of the ecosystem are being carried out prior to the large scale experiment with a special focus on the cod population of the fjord. The paper deals with the migration pattern of wild cod which were caught, tagged and recaptured and also, pond produced cod released in small scale tag-release-recapture experiments. We applied Spearman's rank correlation test and Kolmogrov-Smirnov two-sample test to assess whether larger individuals migrate longer distances than smaller cod.

The major proportion of the immature wild and pond produced cod were nearly stationary and only 15.0 and 7.0 percent, respectively were recaptured more than five kilometers from the release site. However, a larger proportion, 54 percent, of mature cod were recaptured outside the release site, of which the largest individuals were found to migrate the longest distances, with some of the latter intermingling with cod from contiguous fjords.

## INTRODUCTION

This study is a part of a research program investigating the possibility of enhancing the production of coastal cod by release of pond produced fish in Masfjorden. This study was made feasible in 1983 when Norwegian scientists succeed to mass produce juvenile cod (Øiestad *et al.* 1985). Masfjorden, a fjord of western Norway, was selected as the site for a large scale tag-release-recapture experiment. A large scale release program is planned beginning in the autumn of 1988. Prior to this large scale release, parts of the ecosystem of the fjord are being examined with research focussing on migration patterns. A central question for the research program is whether the released individuals will remain in the area from which they were released. Similar small scale tag-release-recapture experiments of both wild and pond produced cod have previously been conducted in other regions of western and southern Norway. The juveniles are reported to be nearly stationary in the area where they

were released (Dahl 1905, Løversen 1946, Dannevig 1953, Danielssen 1969, Godø 1984, Moksness and Øiestad 1984, Svåsand and Godø 1987). However, mature coastal cod have been found to migrate longer distances than the juveniles (Hyllen 1964, Godø 1984, Godø et al. 1986).

This paper analyses the migration pattern of cod from experiments with a small scale release program of tagged pond produced cod and wild cod, focusing on the question of stationarity. We also utilize Spearman's rank correlation test and Kolmogorov-Smirnov two-sample test to determine whether larger individuals migrated longer distances than small cod.

## **MATERIALS AND METHODS**

Masfjorden is a typical fjord on the west coast of Norway, located north of Bergen at 60° 50'N, 5° 25'E. Both Masfjorden and Austfjorden, a contiguous fjord, are connected to the outer coast and continental shelf through Fensfjorden (Fig. 1). A further description of the fjords is given by Salvanes et al. (in prep).

Tag-release-recapture experiments were conducted for pond produced and wild cod. Pond produced cod were released in November, 1985 and December, 1986 (Fig.1). Wild cod were divided into two groups: mature cod caught, tagged and released at the spawning grounds during the spawning season (Winter Group), and cod caught, tagged and released during the summer period (Summer Group). Fig. 3 illustrates the distribution of migration distance from release to recapture for all three groups. The wild cod were captured by trap-net, trammel-net or gill-net. Length-distributions at release for the groups are given in Fig. 2. Data pertaining to the tag-release-recapture experiments are given in Tab. I and Tab. II.

All cod were individually tagged with an external "Floy Anchor Tag". The experiments were announced in the local newspapers and by posters at local post-offices and stores. These outlets also provided catch forms to record information of recaptured cod. A reward of Nkr. 25 (i.e., 4.00 \$U.S) was paid for every tag returned. Recaptures were also recorded during our experimental fishery in Masfjorden. Below we will provide more detailed information of the three different groups of cod.

### **Pond Produced Group**

The cod in this group were produced in Heimarkspollen, Austevoll, as described by Øiestad *et al.* (1985) based on broodstock from the Austevoll region. These juveniles were tagged and released as 0-group in Masfjorden and around the small islands outside the sill which separates Masfjorden from Fensfjorden. Sub-groups of cod were released along the shoreline in sub-areas which were of unequal size. Density of released cod did not exceed 3 tenths per meter of shoreline. Unfortunately, the exact position of release is not known for each individual within the sub-area. We therefore excluded data-sets from sub-areas in which the length of the shoreline exceeded five kilometers. We furthermore defined the migration distance as the distance from the point of recapture to the nearest point where cod from the respective sub-group were released.

### **Summer Group**

This group contains wild cod caught, tagged and released mostly in Masfjorden, from May to November 1987. In addition, a few individuals were also released around the small islands outside Masfjorden. The exact position of capture before they were tagged and released is known for each individual of this group. Cod recaptured less than 0.4 kilometers from the release site, were defined as recaptured within the sub-

area of release.

### Winter Group

The cod in this group were caught by local fishermen during March, 1987 and February, 1988 in Masfjorden, outside, but close to the sill of Masfjorden and in Austfjorden. Detailed information about position of capture before tagging of individual fish was not provided. However, most were caught at or near the spawning localities in Masfjorden and Austfjorden. Since the fishermen caught the cod over large areas, we defined the size of the sub-areas of release to 11 kilometers of shoreline. This group is considered mostly mature cod, since only recaptured cod larger than 45 cm are included in our analysis and 50 percent were found to be mature and above this size (Nordeide et al. 1988).

### Statistical tests

Two different nonparametric tests were applied to determine whether larger cod migrated longer distances than smaller cod<sup>1</sup>. First, the Kolmogorov-Smirnov two-sample test was applied to assess if there was any difference in length-distribution between cod which were recaptured within and outside the sub-areas of release. Secondly, for those cod recaptured outside the sub-areas of release, Spearman's coefficient of rank correlation ( $r_{sj}$ ) was used to test the correlation between migration distance and size of the fish at recapture ( $j=A$ ) and between migration distance and number of days from release to recapture ( $j=B$ ). The tests were applied separately on the Pond Produced Group (P), Summer Group (S) and Winter Group (W). The theory is described in

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<sup>1</sup>Nonparametric tests were applied because assumptions of normality for our data sets were questionable since the dominating part of the recaptures were reported by local fishermen which had fished with several gear types.

Sokal and Rohlf (1981). First, we applied the Kolmogrov-Smirnov two-sample test to assess the following null hypotheses:

$H_{0A}$ : The cod recaptured outside the release sub-area comes from the same length-distribution as the cod recaptured within.

$H_{1A}$ : The cod recaptured outside the release sub-area come from different length-distributions than the cod recaptured within.

$H_{0B}$ : No difference exist in the number of days in the fjord for the cod recaptured outside the release sub-area compared to those recaptured within.

$H_{1B}$ : The cod recaptured outside the release sub-area spent significantly different number of days in the fjord before recapture than those recaptured within.

The test statistic ( $DN$ ) is the maximum difference between the cumulative relative frequency distributions for cod recaptured within ( $f_{ij}$ ) and outside ( $f'_{ij}$ ) release sub-area, separately for fish length ( $j=A$ ); and days in the fjord before recapture ( $j=B$ ); for each of the groups P, S and W. The test statistic is given by the expression:

$$DN = \max | f_{ij} - f'_{ij} | \quad (\text{Sokal and Rohlf 1981})$$

The null hypothesis is rejected if  $DN > \text{critical value}$  at a given significance level.

The second test applied is the Spearman's rank correlation. It was applied on the part of the samples which were recaptured outside the release sub-area for the groups

P, S and W to test the possible association between migration distance and fish length (C) and between migration distance and days elapsed in the fjord before recapture (D). We tested the following hypotheses:

$H_{0C}$ : No correlation exist between migration distance and length of the cod

( $r_{sC}=0$ ), against the alternative that a correlation exist ( $r_{sC}\neq 0$ )<sup>2</sup>.

$H_{0D}$ : No correlation exist between migration distance and number of days elapsed

in the fjord before recapture ( $r_{sD}=0$ ) against the alternative that a correlation exist ( $r_{sD}\neq 0$ ).

In case (C), the migration distance and length of cod were ranked separately, ( $R_{1C}$ ,  $R_{2C}$ ), in case (D) the migration distance and number of days before recapture, ( $R_{1D}$ ,  $R_{2D}$ ) were ranked. Of  $n_C$  and  $n_D$  individuals, respectively, for cases C and D, Spearman's coefficient of correlation, ( $r_{sj}$ ), was computed from the differences between the ranks  $R_{1j}$  and  $R_{2j}$  for individual cod from the following equation (Sokal and Rohlf 1981):

$$r_{sj} = 1 - \frac{n_j \sum (R_{1j} - R_{2j})^2}{n_j(n_j^2 - 1)}$$

The value of  $r_{sC}$  is a measure of the covariation between migration distance and length of cod and  $r_{sD}$  is a measure of the covariation between migration distance and number of days in the fjord. If  $r_{sj} > critical\ value$  at the selected significance level, the

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<sup>2</sup>A two-sided test is applied because the test-statistics is defined in the range (-1.0 - 1.0). This means that there exist a theoretical possibility for large cod to migrate less than small cod, which contradicts our general knowledge about cod populations. However, if the null hypothesis is rejected and the correlation coefficient is positive, we exclude this interpretation.



null hypothesis is rejected.

## RESULTS

The migration distances for the Pond Produced Group (P), the Summer Group (S) and the Winter Group (W) are depicted in Fig. 3. The majority of the P and S group, 93 and 85 percent respectively, were recaptured less than five kilometers from the release site.

For group W, 46 percent were recaptured less than 5 kilometers from the release site.

Of the cod released in Masfjorden, three recaptures (out of 179) from the P group, and 12 individuals (out of 94) of both the W and S groups together, were recaptured in Austfjorden or Fensfjorden (Tab. II, Fig. 4B). Of the 52 recaptured wild cod originally released in Austfjorden and around the small islands outside Masfjorden, three were recaptured in Masfjorden and seven in Fensfjorden (Tab II).

A total of five wild cod were recaptured outside Fensfjorden (Fig. 4A). Four of these were recaptured ripe at other spawning grounds of which three were recaptured during the same spawning season as they were captured, tagged and released.

### Empirical results

We now present the results of the statistical tests. First, from the Kolmogorov-Smirnov two-sample test we note that cod recaptured outside the release sub-area come from a different length-distribution than cod recaptured within for P and S group ( $H_{0A}$  rejected, approximate *P*-value respectively equal to 0.002 and 0.09). The length-distribution of cod recaptured outside was also to the right for those recaptured within for the P and S groups (Fig. 5). Furthermore, cod from group S which were recaptured outside the release sub-area had also spent significantly different number

of days in the fjord than those recaptured within ( $H_{0B}$  rejected, approximate  $P$ -value equal to 0.09).

When applying the Spearman's rank correlation test only on cod recaptured outside the release sub-area we found that a positive correlation, although insignificant, between the migration distance and fish length for cod from group P ( $H_{0C}$  not rejected,  $r_s=0.18$ ,  $0.1 < P < 0.2$ , Tab. III). However, a significantly positive correlation was found for the cod of group W between migration distance and days elapsed in the fjord before recapture ( $H_{0D}$  rejected,  $r_s=0.39$ ,  $0.001 < P < 0.002$ , Tab. III). In other words, cod recaptured far from the release site appeared to have been swimming more days than cod recaptured close to the release site.

## DISCUSSION

One of the most important topics for a research program concerned with increasing the production of a fish population by releasing juveniles, is whether the released fish stay within the area. Our analysis demonstrates that the majority of small scale released immature pond produced cod and wild cod were recaptured closer than five kilometers from the release site. We therefore conclude that the major proportion of immature cod are nearly stationary whether they were pond produced or wild, when released in small scale in Masfjorden. These results are confirmed by similar investigations of pond produced cod conducted in other regions of southern and western Norway (Moksness and Øiestad 1984, Svåsand and Godø 1987), and for wild cod (Dahl 1905, Løversen 1946, Dannevig 1953 and Godø 1984). Although both wild and pond produced immature cod remain in the fjord, in significant numbers, this might not be the case when cod are released in large quantities. Thus, further investigations of the cod migration patterns will be carried out after a large scale release program for juvenile cod.

When considering the P and S groups, we found that the individuals recaptured outside the sub-area of release were larger than those which were recaptured within. Cod in the S group, which were recaptured outside the sub-areas had also spent significantly more days in the fjord before being recaptured. This extra time in the fjord may explain part of the difference in the length-distribution as data sets from longer time-periods are pooled in this analysis. However, when considering only the cod recaptured outside the release site, Spearman's coefficient of rank correlation shows a positive, but insignificant, correlation between migration distance and length at recapture for the P and W groups. Cod of the Winter Group, which were recaptured outside the sub-areas also spent significantly more days in the fjord before they were recaptured. Both of the nonparametric tests therefore indicate a tendency that larger individuals migrate longer distances than smaller individuals. A similar tendency between migration distance and age was also reported by Svåsand and Godø (1987).

When considering mature cod, Jørstad *et al.* (1987) cites Møller's (unpubl.) findings that the cod breeding population in western Norway is composed of two different breeding units. These two units consists of those who remain for their whole life in one area and a mixture of cod which have migrated from more distant areas. Jakobsen (1987) tagged mature cod in several fjords of northern Norway, and although most were recaptured in the same fjord as released, it was not usual that recaptures were reported from neighboring fjords during the first half of the following years. This also indicates that breeders from neighboring fjords appear to mix. Our results also indicate the same pattern, since mature individuals caught at spawning grounds during the spawning season (Winter Group), were recaptured at other spawning grounds than those grounds from which they were released. We also conclude that as the cod matures, a larger proportion migrate, with the largest individuals migrating the longest distances, and some even intermingling with mature cod of contiguous fjords.

A similar migration pattern is also reported for coastal cod off Scotland where the immature cod are nearly stationary in the fjord while mature individuals leave the fjord to join the adult stock at the coast (Hawkins et al. 1985).

Most of the pond produced cod in this study were recaptured before they were mature. The question whether mature pond produced cod will behave in a similar manner as wild cod, must still be investigated in Masfjorden. Further investigations will be conducted as the 1985 and 1986-year-class matures. However, the descriptive results reported on pond produced mature cod off Austevoll emphasize that the percentage contribution of the 1983-year-class of pond produced cod released off Austevoll was the same when recaptured as juvenile cod in 1984 or as mature cod on the spawning ground in 1986 and 1987 (Svåsand et al. 1987). This descriptive data indicate that the released pond produced cod have the same pattern of recruitment as the wild to the breeding population.

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TABLE I.

Data pertaining to tag-release-recapture experiments in Masfjorden.

Group	Sub-area	RELEASE		RECAPTURE		Included in this analysis
		Time	#tagged	#recaptured		
Pond Produced	1,2	Nov.-85	3331	160 (4.8%)		179
Pond Produced	1,2,4,a	Dec.-86	2779	61 (2.2%)		
Summer	1,2	May-Nov.-87	222	58 (26.1%)		58
Winter	1,2,3,4a	Mar.-87	250	55 (22.0%)		
Winter	1,2,3	Feb.-88	436	46 (10.6%)		88

TABLE II.

Wild cod released and recaptured divided on release and recapture area. Data sets from Summer Group and Winter Group are pooled.

AREA	MASFJORDEN		AUSTFJORDEN	FENSFJORDEN	OUTER COAST	TOTAL
	1 and 2		3 and 4a	4b, 5 and 6	and other fjords	
1,2	476	82	6	6	-	94
3,4a	432	3	37	7	5	52

TABLE III.

Spearman's rank correlation coefficient ( $r_s$ ) between migration distance and fish size (C), and migration distance and time elapsed from release to recapture (D). The sample size is (N) and the P-value is the significance level of the two-sided test of  $H_0: r_s = 0$  against the alternative that ( $r_s$ ) is different from zero.

	N	$r_{sC}$	P-value	$r_{sD}$	P-value
Pond Produced Group	65	0.18	$0.1 < P < 0.2$	0.09	$0.2 < P < 0.5$
Summer Group	18	0.01	$P \gg 0.5$	0.05	$P \gg 0.5$
Winter Group	23	0.14	$P > 0.5$	0.39	$0.001 < P < 0.002$



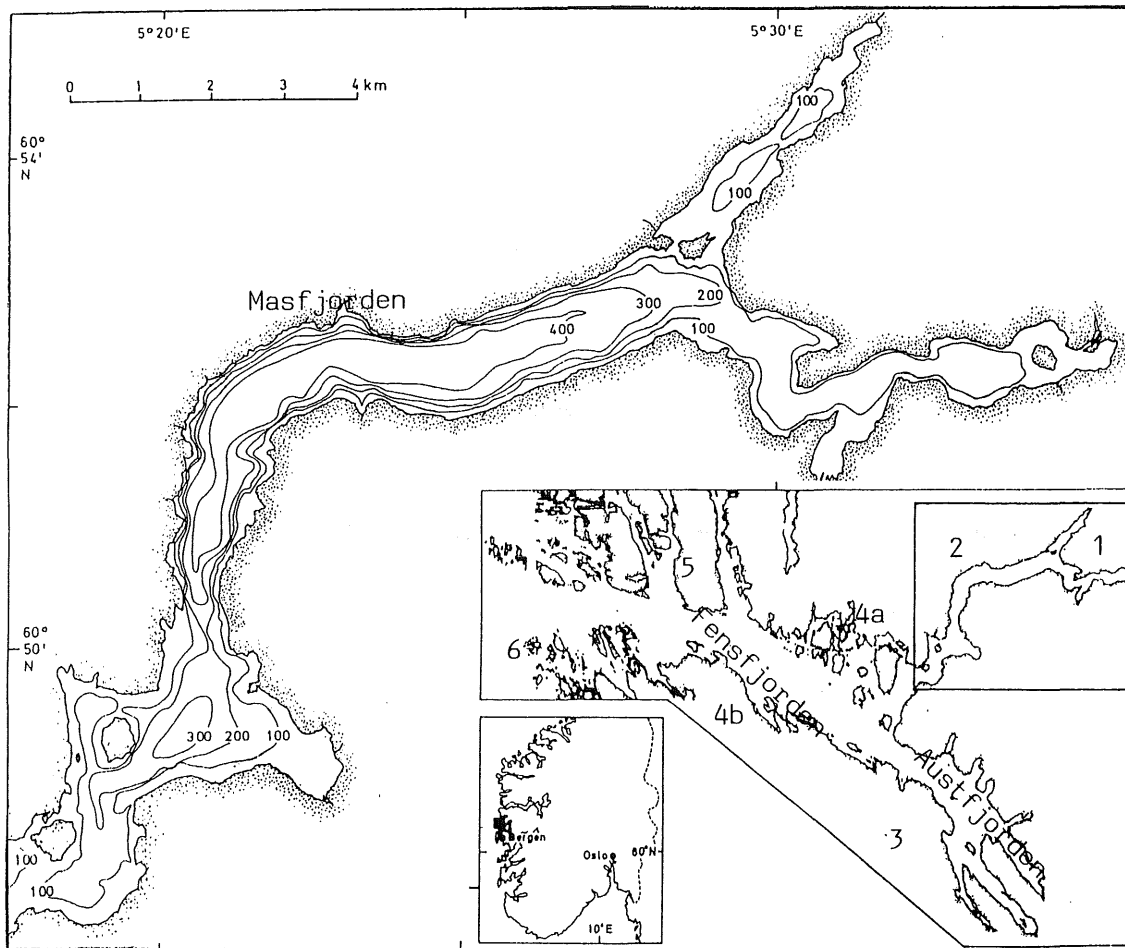





Figure 1. Map of the Fjords including the distinguished areas in which tagging experiments on pond produced cod were conducted.  means that tagged cod were released only in 1985,  only in 1986, and  that cod were released both years.

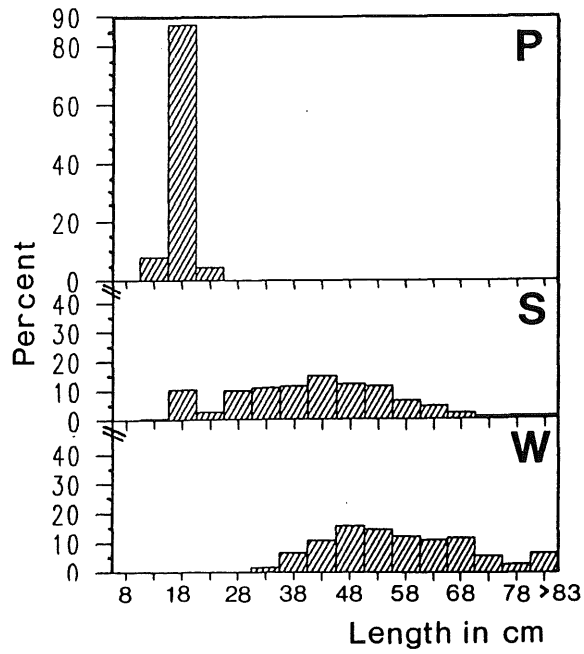


Figure 2. Length-distribution at release of the three groups of cod: Pond Produced (P), Summer Group (S), and Winter Group (W).

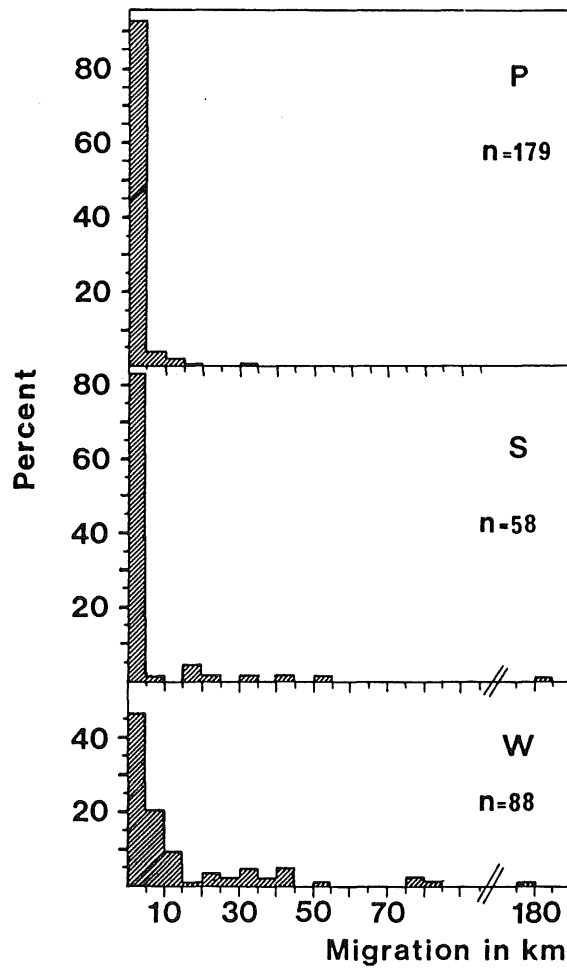


Figure 3. Distribution of migration distance from release to recapture for Pond Produced cod (P), wild Summer Group (S), and wild Winter Group (W). Migration distance for group P is set to 0.0 kilometers when recaptured within release sub-area since individual positions of release within the respective sub-areas are unknown.

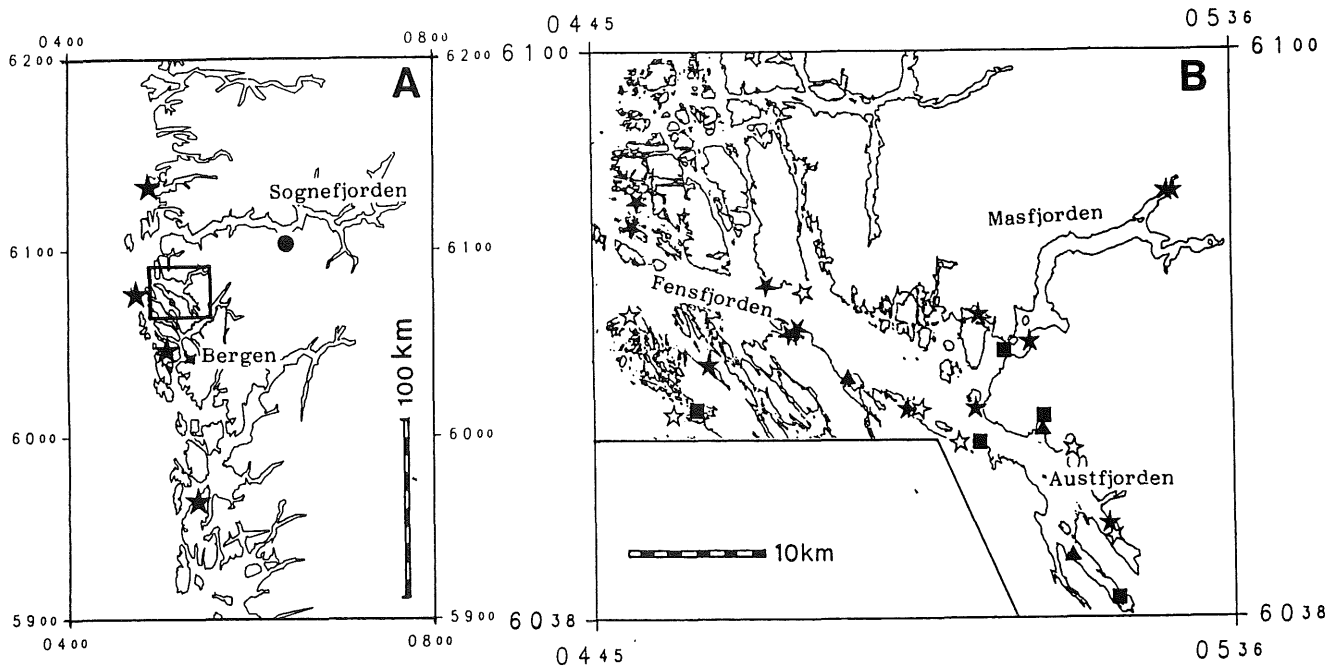


Figure 4. Recapture positions for cod recaptured outside the areas of release. Pond Produced cod ( $\blacktriangle$ ), wild Summer Group released in area 1 and 2 ( $\blacksquare$ ) and 4a ( $\bullet$ ), wild Winter Group released in area 1 and 2 ( $\star$ ), and wild Winter Group released in area 3 and 4a ( $\star$ ).

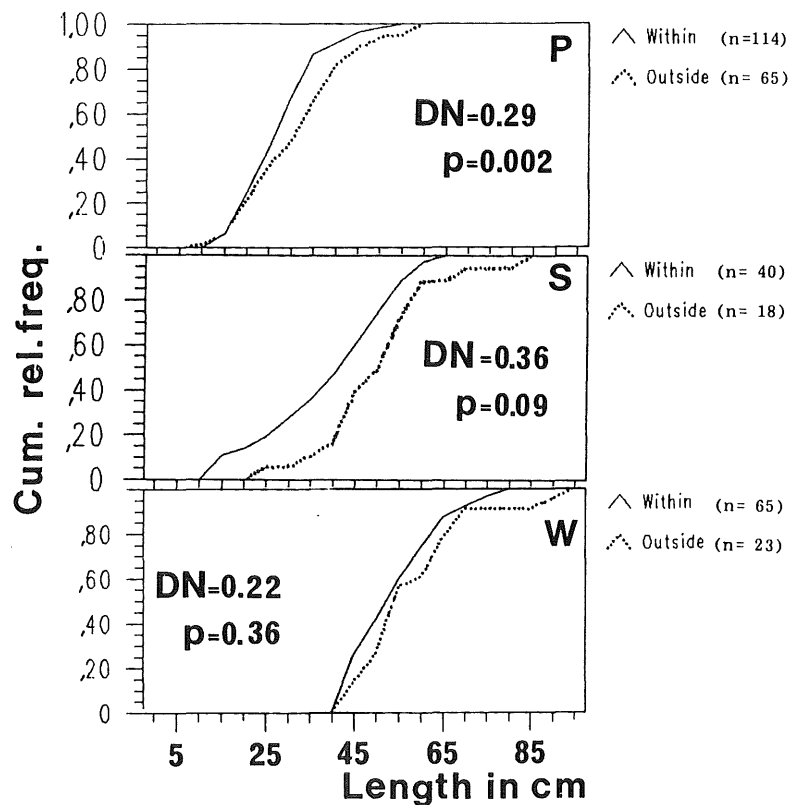


Figure 5. Cumulative relative frequency distribution of length at recapture of cod recaptured within and outside the sub-areas of release. Pond Produced cod (P), wild Summer Group (S) and wild Winter Group (W). DN is the maximum absolute difference between the two curves, and P is the approximate significance level for the Kolmogorov-Smirnov two-sample test.

