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Migration pattern of juvenile cod (*Gadus morhua*) on the Swedish west coast

Leif Pihl, and Mats Ulmestrand

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A tagging experiment was carried out on the Swedish west coast (Skagerrak–Kattegat area, 55–59°N, 11–12°E) to study migration of juvenile cod (*Gadus morhua*). 437 and 4255 tagged (1-group) cod were released in early summer and autumn 1986, respectively, at five shallow (5 to 10 m) stations. Three years after release, 300 (6.4%) tagged cod had been recaptured. During the summer and autumn of 1986 fish released both during the early summer and autumn 1986 were located close to the tagging sites, indicating limited movement during this time. At an age of 2 years and a standard length of 30 to 50 cm, a general offshore migration to deeper water was observed during winter of 1987. The main direction was to the south and west suggesting a migration to spawning areas in the eastern North Sea or in the southern Kattegat. The major offshore migration of 2-year-old cod suggests that local coastal spawning and coastal stocks are of minor importance on the Swedish west coast.

Key words: migration, tagging, juvenile cod (*Gadus morhua*), Skagerrak–Kattegat.

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L. Pihl: University of Göteborg, Marine Research Station at Kristineberg, 45034 Fiskebäckskil, Sweden. M. Ulmestrand: Institute of Marine Research, 45321 Lysekil, Sweden.

Introduction

In the early 1980s a drastic reduction in the landings of cod (*Gadus morhua* L.) was reported in the coastal fishery along the Swedish west coast (Degerman, 1985). Young fish surveys conducted offshore in the Skagerrak–Kattegat area suggested a weak recruitment over several years coupled with a high fishing effort (Pihl and Ulmestrand, 1988). The shallow waters of the Swedish west coast are known to be nursery areas for juvenile fish where cod play a major predatory role in the coastal ecosystem (Pihl, 1982). However, little is known about recruitment and the importance of different spawning stocks, either coastal and offshore, for the cod populations in the Skagerrak–Kattegat area. Moth-Poulsen (1982) demonstrated the existence of four genetically distinct cod stocks in the Skagerrak–Kattegat and adjacent areas: the southern Baltic, the Danish Belt Sea, the Kattegat–northern Sound area, and the Skagerrak. Thus, the cod populations in the Skagerrak and the Kattegat are most probably recruited from different spawning areas.

Juvenile cod in the Skagerrak–Kattegat exhibit a significant difference in length distribution between 1-group cod from the western Skagerrak and 1-group cod from the northern Kattegat (Pihl and Ulmestrand, 1988). In the eastern Skagerrak, however, a polymodal length distribution was found for 1-group cod, overlapping the length distribution from the other two areas. These results suggest that the stocks in the western Skagerrak and northern Kattegat are from separate spawning areas. Due to larval transport these stocks could be mixed when recruited to coastal areas in the eastern Skagerrak. Local coastal spawning has not been reported on the Swedish Skagerrak coast (Pihl and Ulmestrand, 1988).

Both local coastal and offshore spawning of cod have been reported in Norwegian coastal waters (Dahl, 1906; Dannevig, 1966; Dahl *et al.*, 1983; Godø, 1984; Reisegg and Jørstad, 1984). Cod spawn mainly in fjords on the Norwegian Skagerrak coast, and tagging experiments have shown that cod exhibit limited movement during at least their first 4 years (Løversen, 1946; Moksness and Øiestad, 1984). Local stocks in these areas are of considerable importance for the coastal fishery (Dannevig and van der Eynden, 1986), and are clearly separated from the cod populations of the open Skagerrak (Danielssen, 1969).

After several years of low recruitment in the Skagerrak–Kattegat area an exceptionally high recruitment occurred in 1985 (Anon., 1991), as indicated by high densities of 0-group cod in by-catches of the fyke-net eel fishery during autumn. This event offered an opportunity to follow the

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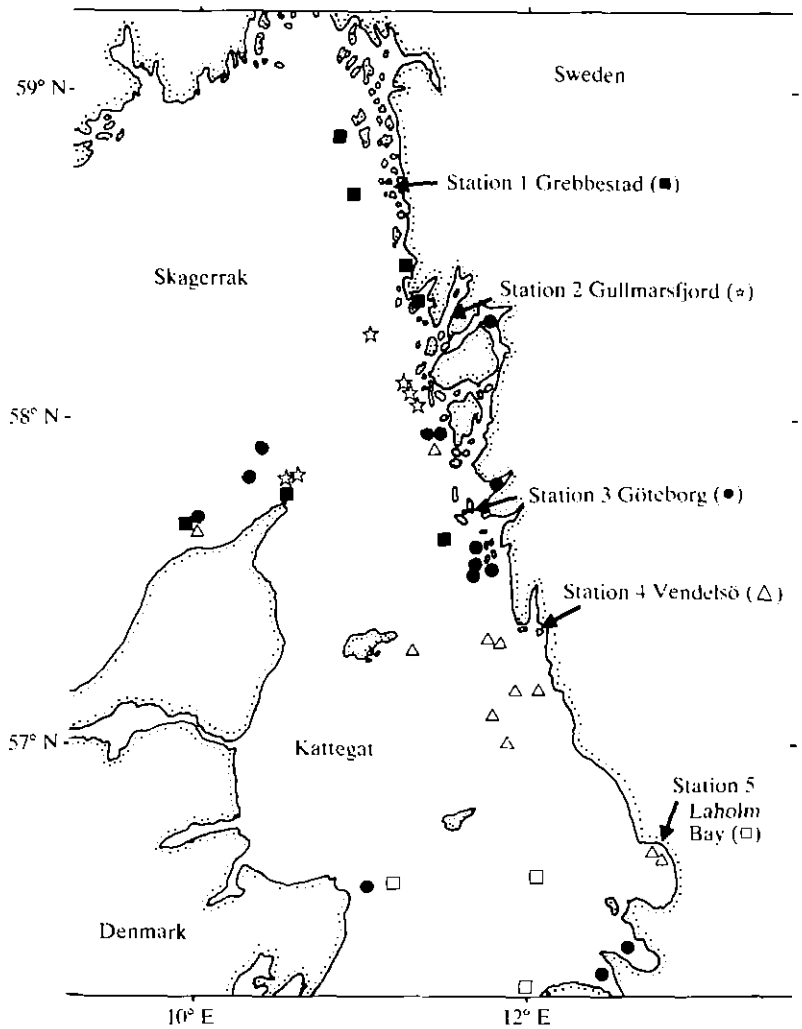

Figure 1. Map of the study area on the Swedish west coast. The figure shows the location of the five stations where the tagged cod were released, and the position of all offshore recaptures made in this study.

development of a strong year-class, and to get more information on the recruitment dynamics of the cod populations and the role of coastal areas as a nursery for different spawning stocks.

Material and methods

Juvenile (1-group) cod were tagged and released at five stations on the Swedish west coast during the early summer (June) and autumn (late September to early November) of 1986 (Figs 1, 2). Each locality was a small bay with a rocky shore line and a water depth varying between 1 and 10 m. Mean water surface temperature is similar in such bays on the Swedish west coast, varying between 5 and 14°C in spring and autumn and between 14 and 20°C in summer (Pihl and Rosenberg, 1982). During winter, ice normally occurs for some weeks. The surface water salinity in the study area is influenced by the north-going brackish water Baltic current. At the northern stations (1 and 2) salinity normally fluctuates between 15 and 25 and at the southern localities (4 and 5) salinity ranges from 15 to 20. At Station 3, situated outside Göta Älv River, salinity varies within a wider range due to fluctuations in fresh water outflow. The tidal range is about 0.2 m at all stations.

Experimental cod were caught in fyke-nets in vegetated (*Zostera marina* L., *Fucus vesiculosus* L., and *Fucus serratus* L.) areas between 1 and 5 m deep. After capture they were held *in situ* in net cages for 1 to 5 days before tagging, and were released near the original capture site in 5 to 10 m depth after being tagged.

Floy flag tags were attached to the dorsal muscle anterior to the first dorsal fin during a handling time of approximately 15 s. Standard length of all tagged fish was measured, and ranged from 19 to 34 cm (mean 26.5 cm). Tagged fish were immediately transferred to a holding

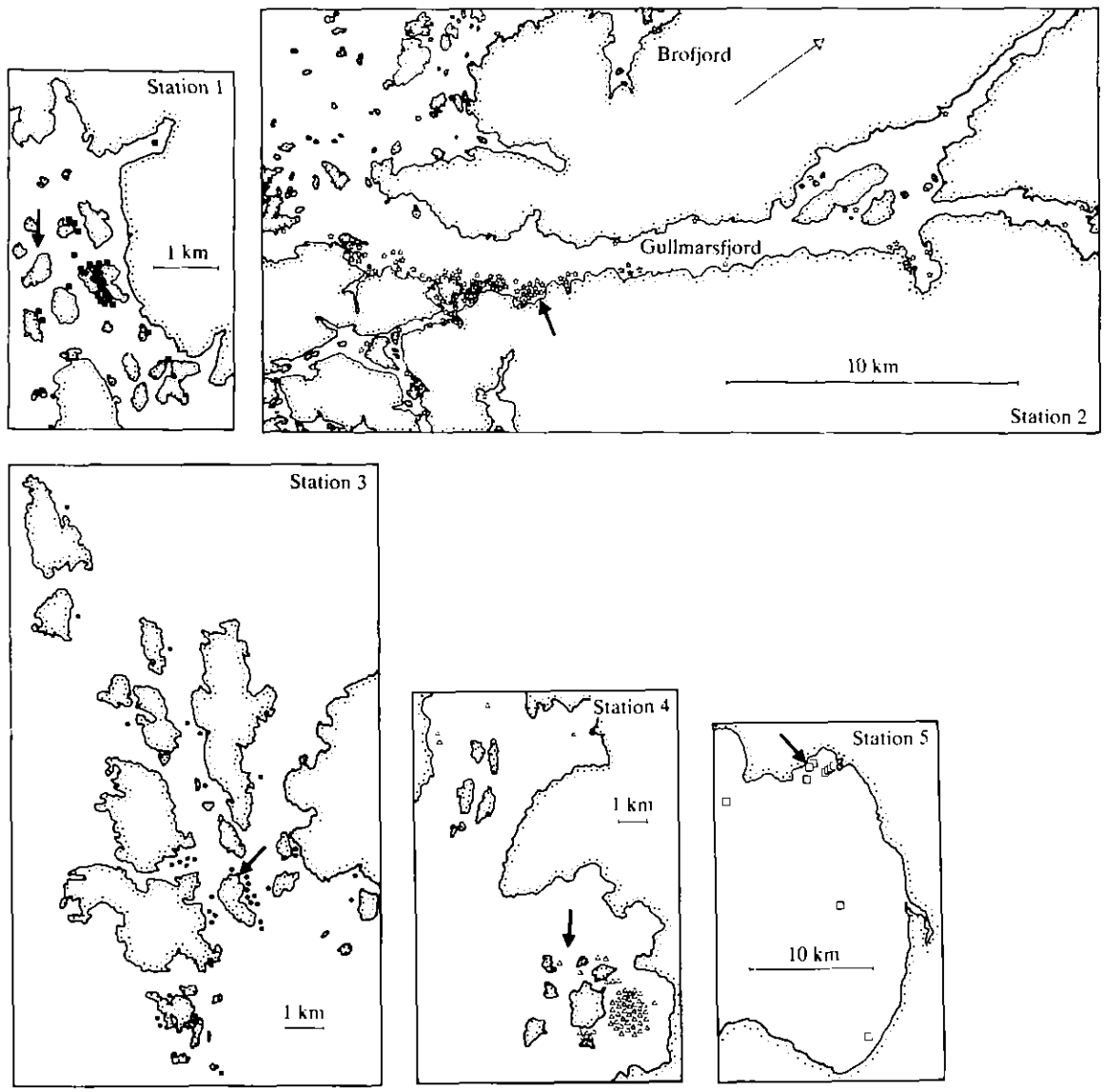

Figure 2. The location of all inshore recaptured cod at Station 1 to 5 on the Swedish west coast. Early summer and autumn released cod are not separated.

cage *in situ*, and held for 1 day to ensure survival from handling before release. No fish died in the holding cage after being tagged and before being released.

All together 4692 1-group cod were tagged. In early summer (June) 437 tagged cod were released at Station 1, 2, and 4 during the autumn (late September to early November) 4255 fishes were tagged and released at Station 1 to 5. The number and size range of fish released at each station on each occasion is shown in Table 1. Mean absolute displacement was estimated for all recaptured cod and mean direction was estimated for offshore migrating cod, according to Svåsand and Kristensen (1990) (Table 2). Cod recaptured inshore were taken with fyke-nets, gill-nets, and hooks, whereas offshore recaptures were made by commercial demersal trawls.

Results

A total of 300 tagged fish (6.4%) was recaptured within 3 years of release. Recaptures varied between 6 and 13% for fish released in early summer and between 2 and 9% for fish released in autumn at the different stations (Table 1). 215 of the tagged cod were recaptured within 100 days and 280 within 300 days of release (Fig. 3). All recaptures, except two, of summer-tagged cod occurred

Table 1. Numbers and size-range (total length, cm) of juvenile cod tagged and recaptured at the five stations on the Swedish west coast during early summer (June) and autumn (late September to early November) 1986.

Locality	Numbers tagged	Size range (cm)	Recaptured (%)	Size range (cm)
1. Early summer	100	20–31	16 (16)	27–31
Autumn	763	21–34	16 (2)	30–38
2. Early summer	85	23–32	11 (13)	23–36
Autumn	1226	20–33	107 (9)	21–50
3. Autumn	1000	23–34	55 (5.5)	25–45
4. Early summer	252	19–29	14 (6)	20–34
Autumn	1001	24–34	68 (7)	27–48
5. Autumn	265	26–34	13 (5)	30–40

Table 2. Mean distance travelled (km) and mean distance travelled per day (m) of juvenile cod released at the five stations on the Swedish west coast during early summer (June) and autumn (late September to early November) in 1986. Standard deviation (S.D.) given in parentheses. The mean directions (°) of offshore migrating cod released during autumn are also given in the table. Range of direction is given in parentheses.

Station	Mean distance travelled (km)	Mean distance travelled per day (m)	Numbers (n)	Mean direction of offshore migration (°)
1. Early summer	1.0 (0.3)	75 (67)	16	–
Autumn	37.4 (65.7)	537 (661)	16	212.7 (166–315)
2. Early summer	1.1 (1.8)	94 (285)	11	–
Autumn	7.3 (12.1)	240 (456)	104	224.2 (210–259)
3. Autumn	20.2 (43.4)	239 (450)	55	197.5 (5–335)
4. Early summer	3.8 (5.9)	164 (318)	14	–
Autumn	14.2 (42.3)	308 (373)	68	230.6 (153–330)
5. Autumn	20.8 (30.9)	189 (246)	13	248.3 (225–262)

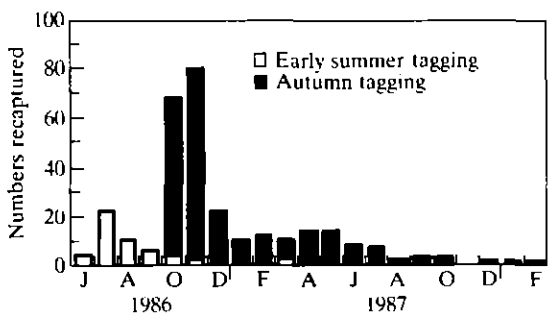

Figure 3. Numbers of recaptured cod each month after the release in early summer (light) and autumn (dark) 1986.

before December 1986. Of the autumn-released cod 65% of the recaptures occurred during the same year, and 12, 11, and 8% were taken during winter (January–March), spring (April–May), and summer (June–August) 1987, respectively (Fig. 3).

Twenty-five out of 32 fish recaptured at Station 1 were caught within 6 months in shallow waters (< 10 m) in the archipelago near the release site (Fig. 2). Despite intensive fishing with fyke nets in the area of Station 1 no tagged cod were caught at any later date in the archipelago. Seven of the recaptured cod made long distance migrations to deeper water (40–90 m) of the south and east Skagerrak (Fig. 1). Of these, four were caught within 6 months of release.

All of the recaptured cod, tagged at Station 2 in early summer and most (90%) of those tagged in autumn were caught within 6 months of release and were found mainly near the mouth of the fjord at depths < 10 m. Only one fish caught in the outer part of the fjord had crossed to the other (north) side. The fjord has a maximum depth of 120 m and a sill depth of 40 m. Seven fish were found in the inner part of the fjord 6 months after release or later and one was recaptured in an adjacent fjord (Brofjorden; Fig. 2). Three of the cod found in the inner part of the fjord were caught at water depths > 10 m. Six individuals tagged at Station 2 were found outside the fjord in deeper water (60 to 90 m) (Fig. 1). The main direction of migration was to the south-west (Table 2), and the time of capture after release varied from 2.5 to 13 months.

At Station 3 tagged cod were only released during the autumn. Forty-two of the 55 recaptured fish were found in shallow water (< 10 m) within the archipelago (Fig. 2).

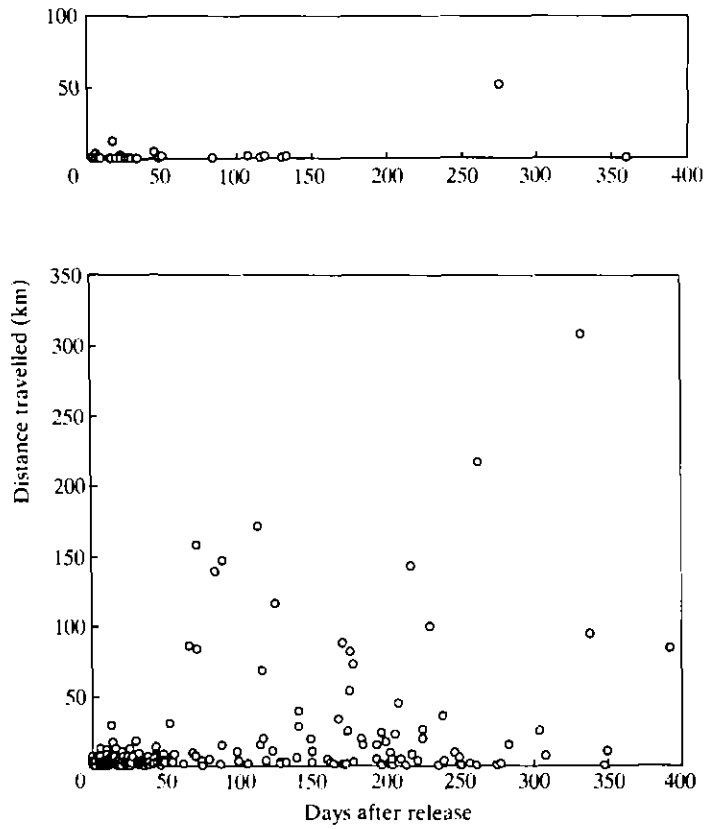

Figure 4. Distance of migration (km) for cod recaptured during 10 days interval after the early summer (top) and autumn (bottom) release. Recaptures from all stations are pooled.

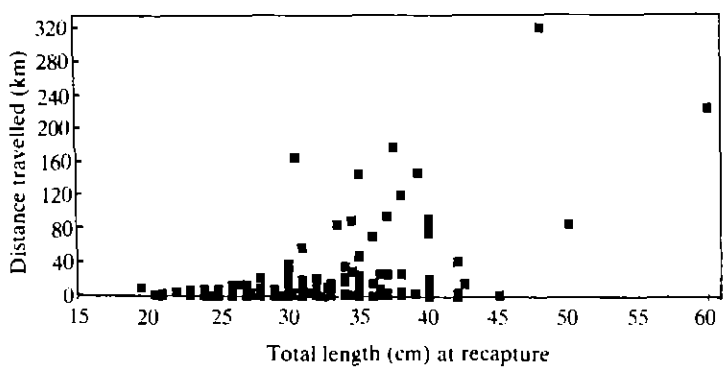

Figure 5. Relation between the body length (cm) of cod at the time of recapture and the distance of migration (km). Level of significance was $p < 0.0001$ (Spearman rank correlation). Recaptures from all stations are pooled.

Eleven of these fish were found at least 6 months after release. Thirteen of the recaptured cod from this station were from deeper (30 to 110 m) offshore water in Skagerrak and Kattegat, eight of which were caught within 6 months after release (Fig. 1). One was caught in the Öresund 176 km south of the tagging site. In addition, one cod was recaptured at 35 m in the Byfjord, about 60 km north from the release site.

Sixty-two of the 73 recaptured cod tagged at Station 4 were found within 6 months in shallow water (< 10 m) close to the release site (Fig. 2). Remaining recaptured cod were caught offshore in deeper (15 to 90 m) water, mainly in the Kattegat (Fig. 1). Eight of these were caught later than 6 months after release.

At Station 5 tagged fish were only released during autumn. Ten of the 13 recaptured cod were found in shallow water (< 10 m) in the Laholm bay (Fig. 2), six of which were found within 6 months of release. Three cod from this station were caught offshore in the Kattegat at depth between 15 and 40 m (Fig. 1).

Seventy-eight per cent of the cod recaptured inshore were taken in fyke nets, 13% were caught with hooks, and 9% were taken in gill-nets. The offshore recaptures were all made by Swedish and Danish demersal commercial trawlers.

The distance the tagged cod had migrated when recaptured varied with season and length of the fish (Fig. 4). The mean distance of migration for cod tagged and released in early summer 1986 was 2.04 km (S.D. = 3.63, n = 39). All, except two, were recaptured within 5 months (summer to early autumn) and the migration distance was similar over this period (Fig. 4). The mean distance of migration for cod tagged during autumn 1986 was 4.48 km (S.D. = 7.65, n = 182) during the two first months after the release (before 1 January 1987) (Fig. 4). For cod captured after 2 months but within 9 months after the release in autumn, the migration distance was variable but generally higher (mean = 35.15 km, S.D. = 65.43, n = 72). The low number of recaptures after 9 months precluded calculations of migration distances.

For cod tagged in early summer the mean distance travelled from the release site ranged for the five stations from 1.0 to 3.8 km and for those tagged during autumn from 7.3 to 37.4 km (Table 2). The mean distance travelled per day for cod released in early summer and autumn ranged from 75 to 164 and 189 to 537 m day^{-1}, respectively (Table 2). About 50% (148 individuals) of all recaptured cod moved less than 100 m day^{-1}, and of these 31 were found at the same place as released. For 43% of the recaptured cod the distance travelled was between 100 and 1000 m day^{-1} and for 7% > 1000 m day^{-1}. The highest "speed" recorded in this investigation was 2.251 km day^{-1}, for a cod released at Station 3 and caught in Skälderviken Bay in the southern Kattegat.

The length of the cod was reported for 66% of the recaptures. It ranged from 19 to 60 cm and was significantly positive related ($p < 0.0001$, Spearman rank correlation) to the distance the fish had moved from the tagging sites (Fig. 5). Fish with a body length < 30 cm when captured were relatively stationary, whereas larger fish exhibited a more variable migration.

Discussion

Although the recapture rate of 6.4% in the present study is comparable to that of other investigations on juvenile cod in coastal areas (Otterlind, 1961; Johnsson *et al.*, 1991), it seems low when considering the rather high fishing intensity in the Skagerrak–Kattegat area. The low recapture rate could be caused by several factors of which tag loss, non-reported recaptures, and tagging mortality are the most probable.

When analysing the result from a tagging experiment it is important to consider the structure and intensity of the fishing effort in the area where the study is conducted. The probability of recaptures generally decrease with time and distance from the release, mainly as a consequence of dispersion and mortality of the fish (Jones, 1966). This pattern was also obvious in the present study where 86% of the recaptured fish were found inshore, mainly at depth < 10 m close to the areas of release. In addition, areas of intensive fishing would be expected to have the highest rate of tag returns and therefore might have biased the interpretation of the migration data. For example, if all the recaptures were from areas of intensive fishing that does not mean that fish might not have been migrating elsewhere. This problem can not be avoided since tag returns in this study were mainly dependent on commercial fishermen.

In the archipelago of the Swedish west coast fyke net fishing is intensive, especially during autumn, and most (78%) of the inshore recaptures were taken in this gear. Of the 437 cod released in early summer 1986, 9.4% were recaptured, and all were taken inshore within 6 months after release. The distance of migration was low and similar for all fish during this period (Table 2 and Fig. 4), indicating relatively stationary behaviour for 1-group cod during summer and autumn, similar to that reported for immature cod in Norwegian coastal areas (Godø, 1984). The absence of long-distance recaptures of cod released in early summer could be due to the low number of tagged fish and increased dispersion and mortality during winter.

Eighty-four per cent of the recaptures from the autumn 1986 tagging were found inshore. Most of the cod were taken during autumn and winter and, despite intensive fishing with fyke nets in the vicinity of the tagging stations, only a few individuals were found in the archipelago later than 6 months after the release. Recaptures during autumn and winter were randomly distributed around the sites of release at all stations except Station 2. Here, a general westerly migration in the Gullmar fjord was observed. There is no indication that this was a consequence of more intensive fishing in the outer part of the fjord, compared to the inner part. Together with the observed low recapture rate inshore 6 months after release this is an indication of an offshore movement during the winter. Bagge (1973) concluded from tagging experiments, carried out in the North Sea and the Kattegat in 1971 and 1972, that immature cod did not undergo extensive migration until reaching a body length of 70 cm. In our study 1-group cod released during both early summer and autumn were relatively stationary during the summer and autumn. During the following winter and spring, however, cod with a body length of 30 to 50 cm were found at a distance of up to 150 km from the tagging sites (see Figs 4, 5), suggesting migration at a smaller size than that observed by Bagge (1973).

Sixteen per cent of the recaptures from the autumn release were caught offshore at depth between 15 and 110 m. Most of these (65%) were taken later than 6 months after the release. The general direction of the

migration for these fishes was to the south-west (Table 2). Cod from Stations 1 and 2 had moved to the south along the Swedish west coast and also to the west to be found north of Denmark. Cod released at Station 3 had migrated either westward to the Skagerrak or southward to the Kattegat, whereas offshore recaptures from Station 4 and 5 were found in the Kattegat.

The offshore migration started during the winter, about 3 months after the release of the fish tagged during the autumn (Fig. 4). At this time the cod were almost 2 years old and the offshore movement was most probably the start of the spawning migration. The migration could have been triggered by decreased tolerance to variation in shallow water temperature and salinity (Dannevig, 1966; Riley and Parnell, 1984), or by a shift in the diet from crustaceans to fish (Börje *et al.*, 1987; Daan, 1973). A similar offshore migration of 2-year-old cod was reported from the North Sea by Riley and Parnell (1984). In the Kattegat adult cod concentrate in the south-eastern part for spawning during February and March (Börje *et al.*, 1985; Pihl and Ulmestrand, 1988). In the Skagerrak, however, mature cod were not found in high densities during winter (Börje *et al.*, 1985; Pihl and Ulmestrand, 1988; Hagström *et al.*, 1990), except in Norwegian coastal waters (Dahl, 1906; Dannevig, 1966; Dahl *et al.*, 1983). The spawning areas for the Skagerrak population are most likely to be located west of Denmark in the eastern North Sea (Bedford, 1966; Jones, 1972; Daan, 1978; Heesen, 1990). This is supported by a tagging experiment carried out on the Danish Skagerrak coast, where 14% of the recaptures, most of which were mature individuals, were from the eastern North Sea (Danielssen, 1969). If cod migrate offshore in spring and summer during their second year of life, as indicated in this study, they could join the parental stocks at the spawning areas during the following winter at an age of 3 years. This is in agreement with data on lowest age at maturity for the spawning population in the Kattegat (Börje *et al.*, 1985; Hagström *et al.*, 1990).

The offshore migration of the 2-year-old cod is generally against the direction of the major currents in the Skagerrak–Kattegat area (in the Skagerrak the Jutland current and in the Kattegat the Baltic current) and would compensate for larval drift from the spawning areas. The Jutland current enters the Skagerrak from the North Sea north of Denmark and generally turns north along the Swedish west coast (Svansson, 1975). The Baltic current enters the southern Kattegat from the Baltic and runs along the Swedish west coast to the north. In this way the southern part of the Swedish west coast would be supplied with larvae from spawning areas in south-eastern Kattegat, whereas the northern part would be supplied with a mixture of larvae from the south-eastern Kattegat and the eastern North Sea. The shallow water archipelago on the Swedish west coast is likely to be an important nursery area for two cod stocks, spawning offshore in the Kattegat and the North Sea, respectively. Juvenile cod utilize the high production of benthic organisms during their two first years of life (Pihl, 1982; Pihl and Rosenberg, 1982), whereupon they join the parental stock offshore. In shallow coastal waters juvenile cod also experience reduced predation by adult cod and other piscivorous fish species which could be significant in offshore waters (Daan, 1973; Riley and Parnell, 1984).

In Norwegian coastal areas spawning of cod has been reported from both inshore and offshore waters (Godø, 1984), and several local coastal stocks have been identified (Reisegg and Jørstad, 1984). Mixing of different stocks occurs and cod from different nursery areas could spawn in the same region. In some fjords local spawning has a significant influence on local fisheries. In our study, however, only a few individuals diverged from the general pattern of offshore migration described above. These cod were mainly from the Gullmar fjord and were found in deeper water (> 10 m) in the inner part of the fjord. This result suggests that spawning may occur locally in the fjord, but is probably of little importance compared to the dominating offshore spawning stocks.

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