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Transplantation-tagging-experiments in preliminary studies of migration of cod off Norway

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Cod along the Norwegian coast show great variability in migration habit. Coastal cod may be stationary for their entire life while mature north-east Arctic cod migrate long distances to reach their feeding areas in the Barents Sea and spawning grounds along the Norwegian coast. In this paper, migratory differences and possible mechanisms behind them are studied by transplanting the two types of cod to a new location and studying their behaviour after release. Individual behaviour is examined by logging information from acoustic transmitters attached to the fish which give continuous information on position and depth.

The data, although limited, show clear differences in migratory activity in coastal cod and north-east Arctic cod; the first show a territorial behaviour compared with a more active and determined migration for the second. It is apparent that the transplantation of north-east Arctic cod induces migratory activity. Low-frequency noise from oceanic waves is suggested as a possible navigational clue for north-east Arctic cod to find their way back to oceanic waters.

Key words: migration, transplantation, tagging, behaviour, cod.

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Introduction

Off the Norwegian coast, coastal cod (*Gadus morhua* L., CC) live their whole life close to the coast, while north-east Arctic cod (NAC) spawn in Norwegian coastal areas but feed in the Barents Sea – Svalbard region. The two types of cod represent extreme differences with respect to migratory activity (Godø, 1984a). In contrast to the apparent territorial behaviour of CC in some areas, NAC may perform yearly migrations of up to several thousand kilometres between their extreme northern distribution in autumn and coastal spawning grounds in March. Hence, in December, when the present experiments were conducted, spawning migration of NAC in the wild had started. After their extremely long migration, the fish are apparently capable of returning to previously visited spawning grounds with high accuracy (Godø, 1984b). The difference between CC and NAC becomes even more complex due to the variable migratory tendency of CC from various areas (Godø, 1986).

This paper studies the possibility and potential for the use of transplantation-tagging experiments to improve the understanding of the migratory diversity of cod in Norwegian waters. Fish of different origin were moved from their capture site and released at a new location. Their behaviour and migration after release were compared by tracking fish tagged with acoustic tags, and by analysing information from tag returns from a parallel conventional tagging experiment.

Materials and methods

Three transplantation-tagging experiments were carried out in 1992–1994. The fish were released in the Fanafjord [(south-western Norway, (Fig. 1)]. Both acoustic transmitter tags and conventional tags were used, and the numbers of CC and NAC released in the different experiments are shown in Table 1. The conventional tags were of the Lea type attached in front of the first dorsal fin (Anon., 1953). The acoustic tags (produced by VEMCO), transmitting at frequencies of 50–77 kHz, were attached with nylon strings along the first dorsal fin. The position of an acoustically tagged fish was automatically recorded when it remained within range of a triangle of hydrophone buoys located 400 m–600 m from each other (Fig. 2). When outside the range of the buoy system, the fish were tracked by a manually operated directional hydrophone lowered from a small vessel. The signals from the acoustically tagged fish were coded for depth, and, hence, simultaneous data on

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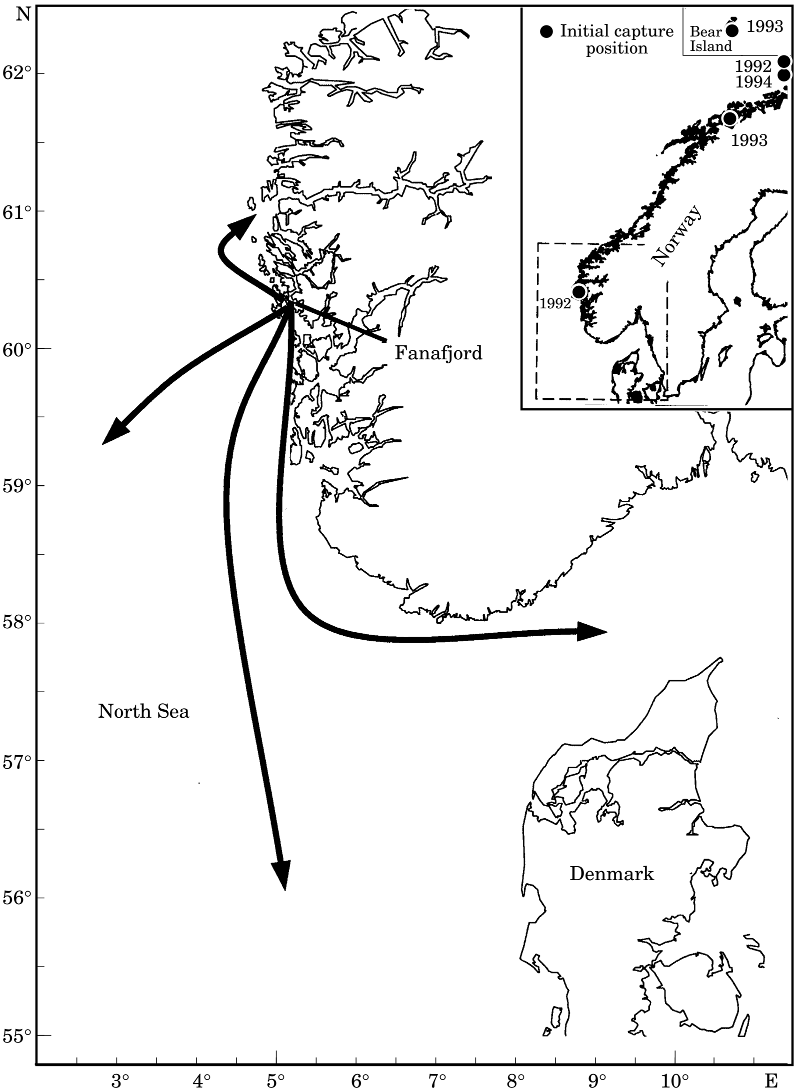

Figure 1. Capture positions and year of the transplanted fish (overview map). Migration of the four fish reported from outside the Fanafjord is shown in the enlarged section. Arrow heads show recapture position.

position and depth were recorded when the tag remained within range of the buoy system or the hand-set hydrophone. Within the buoy system the position of the fish was very precisely determined (to the nearest 5 m), while the deviation using the hand-set hydrophone was in the order of ± 50 m dependent on weather and navigational conditions.

The fish in the 1992 experiment consisted of NAC caught in beginning of October 1992 off the northern Norway coast and then brought directly to Bergen (Fig. 1). The CC were caught at about the same time at the coast outside the Fanafjord (Fig. 1). Both types of cod were kept together in the same tank until the experiment started on December 1.

In the December 1993 experiment NAC were caught in the Bear Island area (Fig. 1) in the beginning of October and transported to Bergen. CC were caught in a northern Norway fjord (Fig. 1) in September 1993, transported to Bergen by boat, and kept together with the NAC until the start of the experiment in December.

The releases in December 1994 were composed of NAC from the 1993 Bear Island cod sample which were kept in tanks in Bergen between the 1993 and the 1994 experiments. Further, a group of fish was captured in October 1994, at a location close to the catch position of the 1992 NAC (Fig. 1), and transported to a storage tank beside that containing the previously mentioned group. At the start of the experiments the fish were

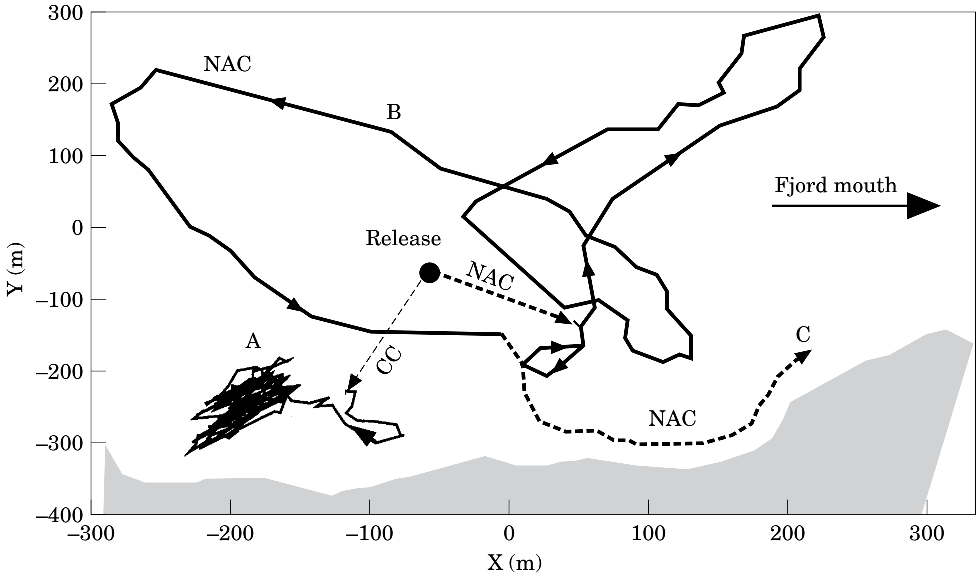

Figure 2. Movements of the first released coastal cod (CC-thin line) and Northeast Arctic cod (NAC-thick line) in December 1992. X and Y is the axis of the automatic coordinate system. The hatched part of the movement paths are partly assumed and partly indicated by the hand-set hydrophone. A, B and C are the hydrophone buoys.

transported from the tanks in Bergen to a pen in the Fanafjord until they were tagged and released.

CC and NAC are normally identified by differences in their otolith structures (Godø, 1984a). In these experiments discrimination was based on the choices of area and time of capture which excluded or minimized the probability of mixing.

Results

Acoustic tagging experiment

In the 1992 trials, two CC were tagged with acoustic transmitters. They had a very similar behaviour after release: a sudden dive of 30–40 m towards the bottom and subsequent movement to the closest shore about 300 m away. There they apparently established territorial behaviour, the fish seldom moving outside a circle with a radius of 50–100 m (Fig. 2). The actual distances moved were difficult to estimate because the fish were out of range of the buoy system for much of the time, probably due to blocking of the acoustic signals by rocks. After the end of the experiment, the presence and approximate position of the fish were observed from a shore position once or twice a week until the beginning of January 1993. Apparently no substantial change in position or behaviour occurred. To locate the final position of the tagged CC, a rubber boat and the hand-set hydrophone was used on 7 January 1993. Divers tested the mobility of the fish to assure that they were still alive. One fish was found in the same position as recorded at the end of the experiment, and was clearly mobile. This fish was recaptured in March 1993 some hundred metres away from this location by a local fisherman. The divers found the tag of the second CC under a popular sport fishing pier, close to the last recorded position. The appearance of the tag indicated that the fish had been recaptured, the tag removed and dropped into the water. Even though the CC were transplanted from a location outside the fjord, there was no evidence of return or movement out of the fjord.

In 1992, two NAC were also released in the same position as the CC. Immediately after release they dived towards the bottom. Thereafter, they gradually approached the surface again and moved in large circles around the buoy triangle (Fig. 2). The first one was subsequently lost from the buoy system, probably among pleasure boats or rocks close to the shore, and contact was not regained during several attempts with the hand-set hydrophone. The second fish was followed with the hand-set when out of range of the buoys. The hand-set was operated from a small rubber boat, and due to rough weather, the fish was lost about 2 h after release more than 1 n.m away from release position. After the first circles this individual seemed to be aiming directly out the fjord at a depth of 10–15 m (bottom depth 80–160 m). Since we were not prepared for such an immediate reaction, we probably lost the first NAC because it left the release area and headed out of the fjord. No recaptures of NAC have been reported from this experiment.

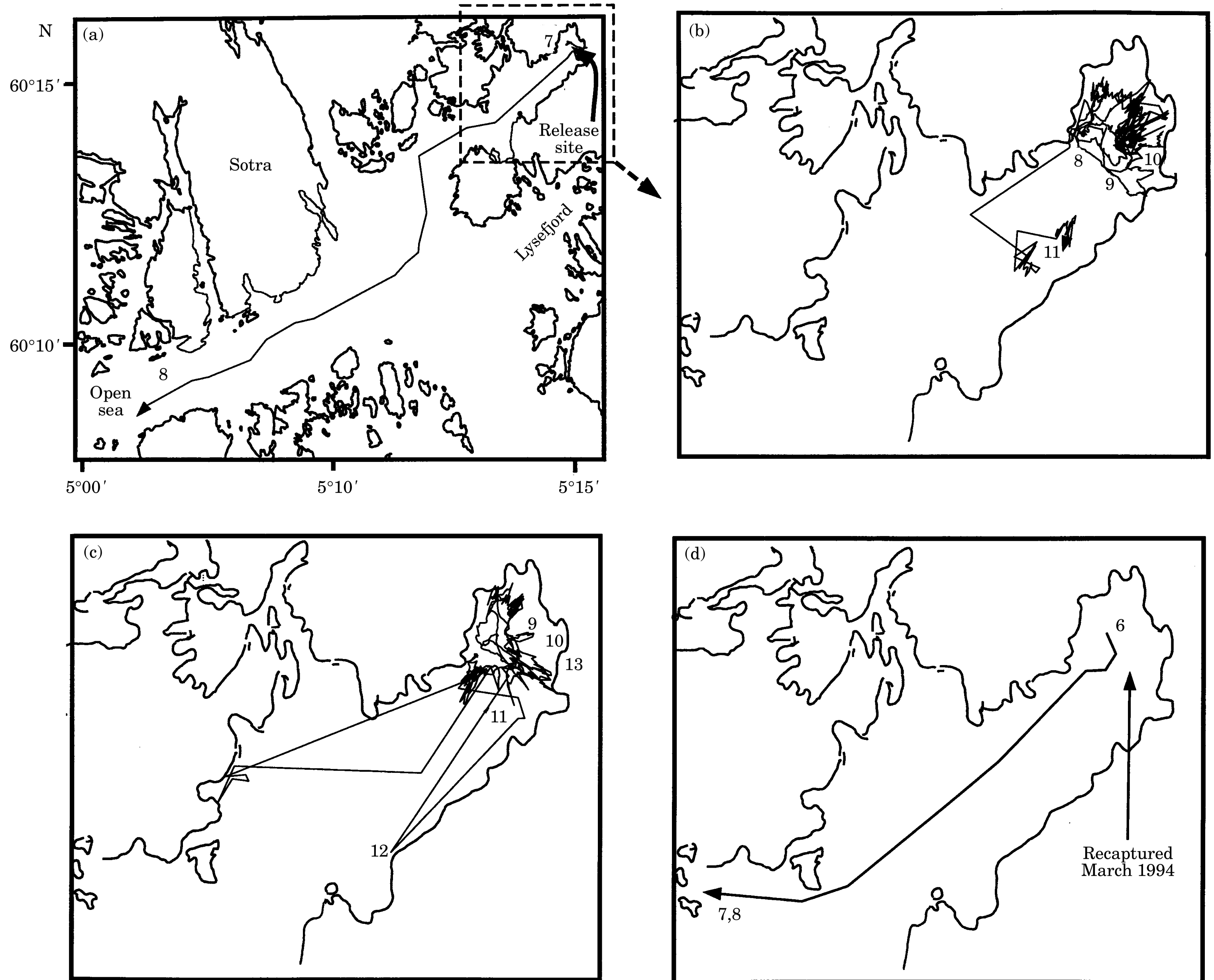

Figure 3. Movements of acoustically tagged cod in the 1993 experiment, NAC 1–3 (a, b, c) and one CC (d). Numbers along tracks are dates during the month of the experiment and indicate position at midnight.

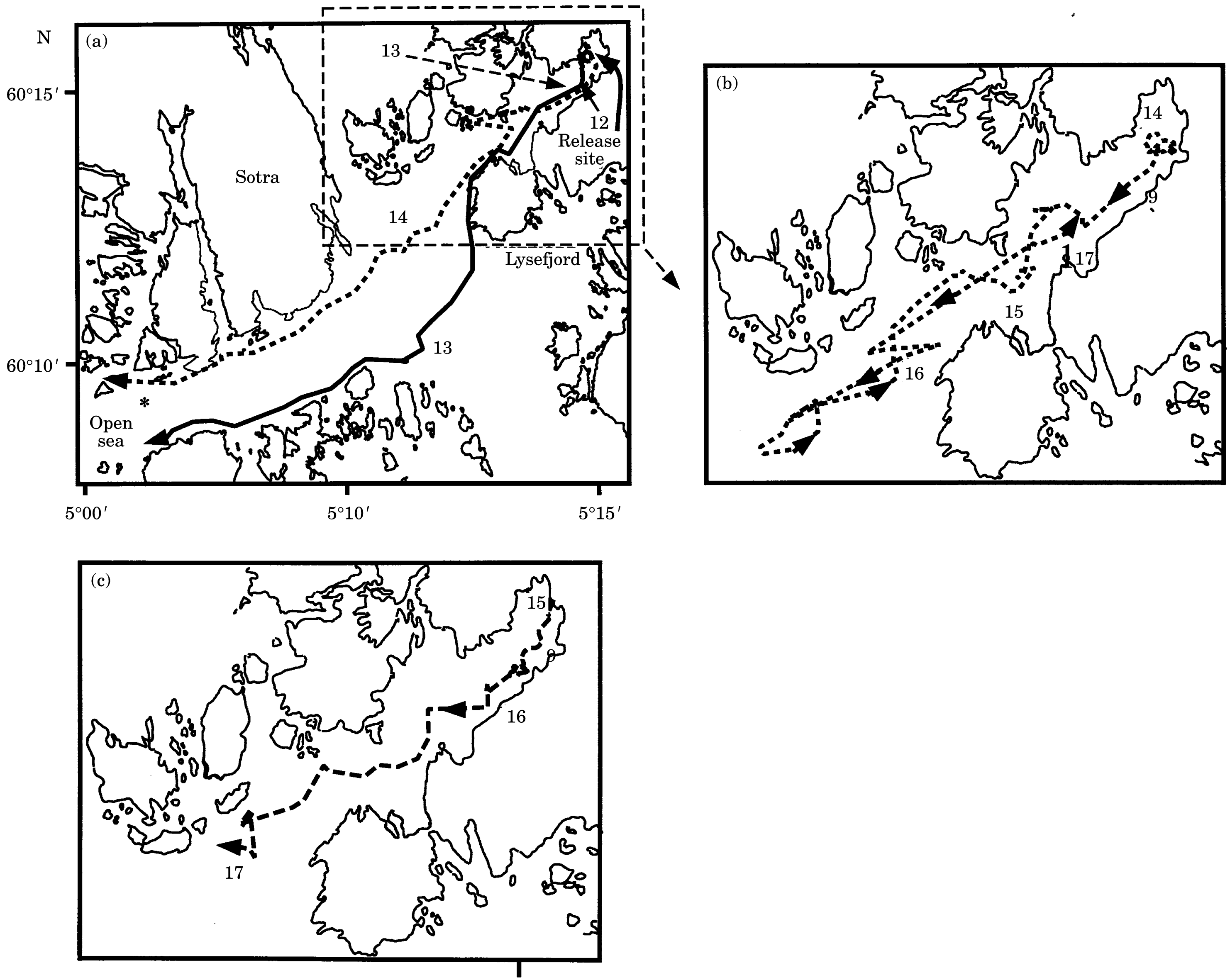

Figure 4. Movements of acoustically tagged NAC in the 1994 experiments. Movement paths of fish 1 (continuous line) and 2 (dashed line) (a), fish 3 (b), and fish 4 (c). Numbers along tracks are dates during the month of the experiment and indicate position at midnight.

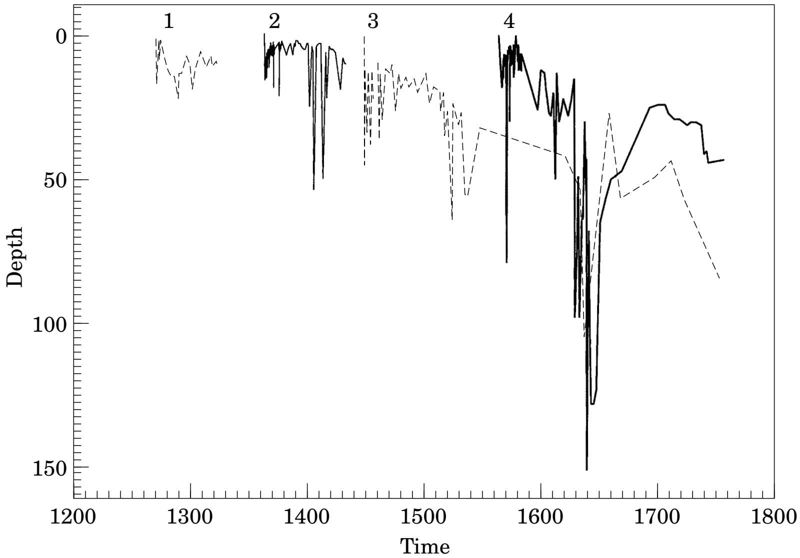

Figure 5. Vertical movements of the NAC (1 to 4 in 1994). The time axis cover the whole experimental period and Time=(day number in December)*100+(hours*100/24).

The first acoustically tagged NAC released in 1993 behaved similarly to the NAC in 1992. The fish remained in the vicinity of the release position for a short period and followed a meandering course. Thereafter, the fish headed out the fjord and was followed until it reached oceanic waters ("open sea" in Fig. 3a). Observation was then terminated, due to the priority to obtain similar data with additional releases of NAC. Another two NAC were tagged acoustically and followed for several days. Their behaviour was somewhat different from the previously tagged NAC; after a dive and meandering movements (similar to the previous observations), the two individuals spent most time in front of a river outlet in the bottom of the fjord close to the release position (Fig. 3b,c). Short movements around the inner part of the fjord occurred regularly, and signified a behaviour different from CC. However, much of the time the two specimens apparently remained inactive like a CC.

In the 1993 experiment the acoustically tagged CC from northern Norway covered a larger area in the Fanafjord than was observed for CC in 1992. After release the fish moved to the outer part of the fjord and settled at 15–20 m from the bottom (see positions in Fig. 3d). This fish was recaptured close to the release location on 1 March 1994.

In 1994, four acoustically tagged NAC were tracked. Two headed directly for the open sea after a short hesitation subsequent to their release (Fig. 4a), the second taking a substantially longer time than the first to reach the ocean (Fig. 5). Fish number three and four stopped before arriving in the open sea (Fig. 4b,c); the third fish moved further from the release site than the fourth, but returned to the fjord at the end of the trial period (Fig. 4b).

All the tracked CC in 1992 and 1993 moved towards the bottom after release. The southern CC settled on the bottom after about 15 min while the northern CC took several hours. The migrating NAC in all experiments mostly remained close to the surface (5–20 m, fish 1 and 2 in Fig. 5). The individuals of this group, which showed a reduced tendency to migrate, gradually approached the bottom and finally settled, as is demonstrated by fish 3 and 4 in Fig. 5. In fish that remained on the bottom, horizontal movement appeared to cease.

Conventional tagging experiment

One conventionally tagged CC from the 1992 experiment was recaptured at the release site in the month of the experiment (Table 1). Six conventionally tagged CC (all transplanted from northern Norway) were recaptured from the 1993 release; five came from the Fanafjord and one, which was caught almost a year after release, from Lysefjord, the neighbouring fjord in the south (see map in Fig. 3a). Three conventionally tagged NAC were recaptured. One was caught in Skagerrak between Norway and Denmark in February 1994, the second was caught at the outer skerries north of the Fanafjord while the last report came from the North Sea south west of the release site (Fig. 1), i.e. all far outside the Fanafjord. Finally, a fish which had lost its identity tag (showing its origin) before the start of the

Table 1. Releases and recoveries of acoustic (Ac) and conventional (Conv) tags. Size at release is average fish length (cm) of the fish tagged with acoustic transmitters.

	Size at release		Number released NAC rel.				CC recovered		NAC recovered	
			CC		NAC		CC		NAC	
Date	CC	NAC	Ac	Conv	Ac	Conv	Ac	Conv	Ac	Conv
Dec 1992	45	62	2	3	2	1	2	1	0	0
Dec 1993	58	68	1	16*	3	32	1	4	0	4**
Dec 1994	—	75	0	0	4	7	0	0	0	0

*CC include both local CC and transplanted CC.
**One of the recoveries was of uncertain origin due to loss of initial group identifier.

experiment, was recaptured in the southern North Sea in 1995 (Fig. 1). Compared with the average sizes at release of conventionally tagged NAC (62.0 cm) and CC (51.5 cm), this specimen of 66 cm was most probably a NAC. No recapture has been reported from the 1994 experiments.

Discussion

The validity and quality of information from fish tracking studies are dependent on the design and duration of the experiments. Hawkins *et al.* (1974) stress the uncertainty caused by the extra weight of the acoustic transmitter. The higher mobility of the cod observed during the initial phase of their experiment is suggested as an effect of buoyancy disturbance caused by the tag. In contrast, Arnold *et al.* (1994) found that similarly tagged fish released at the surface were less active than those released on the sea-bed after a period of confinement. The current experiments were all of short duration and the fish were released at the surface. Consequently, the results suffer from the uncertainty discussed above. These trials were designed for studying possible differences between CC and NAC and, therefore, the buoyancy effect is considered to be of less importance as long as the same procedure was followed during all releases.

The conclusion from this study so far is that CC adopt natural "territorial" behaviour when transplanted to a new position. Northern CC are more mobile than the southern CC, which agrees with earlier observations from tagging experiments (Godø, 1986). Thus, there is no indication that transplantation of CC stimulates migration.

In contrast, the NAC showed a much higher mobility. The tracked NAC either left the fjord or strayed around within the fjord, and all recoveries of tagged NAC were reported from oceanic waters. Although all data clearly show that NAC are more active than CC, it is interesting to note that the migratory tendency of NAC decreased from the first to the last releases both in 1993 and 1994. This indicates that data obtained from fish released immediately after transplantation are not directly comparable with data recorded from later releases. Thus, not only the buoyancy state [see Hawkins *et al.* (1974) and Arnold *et al.* (1994)], but also the transplantation itself may affect behaviour immediately after release.

The NAC which left the fjord during the observation period all followed the same route towards the ocean. An aimed migration may arise when the fish perceive external stimuli that can be used for navigational purposes. Atlantic cod may sense low-frequency noise, and Sand and Karlsen (1991) have suggested infrasound patterns in the ocean to be a possible stimulus during migration. Under normal conditions this sound source is supposed to create resonance between the "walls" of the fjords and hence may lead the fish directly to the ocean. During extremely calm weather, as experienced during the experiment with the second and third NAC in 1993, the underwater noise level may be too low for the fish to detect and use for navigation. The ambient sound in the fjord over this period was probably dominated by the fresh water influx from the river, and, hence, the NAC approached this sound source.

In all cases, when the tagged NAC showed substantial migration, the individuals remained in the surface layer (above 15 m), indicating that orientation stimuli are received here. The different choice of direction by the two conventionally tagged NAC recovered outside the Fanafjord in 1994 (Fig. 1) may indicate a conflict or confusion between several stimuli used for navigational purposes after the fish entered oceanic waters. This compares with the findings of Hylen (1963). He transplanted cod from the Barents Sea to the mid-Norwegian coast, and tagged fish were recovered both north and south of the release position. With increasing time after release northward movements dominated. More extensive experiments of the same type as described in this paper may help to elucidate the questions brought up by these initial trials.

The limited number of cod observed in these experiments precludes any firm conclusions from being drawn. The recoveries of conventionally tagged fish support the results from the tracking experiments and are a useful supplement to this time-consuming and expensive observation method. The results from these studies may become more conclusive if additional recaptures of the conventionally tagged cod are reported.

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