ICES Journal of Marine Science

ICES CIEM International Council for the Exploration of the Sea Conseil International pour l'Exploration de la Mer

ICES Journal of Marine Science (2014), 71(9), 2484–2493. doi:10.1093/icesjms/fsu096

Original Article

Possible influence of salmon farming on long-term resident behaviour of wild saithe (*Pollachius virens* L.)

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Otterå, H., and Skilbrei, O. T. Possible influence of salmon farming on long-term resident behaviour of wild saithe (*Pollachius virens* L.). – ICES Journal of Marine Science, 71: 2484–2493.

Received 11 November 2013; revised 30 April 2014; accepted 4 May 2014; advance access publication 13 June 2014.

The culture of Atlantic salmon is one of the most developed aquaculture industries in the world. The production from smolt to market size usually takes place in sea cages in open waters, and these structures tend to attract wild fish, as they do for other farmed species. For salmon farming, saithe (*Pollachius virens*) is one of the most-frequently observed species around sea cages. An important question is whether the large concentration of salmon farms in some areas might alter the natural behaviour and migration pattern of wild saithe. We tagged 62 wild saithe with acoustic tags and followed their movements for up to 2 years in an area in Southwestern Norway with many salmon farms. Furthermore, nearly 2000 saithe were tagged with external T-bar tags to study migration beyond the study area. The recaptures of the T-bar tagged saithe from offshore areas suggest that the offshore migration routes of saithe are similar to published results from before salmon farming became significant in the area. However, a large proportion of the saithe population appears to remain in the release area and was observed at the salmon farms for much of the time. We conclude that the aquaculture industry is influencing the local saithe distribution. Large-scale population effects are more difficult to prove, but it is possible that the dynamic relationship between the coastal and oceanic phases has been altered.

Keywords: aquaculture, interaction, migration, saithe.

Introduction

Aquaculture is a growing industry in many countries, relying on a wide range of species. One of the most important fish species that are successfully farmed is the Atlantic salmon (*Salmo salar* L.), with an annual worldwide production of ~1.7 million metric tonnes in 2011 (FAO, Fisheries and Aquaculture Department, www.fao.org). Norway is among the major producers of salmon, with annual production of ~1 million metric tonnes from aquaculture in 2011 (Directorate of Fisheries, www.fiskeridir.no). Salmon production is mainly carried out in open seawater systems, with sea cages moored at suitable locations along the coast. In Norway, around 1000 sites have been approved for salmon farming in fjords and along most of the coast (Directorate of Fisheries, www.fiskeridir.no).

There is growing concern regarding the negative environmental impacts of salmon aquaculture. The influence on wild salmonid populations of rising levels of salmon lice near salmon farms (e.g. Krkošek *et al.*, 2013; Skilbrei *et al.*, 2013) and the risks of genetic introgression due to spawning of escaped farmed salmon in rivers (e.g. Glover *et al.*, 2013) have received most attention. However, it has also been recognized that open systems like those used in salmon farming attract wild fish species (Carss, 1990; Dempster *et al.*, 2004, 2009; Arechavala-Lopez *et al.*, 2010, 2011), where they find food and shelter. However, few studies have examined the behaviour of fish attracted to fish farms in any detail. One of the most common wild fish species associated with fish farms in Northern Europe is saithe (*Pollachius virens* L.; Carss, 1990; Bjordal and Johnstone, 1993).

Saithe is one of the most common gadoids in the northern Atlantic and is commercially important in many areas. The saithe stock is divided into several management units (Jakobsen and Olsen, 1987), with more or less distinct biological characteristics and migrations between them (Homrum *et al.*, 2013). The North Sea stock, which is most relevant to this study, had landings of ~90 000 t in 2011, and spawning-stock biomass was estimated to 213 000 t (ICES

Advice 2013, www.ices.dk). The biology of saithe is not very well documented in the literature, but the main spawning grounds of this stock are believed to be in the northern part of the North Sea (Nedreaas, 1987). After spawning in February–March, the larvae and juveniles disperse to the coasts of southern Norway and Scotland, where they remain in their nursery area until they are 2–4 years old (Nedreaas, 1987). As they grow, feeding migrations become more important, and saithe tagged on the Norwegian coast have been recaptured as far away as the Faroes and Iceland (Jakobsen and Olsen, 1987; Armannsson *et al.*, 2007; Homrum *et al.*, 2013). Saithe in other areas such as the Northwest Atlantic (Neilson *et al.*, 2006), Faroe Islands (Homrum *et al.*, 2012), and Scotland (Du Buit, 1991) have similar life history shifts between juvenile coastal feeding and adult offshore feeding and spawning areas. These areas all support salmon farming. Saithe is known to have a more pelagic and schooling behaviour compared with other gadoids (Scott and Scott, 1988), and show also diel and seasonal differences in vertical distribution (Neilson *et al.*, 2003; Armannsson and Jonnson, 2012).

Fishing close to fish farms is often restricted by law or for practical reasons. This may have consequences for the operation of the local fisheries. However, whether these aggregations benefit or harm local wild stocks is a matter of debate (Dempster *et al.*, 2011). The quality of the flesh of saithe that feed around fish farms may also be altered (Skog *et al.*, 2003; Otterå *et al.*, 2009; Fernandez-Jover *et al.*, 2011).The potential for spread of drugs, or pathogens to the wild or between fish farms has also caused concern (Samuelsen *et al.*, 1992; Uglem *et al.*, 2009). In an early study, Bjordal and Johnstone (1993) followed nine acoustically tagged saithe close to a salmon farm in southern Norway for up to 11 days. Similarly, Uglem *et al.* (2009) fitted 24 saithe with acoustic tags, and followed them for 3 months in a small fjord in northern Norway. Both of these experiments showed that saithe captured around fish farms spend much of their time close to the farms. However, both experiments studied saithe behaviour over a relatively short period, so longer studies are required to improve our knowledge of how fish farms may influence certain aspects of the biology of wild saithe.

This experiment used acoustic tags to follow the movements of saithe tagged in a major salmon production area for up to 2 years, as well as their long-distance migrations using conventional external T-bar tags. In particular, we wished to determine how much time the saithe spent around the salmon farms, and to look for evidence of alterations in the traditional migration pattern of wild saithe.

Material and methods

Two release experiments were performed in 2010, when a total of 62 saithe were equipped with acoustic transmitters, and a further 1837 with T-bar anchor tags and released (Table 1).

Study area

The experiment was performed in Ryfylke in southwestern Norway (Figure 1). This is one of the most productive salmon-farming areas in Norway. Some 50 sites have been approved for salmon farming in this fjord system, but less than half of these are normally in use at any given time. Salmon production in the County of Rogaland was 64 000 t in 2010; the study area was the largest contributor to this total. A salmon farm may have a cage volume of ~100 000–200 000 m^3, and support a harvest of more than 1000 t of 3–6 kg salmon after a growing cycle of 18–22 months. Between each growing cycle, a minimum 2-month fallow period is mandatory to reduce the risk of disease transmission between fish groups. The study area includes several deep (up to 700 m) fjord arms, as well as shallow areas and islands. Surface water temperature usually ranges from 3°C in winter to 17°C in summer, but temperatures above 20°C occasionally occur during summer.

There is a small-scale local fishery primarily for saithe, cod (*Gadus morhua*), ling (*Molva molva*), mackerel (*Scomber scombrus*), and herring (*Clupea harengus*), in addition to labrids (*Labridae*) that are sold to salmon farms as cleaner-fish.

Fish capture

Wild saithe for the experiments were captured by purse-seine during the evenings of 21 April (exp. 1) and 10 November 2010 (exp. 2). On both occasions, the fish were captured just outside a salmon farm (Figure 1), and artificial light was used to lure the fish out from beneath the cages into open water, where the purse-seine could be operated. Approximately 2 t of fish were captured for both experiments, transferred to a net pen, and then on to the site where they were tagged (Figure 1). The fish used in both experiments were mainly age 3, as determined by otolith readings.

Tagging and release

Two types of tags were used; acoustic and T-bar anchor tags. Fish were randomly selected from the net pen and tagged with V13 acoustic transmitters with depth sensor (V13P-1x, 4.3 cm long, 1.3 cm diameter, weight in water 6.6 g, 100–180 s between pings, projected battery life 835 d; Vemco Ltd, Nova Scotia, Canada). The fish were anaesthetized with a combination of benzocaine and tricaine methanesulfonate (Finquil Vet®, 300 mg l^{-1}). The dose was adjusted, so that it took 2–3 min until the fish were calm enough for surgery. A 3- to 4-cm-long incision was made 2–3 cm in front of, but 1–2 cm above, the pelvic fin. Terramycin vet (Oxytetracycline) was spread on the tag anchor before inclusion. Tissue adhesive (Histoacryl) was added to the wound after the three sutures had been closed (Supramid 2/0 polyamide monofilament) and tied with surgeon's knots. The equipment and needles were sterilized in 70% ethanol. Finally, length and weight were measured and the fish were also tagged with external T-bar anchor tags (Hallprint, Australia, www.hallprint.com), inserted with a tagging pistol on the left side in front of the first dorsal fin so that they engaged the dorsal pterygiophores (Otterå *et al.*, 1998). The operation took 3–4 min. The fish were first transferred to a tank supplied with running seawater for recovery, and then kept in a net pen for a few days until release.

Table 1. Overview of the two release experiments: date of catch, tagging and release (all dates in 2010), as well as fish size and numbers released.

Exp.	Date			Length		Weight	Numbers released		
	Catch	Tagging	Released	Average (cm)	Min–max (cm)	Average (g)	V13P-1x	T-bar	Total
1	21 April	27 April–7 May	7 May	42.5 (2.6)	38–49	815 (142)	30	929	959
2	10 November	25 November	26 November	51.0 (3.9)	42–59	1 581 (381)	32	908	940

Standard deviations of fish length and weight are given in parentheses.

A larger group of saithe was tagged with anchor tags only. A subsample of the anchor-tagged fish was measured for length and weight. The anchor tags were yellow and had an inscription with return address/website and a unique number, so that a reward of 100 NOK could be paid for returned tags. No advertising campaign was performed, but the release experiments were mentioned in the local newspaper and at the farms equipped with receivers. Table 1 summarizes the number of fish tagged, and the fish size in each experiment. The experiment and the tagging procedure were approved by the Norwegian committee for the use of animals in scientific experiments (FDU).

Tagging and releases for both experiments took place at the Centre for Aquaculture Competence (CAC), Langavik (www.cac-salmon.com, Figure 1). This is a full-scale salmon farm used for testing equipment, feed and farming protocols, and had facilities for handling and tagging the saithe. It was also considered to be the most efficient place to release the tagged saithe, by avoiding further transport, and due to its central location in the experimental area.

Monitoring and data analysis

Besides the reports of recapture of external tags from recreational and professional fishers, we were able to follow the local movements of the acoustically tagged fish in greater detail. Fifteen acoustic receivers (VR2W, Vemco Ltd) were placed at 15 selected salmon cage farms in the release area (Figure 1). They were mounted at a depth of 55 m at the end of a rope with a weight, suspended from the cage framework (usually at the feeding and service platform). This depth was selected based on readings from an initial trial on one of the farms, where receivers were mounted at depths of 3, 22, and 55 m, and the acoustic tags at the same depths, but at different distances from the receivers. At this depth, the receivers are less shaded

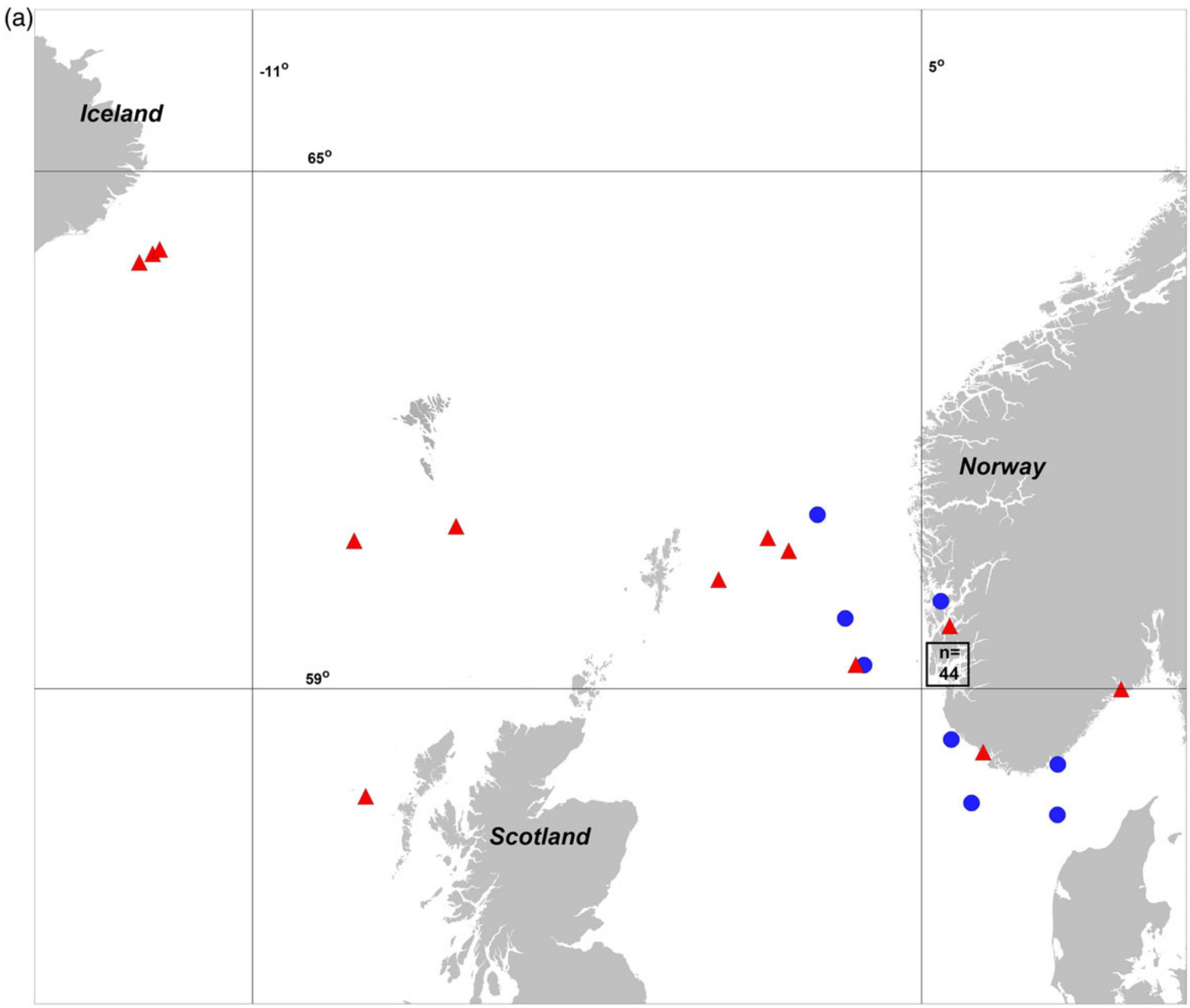

Figure 1. (a) Recaptures of T-bar-tagged saithe, where circles are from the first release and triangles are from the second release. The square indicates the experimental area, Ryfylke in Southwestern Norway, where 44 of the recaptures were made. (b) The experimental area. Positions of the receivers/fish farms are indicated with circles numbered from F1 to F15. Farm 15 was moved from position 15a to 15b on 7 September 2010. The size of each circle is proportional to the total number of observations from that receiver in the course of the experiment. Saithe used in experiment 1 were caught at F7 and those used in experiment 2 were caught at a site close to F15a, both indicated by an open circle. The fish were tagged and released at F1, indicated with a square. Receivers F3, F8, F5, and F14 were lost during the last part of the experiment and were last read in November 2011.

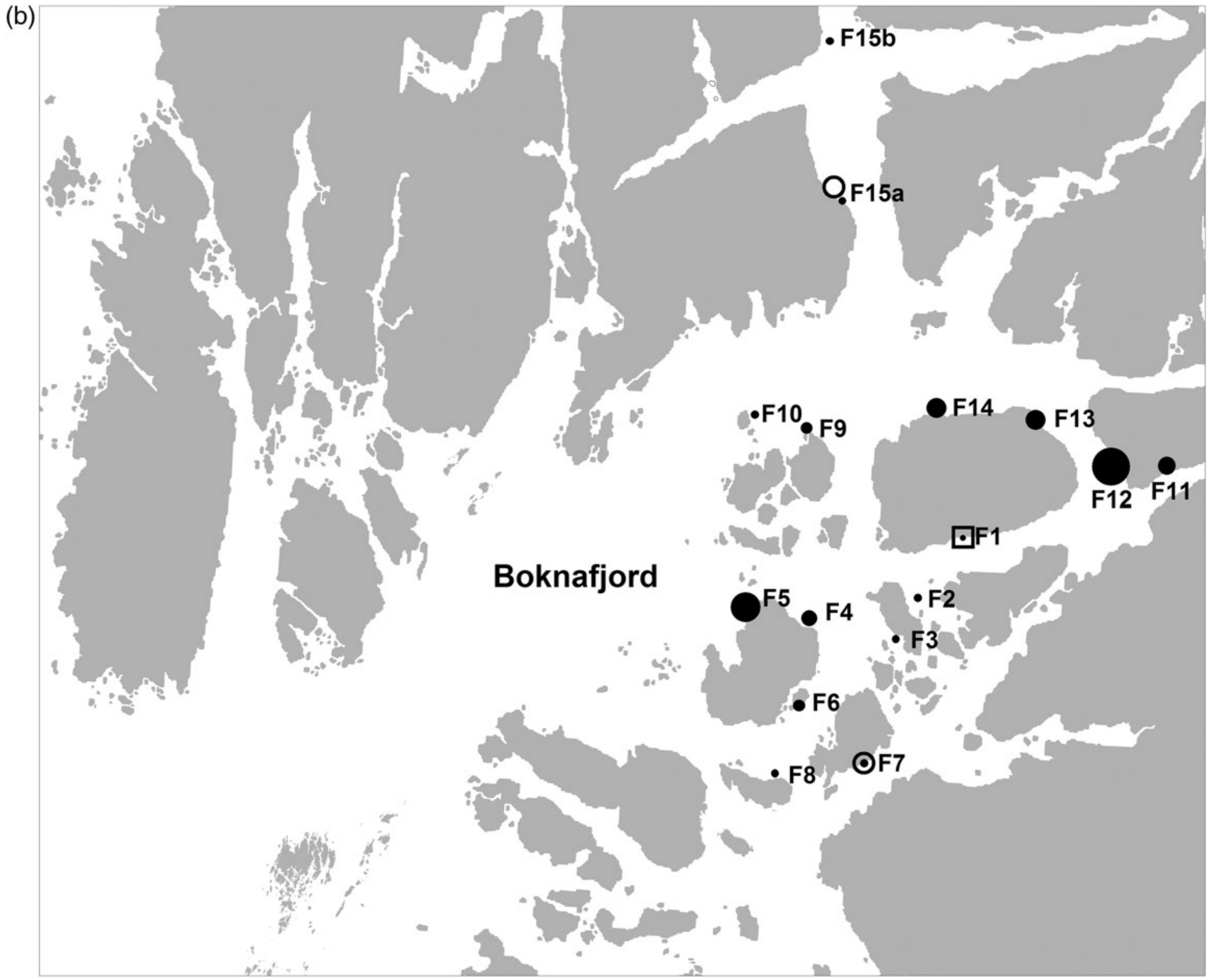

Figure 1. Continued.

by the salmon cages which are 30–40 m deep. The range of reception of the transmitters is ~500 m, but is highly dependent on hydrographical conditions and possible interfering noise (Espinoza *et al.*, 2011). Recordings of this type of tag have been made at distances of 1–2 km (Skilbrei, 2012). Besides the 15 cage farms with receivers, a further ten farms in the area were in operation but did not have any receiver. No receivers were installed apart from fish farms.

With no *a priori* knowledge of the movements of the saithe in the area, we chose an exploratory design, with the available receivers positioned at most of the salmon sites in the area. An alternative design, e.g. with the receivers in increasing distance from the release site, was considered too risky in respect of achieving enough detections, given the limited number of receivers available.

The data analysis and plotting was performed with the software package R (R Development Core Team, 2010) and Microsoft Excel. The raw data were scrutinized to remove any false registrations. Single detections at a receiver were deleted, unless there were recordings of the same individual on close receivers. To detect potential patterns among the fish with respect to the presence or absence in the area covered by the receivers, we used agglomerative cluster analysis (R procedure agnes; Kaufman and Rousseeuw, 1990). Recordings from all receivers were summarized by year–week before this analysis. A Fisher exact test was used for testing differences in offshore vs. release area fraction of reported recaptures between different periods.

Results

External tags

A total of 65 saithe fitted with external T-bar tags were reported recaptured. Most of these (41) were from the second, November 2010 release, while 24 were recaptured from the first release in May 2010. These figures correspond to 4.4 and 2.5%, respectively, of the releases. About 32% of the recaptures were outside the release area; the North Sea, Skagerrak, Norwegian Sea, and as far off as Iceland, as well as a few from the coast of Norway (Figure 1). Offshore recaptures were made by fishing vessels from several countries and were reported to IMR, often via their national fisheries research centres. Fishing gear was usually trawl (100% of those that reported the gear used). Most of the reports of recapture come from the release area (Figure 1). Some of the reports from the release area stated explicitly that the catch was taken close to a salmon farm, while others reported that the stomachs of the saithe were full of herring roe, but in general, we have little information about feed items or details of the recapture site. Recreational anglers and professional fishers contributed to the recaptures in the release area and on the Norwegian coast, and both nets and rods were used. The recaptures were seasonal, with most reports from winter/spring 2011 and 2012 (Figure 2). We find no evidence for change in offshore recapture fraction between periods (Fisher's exact test, $p \sim 0.5$). We then compare three periods with a reasonable number of recaptures; first and second half of 2011 and first half of 2012, and pool recaptures from both releases (Figure 2).

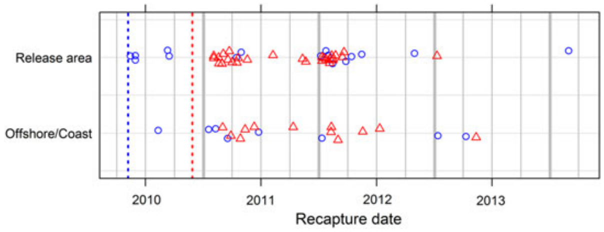

Figure 2. Time of recapture of T-bar-tagged saithe from the first (circles) and second experiment (triangles). Recaptures are divided between the release area (Figure 1) and elsewhere. Stipled vertical lines indicate time of 1. and 2. release.

Some of the recapture reports also included length and/or weight data. The reliability and accuracy of these measures are not known, which limits their value. Nevertheless, in the first quarter of 2012, the weights of 16 recaptured individuals ranged from 1500 to 4080 g, with a median value of 2550 g.

Acoustic tags

The system of 15 receivers functioned well throughout the experimental period, except for the loss of four receivers (nos F3, F8, F5, and F14) towards the end of the experiment (last read November 2011). A large number of individual readings were made (~1.3 million) and we were able to follow a significant number of fish for up to 2 years (Figure 3). The dataset is rather complex to present due to the large number of records, differences in behaviour between fish, as well as differences in the characteristics of the sites with receivers. The vertical distribution of the fish, as well as diel and seasonal variations, will be presented in a separate report.

The cluster analysis did not reveal any apparent grouping of the individuals but a more or less gradual reduction in the number of individuals present in the area covered by the receivers (Figure 3). Of the 30 fish that were released in May, seven individuals were

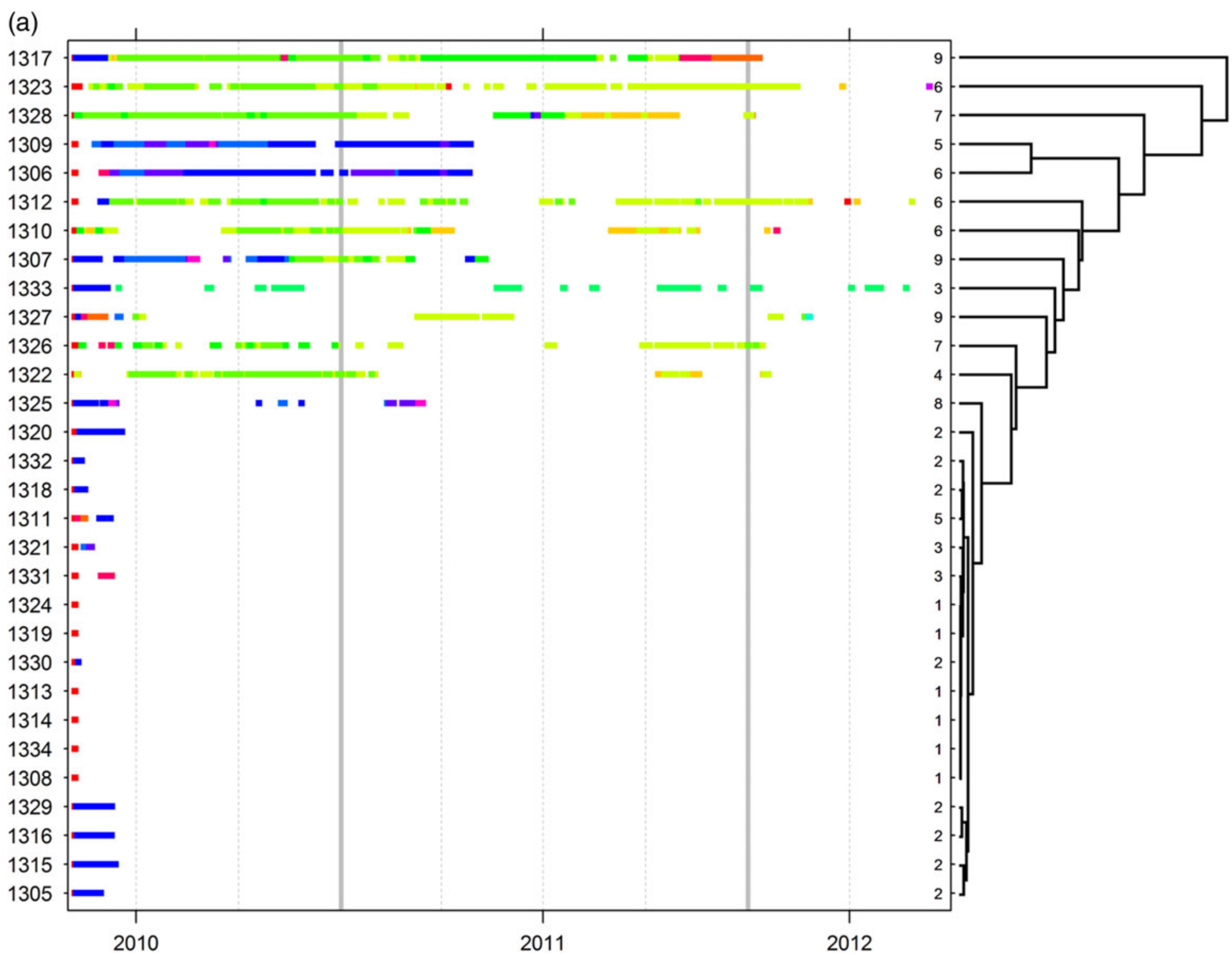

Figure 3. Overview of the recordings from the first (a) and second (b) experiments. Time is shown on the *x*-axis, and the fish (tag-number) on the *y*-axis. Colours identify the receiver at which the observation was made. The numbers at the right of the *y*-axis indicate the number of receivers on which a fish was recorded. Dendrogram from the cluster analysis are shown at right.

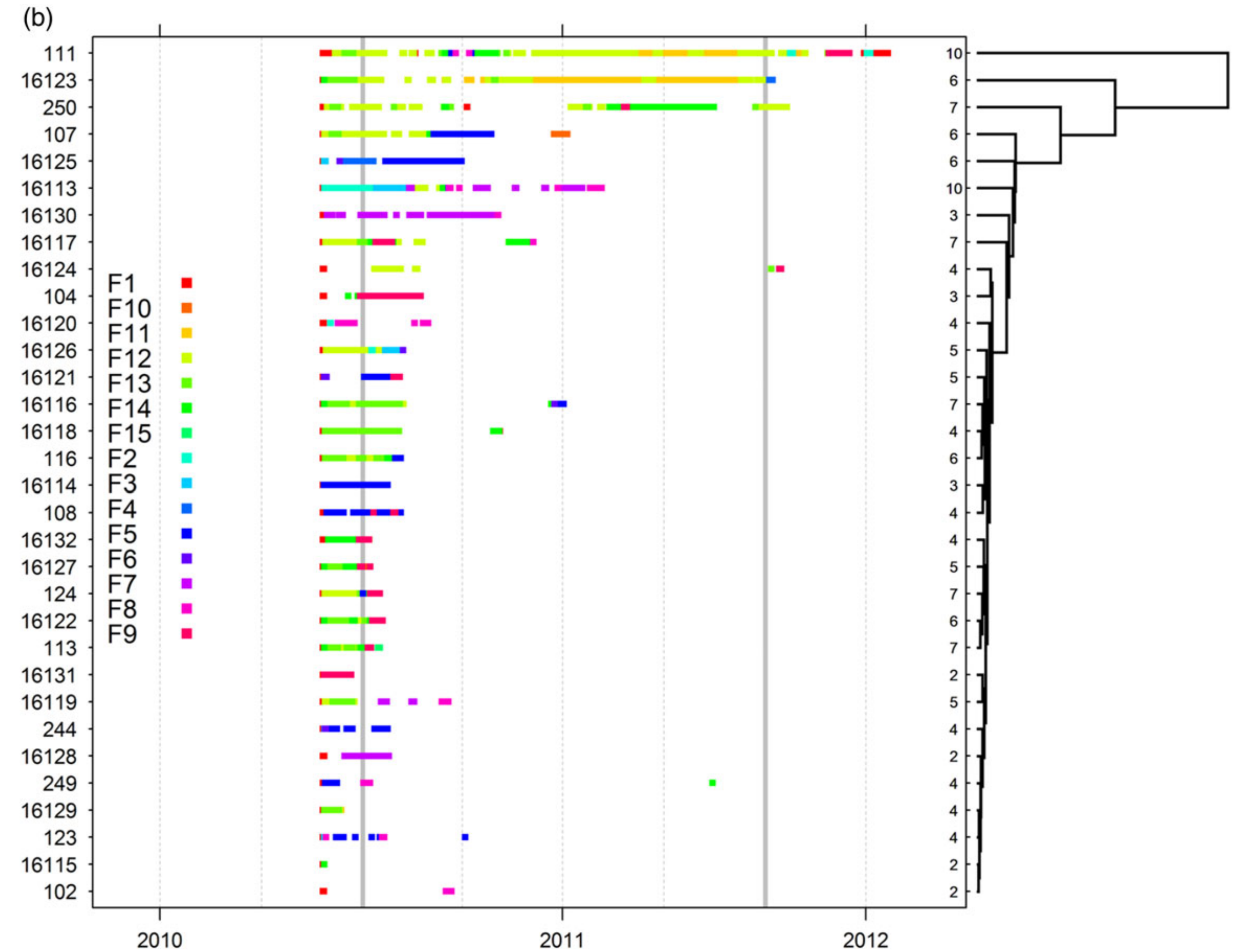

Figure 3. Continued.

observed immediately after release but were not recorded after that. A further ten fish disappeared within a few weeks after release (Figure 3). All these were last registered at one or more of the sites closest to the open sea (F5, F10, F4, F6, F9) before they disappeared. For the remaining 13 tagged fish, we have records for longer periods; nine of them were still being recorded 1 year after release, and three individuals were recorded 2 years after release (Figure 3). The size at release for the three subsets was quite similar, 840, 896, and 751 g, respectively. However, for the latter two (present a few weeks vs. present for a long period), the size difference was significant (*t*-test, $p < 0.05$). The nine fish with records for at least 1 year after release had been registered by an average of 6.2 receiver sites during that period (range 4–9).

We obtained recordings of all the 32 saithe tagged with acoustic tags and released in November 2010 (Figure 3). We lost track of most of them within the first quarter of 2011, but 12 were registered in the area thereafter, and four individuals were still present in spring 2012. The average weight at release was 1745 g for those that were not registered in the area the first quarter of 2011, and 1662 and 1254 g, respectively, for those present until 1 January 2012 or beyond, respectively. The differences in weight were not significant (ANOVA, $p \sim 0.06$). The 12 individuals with the longest observation periods visited an average of six fish farms (range 3–10).

Acoustically tagged saithe were observed at all the 15 sites with receivers, but the number of observations varied widely among sites. Using numbers of single readings as a measure, farm F5 and the four farms in the inner part of the fjord (F11–F14) accounted for 77% of the observations (Figure 1).

Fish moved frequently among fish farms (Figure 3), and altogether the saithe changed position from one receiver to another 719 times in the course of the study. Of these 719 movements, 303 (42%) were between the neighbouring receivers at F12 and F13. If we also include the surrounding receivers at F11 and F14, these four sites in the inner part of the fjord accounted for 467 (65%) of all between-site movements. One fish moved 74 times between sites, and further 20 individuals had 10 or more movements.

It is also clear from Figure 3 that some of the saithe had periods of weeks and months during which they were not observed at any of the sites equipped with receivers, before they reappeared. However, generally speaking, the connection with fish farms seems to have been close. Many of the saithe were observed at one or more farms for more than 75% of the time (Figure 4). The presence at the sites with receivers obviously decreases with time, but there was a suggestion of a weak seasonal trend (Figure 4), with closer connections to the farms during winter (November 2010–January 2011 and November 2011–January 2012) than summer (July–August 2010,

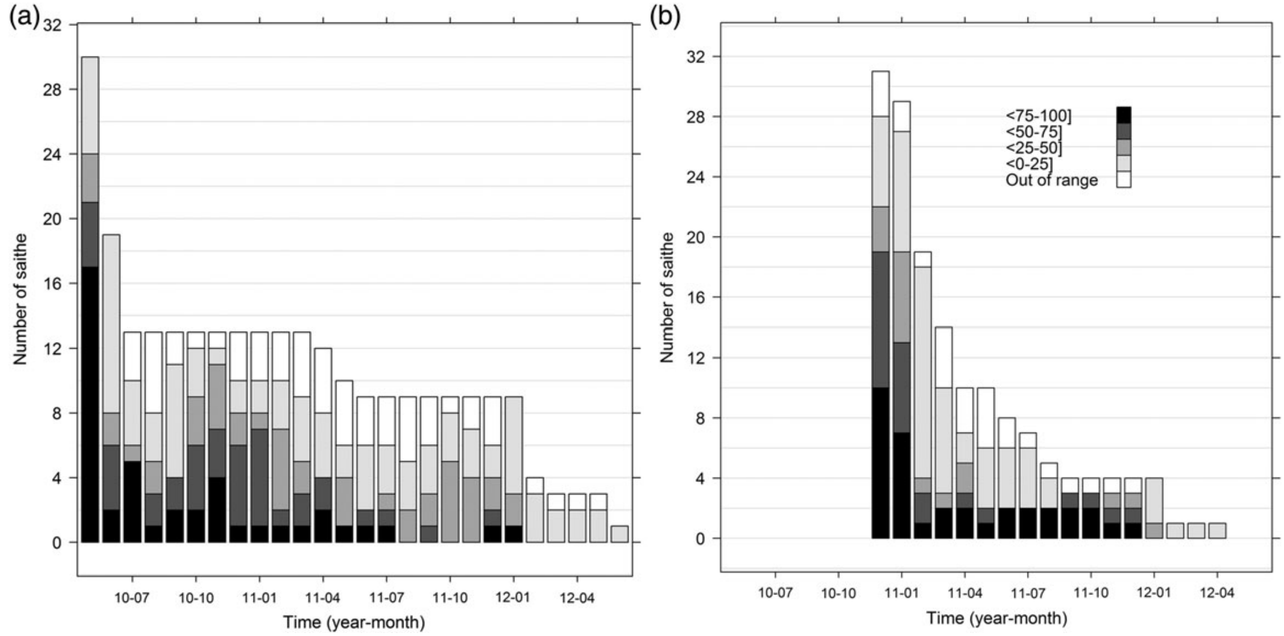

Figure 4. Number of fish present (*y*-axis) per month (*x*-axis). Presence is here divided into four categories represented with different grey scales, e.g. the black bars refer to individuals that were observed at one or more receivers between 75 and 100% of the total hours (24 × 30) each month. "Out of range" are individuals that were not observed in that month, but were later registered in the area. Data from the first experiment in the (a) panel and from the second experiment at the (b) panel. Note that four receivers were lost after November 2011.

June–August 2011, and June 2012). During winter, in average, 82% of the saithe observed in the area had some degree of connection to the farms with receivers, while the rest were out of range (Figure 4). The corresponding number during the summer was 64% (Figure 4).

In one of the sites with most transmitter records, F13, we observed that saithe were less often recorded after the salmon at that site had been slaughtered and feeding had ceased (Figure 5). At the other two sites at which there were many records, the salmon production cycle was delayed, and salmon biomass reduction occurred later when fewer saithe were present. Nevertheless, the data suggest a similar trend in reduced saithe presence after salmon feeding had ceased (Figure 5).

Discussion

This is the first time where the movements of individual wild saithe have been followed for >1 year in a large fjord system with high salmon aquaculture production. The data show that saithe remain in the area for a long period after release and maintain a connection with the salmon farms in the area, but also that long-distance migrations do occur. The key question of whether the large growth of the salmon farming industry has affected the biology and migration behaviour of wild saithe can be approached in two different ways, neither of which is trivial. The first obvious approach is to compare saithe behaviour in areas with and without salmon farming. This is almost impossible to do, at least in southern Norway, where wild fish and salmon interactions have been most in focus. The high density of salmon cage sites, combined with the migratory behaviour of saithe, makes it very difficult to find areas where wild saithe are unlikely to have been in contact with salmon farms.

The other approach is to compare our results with published studies on saithe from before large-scale salmon farming was introduced. The literature on saithe biology and migration is limited, and differences likely occurred between current and historical fishing patterns. Between 1972 and 1974, a series of tagging experiments were performed on 2- to 4-year-old saithe (31–54 cm) along the coast of southern Norway (Jakobsen, 1978a, b). This was before salmon farming in Norway had any significance. Of a total of 6291 tagged saithe, 17.4% were recaptured, compared with 4.4 and 2.4% in the present study. Around 41% of the recaptures came from the release areas and 47% from the North Sea, as opposed to 68% from the release area in the present study. As in our experiment, a few recaptures came from Iceland, the Faroe Islands, and the west of Scotland, but unlike our results, 10% were from the Norwegian coast north of 62°N. They released saithe at the outmost coast and reported no recaptures from the fjord areas. However, the recapture rate, as well as the geographical distribution of recaptures, varied greatly between experiments, and were as low as 6.4% from the releases at Utsira, which is the site closest to our study area. They suggested that differences in tagging mortality could explain the wide range of recapture rate between experiments. They also used a different external tag (Lea type) from that used in our experiments. Further tagging experiments were carried out in 1978–1980, with similar results (Jakobsen, 1985). Comparisons with these studies from the 1970s offer little evidence for a change in migration pattern for the individuals that migrate offshore. A similar conclusion was drawn by Bjordal and Skar (1992), who tagged 2607 saithe caught at a salmon farm in western Norway. At that time, salmon farming was starting to be significant in Norway, but with annual production only one-seventh of that at the time of our study. They suggested, based on catch and length distribution data, a continuous immigration of small saithe (from open waters to the coastal salmon farm) and a marked emigration of larger fish from January to March.

Our results indicate that outward migration now occurs at a larger size than before, and that a part of the saithe population does not migrate offshore at all. Jakobsen (1981, 1985) and Nedreaas (1987) suggested that the saithe on the coast of southern Norway

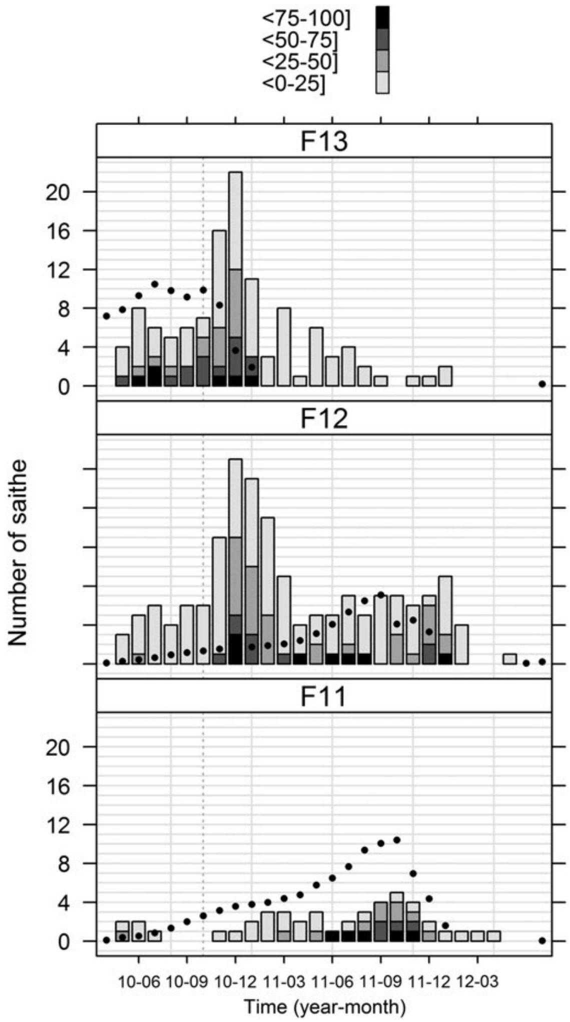

Figure 5. Number of fish present (*y*-axis) per month (*x*-axis) at the three sites with most transmitter records. Presence is here divided into four categories represented by different grey-scale shadings as shown in Figure 4. Biomass (arbitrary scale) of the salmon at that site is indicated by dots. The vertical dotted line indicates the date of the second release.

migrated offshore when they reached a length of 35–40 cm, which corresponds to an age of 2–3 years. Following this, most of the saithe should have left the coast at the time we released our fish. We found that approximately one-third of the acoustically tagged fish released in May 2010 were only recorded for a short period after release, and that their last records were from the outermost receivers, which suggests that they migrated offshore. Many of the acoustically tagged fish from the second release in November 2010 disappeared during the first few months, and usually their last records were from the outer receivers. The size range of our acoustically tagged saithe was quite small, but nevertheless the data suggest that it is the largest individuals that leave first. This is in accordance with Nedreaas (1987), who indicated that the outward migration of the largest individuals occurs gradually during spring to autumn, possibly due to changes in diet from zooplankton to krill and small fish, as well as to growing competition from younger and rapidly growing year-classes. Nedreaas also found clear signs of winter starvation in saithe, a plausible trigger for outward migration.

The presence of salmon farms will help to improve feeding conditions, which, according to this line of argument, should favour later outward migration. In our case, the smaller individuals do not leave later after presumable having grown to a larger size, but rather stays in the farming area. Jakobsen also still obtained recaptures from the Norwegian coast as long as 2 years after release in 1972, while those tagged and released in 1973 and 1974 at the same age and size had left the coast. He suggested that differences in feeding conditions from year to year on the coast could explain the differences in age and size of outward migration, which is also related to year-class strength. The North Sea saithe stock is currently at a low level (ICES, www.ices.dk), which could imply a relatively late outward migration from the coast due to little intraspecific feed competition. However, saithe feed on a variety of organisms (Nedreaas, 1987), and interannual variations in the abundance of other small fish and zooplankton are probably also very important. Our knowledge of the habits of saithe at the fjords and on the coast is limited, and perhaps a small part of the stock has always been resident and even spawned inshore, although we are not aware of any published data to that effect. Our experiments show that a considerable number of saithe remain within the fjord system, and reach a size at which they become sexually mature. Whether this may indirectly influence the rest of the fjord-ecosystem is currently unknown. We have no data that suggest that spawning actually takes place in the fjord.

Partial migration, where some individuals in a populations migrate while others are resident, are well known for many animal groups, including fish as reviewed by Chapman *et al.* (2012). The reason for this bimodality is diverse, but differences in size and diet could be a trigger for saithe as indicated by Nedreaas (1987). Laboratory experiments have shown that brown trout (*Salmo trutta*) reared under low food conditions were more likely to develop the migratory phenotype (Olsson *et al.*, 2006). This is also an intriguing explanation regarding saithe in fish farming areas, where better feeding conditions due to waste feed from the farms increase the proportion of resident saithe as suggested in the current paper.

Salmon farms offer food, shelter, and are often located at, or close to, fishing grounds. Although we did not have any receivers placed at control sites (non-farm sites), the large percentage of time that the saithe were observed by our receivers demonstrates a close association of the saithe with fish farms. If we take into account that only some of the fish farms were equipped with a receiver, and furthermore, that a single receiver at each farm would probably not cover the largest sites at all times, the connection with salmon farms is probably even stronger. A natural follow-up of this study would be to select a smaller part of the study area for more detailed studies of the saithe behaviour around a few fish farms and their close neighbourhood.

The first detailed observations on local movements of saithe around fish farms, based on telemetry (Bjordal and Johnstone, 1993), and also from traditional tagging studies (Bjordal and Skar, 1992) were made in an area in western Norway in 1990–1992. They observed that saithe could gather around the cage for several months at a time (Bjordal and Skar, 1992). Our results show that most of the saithe that remained in the area spent long periods at the same site, but also moved between several sites. This is in accordance with the results reported by Uglem *et al.* (2009) who followed 24 saithe by telemetry in a north Norwegian fjord. They observed 63% of these saithe daily at one or more of the three salmon farms in the fjord over the 3 months of the experiment, and movements between these farms were frequently observed. Fifteen of the tagged saithe moved among farms from 2 to 21 times in the course of the experiment. They also found a diel pattern of residence around the fish farms that correlated with feeding times, and suggested that waste feed was a major attractant. This was in accordance with analysis showing that stomach contents were twice as large in saithe from farm locations vs. control locations (Dempster *et al.*, 2011). Even when waste feed was removed, the stomach content was higher at farming sites. We found a tendency for the number of records of acoustically tagged saithe to decline after the salmon are slaughtered. The most obvious explanation for this is that feeding ceases, but other factors such as the removal of the nets and switching off lights that co-occur may be of importance. Fish farms can act as artificial reefs, which are known to attract fish due to shelter that they offer and their trophic diversity (Buckley *et al.*, 1989), and for salmon farms, the artificial lighting that is often used to delay sexual maturation of the salmon will further increase food availability by attracting zooplankton (McConnell *et al.*, 2010). The attraction of saithe to artificial light was demonstrated when this method was used to catch the fish used in our experiments. The stomachs of saithe captured under farms during the experiment often contained a mixture of pellets and natural prey (HO and OTS, unpublished results).

Using underwater video, Uglem *et al.* (2009) estimated fish abundance around two fish farms in northern Norway (Øksfjord) during a 3-d period in July 2006, and also surveyed two fish farms at Hitra in October (Dempster *et al.*, 2010). The investigation was extended to nine farms in three regions of Norway, including Ryfylke, during summer 2007 (Dempster *et al.*, 2009, 2011). In general, the abundance of wild fish of various species was higher under fish farms than at their respective control sites 1–2 km away, and aggregations of saithe were the main reason for this difference. The biomass of saithe was estimated to be around 40 t under, or in the immediate vicinity of, one of the farms in our study area. In fact, this farm occupied the site with the highest frequency of acoustic observations in our study (site no. F12, Figure 1). This farm is located close to fishing grounds, according to local fishers. Furthermore, estimates made by experienced fishers using fishery sonar have been as high as 250 t of saithe located immediately beneath one of the farms in the study area (Gudmundsen *et al.*, 2012).

The presence of salmon farms may thus attract saithe in several different ways; through trough waste feed, lighting on the cages that attracts natural prey, and the shelter provided, especially if the fish farm are located close to typical locations for saithe fishing grounds.

The combination of our results and earlier descriptions of the distribution of saithe demonstrate that saithe in coastal areas are now heavily influenced by the presence of aquaculture installations. Large-scale population effects are more difficult to prove, but it cannot be ruled out that the dynamic relationship between the coastal and oceanic phases has been altered in such a way that a large proportion of local saithe stocks are now more connected to the coast than they were just a few decades ago. To provide more evidence for this, we see more comprehensive tagging studies as a suitable tool. Such studies should be carefully designed and as far as possible be directly comparable with the tagging studies performed in the 1970s.

Acknowledgements

We greatly appreciate the technical assistance of the staff and management of the fish farms operated by Grieg Seafood, Marine Harvest, Bremnes Seashore, and Eidesvik Laks. Much of the practical work of tagging and holding saithe was only possible due to the skilled technical assistance of the staff at CAC, and to catches made by skipper Jan Henrik Nøstbakken and the crew of F/V "Solfisk". We are also grateful for the help of the crew of F/V "Munin" for their help in inspecting the acoustic receivers. We are particularly indebted to Trine Danielsen (CAC) and Onar Gudmundsen (Directorate of Fisheries) for their help in planning and performing the experiment. At IMR, we have had valuable help from Irene Huse, Odd-Børre Humborstad, Lisbeth Solbakken, Arne Storaker, Merete Nilsen, and Kirsti Børve Eriksen, among others.

Funding

The investigation was funded by the Norwegian Seafood Research Fund—FHF (project no 900302) and the Ministry of Fishery and Coastal Affairs.

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Handling editor: David Secor