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Capture of wild saithe (*Pollachius virens*) and cod (*Gadus morhua*) in the vicinity of salmon farms: Three pot types compared

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ABSTRACT

Large numbers of wild members of commercially important fish species tend to congregate around fish farms. This effect is in conflict with the interests of fishermen because wild fish cannot be harvested close to fish farms due to the fishery exclusion zone, which is intended to prevent fishing gear from damaging the cages. We studied the potential for harvesting wild fish around a Norwegian salmon farm using three different types of pots. Our video observations showed that large quantities of wild fish, in particular saithe (*Pollachius virens*), aggregated in close vicinity of the cages. Pots set underneath salmon cages produced 17 times higher catches of saithe and five times higher catches of cod (*Gadus morhua*) than pots set at a distance of 100 m from the cages. The pots set underneath cages also caught larger cod. Large rigid pots were shown to be more efficient than smaller flexible pots. The stomach content of small cod was dominated by pellets, while large cod were feeding mainly on saithe. We suggest that dense aggregations of saithe and small cod beneath fish cages were associated with the supply of waste feed, whereas larger cod were attracted by the saithe. We conclude that pots have great potential for harvesting gadoids beneath salmon cages, but catches decline dramatically with the distance from cages.

1. Introduction

Several fish species are attracted to moored and drifting floating objects (Fernandez-Jover et al., 2008). It has also been shown that large numbers of wild individuals of commercially important fish species congregate around fish farms (Carss, 1990; Dempster et al., 2002, 2005). On the Norwegian coast, there are 1241 sea-cage fish farm sites (2010), which used 1.4 million tons of fish feed to produce 1.0 million tons of fish (Norwegian Directorate of Fisheries, 2011). The amount of food not eaten by salmon and lost as waste is estimated to be as much as 5% (Otterå et al., 2009), suggesting that thousands of tons of waste feed are available to wild fish each year. The aggregations of wild fish at fish farms are primarily due to the presence of food (Dempster et al., 2010).

Carnivorous gadoids such as Atlantic cod (*Gadus morhua*) and saithe (*Pollachius virens*) are the main species found around Norwegian fish farms (Dempster et al., 2010). It has been estimated that more than 10 tons of gadoids aggregate in less than 1 ha of surface area that a typical salmon farm occupies (Dempster et al., 2009). These fish consume large amounts of waste feed, which is a shift away from their natural diets (Fernandez-Jover et al., 2011). These effects of fish farming are in conflict with the interests of commercial fishermen because aggregations of wild fish in the close vicinity of fish farms are not available to their fishing gear and because the diet shift may affect fish quality (Skog et al., 2003; Otterå et al., 2009). On the other hand, it has been shown that aggregations of wild fish around fish farms provide ecosystem services by reducing the benthic impacts of fish farming because they consume feed and assimilate nutrient wastes, which are directly released into the environment (Vita et al., 2004). Also wild fish that aggregate at coastal fish farms tend to be large adults with increased body condition (Dempster et al., 2002; Fernandez-Jover et al., 2007), which may translate into enhanced spawning success (Dempster et al., 2011).

Nonetheless conflicts between aquaculture and local fishermen do exist (Maurstad et al., 2007). An integration of local fisheries into aquaculture enterprises, complementary to traditional fisheries, may provide the basis for better cooperation and mitigate the conflict (Akyol and Ertosluk, 2010). Fish farms may operate as fish aggregation devices (FADs) and contribute to the yield of commercially important species. However, little is known about the potential for commercial capture of wild fish in the vicinity of salmon farms. This study is the first attempt to fill this gap in studies of wild fish capture around Norwegian salmon farms.

The main objective of the study was to investigate the potential for harvesting wild fish in the vicinity of salmon farms using

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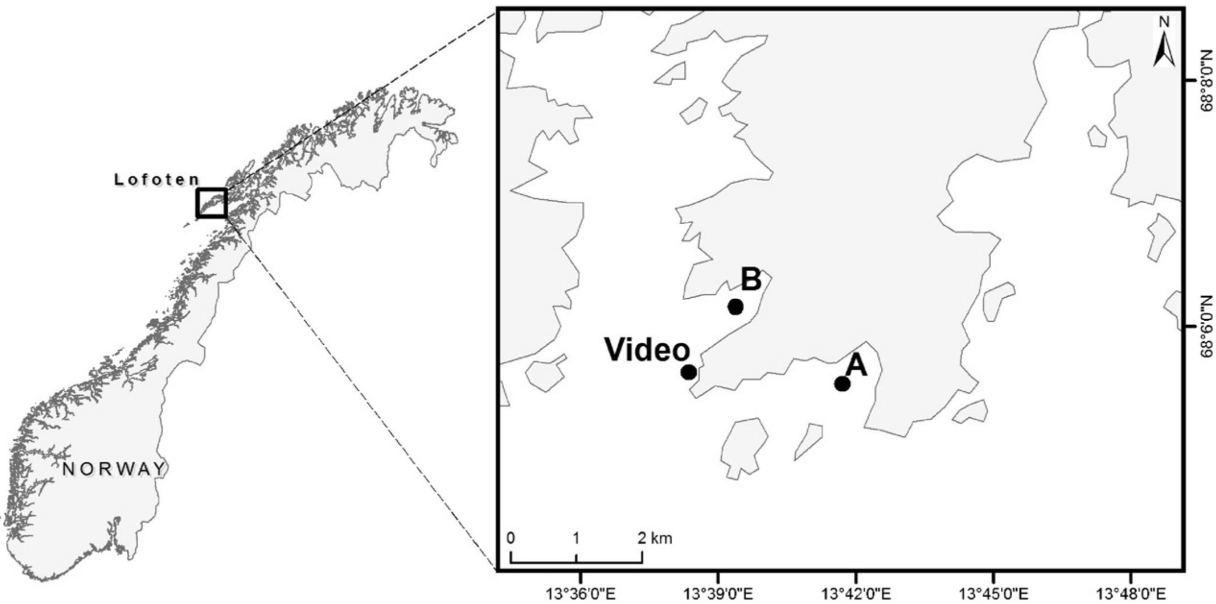

Fig. 1. The study site in the Vestfjord, showing the locations of the fishing trials (A and B) and the behavioural observations (video).

different types of pots. Based on earlier works demonstrating dense aggregations of fish in the very close vicinity of sea cages (Dempster et al., 2010), we predicted that pots set beneath cages would produce substantially higher catches than pots set at a distance of 100 m, which corresponds to the fishery exclusion zone around sea-cage farms. Munro (1974) suggested that less fish escape from large pots, and thus we also predicted that larger pots would display higher catching efficiency than small pots.

2. Materials and methods

The study was performed at a salmon farm in Vestfjord in northern Norway from 28 October to 5 November 2010 (Fig. 1). Three different pot types were used. One was the standard bottom-set two-chamber collapsible pot described in detail by Furevik et al. (2008) – referred to as "standard pot". The second was of the same design as the first pot, but the dimensions (except the entrances) were twice as large in linear dimensions and eight times larger in volume, i.e. 200 cm wide, 300 cm long and 240 cm in height – referred to as "large pot". These collapsible pots are flexible and move with the current. The third pot was designed by a local fish farmer based on the assumption that a rigid construction would display higher catching efficiency (Fig. 2). This was the largest of the three pots (245 cm × 245 cm × 320 cm). It is rigid and has a frame made from 7.5 cm diameter aluminium tubing. The lower chamber is clad in aluminium netting and the upper chamber in 28.5 mm mesh polyamide netting. Like the standard two-chamber pot, it has two entrances in the lower chamber and one between the lower and upper chambers. The entrances of this pot are wider than those of the standard pot (see Fig. 2 here and Fig. 2 in Furevik et al., 2008). This pot is referred to as "rigid pot".

Fishing trials were carried out around sea cages at two sites on the fish farm, at depths of 21–37 m (Fig. 1). In each trial, one pot of each type was set beneath three different sea cages and one pot of each type was set at a distance of 100 m from the cages. A total of six trials were carried out, and the positions of the three pot types set beneath sea cages and at a distance of 100 m were systematically rotated among the trials to avoid spatial confounding. The 100 m distance corresponds to the fishery exclusion zone, which is intended to prevent fishing gear from damaging the cages. The pots were baited with feed pellets put in a 1.5 l plastic bottle with holes that was placed in the lower chamber of the pot. A two-day soak time was chosen, but was five days for two of the trials due to bad weather.

Stomach samples were taken from the cod catches. The components were grouped into three prey categories: saithe, food pellets and other. Samples from cod > 60 cm and < 60 cm in total length were separated in order to identify size-specific differences in prey preferences.

In situ behavioural observations were made beneath a sea cage using the observation platform described in Svellingen et al. (2002). Video observations of fish around and inside the pots were made for two days for each pot type. The observations were made during the hours of daylight from early morning to late evening. The amount of fish made it impossible to record the exact numbers observed. Abundance was therefore categorized into three groups: <10, 10–100 and >100 individuals.

3. Results

A total of 1505 fish were caught, with saithe the most common species (94%), followed by cod (6%). The mean catches per pot of both saithe and cod were significantly higher under the salmon cages than 100 m from the cages ($p < 0.01$, Wilcoxon matched pairs test; Table 1). Cod caught beneath the salmon cages were significantly larger than those caught at a distance of 100 m ($p < 0.05$, Student's t test; 61.9 cm (SE = 1.7) and 44.1 cm (SE = 3.7), respectively), while there was no significant difference for saithe.

The rigid pot caught significantly more cod than both the standard collapsible pot and the large collapsible pot ($p < 0.01$ and $p < 0.05$, respectively, Wilcoxon matched pairs test; Table 2). The rigid pot also caught more saithe than the standard and large pots, but these differences were not significant. The large pot had significantly higher catch rates for saithe and cod than the standard pot ($p < 0.05$). The mean length of the saithe caught in the rigid pot was significantly larger than that of the large pot ($p < 0.01$, Student's t test; 46.1 cm (SE = 1.6) and 39.3 cm (SE = 0.7), respectively), but otherwise there were no significant differences in fish length between pot types.

Cod smaller than 60 cm consumed more pellets than saithe, while the stomach content of large cod was dominated by saithe

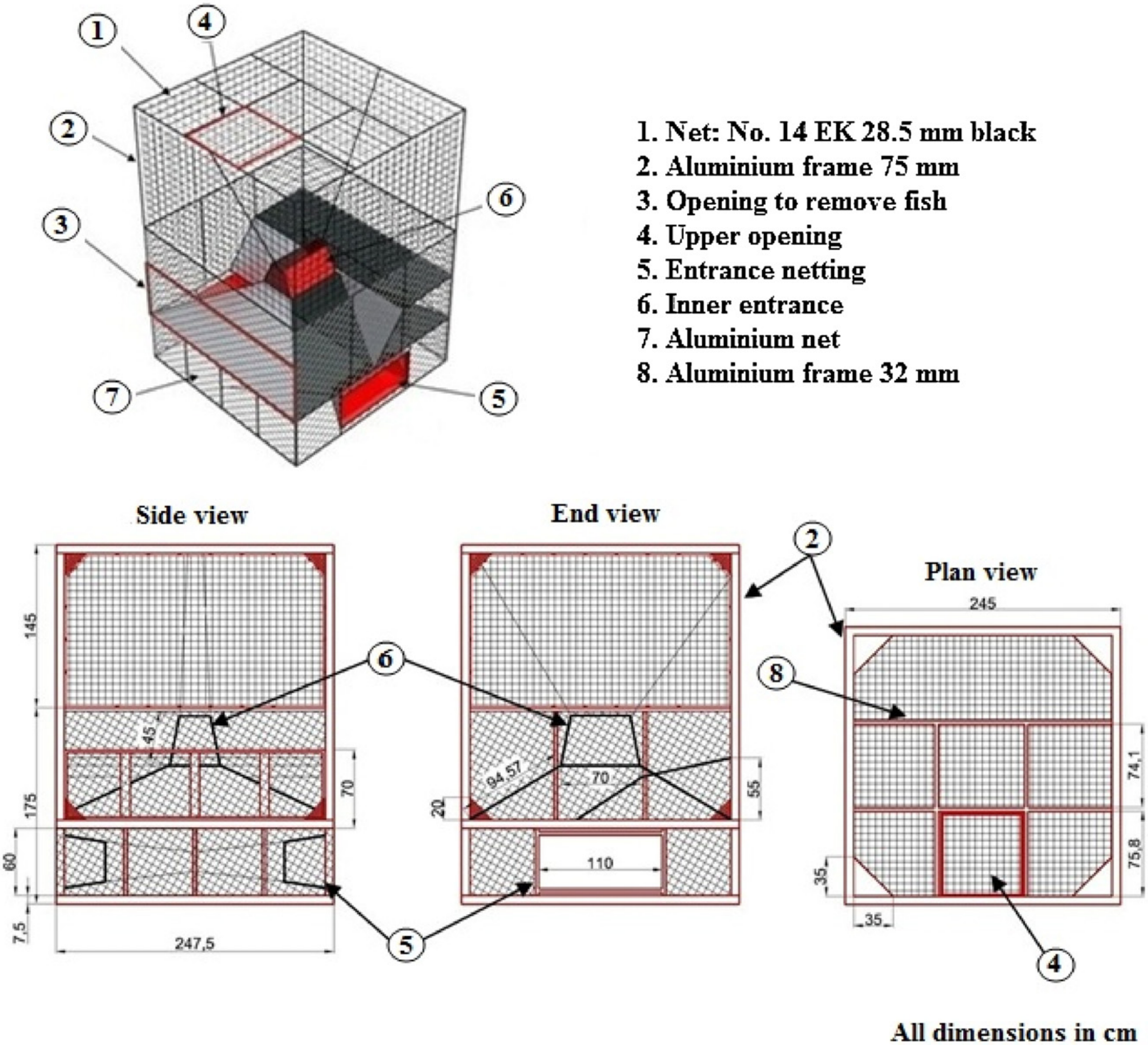

Fig. 2. Design of the rigid pot tested in the fishing trials.

Table 1
Total catches and catch rates (number per pot and day, ±SE) of pots set at salmon cages and pots set 100 m from cages. Data pooled from the catches of three pot types. *p* value is given for Wilcoxon matched pairs test.

Distance	No. of pots	Saithe (*Pollachius virens*)			Cod (*Gadus morhua*)		
		No. caught	Catch rate	*p*	No. caught	Catch rate	*p*
0 m	12	1336	42.94 ± 27.73	<0.01	80	2.61 ± 0.72	<0.01
100 m	12	72	2.56 ± 1.72		17	0.53 ± 0.17	

Table 2
Total catches and catch rates (no. per pot and day, ±SE) of three different pot types (see text). Data pooled from catches taken underneath salmon cages and 100 m from the cages. *p* value is given for Wilcoxon matched pairs test.

Pot type	No. of pots[a]	Saithe (*Pollachius virens*)			Cod (*Gadus morhua*)		
		No. caught	Catch rate	*p*	No. caught	Catch rate	*p*
Standard	10	76	3.02 ± 1.32	<0.05	27	0.87 ± 0.27	<0.05
Large	10	307	9.41 ± 3.51		50	2.05 ± 0.52	
Large	10	305	9.37 ± 3.52	0.507	47	1.99 ± 0.54	<0.05
Rigid	10	1102	45.77 ± 33.57		97	3.83 ± 1.05	
Standard	10	73	2.99 ± 1.33	0.155	26	0.85 ± 0.28	<0.01
Rigid	10	1099	45.71 ± 33.58		96	3.81 ± 1.06	

[a] In two of the six trials, only two of the three pot types were set at a distance of 100 m because either a rigid pot or a large pot was used for the behavioural observations. Thus the number of pots for the paired comparisons is 10 and not 12 pots.

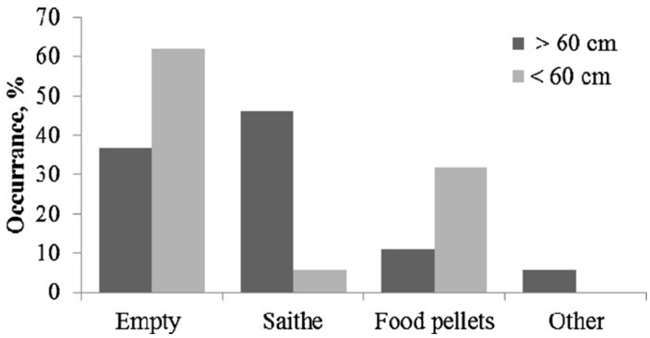

Fig. 3. Stomach content of small (<60 cm, n = 34) and large (>60 cm, n = 46) cod (*Gadus morhua*).

(Fig. 3). The proportion of empty stomachs was higher in small than large cod (62% and 37%, respectively).

The most abundant species observed from the video were saithe, cod and European plaice (*Pleuronectes platessa*). A school of approximately 200 saithe was observed entering the rigid pot during the first few minutes after deployment, after which no fish were seen entering. In the standard and large pots few fish entered during the day, while 79% (n = 14) and 93% (n = 25) respectively, entered outside the observation period (between 5 p.m. and 8 a.m.), i.e. under low light levels.

More saithe were attracted to the pots during the first day of the two-day observation period (n = 651) than on the second day (n = 291). Cod showed the opposite pattern, with somewhat greater interest and ingress rate during the second day (n = 187) than the first (n = 150). Most fish approached the pots upstream (70% of the saithe and 66% of the cod), but a significant relationship between current direction and approach direction was observed only for saithe (p < 0.001, Mann–Whitney test).

When captured in the standard and large pots, saithe tended to panic for a few minutes trying to escape through the net before they calmed down and swam slowly around. Saithe that entered the rigid pot maintained their schooling formation, swimming calmly around in the centre of the pot. Cod entered the pots as single individuals and swam slowly with no panic reaction on capture. However, cod were observed searching for an exit, and one fish escaped from the large pot. Cod were also observed attacking saithe both inside and outside the pots, and three cod were observed swallowing saithe inside the pot.

Several saithe became entangled in the monofilament entrances of both small and large pots. When a fish was entangled and struggled to get loose, schooling saithe displayed a synchronous avoidance reaction and swam rapidly away from the pot.

4. Discussion

This study demonstrated that large quantities of wild fish congregated around the salmon farm, and saithe was the dominating species in the catches taken by pots. Saithe is the most abundant species associated with salmon farms on the Norwegian coast (Carss, 1990; Dempster et al., 2009, 2010, 2011). Seventy-five and 91% of the catches taken at two Norwegian fish farms were saithe (Dempster et al., 2010), and schools of 2000–40,000 saithe have been observed at salmon farm sites (Dempster et al., 2009). Dempster et al. (2002) demonstrated that fish farms act as ‘super-FADs’ in the southwestern Mediterranean Sea, attracting large multi-species schools of pelagic fish.

The concentration of wild fish at fish farms may increase the vulnerability of fish to capture, and has led to the proposed implementation of no-fishing zones around sea-cage farms (Dempster et al., 2006). Continuous concentration of wild fish around farms may create circumstances for the formation of an ecological trap if fishing interacts heavily with aquaculture sites (Dempster et al., 2009, 2011). However, we argue that fishing in the vicinity of fish farms has several advantages within a management framework that restricts fishing effort and total allowable catch. Harvesting dense aggregations of fish is profitable for fishermen, and the principle of fishing at salmon farms is analogous to harvesting fish attracted to FADs. Most importantly, using passive fishing gear such as pots to target fish aggregations is an environmental friendly fishing method due to the fact that this way of capture has low impacts on the habitat and is fuel efficient (i.e. Low Impact and Fuel Efficient (LIFE) fishing, see Suuronen et al., 2012).

We demonstrated that the catch rates of pots set beneath the salmon cages were 17 times as high for saithe and five times as high for cod as those set at a distance of 100 m from the cages. Carss (1990) found that 12 times as many saithe were caught by beach seine close to farm cages than at control sites. Dempster et al. (2010) also found that the greatest concentrations of wild fish occurred beneath salmon cages, with a steep decline in the abundance of fish only tens to hundreds of metres away. Whether wild fish aggregate densely or loosely around farms may depend on species-specific behaviour or on particular physical or biological features of farms (Dempster et al., 2010).

This pattern of dense aggregations of wild fish around salmon farms is presumably associated with the supply of food. Waste feed is available only close to the cages, since pellets typically sink relatively quickly and do not disperse far from the feeding site (Cromey et al., 2002). Dempster et al. (2011) showed that more than 75% of the diet of saithe around fish farms consisted of salmon feed, and Fernandez-Jover et al. (2011) found that waste feed represented approximately 30% of the diet of cod caught close to fish farms. Our study showed that the stomach content of small cod was dominated by pellets, whereas large cod fed mainly on saithe as supported by our video observations of cod attacking and predating saithe.

There were several differences between cod and saithe. The abundance of cod at the cages was lower than that of saithe, and the difference in catch rates between pots set at the cages and those set at a distance of 100 m was less pronounced for cod (five times as high against 17 times for saithe). These results suggest that cod are less attracted to fish farms or have a less tight aggregation pattern around the cages than saithe. Dempster et al. (2010) found that cod were less reliant on waste food than saithe. We found that cod caught beneath the salmon cages were larger than those caught 100 m away, while there was no difference for saithe. Cod preyed on saithe, and aggregations of large prey items are likely to attract large predators. Thus large cod were probably attracted by the aggregation of saithe around the cages, while smaller cod and saithe primarily congregated beneath fish cages due to the waste feed. The importance of feed pellets in attracting saithe is supported by our observations, which showed that saithe predominately approached the pots up-current and more saithe were attracted to the pots during the first day when the release rate of odours from the pellets used as bait was higher than during the second day (Løkkeborg, 1990). The same patterns were not observed in cod, indicating that waste feed was less important as an attractant for cod.

This study demonstrated the potential of pots for making large catches of wild gadoids close to salmon farms. Large pots caught more than three times as many saithe and more than twice as many cod as standard pots. The only difference between the two pots was the size. Larger pots have already been shown to be more efficient than small pots (Munro, 1974; Furevik and Løkkeborg, 1994), and Munro (1974) suggested that escapes from pots are inversely proportional to the area or volume within which the fish are contained.

The rigid pot caught more saithe (although the difference was not significant) and cod than the large pot and the standard pot. The rigid pot and the large pot are similar in volume, but are of very different designs. Due to its construction, the rigid pot sits stably on the sea bed and does not move, whereas the large pot moves with the current and when fish become entangled in the entrance. Such movements may discourage fish from entering the pot, and our behavioural observations showed that fish were scared away when entangled fish struggled to free itself. Saithe schooled in the rigid pot and did not show panic reactions, as they did in the standard and large pots. High and Beardsley (1970) speculated that alternative motivations such as social attraction might lead fish to enter pots. Furthermore, the rigid pot has larger entrances than the two other pot types, which make it easier for fish to enter this pot. Although larger entrances might increase the escape rate, the two-chamber design of these pots may partly counteract such a tendency.

In summary, this study confirms previous studies that have shown that large numbers of wild fish, particularly saithe, congregate close to salmon farms. A plentiful supply of waste feed is probably the most important factor in attracting saithe to fish farms, while large cod prey on the saithe. Pots were shown to have great potential for harvesting gadoids underneath salmon cages, but catches fell dramatically at a distance of 100 m from cages. Large rigid pots were more efficient than both large and small flexible pots.

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