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PERSPECTIVES AND NOTES

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Wild Atlantic salmon enter aquaculture sea-cages: A case study

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Abstract

There are more than 3,000 Atlantic salmon aquaculture sea-cages distributed along the coastline of Norway. Many of these sea-cages are located along the migration routes of wild Atlantic salmon (*Salmo salar*) postsmolts. This study documents for the first time that wild Atlantic salmon postsmolts can enter sea-cages stocked with farmed Atlantic salmon. In addition, wild sea trout (*Salmo trutta*) and salmon/trout hybrid postsmolts were found inside the sea-cages. The extent of such "bycatch" in commercial aquaculture is vital knowledge for the conservation of Atlantic salmon and sea trout. Further studies are encouraged in order to evaluate the extent of this possible ghost fishing phenomena.

KEYWORDS

Atlantic salmon, hybrid, migration, sea trout, trapped

1 | INTRODUCTION

Across the North Atlantic Ocean, the anadromous Atlantic salmon (*Salmo salar*) (Klemetsen et al., 2003) have populations inhabiting more than 2000 rivers (NASCO, River Database: https://nasco.int/about-nascos-rivers-database/). Salmon remain in the river for 1–8 years before migrating to the open ocean at 10–80 g size, where they grow and mature over 1–5 years, then migrate back to the river to spawn (Klemetsen et al., 2003; Thorstad, Whoriskey, Rikardsen, & Aarestrup, 2011) with a maximum size of 33 kg (http://www.fishing-worldrecords.com/). Abundance of wild Atlantic salmon populations have declined (Chaput, 2012; Parrish, Behnke, Gephard, McCormick, & Reeves, 1998), and the species is the focus of conservation efforts in several countries bordering both the Northwest and Northeast Atlantic Ocean (ICES, 2020). In the Northeast Atlantic, Norway has historically been one of the largest wild Atlantic salmon-fishing countries (Hansen, 1988), but is now the world's largest producer of farmed Atlantic salmon (ICES, 2020). In 2019, worldwide production of farmed Atlantic salmon was almost 3,000 times more than the reported nominal catches of wild Atlantic salmon in the North Atlantic (ICES, 2020). Farmed Atlantic salmon are conventionally held in sea-cages for the majority of their production cycle, which are open to the surrounding water masses. As of August 2020, 3,555 sea-cages were distributed among 587 farming sites along the coastline in Norway alone (http://www.fiskeridir.no/fiskeridir/Akvakultur/Statistikk-akvakultur/Biomassestatistikk). Many of these cages are located in fjords along the migration routes of wild Atlantic salmon postsmolts, who pass the farms on their way to the open ocean. Telemetry studies have shown high mortalities of migrating Atlantic salmon postsmolts in Norwegian fjords (reviewed in Thorstad et al., 2012), which have mainly been attributed to high predation rates by cod (*Gadus morhua*) and saith (*Pollachius virens*; Hvidsten & Lund, 1988; Jepsen & Økland, 2006). Indeed, these species aggregate around sea-cages stocked with farmed Atlantic salmon (Dempster, Sanchez-Jerez, Uglem, & Bjorn, 2010; Skilbrei & Otterå, 2016). Recently, Fjelldal et al. (2018) provided the first scientific evidence that wild fish may also enter Atlantic salmon sea-cages and stay until they grew larger than the cage mesh size, resulting in those individuals being permanently trapped. In that study, the sea-cages were located in a Norwegian fjord that also served as a migration route for local wild Atlantic salmon, and eight different species of wild fish were identified within the cages. Among these were sea trout (*Salmo trutta* L.), suggesting that migrating wild Atlantic salmon postsmolts could also be attracted to and enter salmon sea-cages. With the vast number of aquaculture cages and high density of farmed fish being farmed, it is possible that "bycatch" of wild salmonids in sea-cages could be a source of mortality during out-migration that has gone unnoticed.

The present study reports observations of wild Atlantic salmon, sea trout and Atlantic salmon/sea trout hybrid postsmolts that were discovered inside sea-cages in spring 2019, at the same cage facilities as recorded in Fjelldal et al. (2018).

2 | MATERIALS AND METHODS

The Institute of Marine Research (IMR) operates two Atlantic salmon research farming sites in Masfjorden (60°N), on the west coast of Norway, named Smørdalen (Site 1) and Solheim (Site 2) (Figure 1). These sites are within one of the major production areas for Norwegian aquaculture (Production Zone 4), and the experimental farms are situated in a position that experiences environmental profiles analogous to commercial farms located in Norwegian fjords. The depth under the cages varies between 40 and 120 m, and there is a clear temperature and salinity gradient with depth (Oppedal, Juell, & Johansson, 2007), typical of fjords in this area. There are three nearby river systems with populations of sea trout and Atlantic salmon: the Matre River, Haugsdal River and the Stuve River (Figure 1). The latter is very short and runs from Hopsvatnet, which the Store River runs into. During sampling for separate experiments in June 2019, wild salmonid smolts were discovered inside or stuck in the net of sea-cages located at the two sites. At Site 1, the wild salmonids were discovered in a compartment of the sea-cages that did not contain farmed salmon, and they were first differentiated as wild fish based on external morphology. At Site 2, the wild salmonids were first differentiated as wild based on size (the farmed salmon in the sea-cage were >4 kg) and external

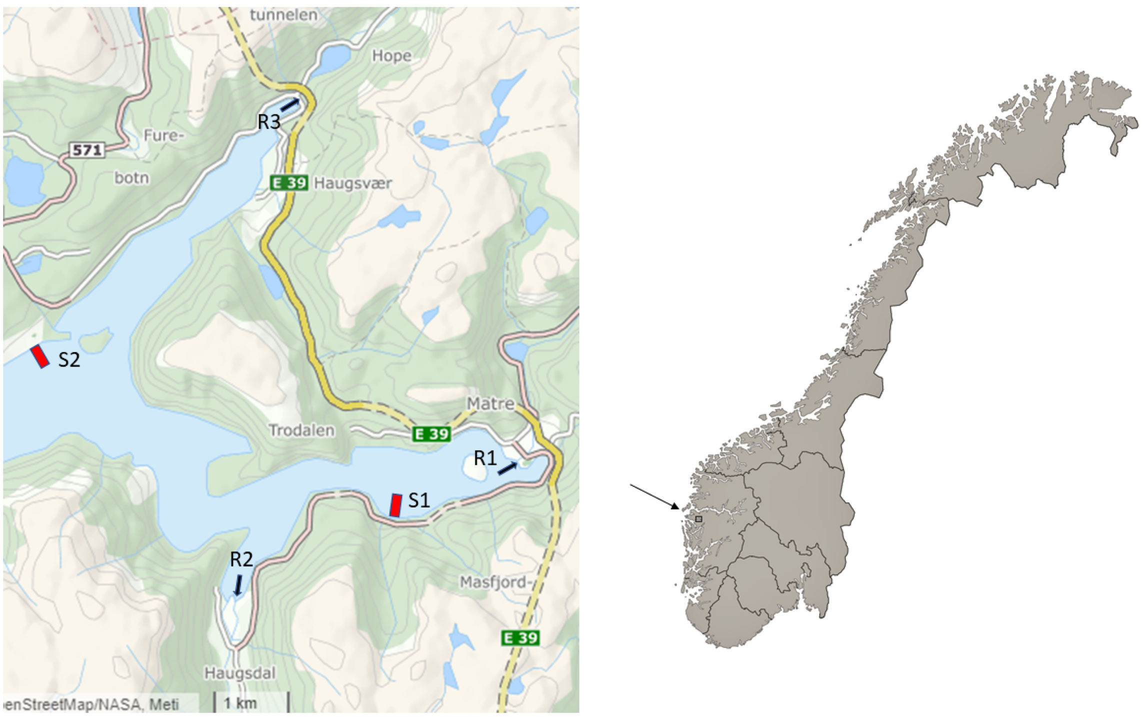

FIGURE 1 Map showing the location of the aquaculture sites Smørdalen (Site 1, S1) and Solheim (Site 2, S2), in western Norway where the present wild salmonids were documented inside sea-cages stocked with farmed Atlantic salmon (*Salmo salar* L.). The nearby rivers with populations of anadromous salmonids are shown as R1 (Matre River), R2 (Haugsdal River), and R3 (Stuve River). The river mouths are indicated with black arrows

morphology. The wild salmonids all had an apparent wild phenotype, and scale samples were taken to further determine if they were of wild origin.

2.1 | Site 1

On June 6, 2019, 5 wild Atlantic salmon postsmolts (Table 1, Fish nos. 1–5) were collected from one experimental sea-cage. The cage was 5 m × 5 m (7 m deep) and contained 1,000 farmed Atlantic salmon postsmolts with an average body weight of 145 g. The half-mask mesh size (knot to knot, hereafter termed mesh size) of the sea-cage was 15.5 mm. The farmed salmon were stocked into the sea-cage on May 15, 2019 (yearling smolts). There was a roof attached inside the sea-cage at 4 m depth, dividing it into two compartments: one below the roof without access to the surface, and one compartment above the roof with an open top and access to surface. Feed pellets were distributed at surface, sinking through the top compartment and net roof. This is a new type of sea-cage technology where salmon are submerged and fill their swim bladders via a submerged air dome in the center of the roof at ~3 m depth (Macaulay, Bui, Oppedal, & Dempster, 2020). The cage modification attempts to avoid the infective salmon lice larvae that mainly aggregate in the upper water layers. Hence, the farmed salmon were stocked in the lower compartment below the roof, with no fish above. When sampling farmed salmon from this cage, wild Atlantic salmon were observed above the white-netting roof inside the sea-cage. The wild salmon were collected for further analysis. Unfortunately, the lower compartment of the sea-cage that contained farmed salmon was not screened for wild fish.

On the same day, routine inspection of the remaining cages revealed a sea trout that was caught in the net of another sea-cage (12 m × 12 m, 15 m deep, and 15.5 mm mesh size). This was a conventional sea-cage without compartments, that was stocked with 3,000 Atlantic salmon postsmolts with an average body weight of 145 g. This sea trout was alive and was released outside the sea-cage without further measurements to prioritize its welfare. It was estimated to be 30 g body weight.

2.2 | Site 2

On June 4, 2019, one wild Atlantic salmon (Table 1, Fish no. 6) and one wild sea trout (Table 1, Fish no. 7) were collected in a conventional sea-cage. The 12 m × 12 m (15 m deep) and 22.5 mm mesh size cage contained 245 farmed Atlantic salmon, with an average body weight of 4,479 g (min 1,625 g, max 7,515 g). The farmed salmon were stocked into the sea-cage on August 22, 2018 as postsmolts with an average body weight of 260 g.

3 | FISH ANALYSIS

The wild salmonid postsmolts were euthanized with an overdose of sedation, measured for fork length and weight to the nearest millimeter and gram, respectively, and frozen at −20°C in individual plastic bags for further analysis. In the laboratory, the fish were thawed and sampled for scales, fin clip, and stomach content. Scale samples for age analysis were taken from just behind the dorsal fin and above the lateral line (Dannevig & Høst, 1931). Scales were used to determine age based on number of annuli (Dahl, 1910), and whether the fish were wild (Lund & Hansel, 1991). Fin clips were used for genetic analysis: DNA was extracted and a standard set of 31 microsatellites was analyzed according to the procedure described in Harvey et al. (2019). The resulting genetic data were used for testing whether individuals were related through sib-ship analysis in the program COLONY (Jones & Wang, 2010). The analysis of stomach contents was performed according to earlier studies on Atlantic salmon postsmolts (Andreassen, Martinussen, Hvidsten, & Stefansson, 2001; Rikardsen et al., 2004), whereby the stomach content were classified into groups of prey organisms, and the dry weight measured. The fish were tested for salmonid alphavirus

TABLE 1 Biological data on seven wild salmonid postsmolts discovered inside sea-cages stocked with farmed Atlantic salmon

Fish no.	Species	Length (cm)	Weight (g)	Age	Site no.
1	Atlantic salmon	16.0	37.4	2	1
2	Atlantic salmon	14.8	26.3	3	1
3	Atlantic salmon	14.7	27.3	2	1
4	Trout/salmon hybrid	15.9	31.8	2	1
5	Atlantic salmon	14.5	35.2	2	1
6	Atlantic salmon	15.9	31.9	3	2
7	Sea trout	15.6	31.7	3	2

(SAV), infectious salmon anemia virus (ISAV), piscine orthoreovirus (PRV), infectious pancreatic necrosis virus (IPNV), and piscine myocarditis (PMCV) using real-time RT-PCR assay. These viruses are widely-prevalent in farmed Atlantic salmon, and with epidemics common in Norwegian aquaculture (Fiskehelserapporten, 2019).

4 | RESULTS AND DISCUSSION

In the current study, in total 6 Atlantic salmon post-smolts with apparent wild phenotype (Figure 2a) were collected inside sea-cages containing both newly-transferred farmed postsmolts (Site 1) and harvest size adult farmed salmon (Site 2). The scale analysis

FIGURE 2 Atlantic salmon (a) and sea trout (b) caught inside a sea-cage stocked with farmed Atlantic salmon. (c) Sea trout trapped in 15.5 mm mesh size sea-cage

confirmed these fish to be of wild origin, and their biological data are shown in Table 1. However, genetic analysis revealed that individual 4 was likely a trout/salmon hybrid. The analysis in COLONY did not identify any sibling pairs among the sampled individuals.

This is the first documented report of wild Atlantic salmon inside Atlantic salmon aquaculture sea-cages. The freshwater age of the wild salmon were 2 ($n = 4$) and 3 ($n = 2$) years. Smolt ages ranging between 1 and 8 years have been reported in wild Atlantic salmon (Klemetsen et al., 2003). Further, Jonsson, Jonsson, and Hansen (1998) studied smolt age in Atlantic salmon in River Imsa, Western Norway, over a period of 11 years, and found that the mean percentage distribution of fish smolting at age 1, 2, and 3 were 14, 78, and 7%, and the mean smolt age was 1.95 years. Hence, 2 and 3 years is within a normal range of smolt age in Western Norway. The Atlantic salmon stomachs analyzed in this study contained euphausiid larvae, *Calanus finmarchicus* and fish (Table 2). This is in line with earlier stomach content analyses reported in wild Atlantic salmon postsmolts (Andreassen et al., 2001; Haugland, Holst, Holm, & Hansen, 2006). The average size of the salmon was 31.7 g which is within the standard smolt size of wild Atlantic salmon (between 10 and 80 g; Thorstad et al., 2011), and therefore the observed size may indicate that the currently investigated specimens entered the sea-cages as newly seawater migrated postsmolts. Indeed, the wild Atlantic salmon described herein were discovered in early June, during the typical period when wild salmon smolts migrate to sea.

In the current study, one sea trout postsmolt was recorded inside a sea-cage (Site 2; Figure 2b), and one was caught in the net of a sea-cage (Site 1; Figure 2c). For the latter individual, the cranial part of this trout was inside the sea-cage while the caudal part was on the outside, hence, the fish was caught in the net on its way into the sea-cage. Both sea trout individuals were ~30 g. Fjelldal et al. (2018) reported sea trout ranging in size from 55 to 994 g trapped in salmon sea-cages in the same facilities (Site 1 and 2) as examined in the current study. This indicates that sea trout can voluntary stay inside salmon sea-cages, at least until they outgrow the mesh size, and get permanently trapped. There are commonly many large predators such as pollack, saithe and cod surrounding salmon farms. Hence, sea trout postsmolts may use sea-cages as a refuge. This could also be the case for wild Atlantic salmon postsmolts, but they may also be attracted to the large schools of farmed Atlantic salmon inside the sea-cages. The high degree of feed availability inside the sea-cage could also be a reason for entering, but as wild fish have never experienced pelleted food and no pellets were found in the current stomach analysis, this is unlikely. On the other hand, the nets of sea-cages may function as standing nets analogous to those in fisheries. If so, wild postsmolts entering sea-cages will most probably leave them as well (and maybe enter the adjacent sea-cage). The fact that the salmon postsmolts at Site 1 were collected in the compartment above the roof—which did not contain farmed salmon—suggests that the entering of the sea-cage was either a random action or a search for refuge during predator avoidance.

Sea trout reside in the fjord systems during their seawater stay, while Atlantic salmon perform long ocean migrations. Whether the different postsmolt migration patterns of sea trout and Atlantic salmon impact on their preference to stay inside salmon aquaculture sea-cages is unknown. Further, the wild salmon found at Site 1 (and possible Site 2) likely originated from the nearby Matre river, the mouth of which is 1.7 km away. This river has recently been naturally repopulated with Atlantic salmon after decades of extinction. It is unknown if the Matre river was repopulated by escaped farmed salmon, wild salmon strays from other rivers, or a mix of both. Although wild hybrids between Atlantic salmon and brown trout have been widely documented before (e.g., Payne, Forrest, & Child, 1972), it was surprising to find a hybrid among the individuals trapped in the sea-cages in the current study. This could indicate that hybrids are relatively prevalent in the study area.

The currently investigated wild postsmolts were all tested for viruses (SAV, ISAV, PRV, IPNV, and PMCV) prevalent in fish farming but all were negative (data not shown). Unfortunately, the farmed salmon in the same cages were not screened for these viruses. Viral infections are prevalent in Norwegian fish farming, and virus transmission from farmed fish to wild salmonids entering aquaculture sea-cages is a possible scenario.

TABLE 2 Stomach content of seven wild salmonid postsmolts that were discovered inside sea-cages stocked with farmed Atlantic salmon

Fish no.	Stomach content (group/species)	Dry weight (g)
1	Euphasid larvae	0.0002
1	*Calanus finmarchicus*	0.0794
2	Teleostei	0.0142
2	Calanus finmarchicus	0.0233
3	Calanus finmarchicus	0.0308
4	Calanus finmarchicus	0.0481
5	Teleostei	0.1522
6	Crustacea	0.0005
6	Calanus finmarchicus	0.0117
7	Teleostei	0.0604

Although the present study and Fjelldal et al. (2018) are the first scientific reports of wild salmonids entering aquaculture sea-cages, there is some evidence for this phenomenon. Indeed, in Canada, the Fisheries and Oceans Canada's (DFO's) Conditions of License for finfish aquaculture require facility operators to maintain an incidental catch log (http://open.canada.ca/data/en/dataset/0bf04c4e-d2b0-4188-9053-08dc4a7a2b03). This database dates back to 2011, and reports that five different species of Pacific salmon have entered aquaculture sea-cages in Canada in the period 2011–2020.

The two major threats the farming of Atlantic salmon impose on wild salmon populations are escaped farmed salmon (Glover et al., 2017), and aquaculture-induced increased salmon lice (*Lepeophtheirus salmonis*) abundance (Forseth et al., 2017; Taranger et al., 2015). The present study shows that it is possible that migrating wild Atlantic salmon and sea trout postsmolts can enter aquaculture sea-cages stocked with farmed Atlantic salmon. This may represent an unexplored threat imposed by sea-cage aquaculture. Considering that there are thousands of sea-cages distributed along the coastline of Norway alone, this warrants further investigation. Thus, enquiries into incidences of wild fish bycatch at sites along smolt migration routes are strongly encouraged, and should include northern regions with anadromous Arctic char (*Salvelinus alpinus*). Those studies should address possible impact of farm site location (fjord vs. costal) and different farming practices (net pen mesh size, artificial light, feeding), and include both empty sea-cages and cages stocked with farmed salmon of different sizes (smolts vs. harvest size). Telemetry studies with wild outward migrating postsmolts from the nearby rivers would also be informative, to describe their interaction with sea-cage structures. Normally, commercial salmon sea-cages are stocked with over 100,000 fish, making identification of possible wild salmonid "bycatches" impossible. Hence, studies with smaller research sea-cages, such as used in the present study, could be useful.

By improving our understanding through these types of studies, there may be new aspects of aquaculture-environment interactions uncovered, leading to significant implications for both salmon conservation and aquaculture management; possible negative effects could apply to wild fish abundance, welfare of trapped wild fish, and facilitate disease transfer between trapped wild and farmed fish.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

AUTHOR CONTRIBUTIONS

Per Gunnar Fjelldal, Tom J. Hansen, Samantha Bui, and Frode Oppedal collected the wild fish. Lea Hellenbrecht performed the stomach analysis. Sofie Knutar performed the genetic analysis. Abdullah Sami Madhun performed the virus analysis. Gunnar Bakke performed the age analysis. Per Gunnar Fjelldal, Samantha Bui, and Abdullah Sami Madhun wrote the first draft of the manuscript. All the authors critically reviewed the intellectual content of the manuscript and gave their approval for the final version to be published.

DATA AVAILABILITY STATEMENT

The dataset analyzed in the current study is available from the corresponding author on request.

ETHICAL STATEMENT

The study was done at the Institute of Marine Research, Matre Research Station (60°N, 5°E, Western Norway) which is authorized for animal experimentation (Norwegian Food Safety Authority, facility 110).

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