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REVIEW

Impacts of wild fishes attracted to open-cage salmonid farms in Norway

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ABSTRACT: Salmonid farming affects both the environment and other industries, with impacts of wild fish attracted to fish farms being a major concern. Here, we summarized existing knowledge on the impacts of such aggregations around open-cage salmonid farms in Norway on the environment and human activities and on the interactions of these impacts. Waste fish feed is considered the major cause for the attraction of wild fish to the cages. The aggregations of wild fish are relatively persistent and can affect the spatiotemporal distribution of several wild marine species. A change in diet by ingesting the high-energy waste feed available close to the cages may increase the energy stores of some of the attracted fish species, and perhaps also their fecundity, but whether this influences offspring viability is unknown. Changes in the distribution and physiology of the attracted fish can influence local fisheries in terms of resource availability and are probably also associated with the softer, lower-quality meat texture of wild fish caught close to salmonid farms. For fish farmers, the attraction of wild fish to the cages is advantageous because attracted fish eat a substantial amount of the waste feed before it can impact the benthos, and because large attracted fish prey on escaped farmed fish. However, movements of wild fish may play a role in the transfer of diseases, and wild fish may cause farmed fish to escape by damaging the net pens. Due to the complexity of interactions, a combined focus on the impacts of attracted wild fishes on the environment and human activities is warranted when developing future management and governance strategies for salmonid aquaculture.

KEY WORDS: Salmon farming · Aggregation of wild fish · Ecological effects · Fisheries

INTRODUCTION

Atlantic salmon *Salmo salar* farming is a major ecosystem modifying factor in coastal areas, with subsequent impacts on human activities (e.g. Maurstad et al. 2007, Wiber et al. 2012). Enormous amounts of fish are produced in relatively small volumes of water and, as of 2014, the maximum number of fish allowed per cage is 200 000. The large amount of food required to feed the fish results in considerable amounts of organic by-products. For instance, in 2013, the salmon farming industry in Norway used more than 1.6 million t of food to produce 1.2 million t of salmonids (Norwegian Directorate of Fisheries 2013). Information regarding the amount of lost food in salmon farming is surprisingly scarce, but it could be as much as 5% (Otterå et al. 2009). This suggests that tens of thousands of tonnes of waste feed are available to wild fish each year. Thus, organic by-products from salmon farming, in terms of uneaten pellets falling through the cages (Dempster et al. 2011); feed that is lost through fragmentation during production and in the feeding machines (Aas et al. 2011); dissolved and particulate nutrients originating from faeces (Holmer 2010); ammonia and urea excreted through the gills (Randall & Tsui 2002) and

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organic matter resulting from mechanical removal of fouling organisms from the net walls (Carl et al. 2011), constitute a significant local introduction of nutrients to coastal ecosystems. For example, estimates indicate that a production of 1.3 million t of salmonids may result in releases of about 60 000 t of carbon, 34 000 t of nitrogen and 9750 t of phosphorus annually (Taranger et al. 2013). In turn, this introduction of nutrients may have a range of ecological effects such as local eutrophication through the release of dissolved nutrients and impacts on benthic fauna through sedimentation of organic waste (Holmer 2010), as well as effects on the local wild fish populations. Salmon farms may, in several ways, be regarded as a good artificial habitat for wild marine fish. Firstly, the abundance of uneaten fish pellets attracts large numbers of wild fish that consume the waste feed (Sanchez-Jerez et al. 2011). Furthermore, smaller fish species that are attracted to the farms may represent an artificial aggregation of natural prey that in turn attracts larger predators (Serra Llinares et al. 2013). The farm structures may also attract fish because they offer shelter (Freon & Dagorn 2000). Hence, salmon farms represent so-called fish aggregation devices (FADs) (Kingsford 1999). If farms generate positive effects for attracted wild fish species, they may represent a population source, whereas they could be regarded as ecological traps or population sinks if the impacts are negative (Robertson & Hutto 2006).

Aggregation of wild fish at salmon farms could also influence various human activities in coastal communities. At present, there are about 1000 salmonid farms spread along much of the Norwegian coast. As large numbers of wild fish are attracted to farms, this may change the availability of these fish species for both commercial and recreational fishing (Fig. 1). In addition, a diet switch from natural prey to salmon feed, that contains relatively large amounts of both marine and terrestrial animal fats, may influence fish physiology, and in turn also flesh quality. Moreover, the large aggregations of wild fish could affect the farming activity itself and potentially lead to adverse effects such as increased escape risk resulting from attraction of large predators which may damage the net cage wall, and through propagation of pathogens to wild fish (Sanchez-Jerez et al. 2008, Arechavala-Lopez et al. 2013).

In Norway, the salmon farming industry has increased considerably during recent decades, while coastal fisheries have declined. This has increased the interactions between these 2 industries and con-

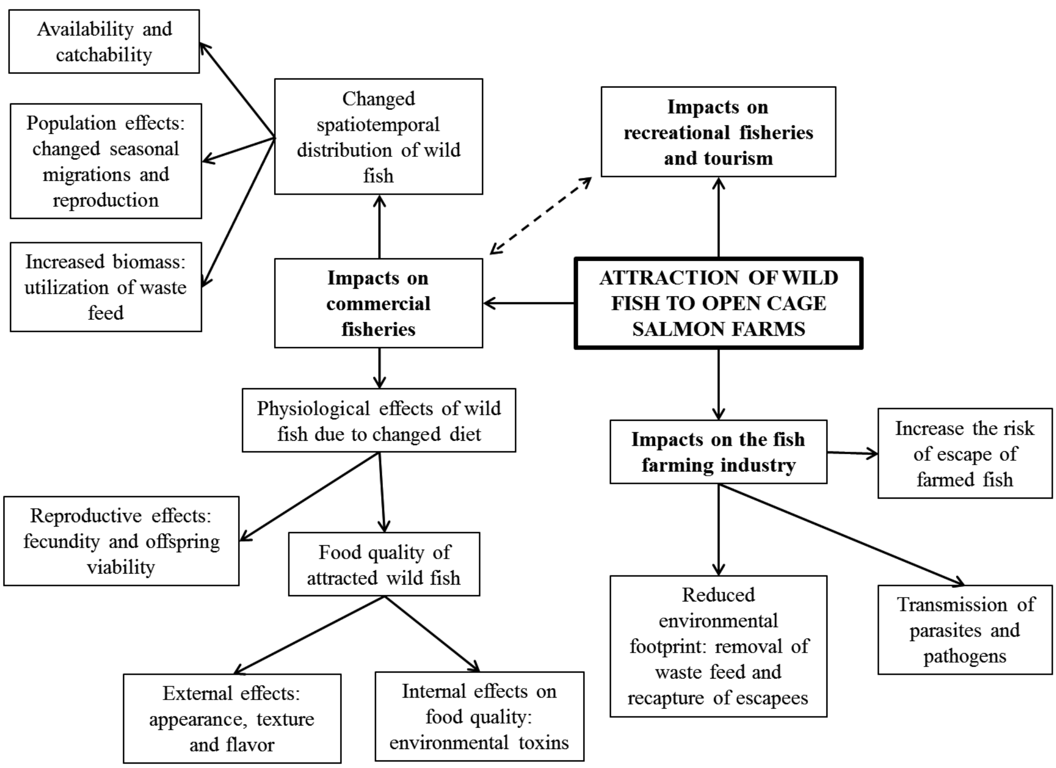

Fig. 1. Conceptual model indicating the potential impacts of wild fish attraction to open-cage salmon farms on the environment and human activities and their interactions in Norway

flict usually stems from the perception that the farming industry affects coastal fisheries in a negative way. Conflicts among stakeholders arise due to lack of information or misunderstandings and there is, thus, a need for knowledge regarding if and how salmon farming in open-cage fish farms affects the various industries. Such understanding will be crucial for facilitating the development of a sustainable coexistence between the different industries through knowledge-based management. In this review, we summarize the existing knowledge regarding the impacts of wild fish attraction to open-cage salmon farms on coastal ecology, human activities and their interactions (Fig. 1). We also discuss the implications for management and recapitulate the need for further study.

ATTRACTION OF WILD FISHES TO OPEN-CAGE FISH FARMS

More than 160 fish species, belonging to about 60 families, have been detected in the near vicinity of open-cage farms (Sanchez-Jerez et al. 2011). The attraction of wild fish to farms has been documented in Norway (Bjordal & Skar 1992, Dempster et al. 2009, 2010, 2011) and other countries (Spain: Dempster et al. 2002, 2004, Boyra et al. 2004, Tuya et al. 2006; Scotland: Carss 1990; Greece: Machias et al. 2006; USA: Oakes & Pondella 2009, Johnston et al. 2010; Indonesia: Sudirman et al. 2009; Brasil: Demetrio et al. 2012; Turkey: Akyol & Ertosluk 2010). Furthermore, wild fish are attracted to the open-cage farms of at least 10 farm species (Table 1). Waste feed pellets are the major cause of wild fish aggregations at open-cage farms (Fernandez-Jover et al. 2007, 2011 Dempster et al. 2011, Sanz-Lázaro et al. 2011).

At least 17 wild fish species are reported to eat waste feed in the vicinity of fish farms (Table 2). In Norway, 15 fish species belonging to 9 families have been observed underneath salmon farms (Dempster et al. 2009), the most common being saithe *Pollachius virens*, Atlantic cod *Gadus morhua*, haddock *Melanogrammus aeglefinus* and mackerel *Scomber scomber*. Most of the wild fish at salmon farms stay close to the net pens (<25 m), i.e. within a distance where the amount of waste feed is highest (Dempster et al. 2010). Relatively large amounts of wild fish are attracted to salmon farms and Dempster et al. (2009) estimated that, on average, 10 t of wild fish aggregated at 9 examined salmon farms at any given day during the summer months. The maximum estimate of aggregated fish at a single farm was 41 t (Dempster et al. 2009). These estimates are conservative since the amount of fish was estimated in a water volume representing a distance of just 5 m outside the cages at a specific point in time. As saithe and Atlantic cod move rapidly and repeatedly among farms and other areas (Uglem et al. 2008, 2009, Otterå & Skilbrei 2014), the total amount of wild fish associated with farms may be considerably higher than estimated by Dempster et al. (2009). A recent study from Canada also indicates relatively large assemblages of wild fish at salmon farms, and the amount of wild fish in coves with farms may be 3 times as high as in coves without farms (Goodbrand et al. 2013).

The extent of the area around salmon farms within which wild fish are attracted has, to our knowledge, not been estimated, but it may be large, as noise and chemical cues can be detected by wild fish over relatively long distances. In the Aegean Sea, the spatial structure of wild fish around Sparidae fish farms was affected at a scale of 10 to 24 square n miles (34 to

Table 1. Farm fish species cultured in open cages at which wild fish aggregations are documented

English name	Latin name	Source
Atlantic salmon	*Salmo salar*	Carss (1990), Dempster et al. (2009)
Rainbow trout	*Oncorhynchus mykiss*	Carss (1990)
Sea bass	*Dicentrarchus labrax*	Dempster et al. (2002), Boyra et al. (2004), Tuya et al. (2005)
Sea bream	*Sparus aurata*	Dempster et al. (2002), Boyra et al. (2004), Tuya et al. (2005), Bacher et al. (2012)
Atlantic bluefin tuna	*Thunnus thynnus*	Šegvić Bubić et al. (2011), Bacher et al. (2012)
White seabass	*Atractoscion nobilis*	Oakes & Pondella (2009)
Brown marbelled grouper	*Epinephelus fuscoguttatus*	Sudirman et al. (2009)
Humpback grouper	*Cromileptes altivelis*	Sudirman et al. (2009)
Rabbit fish	*Siganus* spp.	Sudirman et al. (2009)
Channel catfish	*Ictalurus punctatus*	Collins (1971)
Nile tilapia	*Oreochromis niloticus*	Demetrio et al. (2012)
Meagre	*Argyrosomus regius*	P. Sanchez-Jerez (unpubl.)

Table 2. Wild fish species found eating waste feed from fish farms. Fishes (%): percentages of fish that had waste feed in their stomach. Escaped farmed sea bass, sea bream, meagre and pollack *Pollachius pollachius* also eat waste feed (P. Sanchez-Jerez unpubl.)

English name	Latin name	Country	Fishes %	Source
Rainbow trout	*Oncorhynchus mykiss*	Scotland	30–73	Carss (1990)
Saithe	*Pollachius virens*	Scotland, Norway	14–92	Carss (1990), Skog et al. (2003), Bjordal & Johnstone (1993), Dempster et al. (2011), I. Uglem unpubl.
Atlantic cod	*Gadus morhua*	Norway	11–32	Dempster et al. (2011), Sæther et al. (2012)
Atlantic salmon (escaped farm fish)	*Salmo salar*	Norway	80	Olsen & Skilbrei (2010)
Bogue	*Boops boops*	Spain	90	Arechavala-Lopez et al. (2010)
Horse mackerel	*Trachurus mediterraneus*	Spain	67	Fernandez-Jover et al. (2008)
Snubnose dart	*Trachinotus ovatus*	Spain	80	
Mullet	*Liza aurata*, *L. ramada*, *Chelon labrosus*, *Mugil cephalus*	Spain	78	Fernandez-Jover et al. (2008)
Round sardinella	*Sardinella aurita*	Spain	80	Fernandez-Jover et al. (2008)
Indo-Pacific sergeant	*Abudefduf vaigiensis*	Indonesia	–	Sudirman et al. (2009)
Dark-banded fusilier	*Pterocaesio tile*	Indonesia	–	Sudirman et al. (2009)
Violet damsel	*Neopomacentros violascens*	Indonesia	–	Sudirman et al. (2009)
Silver mooney	*Monodactylus argenteus*	Indonesia	–	Sudirman et al. (2009)
Neotropical catfish	*Iheringichthys labrosus*	Brazil	15–32	Demetrio et al. (2012)
Spotted metynnis	*Metynnes maculatus*	Brazil	17–52	Demetrio et al. (2012)
	Pimelodus maculatus	Brazil	50–98	Demetrio et al. (2012)
Paraguay River eartheater	*Satanoperca pappaterra*	Brazil	29	Demetrio et al. (2012)
Graceful pimelodella	*Pimelodella gracilis*	Brazil	–	Demetrio et al. (2012)
Noja	*Pseudauchenipterus galeatus*	Brazil	–	Demetrio et al. (2012)

82 km^2; Giannoulaki et al. 2005). If this is also the case for salmon farms, the spatiotemporal structure of wild fish is affected in large areas along the Norwegian coast, especially in the most farming intensive regions.

The occurrence of waste feed in stomach samples from wild fish caught underneath salmon farms has been quantified for saithe and cod only (e.g. Dempster et al. 2011), but waste feed has also been observed in stomach samples from haddock, mackerel and pollack *Pollachius pollachius* (I. Uglem pers. obs.). Dempster et al. (2011) reported that waste feed was found in stomach samples of 44% and 20% of the saithe and cod captured at 9 different farms, respectively. Furthermore, waste feed constituted an estimated 71% of the diet of farm-associated saithe and 25% of farm-associated cod (Dempster et al. 2011). Saithe and cod caught simultaneously at control locations away from the farms had no salmon pellets in their stomachs (Dempster et al. 2011). Cod <60 cm total length feed more on pellets than cod >60 cm (32 vs. 11%) (Sæther et al. 2012). The proportion of saithe with pellets in their stomach may be considerably higher than what is published to date (I. Uglem unpubl.: 23 of 25 saithe captured at a farm had pellets in their stomach). The variation in occurrence of pellets in the diet of saithe and cod may be related to the intensity and amount of feeding and, thus, also feed loss, as well as the size of the wild fish aggregations and the level of competition over the available feed.

It has been suggested that wild fish also feed on faeces excreted by the salmon but, to our knowledge, this has not been documented (Otterå et al. 2007), perhaps because faecal matter is difficult to recognize in stomach samples and therefore categorized as unidentifiable (Dempster et al. 2011, Demetrio et al. 2012). Another possibility is that larger wild fish are attracted to salmon farms due to aggregations of smaller prey fish, as documented for sea bass and sea bream farms in the Mediterranean (Sanchez-Jerez et al. 2008). This seems likely, as smaller fish are regularly found in stomach samples of larger predatory fish caught at salmon farms (Dempster et al. 2011, Sæther et al. 2012). Finally, it has been suggested that the farm structures per se would represent shelter for wild fish by providing protection from predation and other environmental factors (Sanchez-Jerez et al. 2011). To our knowledge, this has not been examined for salmon farms, as it would require a comparison of wild fish aggregations between empty and active farms.

INFLUENCE ON COMMERCIAL FISHERIES

In Norway, salmon farms are usually located within fjords or close to the coast to facilitate transport of equipment, feed and personnel to and from the farms, and because such locations are less exposed to harsh sea conditions. This implies that salmon farming predominantly affects fish resources that are exploited by coastal and small scale commercial fisheries, and not by the offshore fishing fleet. Despite fish farming being the larger industry in economic terms, the near-shore fisheries still represent a significant and fairly sustainable industry in coastal communities of salmon producing countries.

Changes in distribution of wild fish and availability for fisheries

Most of the fish that aggregate at open-cage farms would probably stay elsewhere in the absence of fish farms (e.g. Bjordal & Johnstone 1993, Giannoulaki et al. 2005, Uglem et al. 2008, 2009, Dempster et al. 2009, 2010, 2011, Otterå & Skilbrei 2014). Therefore, it is reasonable to assume that the aggregation of wild fish at farm locations does not result from an increase in population size per se, although it could lead to an increase in both biomass and population size. However, results from oligotrophic seas (Aegean and Ionian Seas) indicate that the presence of fish culture could trigger a localised increase in fisheries production (Machias et al. 2005, 2006).

The increased biomass of wild fish feeding on waste salmon pellets has, to our knowledge, not been estimated. Recent measurements of feed loss in commercial salmon farming are lacking, but it is assumed to be around 3 to 5% of the total amount of feed used (e.g. Otterå et al. 2009). According to Dempster et al. (2011), farm-associated saithe were able to consume about 1.3% of the feed used across 9 salmon farms during summer. This indicates that saithe eat a large part of the waste feed, which in turn may result in a substantial increase in wild fish biomass over time, in particular in cases where natural prey are scarce. Given the amount of feed used in Norway in 2013 (1.6 million t) and assuming that the *in situ* feed conversion rate (feed intake/biomass increase) of saithe is similar to that of salmon (~1), consumption of 1.3% of the waste feed by saithe could result in a biomass increase of about 21000 t. However, bioenergetic modeling is required to evaluate how feed loss increases wild fish biomass.

The bulk of the wild fish that aggregate at salmon farms stay within 25 m of the cages (Dempster et al. 2010), and it is reasonable to assume that most of these fish are attracted from nearby traditional fishing grounds. To avoid physical interactions between fishing gear and farm structures, there is a no-fishing zone around farms in Norway. At present, this zone extends 100 m from the perimeter buoys surrounding the farm. The distance from these buoys to the cages varies among farms and the actual no-fishing zone as measured from the edges of the cages is approximately 150 m. Thus, the wild fish at salmon farms are inaccessible for commercial fisheries.

Waste feed could increase the reproductive potential of wild fish, through increasing energy reserves and growth, enhancing fecundity. Dempster et al. (2011) found that the relative gonad mass of farm-associated fish was larger compared to non-associated fish. However, the biochemical composition of salmon feed is most likely not optimal for the egg and larval quality of gadoid fish species. For instance, tissue from farm-associated fish contain lower levels of the fatty acid arachidonic acid, which is believed to be crucial for optimal development of egg and larvae (Fernadez-Jover et al. 2011). Moreover, Atlantic cod that consume artificial feed have a different fatty acid composition in their gonads and reduced reproductive viability compared to cod that feed on natural food; this is most likely due to nutritional deficiencies (Salze et al. 2005, Lanes et al. 2012, Uglem et al. 2012). Additionally, increased energy reserves might reduce the age of sexual maturation (Rowe & Thorpe 1990, Rowe et al. 1991, Taranger et al. 2010) and a changed distribution could influence the spawning migrations of attracted fish (Otterå & Skilbrei 2014). Hence, utilization of waste feed can affect the availability of wild fish for commercial fisheries not only directly through changed accessibility of fish, but also indirectly by influencing reproduction. It is, however, still unclear how indirect impacts may affect local fish population dynamics.

Effects on food quality of attracted wild fish

Appearance, texture and flavour

During recent decades, Norwegian coastal fishermen and fish buyers have claimed that the quality of wild gadoid fish that have been eating waste feed is inferior compared to wild fish that have had a normal diet (Skog et al. 2003, Otterå et al. 2009). Fillets from attracted wild fish are claimed to be soft with a considerable occurrence of gaping, and abnormal coloration and unusual smell have also been reported. Reduced quality of attracted fish is most likely an issue for coastal fisheries only; Fossen (2012) found that fish buyers that predominantly receive fish from the off-shore fleet did not report issues related to reduced quality of saithe that might be due to attraction to salmon farms. On the other hand, after interviewing 9 in-shore fish buyers, Sæther et al. (2013) found that the quality of farm-attracted saithe was perceived low at times in areas with high farming intensity, but also that the problem had decreased during the last decade, possibly due to an altered fishing pattern and improved feeding regimes at the farms. Since the fishermen in some cases are unable to sell their catch, they respond by abandoning locations where the fish are affected by salmon farming. It is hypothesized that the reduction in quality, in terms of soft texture, is related to both pre- and postmortem glycolysis. The former is probably related to stress and/or activity before death (e.g. Kiessling et al. 2004). In both cases, glycogen is broken down to lactic acid, thus making the fish muscle slightly acidic, which may increase flesh softness and gaping (Bremner 1999, Kristoffersen et al. 2006). The quality may also depend on the nutritional state of the fish. A well fed fish has large amounts of lipids and glycogen in the liver and muscles (Rustad 1992), which in turn will result in a high glycolytic potential, a low ultimate pH post mortem and reduced fillet quality (Kristoffersen et al. 2006). The reduced flesh quality of wild fish caught close to salmon farms may, thus, be a consequence of the abundance of waste feed, which results in these fish becoming significantly fatter than fish caught away from the farms (e.g. Dempster et al. 2011). A high fat content might also result in a shorter shelf life for fresh fish (Bogdanovic et al. 2012). Whether or not the reduction in quality is permanent or the fish are able to adjust to a higher feeding intensity over time and deposit less glycogen in the muscle is not known. However, the flesh quality of encaged saithe fed fish pellets in excess for 8 mo was good (Otterå et al. 2009).

The quality of farm-attracted fish has been assessed through sensory analyses involving a trained expert panel that evaluates a large range of parameters related to taste and appearance (e.g. Tomic et al. 2013). The results indicate slight variations, but no consistent trend, in taste and appearance between saithe captured close to farms compared with fish caught away from farms (Skog et al. 2003, Sæther et al. 2012). Furthermore, saithe that were fed salmon and/or cod pellets during an 8 mo period in captivity did not differ significantly in their sensory parameters compared with wild caught saithe at the end of this period (Otterå et al. 2009). Evaluation of quality can also be done for fillets by combining easily estimated parameters like smell, gaping, color, consistency and surface appearance into a quality index value (e.g. Martinsdottir et al. 2003). In the same way as for the more detailed sensory analyses, variations in quality index values have been minor, with no consistent differences among farm-associated saithe caught in the wild or saithe fed salmon/cod pellets in captivity and wild caught non-associated fish (Bjørn et. al. 2007, Otterå et al. 2009, Sæther et al. 2012). The interpretation of the fillet quality index results for wild caught fish may, however, be confounded since the different fish groups were caught using different fishing methods (jigging, pelagic pots or trammel nets) (Bjørn et. al. 2007, Otterå et al. 2009). In general, fish caught by jigging or in pots are expected to be of a better quality than fish caught by nets, as they are caught alive and rapidly killed and bled, while fish caught in nets might be seriously stressed or dead after having been kept in the nets for many hours. Sæther et al. (2012) found that the fillet quality of saithe caught with nets (wild fish not associated with farms) was significantly better compared with saithe caught alive in pots (farm-associated wild fish). Another confounding factor is that the fish quality may depend on the amount of pellets consumed over time and, thus, on the condition of the fish. Therefore, the overall lack of differences in fillet quality index among farm-associated and unassociated saithe may be related to a generally low long-term consumption of pellets that manifests as no major change in the hepatosomatic index between groups (Bjørn et al. 2007, Sæther et al. 2012).

There is a need for further studies in which the wild fish are caught and treated in a standardized manner, and which would allow previous consumption of salmon pellets to be evaluated through analysis of relevant biochemical parameters (Skog et al. 2003, Fernandez-Jover et al. 2011) or by continuous and periodic evaluation of the flesh quality in long-term feeding experiments. At present, a newly initiated study in Norway addresses some of these confounding issues, and preliminary results indicate that there is a consistent difference in the quality between farm-associated and wild saithe when capture and handling procedures are taken into account, with the quality of the former being slightly but significantly reduced compared to the latter group (I. Uglem, B. S. Sæther & Ø. Karlsen unpubl.).

Xenobiotics

Fish farms introduce xenobiotics to marine wild fish, e.g. through fish feed, anti-fouling chemicals or medicinals. Whether residuals from salmon farming results in levels of xenobiotics in wild fish that may be harmful for humans has not been assessed, although amounts of xenobiotics may vary significantly between wild fish caught at salmon farms and other locations away from farms (deBruyn et al. 2006, Bustnes et al. 2010, 2011, 2012). For instance, levels of xenobiotics in wild fish sampled at salmon farms, such as PCB, furans, dioxins, chlorinated pesticides and brominated flame retardants, were well below the assumed harmful levels (Taranger et al. 2013). Furthermore, comparisons of saithe and Atlantic cod caught at farms and at locations away from farms have not revealed any xenobiotic levels assumed harmful (deBruyn et al. 2006, Bustnes et al. 2010, 2011, 2012). Samuelsen et al. (1992) demonstrated that saithe are able to accumulate antibiotics administered in salmon feed. In Norway, the use of antibiotics in salmon culture is almost negligible and accumulation in wild fish would most likely not affect the environment significantly. The situation may, however, be different in other salmon farming countries, where larger amounts of antibiotics are still used. Furthermore, residues of medicinals used for treating salmon against lice (teflu- and diflubenzuron) have been found in water, mussels, crustaceans and saithe close to salmon farms in levels that might be toxic to crustaceans, but most likely not for humans (Langford et al. 2011, Samuelsen et al. 2013). Occurrence of other chemicals used in lice treatment in wild fish have not, to our knowledge, been reported. Shrimp caught around salmon farms are able to accumulate nutrients from salmon feed, so that there is a pathway for uptake of xenobiotics through the feed (Olsen et al. 2012). It is still uncertain if and to what extent antifouling chemicals containing copper may affect the environment around salmon farms (Taranger et al. 2013). Copper is toxic for a range of taxa, but is also quickly accumulated in the sediments under farms (Burridge et al. 2010). The use of copper in antifouling paint for boat hulls is comparable to the use of antifouling chemicals in farms. However, the toxic effect of antifouling paint is assumed to be low, apart from sheltered locations like harbors (Brooks & Waldock 2009).

Since salmon farming introduces large amounts of organic matter into the marine environment, which to a large extent originates from non-local sources, levels of xenobiotics will vary between farm resident organisms and conspecifics from non-farming locations. At present, there is no evidence indicating that salmon farms are a source for the introduction of xenobiotics at levels that are harmful for humans. However, it is a very challenging scientific task to completely exclude the possibility that even low concentrations of some xenobiotics may cause long-term harmful effects. Moreover, the fact that fish and crustaceans are able to reduce the levels of xenobiotics through different detoxification pathways will further complicate the assessment of the extent to which salmon farms may be a source of such substances (Parkinson 1996). Thus, the lack of short-term evidence illustrates the need for more knowledge, and that caution should be shown.

EFFECTS ON RECREATIONAL FISHERIES

Recreational coastal fisheries can be divided into 2 categories: resident inhabitants fishing for personal consumption and/or in a recreational context, or tourist fishermen. Fishing tourism is a growing industry that has already created new jobs and considerable economic value in coastal communities (Vølstad et al. 2011). Borch et al. (2011) identified more than 430 businesses related to coastal fishing tourism in Norway and estimated the associated turnover of goods and services to be 106 million euros in 2008. Results from Scotland indicate that salmon farming, in general, does not affect the tourist industry (Nimmo et al. 2009, 2011). However, the relationship between sea-based fisheries used for tourism and salmon farming has not been specifically examined. It is, nevertheless, likely that the attraction of wild fish to fish farms could affect recreational fisheries since the attracted fish may originate from nearby fishing areas used by recreational fishermen. Furthermore, altered quality of attracted fish may also be an issue for recreational fisheries, as availability and quality of wild fish will be affected in areas with a high salmon farming density. New studies are required regarding the relationship between salmon farming and recreational fisheries.

EFFECTS ON THE FISH FARMING INDUSTRY

The attraction of wild fish to salmon farms may also affect farming practices. Besides increasing the risk of escape from the sea cages and dispersal of pathogens, attracted fish might provide services that could reduce the environmental footprint of salmon farming.

Removal of waste feed and recapture of escapees

Wild fish might reduce unwanted effects on benthos resulting from deposition of particulate waste as they are able to consume significant amounts of the waste feed before sedimentation occurs (e.g. Brown et al. 1987, Ritz et al. 1989, Hansen et al. 1990, 1991, Holmer & Kristensen 1992, 1996, Kutti et al. 2007a,b, 2008). Dempster et al. (2011) estimated that saithe aggregated at Norwegian salmon farms remove as much as one third of the waste feed. Similar results were also found at open-cage farms for sea bass and sea bream in the Mediterranean (Vita et al. 2004, Sanchez-Jerez et al. 2011). Models for predicting the role of fish farming on the nutrient supply in the oceans do not take removal of waste feed by wild fish into account and knowledge regarding both the degree of feed loss under realistic conditions and how much of this is eaten by wild fish is still scarce. There is a need for more detailed knowledge concerning feed loss and utilization of waste feed by wild fish with regard to, for example, season, amount and age of the farmed salmon, as well as the diversity of the wild fish populations around the farms.

Large wild fish aggregating at salmon farms may reduce escape rates, as they prey on smaller fish which constitute a significant part of their diet (e.g. Dempster et al. 2011, Sanchez-Jerez et al. 2011). Thus, predatory fish are attracted to salmon farms not only by the lost food but also by local abundance of prey, including any small fish escaping from the cages. In 3 size groups of small cod equipped with external tags, released from a farm, almost 10% of the fish in the smallest size group (average total length 25 cm) were found in the stomachs of a relatively small sample (N ~ 400) of large cod and saithe caught around the farm. Given the enormous amount of wild fish aggregating at this specific farm during this study, it is likely that most of the smallest escaped cod were 'recaptured' by large predatory fish (Serra Llinares et al. 2013). The predation rates of larger juvenile cod released (mean TL 29 cm: 0.6% and 36 cm: 0%) suggest that larger escapees avoid predation (Serra Llinares et al. 2013). Moreover, Uglem et al. (2013) suggested that predation occurred following release of salmon smolts with acoustic tags from a land-based salmon smolt factory.

Transmission of pathogens

Salmon aquaculture in open sea cages transfers parasites and diseases from farmed salmon to wild salmonids and vice versa, but little is known about the transfer of pathogens to other fish species (Johansen et al. 2011, Taranger et al. 2013). Since the amounts and densities of fish in open sea cages are vast compared to natural situations, not only is a higher local infection pressure due to the high host density likely, but also an increased pathogen virulence as a result of a greater potential for selection (Krkošek 2010, Pulkkinen et al. 2010). Dispersal of pathogens from open-cage aquaculture occurs through ocean currents, transportable equipment and ships, escape of farmed fish and movements of wild farm-attracted marine fish (Johansen et al. 2011, Arechavala-Lopez et al. 2013).

The wild fish might transfer pathogens from farmed fish to other farms or wild fish populations under the assumptions that (1) the wild fish reside close enough to farms for a period of time sufficient for pathogens to be transferred, (2) the wild fish move frequently and far enough among farms and other areas to disperse pathogens and (3) that farmed fish and wild fish are actually carriers of the same pathogens. Wild marine fish may stay in the vicinity of farms for several months and they may move relatively frequently and rapidly among farms and other locations (Uglem et al. 2008, 2009, Dempster et al. 2010, Sanchez-Jerez et al. 2011, Otterå & Skilbrei 2014). In Norway, this is true of Atlantic cod and saithe (Uglem et al. 2008, 2009, Otterå & Skilbrei 2014), and in the Mediterranean for mullets *Liza aurata* and *Chelon labrosus* (Arechavala-Lopez et al. 2010, 2013) and for bluefish *Pomatomus saltatrix* (Arechavala-Lopez et al. 2014). The first 2 assumptions for the transfer of pathogens through wild fish are thus most likely fulfilled. It is, however, unclear to what extent farmed salmonids and wild non-salmonids share the same pathogens, and if these pathogens actually are transferred among species. The little knowledge that exists indicates that the transfer of pathogens from farmed fish to wild marine fish takes place (Heuch et al. 2011, Johansen et al. 2011, Arechavala-Lopez et al. 2013, Taranger et al. 2013). Transfer is more likely amongst closely related species. Recent reviews regarding the possible role of wild fish as vectors for pathogens concluded that the existing knowledge is too sparse for risk evaluations (Johansen et al. 2011, Taranger et al. 2013).

Increased risk of escape of farmed fish

Piscivorous fish attracted to fish farms increase the escape risk of farmed fish. This is believed to take place in Mediterranean open-cage fish farming, where bluefish *Pomatomus saltatrix* often are observed in high densities around farms (Sanchez-Jerez et al. 2008). Bluefish are large predators with large and sharp teeth, which bite holes in the net wall to prey on the farmed fish (Sanchez-Jerez et al. 2008). Similar problems are not documented for salmon farming, but spiny dogfish *Squalus acanthias* are thought to have caused escapes because they created holes in the cage during attempts to prey on dead salmon through the cage bottom (Moe et al. 2005). Farmed cod may bite holes in the cage wall from the inside (Moe et al. 2007, Hansen et al. 2008, Jensen et al. 2010, Damsgård et al. 2012), and wild cod could bite holes in the net from outside a pen.

CONCLUSIONS

Although salmon culture in open sea cages is a significant ecosystem modifying factor in the coastal zone, its ecological impacts in terms of attraction of wild organisms to farms have been studied only for a few of the many species that share the same environment as salmon farms. The ecological impacts of salmon farming due to attraction of wild marine fish species may not necessarily be solely negative or positive, but probably vary along a scale depending on many factors. It is reasonable to expect that potential ecological impacts would vary among species, sexes, seasons, years, ontogenetic stages, locations and many other factors. In addition, the implications of potential ecological impacts may vary between stakeholder groups. For instance, it is possible that wild fish aggregating at fish farms would be positive for the environmental management of salmon farms as they remove waste feed pellets before they reach the benthos (Dempster et al. 2009). Given the additional resources that are available for the wild fish, in terms of waste feed and a possible increase in fecundity without simultaneously compromising gamete viability, attraction to farms could also be positive for wild fish populations (Dempster et al. 2011). On the other hand, attraction of fish to farms may be negative for local fishermen if it reduces the availability and food quality of the wild fish (Otterå et al. 2009). An intensive fishery based on farm-aggregated fish may involve local overexploitation, because the catchability of attracted fish increases, since they are concentrated in smaller areas compared to natural situations. Thus, if attraction of wild fish to farms results in overexploitation, management tools such as fishing quotas or spatiotemporal limitations in fishing, should be considered. This illustrates that an ecosystem approach is required to manage both farmed and wild fish resources in a sustainable manner (FAO 2010). There is a need to focus on ecological processes across trophic levels in future research, e.g. quantifying intake of waste feed by taxa other than gadoid fish and a few other species, as well as expanding models for the prediction of nutrient flow related to aquaculture. In order to refine models of nutrient flow, there is a need for information regarding loss of feed from farms and how much of this feed is eaten by wild fish in relation to factors like season, amount and age of the farmed salmon, and diversity of the wild fish population around the farms.

The existing knowledge indicates that organic by-products from fish farming could affect local recruitment of farm-associated species, but it is still not clear if and to what extent such factors affect the reproductive potential of these species. Thus, there is also a need for information regarding the physiological effects of waste feed and how farms affect the spatiotemporal distribution of various species during spawning. Even though it is unclear if long-term effects on local fish biomass will occur, it is highly likely that open-cage fish farming will result in a significant short-term increase in wild fish biomass, which in turn might be targeted by local fisheries. In this context, it is crucial to develop methods that would ensure that the quality of the wild fish harvested in areas around fish farms is maximized. However, because fish farms serve as fish attraction devices, they could also be advantageous for local fishermen since they concentrate the fish resources in a small and defined area. Actions to avoid local overexploitation should, thus, be implemented. Other issues related to commercial fisheries that are based on farm-attracted wild fish, and which require attention, are the potentially increased risk of escape due to fishing gear damaging the net pens, increased risk of disease transfer due to increased boat traffic and the potential accumulation of medicinals or pollutants used in fish farming in the attracted wild fish.

In conclusion, open-cage fish farming represents a significant factor in coastal marine systems, which affects local ecosystems and, thus, implicitly also other coastal industries. Knowledge regarding ecological processes, not only at a single species level but also across trophic levels, is important for assessing the overall environmental footprint of salmon farming. In the same way that other industries exploit natural resources, salmon farming will indeed affect the environment in various ways and it may be difficult or perhaps impossible to achieve sustainability according to strict no-impact definitions of this term. A more realistic goal would perhaps be to reduce the footprint of the salmon farming industry in some way, while simultaneously maintaining economic viability. This calls for a combined focus on environmental and human impacts and interactions when developing future management strategies.

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