The effect of salmon farming on wild salmon populations

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Abstract

Salmon are farmed in great numbers due to the relative ease of culturing and high market demands. Mainly the Atlantic salmon (*Salmo salar*) is being cultured and mostly in Norway. One might think that salmon culture relieves wild salmon populations, but the opposite seems true. Salmon farming pressures wild salmon populations even further, both directly and indirectly. In this review I explore the effect of salmon farming on wild salmon populations.
Some factors that negatively affect wild salmon populations are; fish feed and pollution created by high stock densities, escaped salmon that dilute the gene pool of wild salmon populations, diseases and parasites such as sea lice that spread from salmon farms to wild salmon and the fact that the high amount of cultured salmon lower the price for al salmon, threatening wild salmon stocks economically.
Effort is being done to minimize these negative effects. For example partial replacement of fish based oil and proteins with plant based products, better and stronger cages reducing the chance of escapes, better understanding of sea lice and other diseases but also new techniques such as the use of cleaner fish to reduce the risk of spreading and lastly marketing wild salmon differently to get a better price for wild salmon.
Even though steps are being taken in the right direction to increase sustainability and reduce the impact of salmon farming on wild salmon populations, the future of wild salmon remains uncertain.

Keywords: Salmon farming, aquaculture, sea lice, fish feed, *Salmo salar*

1 Introduction

The salmon is a well-known carnivorous fish that naturally lives in the Pacific and Atlantic Ocean as well as in many rivers. Typically salmon are anadromous; born in fresh water, migrate to the ocean and finish their life cycle by reproducing in fresh water. The transformation from fresh to salt water is called smolting, the young salmon become silver colored, more streamlined and adapted to salt water. These adapted fish are called smolts. To grow from hatching to smolt, on average takes one to two years, depending on river run-off and temperature (McCormick et al., 1998). After one to three years of growth in the ocean, adult salmons return to their natal streams to spawn.

A result of the anadromous life-cycle with a high affinity for natal spawning areas, is that most salmon stocks are locally adapted and reproductively isolated from other stocks (Nehlsen et al., 1991). This makes them highly vulnerable to changes in their environment by human activities; including overfishing, habitat destruction, climate change, blocking due to hydropower, logging and agriculture (Nehlsen et al., 1991; Noakes, Beamish, & Kent, 2000). Salmon has always been an important source of food, but catches and natural abundance have been declining dramatically since the late 1980s (Ford & Myers, 2008).

Although the catch of wild salmon is decreasing, global consumption of salmon is continuously increasing. The domesticated culture of salmon since the late 1970s explains the increase in consumed salmon. The percentage consumption of cultured salmon compared to wild catches increased from two percent in 1980 to 65 percent in 2004 (Knapp et all., 2007). The worldwide production of cultured Atlantic salmon in 2009 was over 1000 times the reported catch of wild salmon in the North Atlantic (ICES ADVICE, 2010). Factors contributing to this success are market demands and the relative ease to culture salmon (Munro, 1990). Most salmon are cultured at sea in large floating pens, or in saltwater lochs. Smolt production occurs in fresh water tank systems and lakes or lochs (Munro, 1990). The emphasis of this thesis will be on the culture of Atlantic salmon (*Salmo salar)* which by far is the most commonly cultured salmon. However, other salmon species are cultured as well, such as Pacific, Chinook (*Oncorhynchus tshawytscha*) and Coho salmon (*Oncorhynchus kisutch*).

The culture of salmon has greatly contributed to the global supply and has reduced prices. This is good for consumers, but what is the effect of salmon farming on wild salmon populations? One would hypothesize that this increase in cultured salmon would relieve the pressure on natural stocks and thus have a positive influence on wild populations. However this does not seem to be true (Ford & Myers, 2008; Naylor et al., 2000). Salmon farming interacts with wild salmon populations in several ways: for example competition for habitat, diseases transferred from cultured to wild salmon, nutrients polluting natural streams, escaped individuals that lower the fitness of wild salmon and economically by lowering prices for cultured but also wild salmon. In particular, released or escaped individuals, sea louse infestations, the production of fish feed and pollution, are all salmon farming related factors

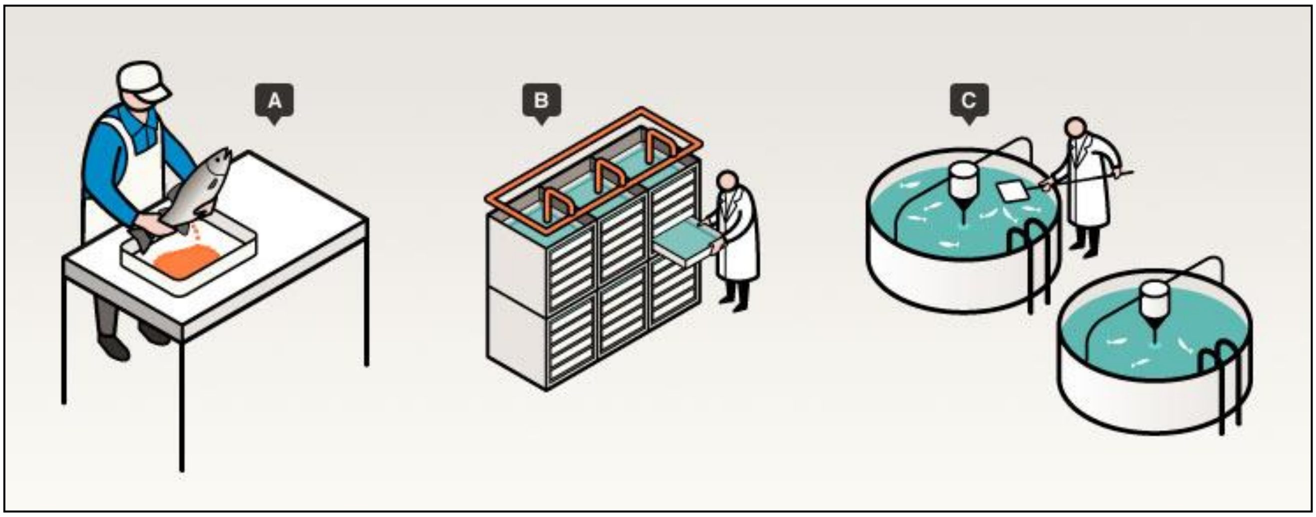

Figure 1: General development of young cultured smolts in freshwater. In the freshwater phase, A: eggs are extracted from females, B: salmon eggs are hatched in incubation tanks C: further development in freshwater tanks

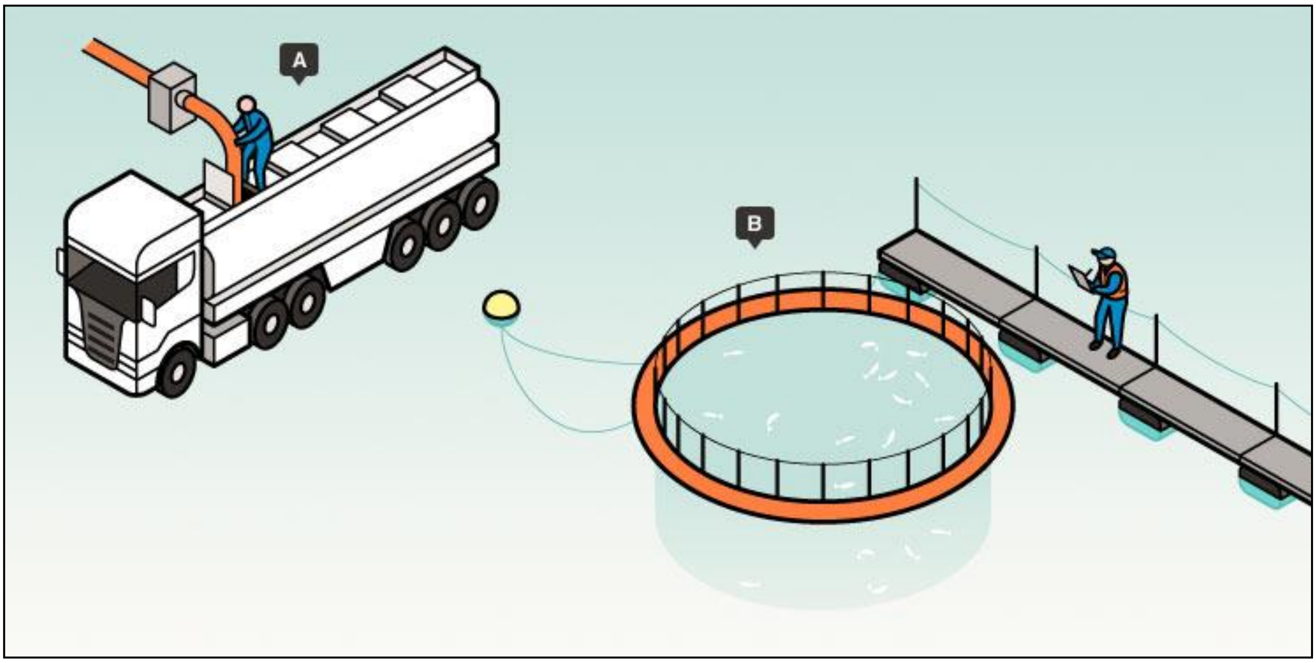

Figure 2: General development of adult salmon in seawater. A: During transport, salinity is gradually increased and then the salmon are released in floating pens, B: In these pens the small salmon are fed until they reach the market weight of around 5 kilograms per individual salmon

that seem to influence wild salmon populations negatively.

In this thesis I evaluate the direct and indirect impact of salmon culture on wild populations; and discuss future directions for salmon aquaculture.

2 Culture

Because of market demands and the relative ease to culture salmon in seawater, salmon have now been commercially cultured as a source of food for more than 30 years. Small salmon are obtained from egg and sperm and reared in freshwater tanks (Fig. 1). After they reach a certain size and start to smolt they are transported to circular net pens to be grown until they are large enough to harvest (Fig. 2). Some of this production takes place in freshwater lakes, for example in the Northern Patagonian lakes of Chile, but almost 99 percent of the total salmon production occurs in seawater environments (Arismendi et al., 2009).

According the Food and Agriculture Organization of the United Nations (FAO, 2009, www.fao.org), Norway, Chile, the United Kingdom and Canada are the four biggest salmon producing countries in the world. Norway accounts for more than 50 percent of the total production. Because of its long coastlines with long fjords that are protected from wave action and input of relative warm water due to Gulf Stream influence, Norway is perfect for aquaculture. The warm water is favorable for growth, and the sheltered sea lochs and fjords increase the durability of the floating net pens. In the United Kingdom salmon are mainly cultured in secluded fjord-like sea lochs. Canada has the world’s largest coastline which makes it very suitable for the culture of salmon. Both on the east and west coast salmon are cultured. Chile also has extensive coast lines and on top of that it has the benefit of being viral-disease and pollutant free. The downside of these prime culturing locations is that they are often nearby or in the middle of migratory routes of wild salmon (Knapp et al., 2007; Krkošek et al., 2008). This leads to negative direct interactions between wild and cultured salmon, such as pollution of the water body, interaction between escaped and wild salmon and the spreading of diseases.

3 Fish feed and pollution

Obviously, the large amounts of confined salmon in aquaculture do not resemble natural conditions. More nutrients than naturally available are put in to sustain growth and in salmon culture, this is mainly fish feed. On the other hand more nutrients are being excreted and wash out into the surroundings waters. This can lead to a variety of problems depending on culturing method, hydrography, stocking density and feed type.

Already between 15 and 20 percent of dry feed and more than 20 percent of wet feed is uneaten and remains in the water (Burd, 1997). Salmon also produce feces that release high amounts of phosphor and nitrogen in the water column. However, the major impact seems to be on a local scale; confined to the surrounding sea bed and less so to the surrounding water body. Anoxic reduction of organic matter on the sea bed may lead to the production of toxic gases such as ammonia, methane and hydrogen sulfite destroying benthic communities near salmon farms (Mente et al., 2006). The amount of damage and impact depends mostly on hydrography, but also stocking density. With a high flow-through the effect is minimal compared to water body’s with a low flow-through and the stocking density can be higher. Although at some place benthic communities are affected, wild salmon do not seem to be affected by this local pollution, but literature is scarce.

Fish meal and oil are obtained relatively cheaply from fisheries industries. In Europe, fish meal and oil is mainly produced from small species of pelagic bony fish not suited for human consumption. In Peru, the number one fish meal producing country in the world, anchovy (*Engraulis ringens*) and Pacific sardine (*Sardinops sagax*) are the most important species for the production of fish meal (Mente et al., 2006). This fish meal is then used to transform relatively cheap proteins and oil in to high value products such as salmon (Bell et al., 2001). Although some of this feed is also produced from by-catch, most of it is caught just to be turned into animal feed. To culture a carnivorous fish, such as salmon, 2.5-5 times more fish protein input is needed than the amount of fish that is produced (Naylor et al., 2000). This raises the question whether it makes sense to turn one food source into another with a 2.5 to 5 times loss ratio.

4 Escapes

Escaped cultured salmon that interact with wild salmon, pose a threat to the stability of wild salmon population. In an industry with billions of cultured fish reared in the open sea, some will escape. In Norway reported escapes between 2001 and 2009 ranged from less than 200 000 to more than 900 000 individuals. Failing technical equipment, often related to storms, is the main cause for these escapes (Skilbrei & Jørgensen, 2010). With increasing number of cultured salmon, there is a concern over the possible effect of escapes. Some wild populations already consist of 20 to 80 percent escaped farmed salmon (Chittenden et al., 2011). This can have serious consequences for the survival of natural populations.

Before salmon were cultured on large scale for food production, large restocking programs already cultured salmon. Billions of smolts were released annually to make up for the decline in wild populations (McCormick et al., 1998; Taylor et al., 2011). Although the idea of releasing a large amount of individuals to secure the wild populations, it is still not clear whether long term effects are positive or negative. Most cultured salmon are genetically less diverse due to selective breeding and have a lower fitness. This can result in less diverse and even maladapted wild populations.

The life-cycle of salmon makes them reproductively isolated and locally adapted, in that they spawn in the rivers that they were born in. A general assumption is that populations with high genetic diversity are more likely to cope with changes than a population with lower diversity. Therefore, if released or escaped salmon decrease the genetic variation of wild populations through inbreeding, they might have a negative effect on natural stocks. McGinity et al. (2009) created regression model based on a 37-year study in Ireland comparing wild and sea ranched Atlantic salmon spawning together in the wild. They showed that escaped individuals can substantially depress natural populations' ability to adapt, in this case to higher winter temperatures related to climate change (McGinnity et al., 2009).

As a result of morphological, physiological, ecological, and behavioral changes that occur in hatcheries, the competitive ability of cultured fish often differs from that of wild fish. Wild salmon have a higher fitness compared to cultured salmon, with lifetime reproductive success of only 17% in cultured salmon compared to similar sized wild salmon (Jonsson & Jonsson, 2006). This is caused by rapid genetic change caused, by intentional and unintentional selection in salmon culture (Fleming & Einum, 1997; Noakes et al., 2000). When wild populations are increasingly being exposed to cultured salmon, intentionally or not, there is a high chance the reproductive success of the wild populations decrease.

When restocking wild populations, genetically similar salmon should be used, preferably from the exact same population. This is not the the case when cultured salmon escape. In culture they selected for certain traits, such as fast growth and being easy to domesticate.

Overall, escapes seem to have a negative effect on wild populations, mostly by lowering the fitness and decreasing the ability to adapt, but also by transferring diseases (Hansen & Windsor, 2006; Jonsson & Jonsson, 2006; Knapp et al., 2007; McGinnity et al., 2009; Noakes et al., 2000).

5 Sea lice

Parasites play an important role in the interaction between wild and cultured salmon. Salmon are naturally parasitized by the sea lice *Caligus elongates* and *Lepeophtheirus salmonis Krøyer* (Fig. 3), both of which are directly transmitted ectoparasites. The life-cycle of the parasites consist of a parasitic stage where they are attached to the salmon, and a free swimming stage where no intermediate host is required (Krkošek, Lewis, Volpe, Krko, & Volpet, 2005). The parasite feeds on surface tissue (Fig. 3) which causes stress, osmotic failure, viral or bacterial infections, and eventually death

(Krkošek et al., 2008). In most wild salmon populations infection rates are low and migratory allopatry explain these low rates. Migratory allopatry is a period of spatial separation between juvenile and adult hosts minimizing the risk of infection. In salmon, the migration from fresh to saltwater causes this spatial separation and prevents parasite transmission from juvenile to adult hosts (Krkošek et al., 2007).

This spatial separation is threatened when salmon farms hold a concentrated large quantity of salmon throughout the whole year. This way domesticated salmon may function as a source for parasites posing a threat to wild salmon. When wild salmon pass these farms they can be directly infected by the free swimming nauplii. Also escaped salmon with high infection rates may disturb the natural balance between parasites and hosts. Thus, when the natural spatial separation of juvenile and adult salmon is lost, the infection rate increase in wild populations (Krkošek et al., 2005).

A comparative study on pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*) salmon in British Columbia, Canada, showed high abundances of lice near salmon farms and almost no parasites in control areas with no salmon farms. Up to 90 percent of the juvenile salmon tested were infected with lethal limits of lice (Morton, Routledge, Peet, & Ladwig, 2004). A similar study found the infection pressure near salmon farms to be 73 times higher compared to ambient levels (Krkošek et al., 2005).

In both studies, the presence of salmon farms near wild populations leads to higher infection rates, resulting in higher mortality. To reduce the influence of farmed salmon on wild salmon, wild populations need to be protected from the high concentrations of sea lice present in salmon farms. There are several techniques to reduce lice infestations.

The most obvious technique is the use of pesticides. The organophosphorus pesticides Nuvan and Neguvon have been used for decades to control sea lice in salmon farms. For the use of aquaculture the pesticide is classified as a medicine. The compounds in these medicines inhibit the nervous systems of insects and thus that of the sea lice as well. The medicine is either diluted in treatment baths, where plastic bags are wrapped around cages and entire cages are treated or mixed with the feed. Bathing is very effective but time consuming. When wrapping cages there is still flow and the medicine gets diluted, thereby not always treating every infection. The same goes for adding the medicine in feed. The last two methods also raise the question of dilution of medicine in the direct environment where it may kill non-target species. However it is argued rapid breakdown and fast dilution ensures that there is no significant threat to surrounding species (Pike, 1989a).

Another proposed method is the use of cleaner-fish (Costello, 2006). Several species of wrasse can successfully control sea lice infestation in salmon farms (Deady et al., 1995).

Medicines and cleaner-fish help to reduce numbers once a population is infected but prevention is cheaper and easier. To minimize the effect of sea lice on salmon farms the following guidelines should be followed to help reduce the risk of lice infestations: (1) Implement a period of 4-6 weeks in which no salmon are present to break the life-cycle of the sea-lice. (2) Treat smolt with parasiticides before transferred to seawater (3) Stock cages with cleaner fish. (4) Remove sick and infected fish. (5) Reduce the risk of escapes to reduce the transfer to wild populations and other farms (Costello, 2006).

Figure 3: A typical heavy infestation of an Atlantic salmon by the sea louse *Lepeophtheirus salmonis*.

6 Economics

Besides environmental and ecological impact, culturing salmon also has a large economic impact. The catch and culturing of salmon has grown in to a multi-billion euro industry. First only wild caught salmon were sold and supply and demand were determined by the annual catch. This has changed completely with the increase of cultured salmon. Today, the majority of global salmon supply is coming from cultured salmon. The total Atlantic salmon catch reported to the FAO, decreased from $13x10^3$ tons in 1980 to only $2.2x10^3$ tons in 2010. Cultured Atlantic salmon on the other hand increased from just a few tons in 1980 to a staggering $1400x10^3$ tons in 2010. According to the Norwegian Directorate of Fisheries, export prices for Atlantic salmon dropped from 11 euros (85 Norwegian Krone) in 1985 to 3 euros (22 Norwegian Krone) in 2004. Production costs showed a similar downward trend, greatly reducing the price for salmon (Knapp et al., 2007).

As a result of an increased production of cultured salmon, market prices no longer depend on the catch of wild salmon. Today wild salmon account for only a small part of that sold worldwide and wild caught salmon prices are closely linked to the prices of cultured salmon. This means that fishermen, who depend on the catch of wild salmon, need to catch more salmon to generate the same profit. Thus, the increased practice of culturing salmon actually pressure wild stocks even further. To stop this trend, wild and cultured salmon should be marketed differently. In some cases this is already being done resulting in higher prices for wild salmon (Knapp et al., 2007; Naylor et al., 2000).

7 Discussion

7.1 Fish feed and pollution

Although some forms of fish culture relieves pressure on ocean fisheries, such as carp, tilapia and mollusks, the culturing of salmon pressure natural stocks of fish only further (Naylor et al., 2000). A carnivorous fish such as salmon requires more wild fish biomass than is harvested, and thereby increase the fisheries on wild stocks. The estimated turnover rate of 2.5-5 is probably outdated as there has been a lot of progress the last 13 years. Still, although a lot has changed and efficient feeding techniques are already being applied the supply of fish feed is not limitless and alternatives should be explored. Less dependence on fish meal and fish oil will result in better profit for the salmon farming companies but also reduces pressure on world fisheries. Plant oil such as rape seed oil may be an alternative, but the digestibility is poor and the amino-acid balance is inappropriate (Turchini, Torstensen, & Ng, 2009). Therefore it is possible to partially substitute fish based feed with plant based feed, but fish meal and oil remain the main feed source (Bell et al., 2001; Torstensen et al., 2008). An increasing effort to optimizing salmon farms will result in a lower demand for fish oil and fish protein. In the future with partial replacement of fish product by plant products salmon culture might even contribute to world fish supplies instead of pressuring fish stocks in the future. Theoretically with reducing pressure on fish stocks worldwide, wild salmon will have more available food and this will increase their chance of survival. However, in practice the pressure on fish stocks may increase because replacing fish feed and fish oil with oils and proteins derived from plants will make for cheaper cultured salmon.

Not many studies are done on the long term effects of salmon farm pollution. One study showed that benthic communities, effected by intensive salmon farming, did not recover a year after the termination of salmon farming in the area (Pohle, 2001). This suggests long term effects on the environment in the area of salmon farms. This might affect wild salmon, as their habitat is being damaged.

7.2 Escapes

Escapes seem to form a serious threat to wild populations. They have a lower fitness and also carry diseases. When farming salmon near wild populations, genetically similar individuals should be used to decrease effect of lowering fitness when individuals escape. Also, genetically similar salmon will be better adapted to the local conditions. However, the most important measure is to make sure no individuals escape. Stronger nets and pens and better control should reduce the chance of escapes. Still, with the increase in farmed salmon, the chance of escapes also increases.

Recapture of escaped salmon might also reduce the number of escapes. Experiments show that bag-nets and angler fishers were able to recapture 79% of 39 released individuals within one month after release (Chittenden et al., 2011). However when salmon escape from a farm, it is likely more than 39 individuals and recapture rates might not be so high. In another experiment 1031 salmon were released and 40% was recaptured with the use of gill-nets (Skilbrei & Jørgensen, 2010). Despite the partial effectiveness, recapturing of escaped salmon costs a lot of effort and money and is not likely to be applied in salmon farming. It seems the easiest way of reducing the threat of escaped farmed salmon it to reduce the chance of escape itself by regular maintenance and stronger cage constructions.

7.3 Sea lice

To reduce the effect of cultured salmon on wild salmon, infection rates of sea lice must be reduced. However with an increase in the amount of cultured salmon, the infection rate of sea lice also seems to increase (Jansen et al., 2012). Despite increased intervention efforts in the period of 2009-2010, infection rates did not decrease. The relationship between sea lice and farmed salmon inhibit the increase in farmed salmon density. With an increase in salmon density, the infection rate of sea lice also increases, reducing the survival chances of the salmon so it is no longer economically feasible to increase stock densities.

Another concern is the reduced sensitivity to against drug most commonly used in the control of sea lice (Torrissen et al., 2013). This calls for different types of pesticides or a different approach. Already mentioned, cleaner-fish might play an important role in the control of sea lice but for now sea lice remain a major problem (Costello, 2006; Deady et al., 1995; Pike, 1989b). As long as sea lice are not under control in salmon farms they pose a big threat to wild salmon populations.

7.4 Economics

Prices for wild and cultured salmon are closely linked which is not beneficial for wild salmon. Better marketing for wild salmon products might be able to change this. For instance, there are indications that wild salmon contain less contaminants compared to cultured salmon. The high concentrations of contaminants such as dioxins and PCB’s in farmed Atlantic salmon might form a health risk, detracting from the positive effects of the consumption of salmon (Hites et al., 2004). This is not the case in wild caught salmon which may lead to better prices. If prices for wild and farmed salmon are decoupled, the financial influence of salmon farming on wild salmon fishing should decrease. If this leads to better prices for wild salmon, pressure on wild stocks might decrease.

8 Conclusion

Cultured salmon has without a doubt an influence on wild populations. With the rapid increase in salmon farming in the last three decades, the influences on wild salmon have also increased significantly.

Nutrients and waste coming from salmon farms have a negative influence on surrounding benthic communities, but the effect on wild salmon seems to be minimal. More research, especially studies to the long time effects of salmon farms on the surrounding water body are needed as information is scarce.

Escaped cultured salmon reduce the fitness of wild salmon populations so the chance of escapes should be reduced to a minimum as recapturing is time consuming and expensive.

Salmon farms function as a sink for sea lice and thereby threaten passing migrating wild salmon. Although a lot of effort is put in to the control of sea lice infestations, sea lice remain a big problem and are even becoming resistant to some of the pesticides. A different approach such as the use of cleaner-fish might be a viable alternative contributing to a solution.

The prices of wild and cultured salmon need to be decoupled, reducing the effect of cultured salmon on wild salmon. Marketing could increase the prices of wild salmon.

Overall salmon farming seems to have a negative influence on wild populations, both directly and indirectly. In the future fish feed might be replaced by plant sources, the turnover rate might increase and the effect of escaped salmon and sea lice might be reduced. In addition, wild salmon should be marketed differently. But, until all these problems are resolved natural populations are still being threatened by the practice of culturing salmon and the future of wild salmon seems uncertain.

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