



## SALMON & TROUT ASSOCIATION

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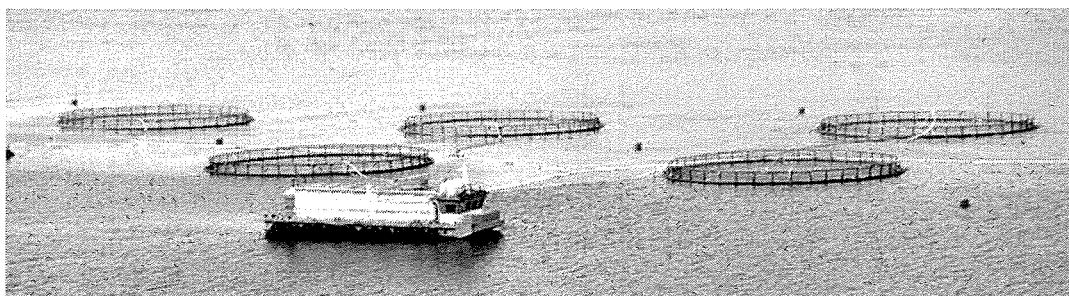
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### Salmon and Trout Association: Aquaculture

The Salmon & Trout Association (S&TA) is lobbying for a sustainable aquaculture industry which does not impact wild salmonid stocks. If fish farming and wild fisheries in Scotland were allowed to flourish together at their optimum, sustainable levels, the benefit to local employment and economies, often in remote communities, would be enormous. As it is, S&TA feels that aquaculture has been allowed to expand with limited consideration given to its impact upon the environment or wild fisheries interests.

Marine fish farming has advantages:

- The price of salmon has dropped, taking some pressure off wild stocks
- Farmed salmon accounts for 40% of Scottish food exports
- Aquaculture is an important employer, often in remote communities.

However, there are also significant disadvantages:

- Sea lice. Lice emanating from farmed salmon attach to wild salmon and sea trout smolts, causing widespread mortalities and the collapse of many Scottish W coast salmonid populations. This has resulted in the loss of fisheries and hotel jobs, a fact seldom taken into account when talking-up the social benefits of aquaculture.
- Chemicals, including antibiotics, used in aquaculture to combat disease and parasites are invariably harmful to the environment, potentially creating barren habitat around farms and killing shellfish populations and many other marine organisms
- Farm escapees endanger wild salmon populations through cross-breeding, creating offspring that are less fit for survival at sea. This puts the wild population at risk.
- Threat to UK salmon biodiversity. UK salmon have unique genetic lineage specific to each river system.
- Net loss: Farmed fish are fed pellets made from marine fish – often depleting those wild fish species on a global scale.
- Sewage from farms pollutes surrounding waters.
- Location of farms. Farms are placed in estuaries and lochs into which salmonid rivers flow – forcing migrating wild salmon and sea trout to run the gauntlet of lice infestation.

### Action

- Sea Cage Location.** The need is to; prevent the transfer of mobile sea lice passing from farms to wild salmon smolts, and/or locally resident sea trout smolts; avoid the transmission of disease and the effects of biological and chemical pollution; and reduce the risk of adult fish farm escapees interbreeding with wild fish. To this end, salmon farms should be moved away from the path of migrating salmon and sea trout smolts. Ideally, this should apply to sites in all estuaries and salt water lochs, as well as on offshore migration routes. In practical terms, it will be necessary to give priority to cages whose location affects the most significant runs of salmon and/or sea trout. Work to establish relative vulnerabilities, and to identify acceptable sites for relocation at or beyond an appropriate safe distance, should proceed as a matter of urgency. Further research will be required to establish offshore migration corridors where a threat may exist. Meanwhile, effective fallowing and stocking cycles, timed to avoid mobile lice production during wild smolt migration periods, must be applied. **No new sites should be allowed in or near sensitive estuaries or lochs, or on potential migration routes. A thorough independent Environmental Impact Assessment must be undertaken on all new applications to ensure minimal impact on wild migratory salmonids. The Precautionary Principle must apply in all cases where doubt exists.**
- Smolt farm location.** To avoid the risk of interbreeding by escaped smolts, the installation and **operation of smolt farms should not be allowed in any river system containing wild salmonids.** This is already the case in Norway, the world's largest producer of farmed salmon, and must be the same in Scotland – **within time scales set by the Scottish Government.**
- Stocking policy.** To allow for the perennial potential for escape from the strongest sea cages, whether due to storm damage or sabotage, **interbreeding of wild fish with escaped adults should be avoided by the mandatory stocking of triploid (sterile) salmon in fish farm units – to be achieved within time scales set by the Scottish Government.**

- d. **Enclosed systems.** Because the remedial actions listed above are limited both in feasibility and effectiveness, the ultimate solution should be for all installations to consist of totally enclosed systems, either land or sea based. Such installations would minimise escapes, prevent the transfer of parasites and the spread of disease, and allow waste effluents to be collected and treated in order to avoid pollution. **The industry must research new technology as a matter of urgency, and within time scales set by the Scottish Government after consultation with aquaculture and wild fish interests. No new sites should be permitted unless assurances of security can be supported; essential in light of the industry's stated objective of increased production within Scottish waters.**

**The S&TA therefore calls for:**

- The target of the industry and Scottish Government must be for the statutory use of enclosed systems for rearing fish, whether on land or at sea, therefore cutting out any interaction between farmed and wild salmon and sea trout. This should be within a timescale agreed between Government, industry and wild fish organisations
- Meanwhile, the Precautionary Principle (as enshrined in EU legislation protecting habitats) should be adhered to at all times
- An effective lice dispersal model must be developed in order to assess acceptable maximum farm/area lice levels
- A list of ecologically and economically sensitive sites should be drawn up immediately
- Sea-based salmon farms must be moved away from locations with significant salmon and sea trout migration runs, within estuaries, lochs and offshore. As a practical start, an experiment should be conducted by removing an individual farm from a sensitive site - agreed with wild fish organisations - and the effect on wild salmon stocks monitored
- No new sites should be permitted in sensitive areas highlighted by the list above
- New fish farm applications must be supported by independent Environmental Impact Assessments
- Salmon smolt farms should be banned from operating within any wild salmonid river
- The impact of escapes should be reduced by the mandatory stocking of sterile fish within an agreed timescale

**Other information**

[Executive Summary of the Impact of Salmon Aquaculture on Our Native Fisheries and the Aquatic Environment. \(2010\)](#)

[Impacts of salmon aquaculture on native salmonids fisheries and the aquatic environment- briefing paper \(2010\)](#)

[Aquaculture Policy Statement \(2010\)](#)

[Salmon Aquaculture Dialogue: Draft indicators for environmentally, socially and economically responsible salmon farming. \(2009\)](#)

[Ford and Myers. \(2006\). A Global Assessment of Salmon Aquaculture Impacts on Wild Salmonids](#)

[Marine Conservation Society. \(2007\). Principles and Criteria for Sustainable Fish Farming](#)

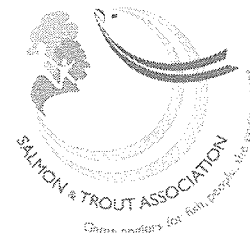
[Lenfest Ocean Program. \(2007\). Aquaculture Impacts on Wild Salmon](#)

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## **Executive Summary**

### **The Impact of Salmon Aquaculture on Our Native Fisheries and the Aquatic Environment.**

Aquaculture has the potential to be a sustainable source of seafood, which could help to alleviate some of the pressures on the world's oceans. However, the current stewardship of fish farms is in question, due to the impact of aquaculture on wild fish and the surrounding environment.

In 1980, commercial wild fisheries harvested 99% of salmon consumed worldwide. By 2003, approximately 60% of marketed salmon was from aquaculture. Salmon is now farmed in 24 countries, with Norway, Chile, Scotland and Canada being responsible for 71% of global production. The Atlantic salmon is the most economically important species, representing 89% of salmon production. The industry has become more technologically advanced, but full-time employment at farms has decreased.

This paper focuses on the scientific evidence of the impact of current stewardship of salmon farms on the surrounding environment and, in particular, wild salmon and sea trout.

#### ***Impacts of salmon farming on wild salmon and the surrounding environment***

Salmon farms pose a threat to wild salmon and the environment in several ways. These include; spreading of parasites – particularly sea lice - and diseases; interbreeding of wild and farmed salmon; chemical waste; biological waste and eutrophication.

#### ***Sea lice***

The sea louse is an ocean parasite of Atlantic salmon, which easily transfers from farmed to wild populations as open cage systems allow its planktonic larval stage to disperse into the surrounding water. This can be detrimental to migrating fish populations, especially juvenile salmon and sea trout, which are most vulnerable during and immediately after smoltation. Sea lice may also spread microbial and bacterial diseases.

Laboratory dose-response studies on wild salmon smolts found infection of 0.75 lice per gram of fish weight would cause death, while monitoring in the Norwegian sea found no live post smolts with more than 10 adult lice. Other experiments have found that 30-50 sea lice larvae can cause death in juvenile salmonids. Sea trout have been captured from fish farming areas with between 3-20 times the natural infestation rate of adult female lice per fish. In Norway, specialists recommend less than 10 lice per wild salmonid to ensure no impact on wild salmonid populations.

Salmon farms alter the natural relationship between lice and wild salmonids. For example, wild salmon infested with sea lice would typically suffer from reduced foraging efficiency, thus increasing host mortality, while this is overcome by artificial feeding in aquaculture. Fish farms also expose salmonids to the parasites at an abnormally young period of development, and studies have shown wild salmon and sea trout numbers declining more significantly in areas with fish farms than areas without. Research from two Norwegian fjords found 86% of wild migrating juvenile salmon died as a direct result

of sea lice infestations whilst migrating past salmon farms, and Canadian scientists calculated a 99% collapse in one local native pink salmon population within four generations if lice infestation continued.

#### ***Disease transfer***

The high density of fish at fish farms functions as a reservoir for pathogens and diseases, providing an ideal breeding ground and facilitating movement into nearby wild populations. In addition, escapees may transmit disease to wild stocks which have no natural defences. Wild fish can also transfer disease to fish farm populations, allowing pathogens to multiply rapidly and exacerbate natural levels.

#### ***Escapee salmon: Interbreeding of wild and escaped (genetically engineered) salmon***

Farmed salmon escape practically everywhere there is aquaculture, often in large numbers compared to wild stocks. In Norway, it is estimated that 1.3 million salmon escape each year and, in 2000, an estimated 500,000 fish escaped in Scotland. There is growing evidence that these escapees are establishing significant populations in the wild. It is estimated that on the west coast of Scotland, 22% of 'wild' caught salmon were farmed escapees and, within Norwegian rivers in close proximity to fish farms, up to 80% of the spawning fish in one season were from fish farms. Experimental ocean fishing off the Faroe Islands during the mid 1990s found 20-40% of salmon caught was from farmed origins.

Farmed salmon typically show lower genetic variability than wild salmon, leading to farmed fish diluting gene pools and local adaptability in wild populations. Farmed salmon differ from wild salmon both morphologically and physically, which can affect behaviour, spawning success and competitive ability. Experiments have shown that farmed fish have survival rates as low as 16% of native fish in the wild.

The use of sterile fish in aquaculture has been found to reduce return rates of escaped farmed salmon to both estuaries and freshwater. This, coupled with their inability to produce viable offspring, could reduce the ecological impact of escapee farm fish.

#### ***Chemical wastes***

Antibiotic and insecticide medication for diseases and parasites in aquaculture can expose the surrounding environment to chemical wastes, which can be toxic to other aquatic organisms.

Outputs from fish farms are controlled by discharge consents. However, the number of drugs permitted by the Veterinary Medicines Directorate for use in fish farms has grown with the scale of the industry, expanding from three drugs in 1989 to 40 in 2002. Between 1985 and 1987 in Norway, antibiotic use increased from 17 to 48 mt per year, exceeding the combined use by humans and terrestrial animals in the country during the same period. The incautious and profligate use of these antibiotics can lead to the development of drug-resistant strains of diseases in both wild and farmed populations.

Elevated levels of zinc, copper and cadmium have been found in fish farm sediments as a result of feed and faecal outputs, and the anti-foulant products used in aquaculture. A survey of metal concentrations in surface sediments at 70 sites around fish farms in Loch Craginich, on the west coast of Scotland, found maximum concentrations of 921, 805 and 3.5  $\mu\text{g g}^{-1}$  of zinc, copper and cadmium, respectively. Elevated levels of sediment metals can have a wide range of impacts on the benthos, including altering community structure and reproductive success.

#### ***Biological Waste and Nutrient Loading***

Sediments from faeces and uneaten food beneath fish cages have been found to be enriched in phosphorus, nitrogen, organic carbon and zinc, posing a major threat to water quality and environmental integrity. The wastes can also smother animal and plant communities beneath cages, disrupting benthic communities and impacting sediment nutrient cycling.

#### ***Summary***

Despite some common perceptions to the contrary, the scientific literature unequivocally demonstrates that, to varying degrees, fish farms are having a detrimental impact on native fisheries, the wider environment and the many public benefits associated with it. In order to make aquaculture a viable and sustainable industry, these threats must be addressed as an urgent priority.



## Aquaculture Policy Statement

Despite some common perceptions to the contrary, scientific literature unequivocally demonstrates that, to varying degrees, fish farms are having a detrimental impact on native fish stocks, the surrounding environment and the many public benefits associated with it. In order to make aquaculture a viable and sustainable industry, these threats must be addressed as an urgent priority. Furthermore, from an ecosystems perspective, the benefits of farmed fish production under current stewardship may be heavily outweighed by wider impacts on the environment and the many other sectors of society that this affects. The Precautionary Principle should be enforced to protect wild Atlantic salmon (an EU Habitats Directive protected species) and sea trout (a Biodiversity Action Plan Species) and the surrounding aquatic environment. This is also implicit under the EU Water Framework Directive (WFD), which requires 'good ecological status' and no deterioration in all freshwater, intertidal and coastal water bodies.

### Required Action

- a. **Sea Cage Location.** The need is to; prevent the transfer of mobile sea lice passing from farms to wild salmon smolts, and/or locally resident sea trout smolts; avoid the transmission of disease and the effects of biological and chemical pollution; and reduce the risk of adult fish farm escapees interbreeding with wild fish. To this end, salmon farms should be moved away from the path of migrating salmon and sea trout smolts. Ideally, this should apply to sites in all estuaries and salt water lochs, as well as on offshore migration routes. In practical terms, it will be necessary to give priority to cages whose location affects the most significant runs of salmon and/or sea trout. Work to establish relative vulnerabilities, and to identify acceptable sites for relocation at or beyond an appropriate safe distance, should proceed as a matter of urgency. Further research will be required to establish offshore migration corridors where a threat may exist. Meanwhile, effective fallowing and stocking cycles, timed to avoid mobile lice production during wild smolt migration periods, must be applied. **No new sites should be allowed in or near sensitive estuaries or lochs, or on potential migration routes. A thorough independent Environmental Impact Assessment must be undertaken on all new applications to ensure minimal impact on wild migratory salmonids. The Precautionary Principle must apply in all cases where doubt exists.**
- b. **Smolt farm location.** To avoid the risk of interbreeding by escaped smolts, the installation and **operation of smolt farms should not be allowed in any river system containing wild salmonids.** This is already the case in Norway, the world's largest

Fishmongers' Hall, London Bridge, London EC4R 9EL

T: 020 7283 5838 | F: 020 7626 5137 | E: [hq@salmon-trout.org](mailto:hq@salmon-trout.org) | W: [www.salmon-trout.org](http://www.salmon-trout.org)

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producer of farmed salmon, and must be the same in Scotland – **within time scales set by the Scottish Government.**

- c. **Stocking policy.** To allow for the perennial potential for escape from the strongest sea cages, whether due to storm damage or sabotage, **interbreeding of wild fish with escaped adults should be avoided by the mandatory stocking of triploid (sterile) salmon in fish farm units - to be achieved within time scales set by the Scottish Government.**
- d. **Enclosed systems.** Because the remedial actions listed above are limited both in feasibility and effectiveness, the ultimate solution should be for all installations to consist of totally enclosed systems, either land or sea based. Such installations would minimise escapes, prevent the transfer of parasites and the spread of disease, and allow waste effluents to be collected and treated in order to avoid pollution. **The industry must research new technology as a matter of urgency, and within time scales set by the Scottish Government after consultation with aquaculture and wild fish interests. No new sites should be permitted unless assurances of security can be supported; essential in light of the industry's stated objective of increased production within Scottish waters.**

The S&TA therefore calls for:

- The target of the industry and Scottish Government must be for the statutory use of enclosed systems for rearing fish, whether on land or at sea, therefore cutting out any interaction between farmed and wild salmon and sea trout. This should be within a timescale agreed between Government, industry and wild fish organisations
- Meanwhile, the Precautionary Principle (as enshrined in EU legislation protecting habitats) should be adhered to at all times
- An effective lice dispersal model must be developed in order to assess acceptable maximum farm/area lice levels
- A list of ecologically and economically sensitive sites should be drawn up immediately
- Sea-based salmon farms must be moved away from locations with significant salmon and sea trout migration runs, within estuaries, lochs and offshore. As a practical start, an experiment should be conducted by removing an individual farm from a sensitive site - agreed with wild fish organisations - and the effect on wild salmon stocks monitored
- No new sites should be permitted in sensitive areas highlighted by the list above
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Comments from:  
**Salmon and Trout Association**  
**Association of Salmon Fishery Boards**  
**Rivers and Fisheries Trusts of Scotland**

on:  
**Salmon Aquaculture Dialogue; Draft indicators for environmentally, socially and economically responsible salmon farming.**

**1. A Salmon Aquaculture Accreditation Scheme must include the following:**

- 1.1 A strengthened industry code of practice. As a baseline standard, the COP must reflect agreements made within the NASCO Salmon Aquaculture Task Force, in conjunction with the ISFA, and to which all NASCO countries are signatories. (Section 2.3)
- 1.2 The acknowledgement of certified companies that salmon aquaculture can create significant impacts on wild fisheries, particularly from sea-lice and hybridisation between wild fish and farm escapees. There must be a signed commitment to improve operating practices towards environmental sustainability, with a built in review process. (Section 2.3)
- 1.3 An effective lice dispersal model must be developed in order to assess acceptable maximum farm/area lice levels (Section 2.7)
- 1.4 Farm accreditation should only run for one year and must be renewed annually against results of review process (Section 2.4)
- 1.5 The standards' document must be restructured, so that the list of indicators is split into those required at individual farm level, and those required at an area level, taking account of the accumulative effect of several farms in a given area (Section 2.5)
- 1.6 The industry must draw up a list of sensitive aquaculture sites and economically important catchments. Farms sited within these areas cannot be certified. (Section 2.6)
- 1.7 The indicators must include the environmental impact on sea trout (*Salmo trutta*) populations, referring to the lice dispersal model, taking into account the coastal habitat of sea trout (Sections 2.7 and 2.8)
- 1.8 Certified farms must only stock smolts produced in enclosed units, or from farms on river systems that have no significant wild salmon populations. (Section 2.9)

**2. General comments**

- 2.1 The Steering Committee must define 'environmental sustainability'
- 2.2 In its current form, the indicators' document threatens to standardise current flawed operating procedures, rather than tackling the deep rooted problems associated with salmon aquaculture. In

order to achieve environmentally sustainable aquaculture, the impacts of escapees, disease and parasite transfer, and water pollution through waste material, must be addressed. We believe the only way to ultimately achieve this is via enclosed aquaculture systems. However, in the short to medium term, the standards within industry codes of practice must be significantly strengthened and adhered to, otherwise any accreditation scheme is in danger of giving a completely false impression to consumers as to the sustainability of salmon farming.

2.3 In Scotland, the Government and industry still officially deny the impact of salmon farms on native salmonids and the surrounding environment. In order to create a level playing field, the final standards should include a declaration by individual companies, acknowledging that salmon aquaculture can create significant impacts on wild fisheries, particularly in the context of impacts by sea-lice and hybridisation between wild fish and escapees, and their commitment to improve operating practices towards environmental sustainability, within agreed timescales and with an annual review process. As a baseline standard, the accreditation scheme must reflect agreements made within the NASCO Salmon Aquaculture Task Force, in conjunction with the ISFA, and to which all NASCO countries are signatories. These objectives can be found by linking to <http://www.nasco.int/pdf/aquaculture/BMP%20Guidance.pdf> - 'Guidance on Best Management Practices to address impacts of sea lice and escaped farmed salmon on wild salmon stocks'

2.4 We strongly support annual certification, and believe that farms must be required to show yearly operational improvements, beyond the set standards, to continue being accredited.

2.5 The standards' document must be restructured, so that the list of indicators is split into those required at individual farm level, and those required at an area level. Area level standards are necessary to tackle the cumulative impacts of farms within a given management area. Therefore, in order for this certification process to assess the impact on wild salmonids, the industry must be required to invest in independent monitoring at an area level. It is therefore unlikely that an individual farm would be accredited within a farming area unless all other units are included in the relevant Area scheme.

2.6 The location of farms is vital in determining their impact on native salmonids. This is lost within the current indicators. It must be explicit that certain farms, such as those located close to wild salmonid migration paths, cannot be certified, because it is impossible to eliminate escapes and disease transfer within open system aquaculture. The precautionary principle must be enforced in two ways:

- ❖ The industry, in conjunction with wild fish interests (including Rivers and Fisheries Trusts where appropriate), must draw up a list of sensitive aquaculture sites where farms cannot be certified, both now or in the future, because of their potential impact on wild salmonid stocks.
- ❖ The industry, in conjunction with wild fish interests (including Rivers and Fisheries Trusts where appropriate), must draw up a list of economically important catchments where there should be a presumption against future aquaculture development (where there is currently none) or a presumption in favour of relocation and restoration (where farm units already exist)



2.7 An effective lice dispersal model must be developed as part of this accreditation scheme in order to assess acceptable maximum farm/area lice levels. Where wild salmonid migration routes are known using both current and future data - farms should only be established if the lice dispersal model shows minimal impact on salmonids using these routes. This model will also be relevant in determining the impact of lice from offshore farms.

2.8 The indicators must include the environmental impact on sea trout (*Salmo trutta*) populations, as they remain in coastal waters throughout most of the marine phase of their life cycle, and therefore may be more vulnerable to local parasite and disease transfer. The lice dispersal model must therefore inform potential to impact sea trout populations, taking into account current research being undertaken into the habits and movements of sea trout in their marine phase.

2.9 All certified farms must be required immediately to stock smolts produced in enclosed freshwater systems, or in systems that have no significant wild salmon populations – either present or historical. Smolt producing units in freshwater pose a greater risk of introgression, due to serial escapes, than from marine cage sites, given the life stage at which escapes will occur. Norway already prohibits smolt units on rivers containing wild salmonids. This should be the basic standard for certificated farms.

### **3. Comments on Principle 3: Protect the health and genetic integrity of wild populations.**

3.1.1. This documentation must be publically available. This should be extended to require the certified companies to make publically available information on their internal research programmes.

3.1.2. If non-endemic notifiable diseases are detected on a farm, it should lose its certification until the cause of disease can be scientifically established, and the threat removed.

3.1.4. This should be changed to: 'Maximum on-farm lice levels, related to a maximum agreed area lice level'. An effective lice dispersal model must be developed as part of this accreditation scheme in order to assess acceptable maximum farm/area lice levels. We support a baseline genetic standard, such as the current Norwegian standards, but in some locations the lice dispersal model may indicate where lower standards are necessary to protect wild fish populations.

3.1.7c. There is a need for specialists to create a standardised protocol for recording numbers of lice on wild fish (e.g. photographic images from counting stations), and a requirement for farms to invest in area/regional monitoring structures.

3.1.8c. We have serious concerns about defining a 'minimum safe distance'. It is impossible to make a generic prediction of a safe distance, given the site specific nature of these impacts. As stated above, a lice dispersal model must be established to determine, as far as possible, the potential impact on wild salmonids. Knowledge of migration routes should also be taken into account as it becomes available, as should the list of sensitive and economically important inshore sites.

3.2.1. The draft suggests that non native species can be introduced if they are assessed to pose an 'acceptable level of risk'. We question how an 'acceptable' level of risk can be determined when we do not understand the ecosystem level impacts of non-native species, and when open systems allow full interactions with the surrounding environment. The impacts of non-natives can be very complex and take time to become apparent. We believe non-native salmon aquaculture should not be permitted for accreditation, unless within closed systems - where stricter control can be exercised and environmental impact genuinely minimised.

3.3. We support prohibiting transgenic salmon on farms, and recommend that the Steering Committee seeks a clear legal definition of 'transgenic' from the technical specialists involved.

3.4. The NASCO Aquaculture Task Force recommendations should be included in the Accreditation scheme. The current indicators state; 'they seek only to minimise escapes from a farm'. It is important that funds are also made available to advance work on the impact of escapees on wild salmonids. The accreditation body must establish a mechanism for collecting area level funds from accredited farms for an independent body (such as local River/Fisheries Trusts in the UK) to genetically sample adult and parr salmonids in local river systems to determine the impact of farm escapees. This data should be used in the future to set standards on 'acceptable' impact.

3.5. It must be explicit that certain farms cannot be certified due to their location, as indicated through the list of environmentally sensitive and economically important sites, the use of the lice dispersal model and any known – and future - information on migration routes.

#### **4. Summary**

We believe that the above are basic principles that must be applied to a certification initiative. The greatest danger of seeking only to set standards on limited criteria – on merely the sustainability of feed sources, for instance – is that the public will perceive the whole of the farming operation to be environmentally sustainable when, in reality, significant impact on wild fish stocks and marine and freshwater habitats could still be occurring.

Meanwhile, further research is required into measures necessary to move the industry towards environmental sustainability, with objectives for achieving a high degree of certainty in the following:

- ❖ Minimising escapes
- ❖ Minimising transfer of disease and parasites between farmed and wild fish
- ❖ Minimising pollution from food and faecal waste
- ❖ Inshore Migration routes of wild salmonids, coordinating data with known offshore routes established through such initiatives as the SALSEA Project.

We make no suggestion as to how such research should be funded, except to note that the company set up to process the accreditation scheme would seem to be a logical coordination point.



## Briefing Paper

### Impacts of salmon aquaculture on native salmonids fisheries and the aquatic environment

Aquaculture has the potential to be a sustainable source of seafood, which could help to alleviate some of the pressures on the world's oceans. However, the sustainability of current stewardship of fish farms is in question. This is firstly due to the impact of the farms on the surrounding environment, including nutrient enrichment, habitat alteration and damage to wild fish populations (Gross, 1998), and secondly the use of wild fish in fish meal to feed farmed carnivorous fish, such as salmon.

In 1980, commercial fisheries harvesting wild stocks produced 99% of salmon consumed worldwide. By 2003, approximately 60% of salmon were produced in fish farms (FAO, 2005). Salmon are now farmed in 24 countries, with Norway, Chile, Scotland and Canada responsible for 71% of global production. The Atlantic salmon (*Salmo salar*) is the most economically important farmed salmon species, representing 89% of salmon production, with the remainder predominately Chinook salmon (*Oncorhynchus tshawytscha*) and Coho salmon (*Oncorhynchus kisutch*) (FAO, 2005).

The industry has become more technologically advanced, and with it full-time employment at farms has decreased. In Chile, 40% fewer people were employed by the industry in 2000 compared with 1998, due to automation of feeding systems and the use of prefabricated PVC cages (Claude and Oporto, 2000).

Salmon, once a food for the wealthy, is now an everyday commodity available to a far wider range of consumers. However, this abundance, deriving from intensive salmon farming in multiple locations, can come at an environmental cost. This paper focuses on the scientific evidence of the impact of current stewardship of salmon farms on the surrounding environment and, in particular, its effects on wild salmon and sea trout (Annex 1: Atlantic salmon biology). An additional paper will be available shortly reviewing the sustainability of using wild fish in fish meal.

#### ***Impacts of salmon farming on wild salmon and the surrounding environment***

Salmon aquaculture is certainly not the only threat to wild salmonid populations. Wild Atlantic salmon populations have been in decline throughout their natural range since the early 1970's, thought mainly to be due to reduced oceanic feeding opportunities related to climate change (Friedland and Reddin, 1993). However, there is evidence that the salmon aquaculture industry can impact already weakened wild stocks.

The risks to society from aquaculture, identified in the FAO technical paper (2008) '*Understanding and applying risk analysis in aquaculture*' include:

- Environmental risks; pollutions from feeds, drugs, and chemical wastes, and alteration of water currents and flow patterns
- Biological risks; introduction of invasive alien species and pathogens, and genetic impacts on native stocks
- Social risks; displacement of artisanal fishers, and food safety issues.

A study carried out by Butler and Watt (2003) found compelling evidence that salmon farms could have a serious and sustained detrimental impact on the abundance of wild juvenile salmon, as surveys on 230 sites in 35 rivers revealed rivers with fish farms in their sea lochs had 62-82% and 44-62% lower mean abundances of salmon fry and parr, respectively. The study also found severe collapse of adult Atlantic salmon stocks in 50% of the rivers with farms, where only remnant stocks remained. Ford and Myers (2008) compared marine survival of salmonids (Atlantic salmon, sea trout, pink chum and Coho salmon) in areas with and without fish farms in Scotland, Ireland and Canada. The results showed, on average, that fish farms had a significant negative impact on salmonid populations, typically in the order of a 50% reduction in survival or abundance of salmonids.

The threats that salmonid farms and farmed fish pose to wild fish stocks and the environment, include:

#### ***Disease and other parasite transfer***

Open system aquaculture entails the transfer of unregulated water supply between wild and captive salmonid populations, which can result in exposure to diseases between both. The high density of fish at fish farms can function as a reservoir for pathogens and diseases, potentially providing an ideal breeding ground and facilitating movement into nearby wild populations (McCallum and Dobson, 1995; Daszak *et al.*, 2000). Transmission could also be amplified by escaped fish. In turn, diseases could theoretically be transmitted from wild stocks to the large numbers of farmed fish.

For example:

- ISA is a lethal, highly contagious viral disease spread adult-to-adult in freshwater and seawater (Håstein, 1997). ISA was first discovered in 1984 in the Norwegian salmon fishing industry, and quickly spread to over one hundred farms (Thorud and Djupvik, 1988). Mortality rates associated with ISA during this outbreak varied considerably, from low mortality to some farms losing 80% of the fish stock (Hastein *et al.*, 1999). By 1999, it had spread to approximately 10% of all Scottish salmon farms. There is some evidence of the ISA virus in disease in wild salmon parr, juvenile brown trout and sea trout, and eel (Raynard, 2000). The virus is thought to be carried in the mucus, urine and faeces of salmon. Therefore, the high densities in farms create contagious areas for nearby wild salmon.
- Furunculosis, caused by the bacterium *Aeromonas salmonicida*, is one of the most serious infectious diseases of wild and farmed salmonids throughout the world (Ellis, 1997). Furunculosis, which is often fatal, is generally associated with crowded conditions. It was thought to be a disease occurring exclusively in salmonids; however several cases of *Aeromonas salmonicida* infections have been reported in non-salmonids, which have had some form of contact with infected salmonid populations (Bernoth, 1997).

Other viral diseases which have had a significant impact on the European aquaculture industry include; inter alia Infectious Pancreatic Necrosis (IPN), Viral Haemorrhagic Septicaemia (VHS), Pancreas Disease (PD) and Ulcerative Dermal Necrosis (UDN). Movements of fish for public and commercial fish farming have also been linked with the movement of pathogens, for example *Gyrodactylus salaris* in Europe, and whirling diseases in the United States (St-Hilaire *et al.*, 2002; Murray *et al.*, 2002).

Farmed systems are different from the wild, in that diseased, weaker wild fish are constantly being removed by predators (Mesa *et al.*, 1998), lowering the number of new infections likely from each

infectious individual (Reno, 1998). This is not the case in aquaculture units, when although good husbandry practice supports the routine removal of moribund stock, this is not always achievable.

As aquaculture continues to expand and diversify, new diseases will continue to emerge, affecting wild and farmed stocks alike. Biosecurity programmes, such as improved operational husbandry, could help mitigate this risk (Murray and Peeler, 2005).

### **Sea lice**

The sea louse (*Lepeophtheirus salmonis*) is a marine parasite of salmonids, which grazes the surface of the fish (Pike and Wadsworth, 2000; Costello, 2006). Despite more than 800 sea lice research publications over the last 30 years, it is estimated that, globally, sea lice cost the aquaculture industry US\$480 million a year (Costello, 2009a). Sea lice transfer readily between farmed and wild fish populations (Murray and Peeler, 2005). Open cages allow planktonic larvae to disperse from dense agglomerations of adult lice on farmed salmon into the surrounding waters (Costello *et al.*, 1996). This can be detrimental to migrating fish populations, either young smolts leaving freshwaters for coastal areas and the open ocean, or mature fish returning to rivers to spawn.

When present in large numbers, pre-adult and adult lice can cause severe damage whilst feeding on hosts (Brandal and Egidius, 1979; Grimnes and Jakobsen, 1996), including ingesting the entire skin layer of the fish and leaving open wounds. In such circumstances, plasma cortisol and plasma glucose rise, killing cells in the process (Mustafa *et al.*, 2000; Easy and Ross, 2009) and impairing the immune response of the fish to the lice (Heuch *et al.* 2005). Sea lice have been shown to significantly affect ion regulation, indicating juvenile salmon are most vulnerable during smoltation (Brauner *et al.*, 2009). Salmon survival and spawning success can also be jeopardised by reduced blood circulation and approximately 20% less agility in the water (Wagner *et al.* 2007).

In addition to the lesions and skin erosion caused by the lice, sea trout (*Salmo trutta*) have also been found to prematurely return to freshwater, a behavioural response of the host fish, attributed to excessive sea lice burdens (Tully *et al.*, 1993; Birkeland, 1996; Birkeland and Jakobsen, 1997; MacKenzie *et al.*, 1998; Bjørn *et al.*, 2001; Tully *et al.*, 1999). This behaviour, in the short term may improve survival, but growth potential will inevitably be compromised by sacrificing important foraging opportunities (Webster *et al.*, 2007). The fish is also exposed to an increased risk of secondary infection through the lesions in freshwater (Wells *et al.*, 2007). Furthermore, sea lice themselves may also be vectors for microbial and bacterial diseases (e.g. Infectious salmon anaemia (ISA) (Nylund *et al.*, 1993), although this has not yet been proven (Revie *et al.*, 2009). In Norway, sea trout post-smolts heavily infected with sea lice have only been captured in areas where salmon are farmed (Birkeland and Jakobsen, 1997; Bjørn *et al.*, 2001), and in Ireland the highest sea lice abundances have been recorded on post-smolt sea trout within 20km of salmon farms (Gargan *et al.*, 2003). In western Scotland, 14-40% of sea trout were found to carry potentially lethal lice infections in June 1998-2000 (Butler, 2002).

The severity of lice infection on farmed and wild salmon is dependent on a number of factors including; number of lice (infection pressure), transport of lice through currents (Wallace, 1998), behavioural impacts of salinity (sea lice avoid water with less than 20‰ salinity), temperature (Heuch, 1995), infection success and survival (Tucker *et al.*, 2000; Johnson and Albright, 1991), and susceptibility and behaviour of hosts (Heuch *et al.*, 2005). For individual fish, the impact of infection and vulnerability to sea lice is difficult to define because it is dependent on sea lice density and the developmental stage of the parasite (Grimnes and Jakobsen, 1996), the size of the host (Finstad *et al.*, 2000; Glover *et al.*, 2001), the hosts physiological and immunological state, and the time of year (Revie *et al.*, 2009). Research by Penston and Davis (2009) found a positive relationship between the scale of salmon production and sea lice larval abundance in Loch Torridon, Scotland. Costello (2009b) suggests that, as more farms develop in a given area lice, transmission between farms can compromise the individual farms efforts on lice control.

Laboratory dose-response studies on wild salmon smolts found infection of 0.75 lice per gram of fish weight would cause death (Finstad *et al.*, 2000). Post-smolt monitoring of more than 3,000 fish from the Norwegian Sea for lice, revealed no fish carrying more than 10 adult lice were found alive (Holst *et al.*,

2003). An experimental study on juvenile Atlantic salmon found attachment of between 30-50 sea lice larvae can cause the death of a 40g post-smolt (Grimme *et al.*, 1996). In sea trout, the natural infection intensity with adult female lice in spring is thought to be 0-3 per fish (Heuch *et al.*, 2002; Rikardsen, 2004). However, wild sea trout captured from fish farming areas have been recorded in the summer with between 10-20 adult female lice per fish (Björn *et al.*, 2003). Wells *et al.* (2006) reported 13 mobile sea lice per wild post-smolt sea trout, weighing between 19-70g, resulted in sub-lethal stress responses. In Norway, based on experimental results, specialists recommend less than 10 lice per wild salmonid to ensure no negative effect on wild salmonid populations (Björn *et al.*, 2008, 2009).

Although salmon farms are stocked with louse-free fish, the lice exist naturally on wild salmonids, which in part provide a source of infection, along with drifting infection from neighbouring farms. The high densities of salmon in farms then provide an ideal environment for lice reproduction (Costello, 2006), meaning the farms boost sea lice production above natural background levels (Tully and Whelan, 1993; Heuch and Mo, 2001). The aquaculture environment can overcome the natural self-regulation of micro-predators such as sea lice. For example, wild salmon infested with sea lice might suffer from reduced foraging efficiency through the resultant infection, thus increasing host mortality. However, in aquaculture, this does not occur and the cycle is therefore not broken (Frazer, 2008). Also, natural migratory life cycles of salmon spatially separate adults from juveniles, therefore protecting juveniles from parasites associated with adult hosts (Krkošek *et al.*, 2006). Fish farms prevent the functional role of migration from protecting the juveniles, and expose salmonids to the parasites at an abnormally young age (Krkošek *et al.* 2005). Sea-trout post-smolts generally do not travel far afield but remain year-round in local coastal waters. This may increase exposure to sea-lice and thus help to maintain a local sea louse over-wintering population (Butler, 2002; Rikardsen, 2004).

Studies, from different geographical locations, have linked high levels of sea lice on wild salmon with infestations in salmon farms, nearby or along native salmon migration paths (Tully *et al.*, 1993; Finstad *et al.*, 1994; Gargan *et al.*, 2000). Research from Scotland (Butler and Watt, 2003), Western Ireland (Gargan *et al.*, 2003) and Norway (Holst *et al.*, 2003; Heuch *et al.*, 2005) have shown wild salmon and sea trout numbers declining more significantly in areas with fish farms, than areas without. Studies in Canada on juvenile pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*Oncorhynchus keta*) found during the downstream migration the sea lice infection rate was 73 times greater near a fish farm than ambient infection levels (Krkošek *et al.*, 2005). A later study in the Broughton Archipelago, Canada, indicated sea lice-induced mortality of pink salmon was commonly over 80%. They calculated that, if outbreaks continue, a 99% collapse in native pink salmon populations is expected in four generations (Krkošek *et al.*, 2007).

Research on sea trout has also shown higher sea lice infection rates in areas with intensive fish farming activity (Tully *et al.*, 1999; Björn *et al.*, 2001; Gargan *et al.*, 2003). Research from Ireland, Scotland and Canada indicates sea lice may disperse for up to 30 km from one site (Tully *et al.*, 1999; Gargan *et al.*, 2003; Krkošek *et al.*, 2005). A recent study by Penston and Davis (2009) confirmed a significant relationship between the numbers of gravid (egg-bearing) sea lice on farmed salmon in Loch Torridon, Scotland, and densities of the copepodids in the water column. This evidence supports the hypothesis of 'self seeding' infections, described in previous reports (Tully, 1989; Bron *et al.*, 1993a, b; Jackson *et al.*, 1997; Grant and Treasurer, 1993).

In 1997, Norway developed the 'National Action Plan against Salmon Lice on Salmonids' (NA), with the goal of reducing the effects of lice on farmed and wild salmonids (Eithun, 2000). The plan included a legal limit of two adult female lice per fish, which was revised to 0.5 adult females per fish in January 2000 (Heuch *et al.*, 2005). In 1999, a modelling study by Heuch and Mo (2001), based on the figure of 2 adult lice per fish, estimated 111 billion lice eggs would have been produced by farmed salmon around the Norwegian coast between April-June, during the wild smolt run. From an ecosystem approach, as the number of salmon in fish farms continues to increase every year, for lice production to remain constant the allowable limit per fish must be lowered every year (Heuch *et al.*, 2005).

Climate change is likely to alter the geographical ranges of sea lice and their hosts (Dulvey *et al.*, 2008; Marcogliese, 2008). Research already shows temperature variations, between years, can greatly affect

sea lice abundances (Hewitt, 1971; Tully, 1992), with sea lice populations shown to thrive in high water temperatures (Deady *et al.* 1995). This supports early studies indicating that parasites' impacts on hosts will be greater due to rising temperatures associated with climate change (Harvell *et al.*, 2002; Poulin and Mouritsen, 2006).

The debate on the impact of lice from farmed salmon on wild populations is fuelled by two uncertainties; 1) the lack of reliable data on sea lice abundances pre-salmon farming (Beamish *et al.*, 2007) and 2) the sample bias as you can only sample fish that have survived infestation (Revie *et al.*, 2009). However, the growing body of evidence showing the detrimental impacts of sea lice from fish farms on nearby wild salmonids provides sufficient evidence to question the economic and political issues underpinning the current aquaculture and fisheries resource management (Costello, 2009b).

#### ***Escapee salmon: Interbreeding of wild and escaped salmon***

Farmed salmon escape practically everywhere there is aquaculture. Thorstad *et al.*, (2008), on behalf of the Salmon Aquaculture Dialogue which investigated the incidence of farmed Atlantic salmon in the wild, concluded that, internationally, numbers of farmed salmon escaping are large in relation to the abundances of their wild counterparts. In Norway, it is estimated that 1.3 million salmon escape each year (Weber, 1997), although in 2007 the official statistics quote 450,000 cultivated salmon escaped in Norway (Statistics Norway, 2009). In Scotland, official statistics in 2002 show 309,996 Atlantic salmon escaped from fish farms, and figures for 2009 shown 131,971 Atlantic salmon escaped, predominately due to holes in the cage nets (Scottish Government, 2009). There is growing evidence that these escapees are establishing significant populations in the wild. It is estimated that within Norwegian rivers in close proximity to fish farms, up to 80% of the spawning fish in one season were from fish farms (Fiske *et al.*, 2006, referenced in Hindar *et al.*, 2006). In New Brunswick, Canada, within four years of the first fish farms being built in 1979, 5% of the salmon in the nearby Magaguadavic River were shown to be escapees and, by 1995, this had risen to 90% (Weber, 1997). In the North Atlantic, experimental ocean fishing off the Faroe Islands during the mid-1990s found 20-40% of salmon caught was of farmed origin (Hansen *et al.*, 1999).

The replenishment of wild salmon populations with farmed smolts was thought to be a viable and effective solution to declining populations, as reported by McGinnity *et al.* (2003b). However, farmed salmon typically show lower genetic variability than wild salmon (Norris *et al.*, 1999; Skaala *et al.*, 2004). This means that, when captive salmon escape and breed with wild salmon, the gene pool is changed and diluted, potentially compromising the genetic integrity of the wild salmon population and its genetic adaptation to localised habitats (Crozier, 1993, 2000; Fleming *et al.* 2000). The effect of farmed fish will depend upon a number of factors, including genetic origin, rearing conditions, the condition of the wild population, and the number, timing, magnitude and frequency of escapes (Hutchings, 1991). There is also the possibility that escaped salmon could hybridise with native trout (*Salmon trutta*), as hybrids between Atlantic salmon and trout do occur naturally in the wild (Hurrell and Price, 2006).

Farmed salmon differ from wild salmon both morphologically and physiologically, which can affect behaviour, spawning success and competitive ability (Thorstad *et al.*, 2008). Research from Scotland has found that farm escapees can successfully breed in local rivers to the fish farms (Webb *et al.*, 1991; 1993a). A survey in 1991 found 11 of 12 Scottish rivers within fish farming areas had juveniles of farmed parentage (Webb *et al.*, 1993b). McGinnity *et al.*, (2003b) found in experimental studies in the Burrishoole system, in Western Ireland, hybrids (from a two-generation experiment) and farmed fish had lower survival rates than their wild counterparts. Fleming *et al.* (2000) found that the lifetime reproductive success of escaped farmed salmon was only 16% of that of native fish. Farmed salmon can also demonstrate uncharacteristic migratory patterns, such as dispersing into many rivers. This therefore has the potential to impact more than one wild population (Weir and Fleming, 2006).

Genetic changes, through interbreeding, may result in changes to the ecological and behavioural traits of native salmonids (Holm and Dalen, 2003). Clifford *et al.* (1998) found interbreeding between farmed and wild salmon resulted in four of the seven loci examined shifting in the direction of the farmed salmon, resulting in lower overall heterogeneity of allelic frequencies between the two types. McGinnity *et al.* (2003b) found that the interbreeding of typically smaller wild and bigger captive salmon brought

about behavioural suppression of the wild stock by intermediately sized hybrid stock. Simulation studies based on a fixed escape rate of 20% of farmed salmon at spawning suggest 'substantial changes' will take place to the wild salmon population within ten salmon generations. The report also indicates that, even with lower invasion rates, recovery of the wild population genetic stock is not likely even if no further escapes occur (Hindar *et al.*, 2006).

The Scottish Fisheries Research Report, by Middlemas and Steward (2008), found first year salmon smolts significantly larger than two and three year old smolts in the River Balgy, a small catchment dominated by freshwater lochs, which are used for cage rearing salmon smolts. This could suggest that all the first year smolts caught had escaped from the smolt farms. This indicates it is possible for salmon to escape at all life stages, and that juvenile fish, via freshwater smolt rearing facilities, could also pose a problem to native populations (Clifford *et al.*, 1998; Carr and Whoriskey, 2006).

Atlantic salmon are in decline throughout their native range. Multiple factors are contributing to this decline, which makes it very difficult to determine the individual impact of each stressor. This confounds attempts to assess the discrete impact of escapees on population size and productivity. However, it is likely that wild populations are more vulnerable to the effects of escaped salmon due to the additional stress from other pressures (Thorstad *et al.*, 2008). In order to allow the species as a whole to keep pace with a changing environment, genetic variation between populations must be maintained (McGinnity *et al.* 2003a). The use of sterile fish in farms is a measure supported by scientists to minimise the impact of farmed fish on wild salmon genetics (Hindar *et al.*, 1991; Anon, 1994; Hansen and Youngson, 1998). Cotter *et al.*, (2000) found reduced return rates of triploid salmon to both estuaries and freshwater, coupled with their inability to produce viable offspring, demonstrated how the farming of triploid fish could reduce the ecological impact of escaped farm fish.

#### **Chemical wastes**

A range of chemicals are used in aquaculture, including disinfectants, antifoulants, medicines (including antibiotics), vaccines (Costello *et al.*, 2001) and insecticides (including organophosphates and synthetic pyrethroids). These can be toxic to other organisms in the water column, and some chemical wastes can also bioaccumulate and therefore remain in the environment for extensive periods. Chemicals administered in feed or as bath treatments, can both permeate into the wider environment.

Outputs from fish farms are controlled by local and national waste discharge consents (Costello *et al.*, 2001). However, the rapid expansion of fish farming in the 1980s and 1990s saw a dramatic rise in the use of antibiotics on farms. Between 1985 and 1987 in Norway, antibiotic use increased from 17 to 48 mt per year, exceeding the combined use by humans and terrestrial animals in the country during the same period (Weber, 1997). By 1998, the Chilean salmon farming industry was using 100 mt of antibiotics (Claude and Oporto, 2000). The profligate use of these antibiotics can lead to the development of antibiotic-resistant strains of bacteria in both wild and farmed populations. Recent anecdotal evidence of increasing sea lice numbers in Norway and British Columbia has heightened concern of resistance to anti-lice treatments.

Elevated levels of zinc, copper and cadmium have been found in fish farm sediments as a result of feed and faecal outputs, and the anti-foulant products used in aquaculture (Brooks and Maknsen, 2003; Schendel *et al.*, 2004; Dean *et al.*, 2007). A survey of metal concentrations in surface sediments at 70 sites around fish farms in Loch Craignish, on the west coast of Scotland, found maximum concentrations of 921, 805 and 3.5  $\mu\text{g g}^{-1}$  of zinc, copper and cadmium, respectively (Dean *et al.*, 2007). Elevated levels of sediment metals can have a wide range of impacts on the benthos, including altering community structure and reproductive success (Dean *et al.*, 2007).

#### **Biological Waste and Nutrient Loading**

Biological waste, such as extra food and faeces, can accumulate in the water and sediments surrounding fish farms. Sediments beneath fish cages have been found to be enriched in phosphorus, nitrogen, organic carbon and zinc (Cornel and Whoriskey, 1993; Kelly, 1993; Troell and Berg, 1997). Factors affecting waste production include fish size, water temperature and husbandry practices including feed composition and feeding methods (Podemski and Blanchfield, 2006).



In areas with significant aquaculture production, the accumulation of organic matter can be detrimental to the surrounding environment (Naylor *et al.*, 2000; Beveridge, 2004). Biological wastes can lead to an overabundance of phosphate and nitrogen, which can result in eutrophication (wherein high concentrations of nutrients permit the over-proliferation of algae and other aquatic plants). This can pose a major threat to water quality and environmental integrity (Nijboer and Verdonchot, 2004; Smith and Schindler, 2009) and, in extreme cases, can lead to a completely de-oxygenated (anoxic) environment (Stutter and Lumsdon, 2008). Organic enrichment can lead to decreased species richness and diversity, and an increase in the abundance and dominance of organisms resistant to sedimentation and low oxygen availability (Hynes 1963; Johnson *et al.* 1993; Brooks and Mahnsen, 2003; Brooks *et al.*, 2003; Edgar *et al.*, 2005). The wastes can also smother animal and plant communities beneath cages (Weber, 1997). Disrupting or altering these benthic communities can impact sediment nutrient cycling, much of which is anyhow mediated by organisms associated with the sediment. The severe effects of biological waste from salmon farming appear to be relatively localised (Brown *et al.*, 1987); however less severe environmental effects may be spread over a large area (Carroll *et al.*, 2003). Sediment anoxia and the absence of macrofauna have been reported due to salmon farming in the North Atlantic (Hansen *et al.*, 1991), the Baltic Sea (Holmer and Kristensen, 1992) and Chile (Soto and Norambuena, 2004). In Chile, research from eight salmon farms located along 300km of coastline showed the salmon farming resulted in at least a 50% reduction in benthic biodiversity due to organic matter, low oxygen levels in the sediment and the deposition of copper as a result of these aquaculture operations (Soto and Norambuena, 2004).

Faecal production and waste feed are difficult to estimate accurately, and so are rarely reported. Research from Canada suggests faecal production ranges from 15% to 30% of applied feed (Costello *et al.*, 1996; Cho and Bureau, 2001; Bureau *et al.*, 2003), and waste feed could constitute between 3–40% of feed (Weston *et al.*, 1996). Research in southern Chile found significantly higher concentrations of ammonium nitrogen near salmon cages, compared with control areas, and seaweeds exhibiting faster growth rates and tissue nitrogen content when cultured near fish farm cages (Troell *et al.*, 1997).

Little data exists on the recovery of sediments following the removal of fish farms. However, in Scottish saline lochs, significant alterations in benthic communities below cage sites were still apparent more than 3 years after the farming in the area had ceased (Doughty and McPhail, 1995). Recovery of lotic systems is thought to be more rapid due to the water flow increasing the dispersion of wastes and allowing re-colonization by invertebrate drift (Doughty and McPhail, 1995). The length of rehabilitation will depend on local topographical conditions (Holm and Dalen, 2003).

## Conclusion

Despite some common perceptions to the contrary, the scientific literature demonstrates that, to varying degrees, salmon farms are having a detrimental impact on native salmonid fisheries, the wider environment and the many public benefits associated with it. In order to make aquaculture a viable and sustainable industry, these threats must be addressed as an urgent priority. Furthermore, from an ecosystems perspective, the benefits of farmed fish production under current stewardship may be heavily outweighed by wider impacts on the environment and the many other sectors of society that this affects. We believe that the Precautionary Principle should be enforced to protect wild Atlantic salmon (an EU Habitats Directive protected species), sea trout (a Biodiversity Action Plan species) and the surrounding aquatic environment. This is also implicit under the EU Water Framework Directive (WFD), which requires 'good ecological status' and no deterioration in all water bodies.

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## **Annex 1:**

### **Atlantic salmon biology**

The Atlantic salmon (*Salmo salar*) is found in the temperate and arctic regions of the Northern Hemisphere. Atlantic salmon are anadromous migratory fish, meaning they migrate from the sea into freshwaters to spawn in their native rivers. Spawning time varies between rivers and may be influenced by the water temperature and amount of daylight. Generally, spawning will occur during the period November-December in Great Britain. Approximately 90-95% of all Atlantic salmon die following their first spawning, but some survive to spawn two or three times. The survivors, predominantly female, return to sea to feed between spawnings.

The eggs are laid in depressions called 'redds' excavated by the female fish in the gravel of the river. After the eggs are deposited, they are immediately fertilised by an accompanying male. Hatching usually occurs in early spring and the young fish, known as alevins in this life stage, remain in the redd for a number of weeks, nourished by an attached yolk sac (Thorpe *et al.* 1999). When they emerge from the gravel in April or May, they are about one inch in length. As they grow, the young fish develop prominent 'dirty thumbprint' markings on their sides and are known as parr. The amount of time parr stay in the river is dependent upon the water temperature and the availability of food. Parr then, by improving their hypo-osmoregulatory performance (Waring and Moore, 2004) and developing a flush of silver scales, undergo smoltification (a process transforming parr to smolts). Smolts then have the ability to inhabit saline waters (Madsen *et al.* 2004). Once smolts have left freshwater, they are believed to demonstrate schooling behaviour whilst heading off to oceanic feeding areas, of which the best known are in the Norwegian Sea and the waters off Southwest Greenland. Salmon that remain at sea for more than one winter undertake the longest migrations, whilst grilse, which have only spent one winter at sea before returning to freshwater, tend not to travel beyond the Faroe Islands and the southern Norwegian Sea.

When salmon begin their migration back into freshwater, typically after between 1-4 years at sea (Hendry and Cragg-Hine, 2003), they stop feeding, and live on fat stored in their tissues. This affects the taste of the flesh, and therefore most salmon caught for food are netted at sea, in estuaries or the bottom of river systems.

Salmon aquaculture mimics this lifecycle. Production starts as mature adult salmon are stripped of the eggs and milt in freshwater hatcheries. The subsequent development of the fertilised egg is accelerated by heated water. Once hatched, the fry are reared in high densities in tanks, until they reach smolt size (60-125 grams). After the transition to smolts, which typically takes one year (compared with the average of 2 years in the wild), the fish are moved to 'grow on' operations in floating cages or pens in sheltered coastal areas, anchored to the seabed or land. The cages are open to the marine environment to allow water circulation to increase oxygen levels and remove waste materials and surplus food.