SUBJECT Effects of mariculture on populations of wild fish

Advice Summary

In the OSPAR area, the degree of interactions may be moderate between finfish mariculture and wild fish populations at the scale of a river local to a salmon farm, but are lower at a broader scale. The supply of food for mariculture creates a demand for small pelagic fish. ICES has advised that the fishing mortality on some small pelagic stocks should be reduced. A risk assessment is presented that identifies the research needed to more fully understand the nature and impact of these interactions and pressures.

Request

Effect of mariculture on populations of wild fish (OSPAR 2010/3)

> *While there is general agreement on the range of potential forms of interaction between farmed and wild stocks, there is much less agreement on the current and future significance of these interactions for wild stocks. OSPAR ask ICES:*
>
> *To provide advice on the current state of knowledge on the interaction of finfish mariculture on the condition [of] wild fish populations (both salmonid and non-salmonid) both at a local and regional scale, including from parasites, escaped fish and the use of fish feed in mariculture. Advice is requested on how the interactions will change as a result of an expansion of mariculture activities.*
>
> *OSPAR suggest that this should be addressed through a risk analysis approach, making best use of both quantitative and qualitative methodologies, and that an important aspect of the outcome will be clear identification of the specific aspects of the risk analysis where additional research effort may best be targeted to reduce the uncertainty in the risk analysis.*

ICES Advice

Introduction

ICES reviewed the interactions of mariculture with wild fish populations in the OSPAR area. Most finfish mariculture in this area is of Atlantic salmon *Salmo salar*, and most information comes from interactions with salmon farming. Potential interactions include the effects of escaped fish, parasites, other pathogens and the use of wild fish as mariculture feed. A risk assessment of these interactions was conducted. Most of these interactions are with wild salmon populations that are already stressed and in some cases depleted. The significance of any interactions will depend, in part, on the existing condition of the wild salmon populations and whether the management objective is enhancement or maintenance of those populations. There is no evidence of effects on populations of wild fish from local-scale issues such as from excess feed near fish cages.

Summary of knowledge

Escaped fish

The impact of escapees from mariculture on wild fish populations depends on the occurrence of escapees in the wild and the numbers of escapees relative to the size of the local stocks but is difficult to determine without reliable information on the numbers of escapees present. Limited information is available to evaluate risks from non-salmonid mariculture, concerns exist particularly in areas where wild stocks are in poor condition.

Parasites

Infections of wild salmon with salmon lice are higher in populations occurring in the proximity of salmon mariculture. Effective management of lice populations on farmed salmon has been associated with reduced louse levels on adjacent wild salmon. There are a number of chemical treatment options for salmon lice but there is also evidence of resistance to these compounds in several areas. The negative effects of lice infections on individual salmon are well documented. In the absence of new and effective salmon louse treatments, continued expansion of salmon mariculture will increase the risk of population-level effects.

Other pathogens

Wild fish populations are infected by other pathogens. However, there is no evidence that viral or bacterial diseases in farmed fish cause significant population effects in wild stocks..

Use of fish feed in mariculture

Various stocks of wild fish are harvested and subsequently used in the manufacture of feeds for mariculture. Most of these stocks are of small pelagic or semi-pelagic species including, in the OSPAR area, sandeels *Ammodytes* spp., sprat *Sprattus sprattus*, blue whiting *Micromesistius poutassou*, capelin *Mallotus villosus* and Norway pout *Trisopterus esmarkii*. Supplies of protein and oils for fish feed can also come from stocks harvested elsewhere on the planet (e.g. Peruvian anchovy *Engraulis ringens*) and from vegetable and algal sources. The great reliance on fishmeal to feed maricultured species farmed in OSPAR countries may be contributing to high exploitation rates and diminished sizes of wild stocks of forage fish. Some stocks (or sub-stocks) of these wild fish are either depleted or are being overfished. However, the degree to which these problems can be attributed to mariculture is difficult to establish. Harvesting of forage fish can affect the prey available to other wild fish populations and in some areas, management measures have been implemented to ensure this food supply.

Risk Assessment

The risk assessment (Table 4) identified six moderate and one high hazard:

- hazards related to interactions of escaped salmon with wild conspecifics in freshwater
  - competition for food (first freshwater phase) (moderate risk)
  - space (first freshwater phase) (moderate risk)
  - competition for food (second freshwater phase) (moderate risk)
  - space (second freshwater phase) (moderate risk)
  - competition for reproduction(second freshwater phase) (moderate risk)
- hazards related to the use of fish feed in mariculture
  - impacts on targeted fish stocks (high risk)
  - ecosystem effects (moderate risk)

The consequences of these hazards include:

- changes in fish populations in terms of abundance and diversity on an annual temporal scale and moderate (bay or regional) spatial scale.
- wild (feed) fish stocks are fished beyond sustainable limits, with geographic ranges of fished stocks being reduced
- ecosystem effects of fishing through the food chain

Risks concerning non-salmonid farmed fish were classified as low, but with high uncertainty. This is a result of the low availability of information for use in assessing risk. In some cases it was not possible to estimate a risk. There is lack of information on disease transfer in non-salmonid species. In addition, there is no information on interactions from captive non-salmonid fish caused by release of their gametes or transfer of their parasites.

Future trends

Within the OSPAR area, salmon mariculture has expanded in some countries, notably in Norway, but has declined elsewhere (Table 1). Market conditions for farmed salmon and the potential (or otherwise) for geographic expansion are the likely drivers behind these changes. Future market conditions are difficult to predict, but it seems reasonable to expect that expansion will likely continue in Norway. Any increase in production would likely increase interactions, with the greatest risk likely being those where there is currently highest risk – most notably the effects from harvesting of small wild fish and the ecological consequences of that activity, and interactions with wild salmon in the freshwater phase.

Expansion of salmon mariculture may be constrained by insufficient wild fish being available to use in mariculture feeds. A further constraint may arise if the incidence and severity of salmon lice infections cannot be controlled.

Efforts continue to reduce the effects of interactions. In many jurisdictions, reductions in the incidence of salmon lice are now required both by the mariculture industry and to reduce potential effects on wild salmon. In the absence of new compounds with novel modes of action against salmon lice, opportunities for chemical treatment will be limited. Salmon lice control practices may need to change to include strategic rotations of existing compounds and the use of non-chemical methods, including integrated pest management (Brooks 2009). Other approaches to salmon lice management, such as selective salmon breeding for resistance or vaccination, remain either experimental or impractical for wide-scale commercial applications.

There is a strong economic incentive to reduce the number of escapees. The effects of escapees on wild salmon populations may be reduced with the possible future introduction of sterile fish in mariculture. When wild populations are in a healthy condition, any genetic effects caused by farmed fish will be reduced.

There is insufficient information to determine what the potential effects might be of the expansion of non-salmonid mariculture, or of the effects of diversification of species used in mariculture, including herbivorous fish.

Recommendations

ICES notes that there is almost no information on the environmental interactions, including genetic effects, of non-salmonid escapees and wild fish populations. Disease transfer from escapees to wild fish populations of the same species is not well studied. Both topics require further research.

Although not directly relevant to the request from OSPAR, a recommendation for future monitoring of escapees from salmon farms is included at Annex A.

Basis of advice

Background

The scale of cultivation of both fish and shellfish species in coastal waters of the OSPAR area continues to increase. In some countries, the value of aquaculture products exceeds that from wild capture fisheries. Aquaculture is currently concentrated in coastal waters. taking advantage of the sheltered conditions available there, and also in response to other practical economic and engineering factors, such as accessibility for operators and to downstream processing facilities, and the difficulty and cost of maintaining structures in open water offshore areas.

Some of the environmental interactions of coastal aquaculture operate on very local scales. These include enrichment of the seabed by waste feed and faeces, or the potential toxic effects of used chemicals such as medicines and antifoulants. These generally can be regulated through local licensing and consenting systems.

However, other forms of environmental interactions have the potential to have influence over rather larger areas. A number of these concern wild fish populations. Examples include the pressure on wild stocks to provide raw materials (fish protein and lipid) for pelleted diets for farmed fish, interbreeding of escaped farmed fish with wild stocks reducing their fitness, and the more direct stress arising from the possible transfer of parasites of farmed to wild stocks (notably sea lice from farmed salmon to wild salmon and sea trout) and consequent impacts on wild populations.

While there is general agreement on the range of potential forms of interaction between farmed and wild stocks, there is much less agreement on the current and future significance of these interactions for wild stocks.

OSPAR suggested that the request should be addressed through a risk analysis approach, making best use of both quantitative and qualitative methodologies, and that an important aspect of the outcome will be clear identification of the specific aspects of the risk analysis where additional research effort may best be targeted to reduce the uncertainty in the risk analysis.

Current production from mariculture

The mariculture of finfish in the OSPAR area continues to increase with most of the production focused on Atlantic salmon. Most of that production and its expansion are taking place in Norway while in other OSPAR countries there are declines in the production of Atlantic salmon (Table 1). The mariculture of other species in the OSPAR region is summarised in Table 2.

Table 1 Production (1000s tonnes) of farmed Atlantic salmon in the OSPAR area in round fresh weight, 2004 to 2009. Data for 2009 are provisional (ICES, 2010a).

Year	Country					
	Norway	Scotland	Faroes	Ireland	Iceland	Total
2004	564	158	40	14	7	783
2005	587	130	19	14	6	716
2006	630	132	12	11	6	791
2007	744	130	22	10	1	907
2008	738	129	36	11	<1	915
2009	857	133	36	10	<1	1,037
5-yr mean 2004-2008	653	136	26	12	4	830
Percent change between 2004 and 2008	+31	-18	-10	-21	-86	+17

Table 2 Annual production (1000s of tonnes) of the 5 most important fish species (by biomass) and total production of fishes in marine/brackish aquaculture in the northeast Atlantic by OSPAR countries since 1999. Data from FAO (2010).

Species	Year									
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Gilthead seabream	1.4	1.8	1.8	3.5	3.0	3.2	4.0	3.7	4.3	3.4
Turbot	4.1	4.8	4.9	5.3	5.4	6.0	6.8	7.7	8.2	9.5
Atlantic cod	0.2	0.2	1.0	1.5	2.6	3.8	8.1	13.2	13.7	21.4
Rainbow trout	75.9	74.5	97.4	113.6	99.8	91.6	87.1	90.6	106.4	108.6
Atlantic salmon	613.3	623.0	647.0	678.4	728.3	784.3	756.7	792.7	908.9	921.6
Total	697.9	707.3	755.0	805.5	843.2	893.5	869.9	916.0	1050	1072

A. Interactions with escapes from mariculture

Introduction

The possible effects of interactions between farmed and wild fish depend on a number of different parameters, such as genetic diversity, local adaptation, and the relationship between the number of farmed escapees and the wild conspecifics. Farmed marine individuals that are offspring of locally caught broodstock will not have the same potential genetic effect on the wild local population as offspring from broodstock collected from a population genetically different from the wild local individuals. Locally caught broodstock are less divergent than individuals based on broodstock from distant populations (e.g. Arctic cod vs coastal cod). Another important factor is the behaviour of the species in question; e.g. does it migrate over long distances, or does it stay within a limited range.

Genetic interactions between cultured and wild fish

Genetic subdivision of a species indicates potential for local adaptation, and the genetic differences observed among populations are a key component of genetic diversity. Local environment can be different at different scales: geographically (across the natural range of a species) or spatially (related to human activity, e.g., mariculture). Many marine species show relatively low levels of genetic structuring even over large distances.

A risk associated with translocation of marine finfish is from hybridisation of wild fish with reared individuals. Fish in mariculture are selected for traits such as rapid growth rates, high feed conversion and resistance to disease. These may not be good traits in the wild, thus hybridisation with escapees could have adverse effects on wild fish populations (e.g. Utter 1998).

The experimental evidence of adverse effects on wild fish populations is limited, although knowledge about harmful effects exists for Atlantic salmon (Flemming *et al.* 2000, McGinnity *et al.* 2003). For Atlantic salmon several attempts at quantifying interactions between farmed and wild conspecifics have been published (Crozier, 1993, Clifford *et al.*, 1998a, 1998b, Crozier, 2000, Skaala *et al*., 2006). These range from quantification of gene-flow from single escapement events affecting specific wild populations, to investigations quantifying genetic changes in historical and contemporary samples of wild populations that have been subject to differing numbers of farmed escapees. Both approaches have demonstrated genetic changes in wild populations, although the full extent of hybridisation and the long-term implications for conservation remain subject to debate.

Cod always live in the marine environment and can spawn in the mariculture cages if the cod mature before they are harvested. Such spawn, if fertilised and viable, can drift out into the wild and produce viable larvae that can represent a considerable fraction of the total number of larvae (20–25%) in the vicinity of a cod mariculture site and the larvae can drift a great distance (Jørstad *et al*., 2008). This indicates the potential of genetic spread to the wild stock through interbreeding with wild individuals, but there is no direct evidence of this having occurred.

Populations of coastal cod in Norway are severely depleted; for several years ICES has recommended no fishing on this stock (ICES, 2008). Therefore the possibility of interaction with these wild stocks from large mariculture production is increased.

There are no available data on the number of escaped farmed turbot or of sea bream nor is there any knowledge about genetic differences between farmed and wild individuals of these species.

Reported escapes

In many countries it is a mandatory requirement of an aquaculture licence to report any escapees to the relevant authorities, but this is not consistent across the OSPAR region. Information is available from 1996 to 2009 on the total reported number of escapees from Ireland, Scotland and Norway (Table 3). It should be noted that these figures are of reported escapees and may not represent all of the incidents and should be considered as minima. These figures can be compared to the total prefishery abundance estimate of wild salmon in their first winter at sea in the Northeast Atlantic area for the same years which has ranged from 2.5 to 4 million fish.

Table 3 Reported escapes (in thousands) of farmed salmon in Ireland, Scotland and Norway. (- = no escapees reported)

Year	Ireland	Scotland	Norway	Total
1998	74	67	553	694
1999	12	258	348	617
2000	159	428	276	863
2001	105	66	272	443
2002	-	367	477	844
2003	3	105	407	515
2004	-	84	553	637
2005	-	878	715	1593
2006	-	156	921	1077
2007	-	154	298	452
2008	-	689	111	800
2009	25	132	170	327

Incidence of farmed salmon in coastal areas

There are significant technical challenges in identifying farmed salmon in the wild, however there is information on escapees in both catches from coastal waters and in freshwater from a number of OSPAR contracting parties (ICES, 2010a). These numbers in themselves do not describe the potential for interaction with wild populations since the relative number of escapees to wild fish is of importance. Numerous studies have demonstrated that the differences in behavioural characteristics between wild fish and escapees influence their interaction. These characteristics include:

- Wild salmon normally return to the river that they left as smolts.
- Hatchery-reared salmon released as smolts return to spawn in the river in which they were released.
- Hatchery-reared salmon released as smolts from a marine site return to the same geographical sea area in which they were released, and enter rivers in this area to spawn.
- Farmed salmon released as postsmolts from a marine site survive poorly and stray in larger numbers and over greater distances than salmon released as smolts.
- Escaped large farmed salmon may be ‘homeless’ and appear to move with the prevailing current.
- Survival from escape to spawning is higher (possibly because of the shorter time period) if they escape close to maturity.
- Survival and migratory patterns of farmed fish appear to be dependent on the season of escape.

Further detailed information on these studies is provided by Hansen (2006) and Whoriskey *et al*. (2006).

B. Parasites

All fish are susceptible to parasitic infections. High densities of cultured fish often lead to increased infection rates by parasites (Kent, 2000, Kent and Poppe, 2002, Seng and Colorni, 2002, Sitjà-Bobadilla, 2004, Nowak, 2007). Knowledge of effects and infection rates in wild populations of fish is poor. There has been particular concern over the possible infection of wild salmon by increased levels of salmon louse *Lepeophtheirus salmonis* that is attributed to transmission from cultured stock, both by escapees and from caged fish. Concern over transmission of other parasites is low or non-existent. The abundance and frequent occurrence of salmon lice, their widespread geographic distribution and ability to contribute to a progressive decline in fish health suggests that salmon lice derived from mariculture may be harmful to wild salmonids when infections exceed natural levels. The relationship between the management of salmon lice in salmon mariculture and measurable impacts of salmon lice to the health of wild salmon populations was recently reviewed (Jones, 2009). The findings of this review are summarised below.

A higher occurrence of salmon lice on wild salmon collected from coastal areas with salmon mariculture is commonly cited as evidence that mariculture is a source of the infections (Tully and Whelan, 1993, Tully *et al.*, 1999; Bjørn *et al.*, 2001, Bjørn and Finstad, 2002). The ability to verify any correlations is limited though by the lack of long term datasets on salmon louse infection from either the farmed populations or the wild populations.

There is evidence that the risk of infection among wild salmon populations can be elevated in areas that support salmon mariculture and that salmon louse management activities within mariculture reduce the prevalence and intensity of infection on the wild fish (Penston and Davies, 2009, and references therein). A series of hydrodynamic models provided the quantitative framework for understanding spatial and temporal aspects of this relationship (Amundrud and Murray, 2009, and references therein). Spatial and temporal aspects of this zone of elevated risk of infection will therefore be strongly dependent on local hydrological processes and on the management practices employed in mariculture.

The extent to which the elevated infections pose a risk to the health of wild salmon populations is uncertain. Controlled laboratory studies have shown that several parasite- and host-related factors contribute to harm to individual salmon. Skin damage increases with the numbers of parasites and the stage of their development. Similarly, susceptibility to the adverse effects of the infection decreases with increasing host age or size and there are significant differences in susceptibility among host species (Wagner *et al*., 2006).

There is a poor understanding of the factors influencing the survival of wild salmon in the ocean and no long-term study of salmon lice. The inability to trace the parasites limits the extent with which causal relationships can be established between mariculture and wild populations.

Despite this uncertainty, numerous jurisdictions have established strategies to minimise the dispersal of salmon lice from mariculture and thereby minimise any possible effects on wild population of fish. Most of these require that treatment, harvest or other actions are undertaken when infections in cultured stock exceed prescribed thresholds.

Within mariculture sites salmon lice are commonly managed through systematic surveillance combined with the use of chemicals (Rae, 2002). A limited number of chemicals are licensed and available for use against salmon lice (Grave *et al*., 2004, Jones, 2009). The widespread use of single classes of compounds has led to resistance in salmon lice against several classes of compounds (Sevatdal *et al*., 2005).

Further information is available in ICES (2010b).

C. Disease

Background

Infectious agents such as viruses, bacteria and parasites are frequently documented within wild populations of aquatic organisms. Less well documented, however, are the risk factors and processes leading to disease states caused by these pathogens that are capable of eliciting measurable population-level changes. The detection and impact assessment of diseases in marine populations are faced with a number of challenges. For example:

1. Systematically collected data on changes in disease prevalence or disease severity in wild fish and shellfish are rare. Similarly, quantitative disease assessment data are virtually absent from traditional stock assessments.
2. When data are available, they are mostly derived from studies in adult specimens and do not include young life stages that may be more susceptible.
3. Most efforts to assess effects of disease in wild populations focused on mortality estimates. However mortality effects in wild populations are hard to identify and to quantify because, in many cases, mortality is ‘cryptic’, occurring unobserved.

4. Population effects may be caused by sublethal disease effects, e.g. on growth and reproduction. However, there are few data on such effects from studies in wild fish.
5. Disease epidemics are the result of the complex combination of pathogen, host and environmental factors. Rarely are there sufficient data to make predictions or to model the dynamics and effects of diseases.
6. The growth, reproduction, recruitment, abundance, biomass and natural mortality within a stock or population are regulated by numerous natural or anthropogenic factors.
7. In summary, factors associated with diseases in wild populations are rarely understood well enough to discriminate true disease effects at the population level. Thus even if a disease is transmitted from mariculture to wild populations of fish, it is difficult to distinguish disease associated population effects from effects caused by other processes.

D. Effects of the use of wild fish in mariculture feed on wild fish populations

The effects of the use of wild fish populations as mariculture feed may be divided between direct primary effects on wild fish populations from harvesting and the indirect secondary effects on the marine food chain or the habitat of wild fish populations.

Of the approximately 6 million tonnes of fish meal and 1 million tonnes of fish oil produced annually from capture fisheries and other sources (fish by-products, etc.), approximately 50-68% and 80–88% (Bell and Waagbø, 2008; Péron *et al*., 2010; Tacon and Metian, 2008), respectively, are used in the fabrication of mariculture feed. Of this, the proportion of the total of all fish meal and fish oil produced destined for salmon mariculture feed is 15–17% and 43%, respectively, that for trout 6% and 11–13%, respectively, and that for marine finfish, including cod and sea-bream 15–17% and 14–20% respectively (Tacon and Metian, 2008). The great reliance on fish meal and fish oil for species farmed in OSPAR countries may thus have a considerable impact on wild stocks of forage fish (e.g., Naylor and Burke 2005) as, although the proportion of fish products in mariculture feed is declining, the total quantity used is actually increasing because of the growth of the industry (Naylor *et al*., 2009).

Most fish harvested to produce the raw ingredients used in fish feeds are small pelagic species, most of which are prone to large inter-annual and inter-decadal variation of abundance, especially when fished. Such species typically school and thus may still be fished economically even when their abundance is not great, further contributing to the inter-annual variability and increasing the chance for overexploitation if fisheries for them are not properly managed (Fréon *et al.*, 2005). The wild fish populations exploited in the OSPAR area for fish meal include sandeels *Ammodytes* spp., sprat *Sprattus sprattus*, blue whiting *Micromesistius poutassou*, capelin *Mallotus villosus* and Norway pout *Trisopterus esmarkii*. Supplies of protein and oils for fish feed can also come from fish harvested elsewhere on the planet (e.g. Peruvian anchovy *Engraulis ringens*) and from vegetable or algal sources.

The precise composition and origin of fish food depends on a number of factors including the species and growth stage of the fish being fed, market conditions (both for supply stocks and for fish in mariculture) and availability. The stocks of wild fish used in the manufacture of mariculture feeds are also used in other ways, for instance in manufacturing feed for agricultural uses (e.g. food for chickens and pigs) or for human food such as the manufacture of margarine. Current ICES advice on stocks of some of these small pelagic or semi-pelagic fish shows that some are in a poorer state than in the past. For example, sandeel fisheries in the North Sea are much more restricted in distribution than in the past due to the poor stock condition on some grounds; blue whiting are being fished at levels above the target defined by the agreed management plan. It is however very difficult to separate the effects of fishing from possible natural changes in conditions.

Ecosystem-level consequences of harvesting fish to produce fish meal and fish oil for mariculture may occur because targeted species are often important prey species for marine predators. Should exploitation lead to some populations of target fishes becoming depleted there may be impacts for populations of their natural predators as well as other parts of the ecosystem. A closure of the sandeel fishery in an area of sea off east Scotland that commenced in 2000 was put in place to safeguard the supplies of fish for dependent marine predators, including fish.

Risk analysis

ICES used the risk assessment framework as outlined by Crawford (2003) with the addition of a estimate of uncertainty for each parameter evaluated. The inclusion of this latter information adds important information for managers to consider when conducting the full risk analysis and identifying research priorities. A semi-quantitative assessment was thus made of the consequences and likelihood of an event for the interactions of finfish mariculture and wild fish populations (Table 4).

Table 4 Risk assessment of interactions between finfish mariculture and wild fish populations. Risks are derived from the matrix presented in Table 5 with uncertainty (deriving from either the consequence or the likelihood) ranging from high (**) to low (*). For details on classification see Annex B and ICES (2010c).

Hazard	Consequence	Likelihood	Risk
Atlantic salmon (and other related species)			
Interactions when fish are in cages			
Parasite transfer	Minor	Rare	Low **
Disease transfer	Insignificant	Rare	Low **
Escapes of fish from culture sites (inter-specific interactions)			
Predation on wild fish stocks of other species	Minor	Rare	Low **
Competition with wild fish stocks (food/space)	Minor	Rare	Low **
Parasite transfer	Insignificant	Rare	Low **
Disease transfer	Insignificant	Rare	Low **
Escapes of fish from culture sites (intra-specific interactions)			
Competition for food			
First freshwater phase	Minor	Likely	Moderate *
Marine phase (immediate / oceanic)	Minor / Insignificant	Rare / Rare	Low ** / Negligible *
Second freshwater phase	Minor	Likely	Moderate *
Competition for space			
First freshwater phase	Minor	Likely	Moderate *
Marine phase (immediate / oceanic)	Minor / Insignificant	Rare / Rare	Low ** / Negligible *
Second freshwater phase	Moderate	Likely	Moderate *
Competition for reproduction			
Second freshwater phase	Moderate	Likely	Moderate *
Parasite transfer			
Marine phase	Minor	Rare	Low **
Second freshwater phase	Insignificant	Rare	Negligible **
Disease transfer			
Marine phase	Minor	Rare	Low **
Second freshwater phase	Insignificant	Rare	Negligible**
Atlantic cod (and other species likely to spawn in farms)			
Interactions when fish are in cages			
Release of gametes			No data
Parasite transfer			No data
Disease transfer			No data
Escapes of fish from culture sites (inter-specific interactions)			
Predation on wild fish stocks of other species	Minor	Rare	Low **
Competition with wild fish stocks (food/space)	Minor	Rare	Low **
Parasite transfer	Minor	Rare	Low **
Disease transfer			No data
Escapes of fish from culture sites (intra-specific interactions)			
Competition for food	Minor	Rare	Low **
Competition for space	Minor	Rare	Low **
Competition for reproduction	Minor	Rare	Low **
Parasite transfer	Minor	Rare	Low **
Disease transfer			No data
Use of fish feed in aquaculture			
Impact on fish stocks	Major	Likely	High * (1)
Ecosystem effects of fishing of these species	Moderate	Likely	Moderate *

Footnote (1) This risk relates to the ability of managers to take measures to harvest wild fish stocks sustainably

Table 5 Risk analysis matrix. Risk is a function of the likelihood of an event occurring and its consequence. For details on classification see Annex B and ICES (2010c).

Likelihood of event occurring	Consequence			
	Insignificant	Minor	Moderate	Major
Rare	Negligible	Low	Low	Moderate
Unlikely	Negligible	Low	Moderate	Moderate
Moderate	Negligible	Low	Moderate	High
Likely	Negligible	Moderate	Moderate	High
Almost certain	Negligible	Moderate	High	High

Future trends

Several strategies are possible to reduce the future effects of escapees on wild fish populations. The use of sterile individuals in fish farming may reduce any genetic interaction from escapees. From studies of Atlantic salmon the sterilization methods that are currently available seem to have negative effects, both on the welfare of the fish as well as their productivity. At present sterile fish can be produced either by crossing different species (hybrids) or by producing triploids. However some hybrids have been shown to mature and be fertile, and therefore triploids are the preferred solution. Triploid (all female) sterile rainbow trout are produced by exposing newly fertilized eggs to high pressure. Triploid Atlantic cod have been produced at the Institute of Marine Research (Norway). Although these cod seem to be growing slower than the control diploid cod, it is still too early to tell what will happen when the diploid cod start the maturation process e.g. their growth rate is halted. Production of all-female stock would remove the potential problem of spawners in the cod mariculture net-pens.

Differences in susceptibility to any diseases between the farmed and the wild individuals would ultimately affect the genetic composition in the wild. If the farmed individuals are made resistant to diseases they could still be carriers and transfer the disease to wild conspecifics.

When wild populations are in a healthy condition, any genetic effects caused by farmed fish will be reduced. There is less chance for a relatively small number of successful spawners from a farm to pose a threat to a large and healthy wild population.

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Annex A: Recommendation for the monitoring of escapees from salmon farms

Walker *et al.* (2006) noted the poor overall association between the incidence of fish farm escapees in catches and rivers stocks and either farm production or the level of escapees reported annually to the authorities. A risk based approach should be developed to predict the likely incidence of fish farm escapees in catches and stocks:

ICES recommends that sampling of in-river stocks should be the principal method for collecting data and ideally be from fishery-independent sources. The identification of origin should be based on at least two methods, and a sample of 'wild' fish should be examined using these methods to assess the rate of incorrect classification as wild. While it is unlikely that resources would allow additional validation of all catches in many countries, and the low frequencies of escapees in many catches do not warrant greater accuracy, it may be appropriate to validate subsamples and assess the rate of incorrect classification.

Monitoring efforts should be targeted primarily in those regions where farms are sited. However, given the occurrence of escapee salmon in many areas of the northeast Atlantic, programmes should also include a network of sampling in regions without farms.

The reporting of all escapes should be a requirement for all production facilities, both in the freshwater and marine environments, and there should be better coordination between the timely and accurate reporting of escapes and monitoring of in-river stocks within the area.

Extra care should be taken in areas where enhancement of stocks using hatchery reared fish occurs, as this may make it more difficult to identify fish as escapees in the samples or catches.

Annex B. Classifications used for risk assessment

It is difficult to classify the ecological consequences of an activity due to the complex nature of ecosystems and variations in knowledge of ecosystems and detrimental ecological effects. Crawford (2003) suggests that predefining a scale of impacts may facilitate the task. In the current process, a number of qualitative measures of consequences were developed to consider the impact of fish farming on the ecological interactions between farmed fish and wild fish of the same or different species (Table B1). Qualitative measures of consequences of commercial fishing for fish products used in the production of mariculture feeds were also developed for impacts on wild fish stocks (Table B2) and on the ecosystem (Table B3).

A component of a risk assessment is the likelihood of a given consequence occurring. This is divided into 5 unequal classes (Table B4).

It may be important to know the level of uncertainty when evaluating risk. Uncertainty is least when there is a substantial weight of peer-reviewed information (e.g. scientific articles, studies, etc.) on a given subject and greatest when there is little or no information on a given subject. The uncertainty of each magnitude and likelihood of each risk was classified (Table B5) but only High and Low categories were eventually used (Table 4).

Table B1 Estimates of the consequences of various ecological interactions between fish from mariculture on wild populations of the same or other fish species.

Level	Consequences
Insignificant	No impact, or changes in fish populations not readily detectable or of short duration and small spatial scale
Minor	Limited impacts, changes in fish populations in terms of abundances and diversity are detectable but are of short duration (less than annual) and small spatial scale (immediate vicinity of farm site)
Moderate	Considerable impacts, changes in fish populations in terms of abundances and diversity are of annual temporal scale and bay or regional spatial scale
Major	Great impacts, changes in fish populations in terms of abundances and diversity are marked and are of long (multi-year scale or permanent) duration and large spatial (coastal scale or greater)

Table B2 Estimates of the consequences of the use of fish feed in mariculture: impact on target fish stocks.

Level	Consequences
Insignificant	No targeted fisheries products are used in feed, only fisheries by-products used
Minor	Stocks fished within sustainable limits
Moderate	Stocks fished within sustainable limits but geographic range reduced
Major	Stocks fished to beyond sustainable limits

Table B3 Estimates of ecosystem consequences (through food chain effects or habitat change) of the use of wild fish to produce mariculture feed.

Level	Consequences
Insignificant	No detectable bycatch or food chain effect. No physical impact of fishing activity on habitat.
Minor	Limited bycatch and food chain effect. Short-term (less than annual) and small spatial scale physical impact on habitat.
Moderate	Considerable by-catch and food chain effects. Long-term (annual) or regional spatial scale physical impact on habitat.
Major	Substantial bycatch and food chain effects. Multi-year scale or permanent destruction of habitat at a large spatial scale (coastal or greater).

Table B4 Estimates of likelihood with respect to interactions from cage finfish culture.

Level	Description	Probability of event occurring
Rare	Event may only occur in exceptional circumstances	<5%
Unlikely	Event could occur but is not expected	5 - 15%
Moderate	Event might occur at some time	16 - 50%
Likely	Event will probably occur in most instances	51 - 95%
Almost certain	Event is expected to occur in most instances	>95%

Table B5 Levels of uncertainty with respect to consequences and likelihood of various ecological interactions between fish from mariculture on wild populations of the same or other fish species.

Level	Description
High (**)	Little or no information; expert opinion based on general principles; "best guess"
	Limited information; third party observational information or circumstantial evidence
	Moderate level of information; first hand, unsystematic observations; opinions based on related systems
	Considerable scientific information; non peer-reviewed information
Low (*)	Extensive peer-reviewed body of scientific information