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THEMATIC REVIEW

A conservation plan for Atlantic salmon (*Salmo salar*) and anadromous brown trout (*Salmo trutta*) in a region with intensive industrial use of aquatic habitats, the Hardangerfjord, western Norway

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Abstract
Extensive use of aquatic habitats, mainly for hydropower and aquaculture, has a negative impact on anadromous salmonid populations of the Hardangerfjord region, western Norway. High infection levels of salmon lice, and high proportions of escaped farmed salmon in spawning rivers, appear to violate the goals in the 'Strategy for an Environmentally Sustainable Aquaculture Industry' set by the Norwegian government. An overview of the anadromous populations in the fjord, their status and the major threats are presented. A conservation plan with mitigation efforts consisting of seven steps is presented: (1) genetic assessment of Atlantic salmon and anadromous brown trout populations, (2) reducing gene flow from escapees, (3) reducing infection pressure from salmon lice, (4) conduct an assessment of the freshwater habitats for anadromous salmonids and then implement it in order to restore smolt production, (5) efforts to reduce risk of river pollution from agriculture and industry and minimize impacts from hydropower production, (6) when and where necessary and practical, plant out eyed eggs from the Norwegian Genebank to increase parr and smolt production, and finally, (7) monitor spawning populations and parr densities to evaluate potential effects of the mitigation efforts. Experience and knowledge gained through the plan will be useful for other regions with similar challenges. We call for an initiative to establish a national fund under democratic and public control, where funding can be obtained for projects which focus on mitigation efforts and conservation of salmonid populations.

Key words: *Anadromous salmonids, threats, salmon farming, hydropower development, stock rehabilitation*

Introduction

Anadromous brown trout (*Salmo trutta* Linnaeus, 1758) and Atlantic salmon (*Salmo salar* Linnaeus, 1758) migrate between freshwater and marine environments. To survive and thrive, their habitats must meet a number of physical, chemical and biological requirements (Verspoor et al. 2007). Changes in both the freshwater environment (Borgstrøm & Aas 2000; Rosseland 2000) and the marine environment, either due to natural causes or human activities (Ford & Myers 2008; Gargan et al. 2012), may affect salmonid populations. The impact on wild salmonid populations as a result of human activities has received significant attention over recent decades, and impact factors are well documented. In 1983, an intergovernmental organization, The North Atlantic Salmon Conservation Organization (NASCO; www.nasco.int), was established with the objectives to conserve, restore, enhance and rationally manage the Atlantic salmon through international cooperation. Since then, a number of international symposia have addressed and documented the impacts (see, for example, Anon. 1991; Hutchinson 1997, 2006). In 2001, an initiative was taken to sum up existing

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knowledge about genetics, conservation and management of the Atlantic salmon with funding from the European Commission (Verspoor et al. 2007). In brown trout, the extensive genetic variation caused by its wide distribution and high propensity for colonization and establishing local populations in rivers and lakes has also focused attention on the need for conservation and management (Laikre 1999). In Norway, the fine-spotted brown trout in the Hardangervidda mountain plateau has received particular attention due to its rare and genetically determined pigmentation pattern (Skaala & Jørstad 1987; Skaala et al. 1992).

More recently, the research programme 'Ecological Processes and Impacts Governing the Resilience and Alternations in the Porsangerfjord and the Hardangerfjord (EPIGRAPH)', was initiated by the Norwegian Ministry of Fisheries and Coastal Affairs in 2008, motivated by the high level of human activity in coastal waters and the need for more information about the impact of this activity on the ecosystems. The situation for the Atlantic salmon and the brown trout was of particular concern. As a follow up, the Norwegian Directorate of Fisheries in close cooperation with the Directorate for Nature Management, the Norwegian Food Safety Authority and the Hordaland County Governor in 2010 called for an assessment of the anadromous populations in the Hardangerfjord and suggestions for immediate mitigation efforts that could reduce pressure on the populations (Skaala et al. 2010). In 2009, the Ministry presented its 'Strategy for an Environmentally Sustainable Norwegian Aquaculture Industry' (Anon. 2009; Taranger et al. 2011). Five areas in which salmon farming has the potential to negatively affect the environment were stressed: genetic introgression with wild fish, pollution, transmission of diseases including salmon lice to wild populations, allocation of aquatic habitat to fish farming, and the problem of obtaining adequate feed resources from an already heavily exploited marine ecosystem. Two of the goals in this strategic plan are of particular relevance for wild populations of anadromous fish:

- fish farming should not contribute to permanent genetic changes in wild fish populations; and
- diseases in farmed fish must not be allowed to reduce the size of wild fish populations.

Atlantic salmon farming has expanded rapidly in many coastal areas in Norway, with a total production of more than one million tonnes in 2011 (Anon. 2012). The Hardangerfjord region has one of the highest densities of salmon farms in Norway, with an annual production of approximately 80,000 t of farmed salmon in 2011 (Knut Johnsen, The Norwegian Directorate of Fisheries, pers. comm.), or more than 5000 times that of wild salmon in the same region. In several rivers, the recorded number of escaped farmed salmon has been high, even exceeding the number of wild salmon in some years (Anon. 2011). Moreover, very high infection levels of salmon lice *Lepeophtheirus salmonis* Krøyer, 1837 have been recorded, particularly in anadromous brown trout. Monitoring projects have revealed high incidences of prematurely returning anadromous brown trout, as well as wounds and skin damage related to salmon lice infection (Heuch et al. 2005; Bjørn et al. 2011; Taranger et al. 2011; Skaala et al. 2014). This has led to serious concern for the wild populations of salmonids in the Hardangerfjord among management authorities and river owners, as well as among the general public.

A recently developed model based on recorded numbers of farmed salmon in Norwegian salmon rivers (1989–2009) and the spawning success and competitive ability of escaped farmed salmon (Diserud et al. 2012) suggest that many wild Norwegian salmon populations are already affected genetically by escaped farmed salmon. Some areas with high densities of salmon farms, such as the Counties of Hordaland, Sogn og Fjordane, Møre og Romsdal and parts of Rogaland in particular, appear to be seriously affected. A recent risk assessment related to environmental effects of salmon farming concluded that in some geographical regions on the west coast there is a high probability of conflict between the goals of the management authorities and the observed numbers of escaped salmon in rivers (Taranger et al. 2011).

In an earlier report, Otterå et al. (2004) concluded that the situation for the wild salmonid populations in the Hardangerfjord was critical and that escaped farmed salmon and salmon lice were responsible for an important part of the problem. Although management authorities and salmon farmers have introduced a number of measures to reduce the infection pressure of salmon lice on wild fish, infection levels continue to be high and appear to be closely associated with the localization and biomass of farmed salmon (Taranger et al. 2011). Moreover, the number of escapees in many of the rivers continues to be above critical values for wild salmon populations (Anon. 2011; Vollset et al. 2014).

The aim of this article is to develop a conservation plan for wild Atlantic salmon and anadromous brown trout populations in the Hardangerfjord, based on a biological and genetic assessment of the populations and existing knowledge related to the conservation of fish populations. Although the conflicts between exploitation of aquatic environments by man and salmonid species appear particularly pronounced in the Hardangerfjord area, the conflicts are by no means unique to this region (Ford & Myers 2008; Buschmann et al. 2009; Anon. 2011; Waples et al. 2012). The pressure on freshwater habitats is a global phenomenon (Dynesius & Nilsson 1994) and the most important impact factors seen in the Hardangerfjord area are known to affect a significant part of Norwegian populations of Atlantic salmon (www.Lakseregisteret.no). Therefore, the experience gained from the implementation of a conservation plan for salmonid species in the Hardangerfjord region will have relevance for several coastal areas in Norway and other countries where salmonid populations are under pressure due to extensive use of aquatic habitats by man.

The anadromous populations in the Hardangerfjord basin

There are 27 rivers with known anadromous salmonid populations in the Hardangerfjord basin, in addition to numerous small streams in which anadromous brown trout may spawn occasionally (Figure 1). Previously, there was substantial fishing activity for Atlantic salmon with gillnets and bag nets in most of the fjord, with more than 150 licensed locations registered (Hordaland County Governor, pers. comm.). Fishing in the rivers has been widespread and substantial, mostly as a recreational activity for the local population, but also for non-resident anglers in some of the rivers. Of the rivers with anadromous populations, 12 include stretches with more than 4 km available for salmon and anadromous brown trout (Table I). Of these rivers, the River Etneelva has been established as a national salmon river, which means that particular attention is paid to this population regarding protection from human impacts (Anon. 2002). The larger rivers with the greatest potential for smolt production are the River Etneelva, the rivers in Eidfjord (River Eio, River Bjoreio, River Veig), and rivers Uskedalselva, Æneselva, Granvinselva, Mehlselva in Rosendal, Kinso, Steinsdalselva, Sima, Omvikedalselva, Opo, and Ådlandselva. According to Skaala et al. (2010), four of the larger rivers are little affected by physical changes, while five are moderately affected due to hydroelectric power production.

Salmon catch statistics exost from some of the rivers, such as River Etneelva, where reported annual catches typically ranged from 2000 to 3000 kg

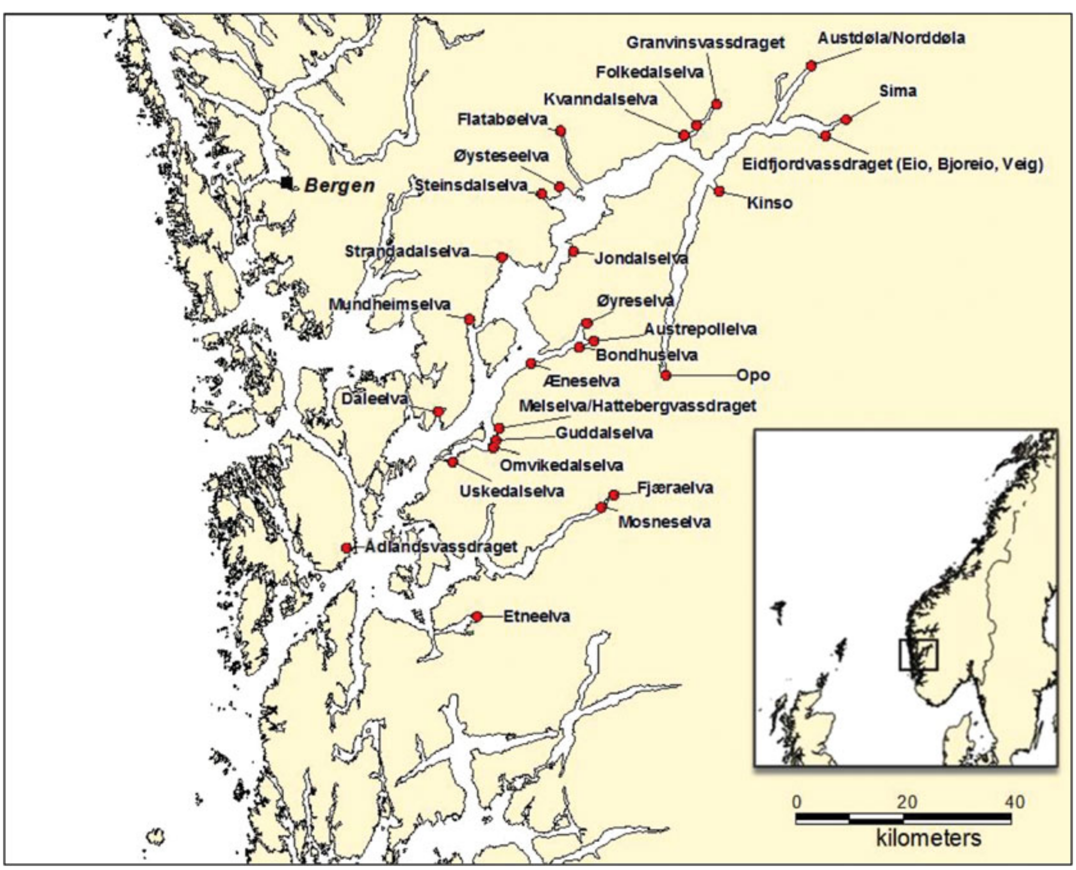

Figure 1. Map of the Hardangerfjord basin, with location of rivers with Atlantic salmon and anadromous brown trout.

Table I. The 12 largest rivers with Atlantic salmon and anadromous trout in the Hardangerfjord, showing length of river available for anadromous fish, extent of water regulation (No; +: some; ++: extensive), level of impact on populations of salmon (S) and anadromous trout (T), and major category of impact. L: salmon lice; W: water quality; R: hydropower generation.

River	Length (km)	Regulated	Affected populations	Factor
Etneelva	12.2	+	S + T: moderately	L
Uskedalselva	10.3	No	T: moderately	W
Granvinelva	7.5	+	S + T: highly	L
Eidfjordvassdraget	6.6	++	S: highly; T: moderately	R
Opo	1.5+	No	S: highly; T: moderately	L
Æneselva	5.7	No	T: highly	L
Steinsdalselva	5.0	No	S + T: highly	L
Rosendalselva	5.0	+	S + T: highly	L,R
Ådlandselva	4.6	No	T: moderately	L
Omvikedalselva	4.4	No	T: moderately	L
Sima	4.3	++	T: highly	R
Kinso	4.2	No	S: highly; T: moderately	L

between 1969 and 2008 (peak > 5400 kg in 1974) and provide an indication of angling activity. In another major river system, the Eidfjord water course in the inner part of the fjord, reported catches of salmon have ranged from a few hundred to over 2000 kg in the early 1970s, with a falling trend in recent years (Figure 2). For anadromous brown trout, reported catches in the River Etneelva have ranged from about 200 to almost 1000 kg in the same period, with a marked falling trend (Statistics Norway 2010). With the decline in many of the anadromous brown trout and Atlantic salmon populations in these rivers, interest in angling activity also appears to have declined, with a corresponding bias in catch statistics. From about 2000, restrictions in river angling and sea fishing for anadromous fish have been gradually introduced to reduce mortality and protect spawning populations. Since 2004, spawning populations have been assessed in the rivers by divers from Uni Research (Skaala et al. 2010; Vollset et al. 2014). In most river systems in the region, numbers of wild spawning salmon have been low, and estimated egg deposits have been below 2–4 eggs/m^2, i.e. below the recommended density for sustainable recruitment (Jonsson et al. 1998). The exception is River Etneelva, which still has a stable spawning population of sufficient size to support recreational angling. The situation for anadromous brown trout is more variable, but once again, the numbers of spawners are low in most rivers, in spite of fishing pressure restrictions, with rivers Uskedalselva and Omvikedalselva as possible exceptions (Vollset et al. 2014). In a study of gene flow and effective population size of several anadromous brown trout populations in the Hardangerfjord basin, Hansen et al. (2007) identified the River Etneelva as supporting the largest population. This population may therefore be the most important population in future conservation work. However, the study also found evidence for adaptive divergence among populations at immune system loci, which must also be taken into account in the conservation plan for anadromous brown trout.

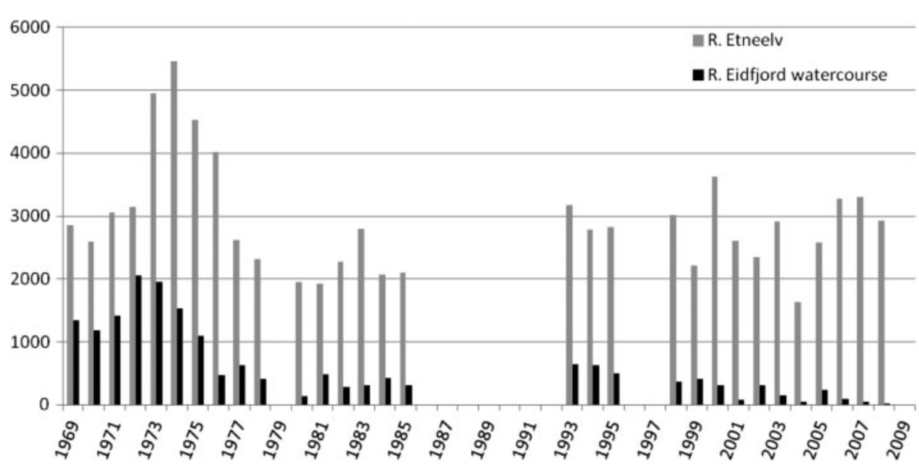

Figure 2. Atlantic salmon catch statistics for the River Etneelva, and River Eio and River Bjoreio in Eidfjord, the major river systems in the Hardangerfjord basin (Statistics Norway 2010).

Major population threats

As anadromous salmonids migrate between freshwater and the marine environment, they are faced with a range of environmental impacts due to human activities on local, regional and global scales, in addition to natural mortality factors. In a survey of river systems in the northern third of the world, Dynesius & Nilsson (1994) found that 77% of the 139 largest river systems were seriously or moderately affected by fragmentation, damming and water regulation. A recent survey of 481 Atlantic salmon populations in Norway suggests that escaped farmed salmon, salmon lice and hydroelectric power are the three major factors that impact production (www.lakseregisteret.no). While 340 populations are believed to be negatively affected by escaped farmed salmon and 187 by salmon lice, hydroelectric power production affects 110 populations. In the Hardangerfjord region, hydroelectric power production has changed annual patterns of discharge in some rivers considerably, reducing available juvenile habitats. Furthermore, due to lower winter discharges after spawning in these rivers, redds may become isolated, resulting in massive egg mortality (Barlaup et al. 1994; Grabowski & Isely 2007; Nagrodski et al. 2012). In some rivers, the water inlet to the hydroelectric power station has been designed to maximize water intake without any attempts to allow descending fish to bypass. As a result, large numbers of smolts and overwintering fish may be seriously injured or killed as they pass through the turbines (Ferguson et al. 2006). Old dams without fish passage still exist in some rivers. In some large power plants, water from one drainage system is transferred to another, and in some the water from the power plant is released directly into the fjord with a reduction in available habitat as a consequence. In other regulated rivers, water is not transferred between drainages, but reduced discharges may have detrimental effects on salmonid production (Saltveit et al. 2001; Johnsen et al. 2011). Other effects on freshwater habitats include changes in water chemistry and temperature (Saltveit 1990), and channelization and draining of side-branches of rivers, which either reduce available habitat or make it otherwise less favourable. As a response to structural changes in agriculture in recent years, concrete tanks have been built to hold large volumes of livestock manure, usually located close to riverbanks. Accidents involving manure releases (e.g. River Omvikedalselva) have resulted in up to 100% mortality of salmonid fish populations below the point of release (Urdal et al. 2011).

In the marine phase, salmon farming has a major impact on wild anadromous populations, particularly through infection by the salmon louse *Lepeophtheirus salmonis*. The parasite affects Atlantic salmon and anadromous brown trout by feeding on tissue and mucous, thereby causing physiological stress to individual fish, reduced growth and reproductive capacity, and ultimately greater mortality (Heuch et al. 2005; Krkošek et al. 2007, 2011, 2013; Wells et al. 2007; Bjørn et al. 2011). The impact level depends on several factors, such as the density of salmon farms, water temperature, migration routes and duration of migration in the fjord. In some years, post-smolts may leave the fjord before infection pressure increases, which means that survival is determined by natural mortality factors. However, the marine migration of anadromous brown trout is restricted to the fjord basin where the fish may remain for several months before returning to freshwater (Klemetsen et al. 2003). This means that anadromous brown trout may be more severely affected than Atlantic salmon by the parasite.

Escaped farmed salmon were detected in the sea fisheries in the Hardangerfjord already by the late 1980s (Atle Kambestad, Hordaland County Governor, pers. comm.), and between 1989 and 2010 the percentage of escaped farmed salmon was dominating in some rivers in some years (Otterå et al. 2004; Anon. 2011). However, unlike the national monitoring programme on salmon lice which was planned, organized and carried out by research institutions, the current monitoring of escapees in wild salmon populations is suffering from a high degree of fragmentation where observations are collected by various privately and publically funded projects using varying methods and a varying level of precision (Skilbrei et al. 2011). Accordingly, there is a degree of bias in the different data sets on the amount of escapees in wild populations, which is a challenge for the use of the data sets by management authorities. Since 2004, numbers of wild Atlantic salmon and anadromous brown trout spawners and escaped farmed salmon have been recorded in the rivers by snorkel surveys (Vollset et al. 2014). Analyses of growth patterns of salmon scales have shown that some individuals that superficially appear to be wild spawners are actually escaped farmed salmon (Sægrov & Urdal 2006). Accordingly, visual counts of salmon spawners are probably minimum estimates of escapees, with a corresponding overestimation of wild salmon spawners. In the River Etneelva, where records of escaped salmon are most complete, the average number of escapees reported in autumn samples between 1989 and 2009 was 77.6 ($\pm$SD 66.4; $n_{\mathrm{Tot}} = 1474$), giving an average percentage of escapees estimated at 57.3% ($\pm$SD 22.5%) (Anon. 2011). The snorkel surveys have confirmed the high proportion of escaped salmon in the River Etneelva and other rivers in the Hardangerfjord, but with a lower abundance of escapees in the rivers in inner parts of the fjord (Vollset et al. 2014).

In a study of temporal genetic stability in seven populations of Atlantic salmon based on eight DNA microsatellite loci, Skaala et al. (2006) found that three of the populations, of which two were from the Hardangerfjord (the rivers Opo and Eio), had changed genetically, most likely due to introgression by farmed escapees. In a larger follow-up study with 21 salmon populations along the Norwegian coast, Glover et al. (2012) found significant genetic changes in 6 populations, particularly in the River Opo, where most of the individuals now fail to assign to the DNA profile of the historic population. However, in spite of a high abundance of escaped farmed salmon for a number of years in River Etneelva, DNA microsatellites and DNA SNP marker studies suggest that so far there have only been small changes in the DNA profile of this population (Skaala et al. 2006; Glover et al. 2012).

While assignment tests revealed that 100% of the individuals in the contemporary sample from the River Opo were excluded from the historical profile, the exclusion of individuals in the contemporary sample in the River Etneelva was only 5–16%, depending on significance level (Glover et al. 2012). Furthermore, the low genetic differentiation between historical and contemporary samples, as measured by Fst and the large differences in growth between salmon from the River Etneelva and farmed salmon under controlled conditions (Glover et al. 2009) strongly suggests that this population has so far experienced little genetic introgression from farmed salmon. In summary, the major threats to anadromous populations in the Hardangerfjord appear to be degradation of the freshwater habitat, increased mortality due to high levels of salmon lice infection derived from fish farms, particularly in anadromous brown trout, and reduced production of wild salmon due to genetic introgression from escapees.

A conservation plan for anadromous salmonid populations

Rehabilitation of freshwater habitats

According to official statistics, the freshwater habitat available for anadromous salmonids in the Hardangerfjord rivers is about 1,764,000 m^2 (Skaala et al. 2010). Although many Norwegian salmon populations have suffered significant impacts from a variety of stressors (Anon. 2011), information regarding the quality of the freshwater habitat and the actual smolt production from the Hardangerfjord region is scarce. In Guddalselva, however, anadromous brown trout and Atlantic salmon smolt production has been estimated every year since 2000, after construction of a Wolf smolt trap. In this summer-cold river, which is partially fed from the Folgefonna glacier, the individual growth of Atlantic salmon and anadromous brown trout juveniles is low, and the average age of smolts is about three years in both species. The production of anadromous brown trout smolts is about 6 per 100 m^2. Most likely, the production is higher in more summer-warm rivers.

To restore smolt production in the affected rivers, it is essential to map different impact factors. This must be carried out by biologists in close collaboration with local management authorities and the Norwegian Water Resources and Energy Directorate. Barriers for ascending fish need to be identified and removed. Where water inlets in local hydropower plants direct smolts and spawned fish through turbines, bypasses need to be built. Storing tanks for manure need to be secured to avoid accidents resulting in pollution and fish mortality. Tributaries, which are either blocked or otherwise made useless for anadromous fish, need to be restored. Finally, public awareness of habitat requirements of anadromous salmonid fish and the importance of these species for recreation and tourism needs to be strengthened (Dodson et al. 1998).

Use of DNA markers to identify wild spawners. Most Atlantic salmon escapees in the spawning areas of wild salmon can easily be identified by phenotypical characters such as fin erosion, shortened opercula and growth patterns in scales (Lund et al. 1991). However, it has been argued that in recent years a large proportion of escapees in rivers have become more difficult to identify (Sægrov & Urdal 2006). This means that more sophisticated methods have to be included to distinguish between wild and farmed spawners, particularly when wild spawners are to be used for conservation purposes, such as preservation in gene banks or for planting eggs in rivers for population enhancement. Trained personnel can study scale growth patterns locally. This usually requires individual tagging of spawners and keeping them in tanks until the results of the scale reading become available. It is expected that with the high proportion of escapees observed in some rivers, and the reduced spawning success of farmed salmon (Fleming et al. 2000), a high proportion of the population will be crosses between farmed females and wild males. At present, it is not possible to detect these hybrids by phenotypic characters or growth patterns. However, developments in statistical analysis, molecular techniques and genomic tools mean that DNA-SNP and/or microsatellite markers distributed across the genome can now be analysed. Various assignment tests (Anderson & Thompson 2002; Falush et al. 2003) can subsequently be used to classify individuals as wild, farmed or F1 hybrids (Vähä & Primmer 2006; Hansen & Mensberg 2009; Glover et al. 2010, 2012; Karlsson et al. 2011). Thus, farmed and F1 hybrids can subsequently be eliminated from spawning populations or from brood stock for the gene banks. A practical side of the field operation of this approach is to tag the spawners individually and hold them until their wild, farmed or hybrid status can be determined, a procedure which requires the use of rapid genotyping.

Preservation of genetic material in the Genebank

Because of the severe threats to many Atlantic salmon stocks (Aas et al. 2011), the Norwegian government implemented the Genebank programme for wild Atlantic salmon in 1985. The programme was financed by the Ministry of Environment and established in 1986 by the Directorate for Nature Management. It involves both a milt bank, consisting of cryopreserved sperm, and a more traditional living Genebank. The purpose of the milt bank was to preserve the genetic diversity and characteristics of natural salmon populations. The first living Genebank was started due to the infections with the ectoparasite *Gyrodactylus salaris* Malmberg, 1957 and a subsequent decrease to near extinction of many Atlantic salmon populations (Johnsen & Jensen 1991). However, the programme subsequently acquired even higher importance after the detection of escaped farmed salmon in many rivers, especially in western Norway.

The purpose of the living Genebank was to establish a reservoir of genetic material, which can be used for the reestablishment or enhancement of threatened populations. The milt bank is primarily a long-term measure aimed at general conservation of genetic variation, while the living Genebank is a temporary measure aimed at supplementing and replenishing the most threatened populations. Eyed eggs are delivered to local hatcheries or directly to the rivers for egg planting (Figure 3). The most important aim is to create a good founder population in the living Genebank, which essentially means maintaining a sufficient number of parental fish to avoid inbreeding in the short term (Franklin 1980), i.e. at least 25 of each sex, representing the whole river and all year-classes. Frozen milt from the milt bank is used to increase genetic variation and reduce

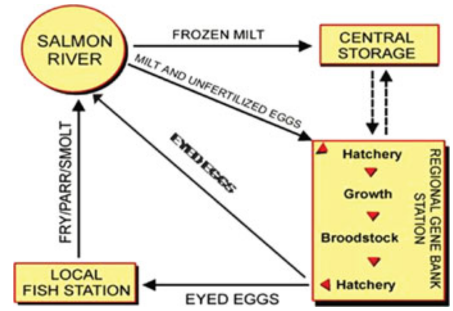

Figure 3. Diagram showing movement of unfertilized eggs and milt between salmon river and the gene bank, movement of eyed eggs from gene bank to local fish station and salmon river, and movement of fry and parr from local fish station to salmon river.

loss of variation during the production period within the living Genebank. It is important to acknowledge that the use of gene banks is not a perfect solution, as adaptation to the captive environment will inevitably take place, possibly within only a few generations (Araki et al. 2007). A living Genebank for anadromous brown trout has also been established. Two salmon populations from the Hardangerfjord basin are now present in the living Genebank at Eidfjord: the populations in the Eidfjord watercourse and in the River Etneelva (Table II).

From 1986 to 1999, milt was collected from 295 Atlantic salmon captured in 11 rivers in the Hardangerfjord region (Table III). Only 212 of these individuals were verified as wild salmon by means of analyses of scale growth patterns. The rest were classified as escapees and discarded. The major contributors in the Hardangerfjord to the cryopreserved milt bank are the larger rivers such as the River Etneelva in the outer part of the fjord and the Eidfjord watercourse, the River Opo and the River Granvin in the inner reaches of the fjord. The collection of milt was stopped in many rivers because of the large numbers of farmed salmon in the region, and also due to limitations in the methods used to distinguish between wild, hybrid and farmed salmon.

Planting of eggs from the Genebank

Hatchery-produced fish are sometimes released in order to compensate for reduction in freshwater

Table II. Number of family groups and brood fish from Hardangerfjord rivers in the living genebank.

River	No. of family groups	No. of individually marked fish	No. of group-marked fish
Eidfjordvassdraget	56	523	2500
Etneelva	33	0	5000
Total	89	523	7500

Table III. Number of milt samples collected from Atlantic salmon in Hardangerfjord rivers from 1986 to 1999.

	Year														
River	86	87	88	89	90	91	92	93	94	95	96	98	99	sum	wild
Eidfjordvassdraget		2	7	2	9				8	6	3	2	3	39	35
Etneelva	16	12	3	7	12									50	45
Granvinselva				10	7	12	5	6	10		2			52	35
Jondalselva				7	8	7								22	13
Omvikedalselva				7	4									11	8
Opo			8	10		3	5		4	4	4	2		40	24
Rosendalselva				2	3	4	1	4						14	6
Guddalselva						1	1							2	2
Steinsdalselva						3	1	6	2					12	8
Uskedalselva				3	5	2	3		5					18	13
Øysteseelva				10	11	8	6							35	23
Total	16	14	18	58	59	40	22	16	29	10	9	4	3	295	212

habitat due to hydropower production (Johnsen et al. 2011) or other human activity (Jonsson et al. 2011). However, using hatchery fish removes part of the process of natural selection (Einum & Fleming 2001; Araki & Schmid 2010; Lorenzen et al. 2012). When spawners are collected and stripped artificially, the intense competition on the spawning ground disappears. In nature, usually less than 5% of the eggs survive to the smolt stage (Jonsson et al. 1998), while under hatchery conditions survival may be very high, with a corresponding change in selection (Piggins & Mills 1985; Thorpe 2004). Several studies have also revealed negative effects on wild populations from hatchery releases (reviewed by Araki & Schmid 2010). Furthermore, it has been demonstrated that hatchery-produced smolts have a higher straying rate than naturally produced smolt (Stabell 1984; Altukhov & Salmenkova 1994; Jonsson et al. 2003), which in turn can lead to reduced genetic differentiation among populations.

In connection with rehabilitation of populations, it has been recommended to plant eggs in rivers in order to minimize genetic changes associated with the altered selection regime (Barlaup & Moen 2001). Suitable areas have to be identified prior to planting. In some rivers such as the River Opo, large areas above the anadromous stretch, with a high potential for smolt production, may be used for plantings. Eggs supplied from the Genebank are colour-marked in order to allow estimation of survival, to identify returning individuals, and distinguish planted fish from spawners from other sources (Moen 2000). Survival from planting of eyed eggs to swim-up stage is usually > 80% (Bjørn Barlaup, pers. comm.). In controlled studies in the River Guddalselva, survival from eyed eggs to the smolt stage has been over 6% in some families, although 2–3% was more typical (Skaala et al. 2012). With the high survival rate in hatcheries, large numbers of offspring can be produced from a small number of parental fish. This in turn may reduce the effective population size and therefore the genetic variability of the population, compromising the goals of the conservation efforts (Ryman & Laikre 1991). The potential drawbacks of supplementary stocking, such as altered selection regime, outbreeding effects and changes in the effective populations size N_e, needs to be carefully considered before implementation.

Removal of escaped farmed salmon from spawning areas

Several methods of removing escaped farmed salmon from the spawning areas of wild populations have been tested through a series of small projects, ranging from angling, gillnetting and harpooning in the rivers to fyke nets in the estuaries and trawling in the fjord (Lehmann et al. 2008). In a number of release experiments using farmed salmon, Skilbrei (2010) and Skilbrei et al. (2010) demonstrated that once the farmed salmon are out of the net pens, they tend to spread over large areas, and after only one week they may have moved as far as 40 km from the release point. A large proportion of the escapees also swim down to depths at which they are far beyond the reach of traditional fishing gear. As a result, attempts to recapture escapees by twin trawling in the open fjord areas shortly after they escape from the sea cages has had little success. At present there is no national coordination or plan to remove escapees from the spawning areas of wild Atlantic salmon, and much of this activity is based on volunteers working on a year-to-year basis in individual rivers. Furthermore, the potential for capturing and removing escaped salmon from wild salmon spawning areas varies from river to river, depending on physical factors such as easy access to the river, river size, water discharge, topography, and the distribution of escapees throughout the river. A combination of high discharge and high water velocity is a challenge. In small rivers with water discharge up to about 30 m^3/s, fish can often be successfully removed by gillnetting just before the spawning season, especially during periods of low water discharge. In larger rivers, removal is more difficult (Lehmann et al. 2008; Skaala et al. 2010).

Current efforts to remove escaped farmed salmon from rivers also suffer from lack of a national funding plan, coordination and reporting, fragmented efforts, problems in identifying some escapees, particularly hybrids, and finally health and safety problems for the personnel involved. To date, there has been little technological effort at the national level to develop new methods for removing escapees from rivers.

Resistance board weirs, concepts and use

Adequate information about adult spawner abundance is a critical aspect of a viable salmonid population management strategy (Foose et al. 1995; Botkin et al. 2000). Anadromous salmonid passage counts are important to fisheries managers for setting fishing seasons, estimating run size, determining in-river survival, estimating escapement to spawning grounds, and establishing and monitoring various compensation and enhancement programmes (Hatch et al. 1998). Determining demographic information, such as the proportion of male and female adult spawners and origin (e.g. farm versus wild) of fish returning to natal streams, is important in evaluating production goals and estimating stock reproductive potential. Physically counting and collecting information on salmonids at passage facilities can be time-consuming and expensive (Hatch et al. 1998). In the Pacific Northwest of North America there is great interest in developing rapid and practical methods of identifying species, population and other information on live salmonids in rivers.

Snorkel surveys have been the most common means of enumerating adult salmon escapees in Norwegian streams. However, this is only feasible when environmental conditions are optimal (Orell & Erkinaro 2007). Various monitoring methodologies are used in the Pacific Northwest of the United States to evaluate adult salmon escapement, including aerial and tower-based photography (Bevan 1961) and visual survey methods, in which field personnel make periodic counts of spawner abundance throughout a spawning season (Irvine et al. 1992), redd counts (Vinzant et al. 2010), hydroacoustic techniques (Ransom et al. 1998), video monitoring and computerized systems in fish ladders (Merz & Merz 2004). Escapees can be estimated by means of various sampling methods, including carcass surveys, which use post-spawning carcass counts and statistical modelling (Schaefer 1951; Seber 1973) to calculate the total number of spawners in each stream reach sampled. However, this technique is only feasible with semelparous salmon, and differences in behaviour between males and females can confound estimation errors (Murdoch et al. 2009).

A more direct assessment of salmon spawning migrations, when fish ladders or other constructions are unavailable, is the resistance board weir (Tobin 1994; Figure 4). Portable trap facilities such as resistance board weirs (RBWs), which have been in use in North America for about two decades (Tobin

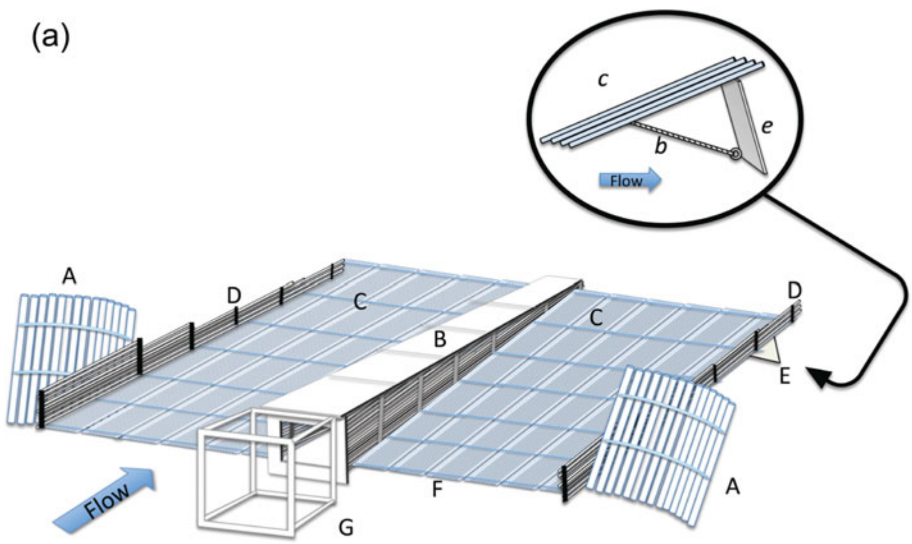

Figure 4a. Generalized schematic of resistance board weir installed in a gravel bed stream. A, Rigid weir; B, Fish way; C, Picket weir panels; D, Bulkhead; E, Resistance board; F, Substrate rail and anchor; G, Live trap location; Inset: b, Tension harness; c, PVC pickets; e, Resistance board. Flow pressure against board causes lift of weir panels.

Figure 4b. Photo of complete trap in Williamson River, Oregon (Photographer: J. Anderson).

1994; Anderson et al. 2007), have still to be tested in Norwegian rivers, although such permanent or portable systems would appear to be rather useful in removing farmed salmon escapees from rivers. At the same time, such systems would provide good opportunities to improve the monitoring of wild anadromous populations by introducing a consistent sampling method, reducing sampling bias in data sets and allowing for development of time series, all of which are extremely valuable management tools. RBWs are a relatively new modification of very old technology (Moss et al. 1990; Petersen et al. 1994) and are typically operated in close proximity to known spawning areas. RBWs, widely implemented in Alaska, have been used to estimate numbers of anadromous salmonid spawners since the early 1990s (Tobin 1994). In the winter of 2002, an RBW was installed in the Stanislaus River in California to test the use of this technology for monitoring Chinook salmon populations *Oncorhynchus tschawytcha* Walbaum, 1792. The weir was originally constructed using a combination of resistance board panels (Tobin 1994; Stewart 2003) and rigid weir panels. A series of panel and component modifications (compared to Tobin 1994; Stewart 2003) tailored the RBW to its current site. The utility of RBW technology was improved in 2003 by the addition of a passive fish counter (RiverWatcher), manufactured by Vaki Aquaculture Systems Ltd (Kopavogur, Iceland), which counted adult salmon passing the weir using digital and infrared technology (Anderson et al. 2007). Shardlow & Hyatt (2004) showed that the RiverWatcher system was better than 95% accurate for Pacific salmon when migration rates were less than 500 fish/h (= a high rate of passage). Other studies (Fewings 1994) found the accuracy of this technology to be even higher (approaching 100%). Data collected in subsequent seasons on the Stanislaus River proved to be highly efficient in enumerating Chinook salmon run size and timing and in identifying marked hatchery salmon, as well as other fish species in comparison with traditional carcass and redd surveys (Anderson et al. 2007). Incremental improvements in weir operations and image-recording data collection have been made with each passing season, with weirs now being used throughout California to enumerate salmon spawner escapement, collect hatchery salmon, and segregate different salmon populations within individual systems. The use of the technology is now growing internationally.

Recommendations

Based on existing data on the populations of anadromous brown trout and Atlantic salmon in the Hardangerfjord basin and available information about impact factors in freshwater and in the fjord, we recommend that a conservation plan for Atlantic salmon and anadromous brown trout populations in the Hardangerfjord region be implemented. The conservation plan should include the following steps numbered according to priority: (1) assessment of the genetic structure of brown trout and of Atlantic salmon populations in the fjord, quantification of the degree of introgression from farmed salmon, and identification of remaining wild spawners; (2) reducing gene flow from escapees, either by changing the aquaculture production in the fjord from fertile to sterile salmon or by removing farm escapees from the most important spawning areas, or by a combination of the two; (3) reducing infection pressure from salmon lice has been discussed for a number of years. Various efforts have been discussed and tested without meeting the goals, and increasing resistance in salmon lice to chemotherapeutics is a growing problem. Thus, it appears that a reduction must be obtained either by introducing closed sea cages or by reducing the biomass of farmed salmon in the Hardangerfjord; (4) conduct an assessment of the freshwater habitats for anadromous salmonids in order to improve the habitats and then implement it in order to restore smolt production; (5) efforts should be made to reduce risks of river pollution from agriculture and industry and to minimize impacts from hydropower production; (6) where necessary and practical, plant eyed eggs from the Norwegian Genebank to increase parr and smolt production, following genetic guidelines for supplementary stocking; and (7) monitor spawning populations of Atlantic salmon and anadromous brown trout and record parr densities of both species to evaluate potential effects of the mitigation efforts.

Conclusions and outlook

It is concluded that the anadromous populations of Atlantic salmon and brown trout in the Hardangerfjord basin are severely affected by human exploitation of the aquatic habitats. This conclusion is based on scientific information about anthropogenic impact factors known to affect wild anadromous populations, presented and discussed in a number of international symposia and journals over more than 20 years. More recently, information has been acquired through the interdisciplinary research programme 'Ecological Processes and Impacts Governing the Resilience and Alterations in the Porsangerfjord and the Hardangerfjord (EPIGRAPH)' and closely related projects and monitoring programmes on salmon lice infection levels. Furthermore, spawning surveys have documented a high percentage of escapees in several rivers, including the national salmon river, Etneelva. In some of the populations, like in the Rivers Opo and Eio, significant genetic changes, most likely caused by gene flow from escapees, have been documented. The infection levels of salmon lice on anadromous brown trout in central and outer parts of the Hardangerfjord are among the highest observed in Norway, and it is concluded that salmon lice from farms have a negative impact on the wild populations, particularly of anadromous brown trout but also on populations of Atlantic salmon. As sampling of post smolts of Atlantic salmon is difficult and expensive, less-accurate data exist on the infection levels of this species. However, in some years the majority of salmon smolts from rivers in the outer and central parts of the fjord seem to have left the basin before infection pressure was peaking and thus obtained a higher survival. This has been reflected in increased numbers of Atlantic salmon spawners in 2011 and 2012. The situation for salmon populations from the inner parts of the basin may be more adverse, as there are indications that they migrate somewhat later in spring and therefore may suffer from higher infection levels. There is less scientific information about the effect of hydroelectric production and agriculture in the Hardangerfjord rivers, but surveys during the programme period suggest that production of wild parr and smolts is less than optimal in several rivers. Also, with the observations of farmed spawners in the rivers, we conclude that an unknown fraction of the parr and smolt produced in many rivers is now offspring of farmed salmon rather than wild salmon. Given that the reduced return rates of offspring of farmed salmon observed in other studies also holds true in the Hardangerfjord, offspring of farmed salmon may contribute to a further reduction in numbers of wild spawners to the Hardangerfjord rivers. Finally, salmon farming in the Hardangerfjord appears to violate the goals developed by the Norwegian government concerning genetic impact and diseases in the 'Strategy for an Environmentally Sustainable Norwegian Aquaculture Industry'. For the stocks to recover from the impact caused by human activities in freshwater and marine habitats, a conservation plan must be implemented. Also, the general awareness of the requirements of anadromous salmonids in the general public and among management authorities at the local and regional levels has to be improved by communication of the problems and solutions.

Technically speaking, there are no large challenges that would prevent implementation of the seven prioritized steps of the conservation plan. Step 1: to some extent population genetic data exist for both Atlantic salmon (Skaala et al. 2006; Glover et al. 2012) and anadromous brown trout (Hansen et al. 2007). Step 2: reducing abundance of escapees in wild spawning areas has been done with success for a number of years. The major challenges are unpredictable funding and also the lack of quality control of methods and data, the latter being a responsibility of management authorities. Step 3: reducing the infection pressure of salmon lice by reducing the biomass of farmed salmon or by introducing closed cage culture is technically possible. It is also in accordance with the Aquaculture legislation, which allows for a change of aquaculture permits when production is not environmentally sustainable. Step 4: an assessment of the freshwater habitats is required also according to the Water Framework Directive in Norway. Step 5: minimizing pollution and impacts on freshwater habitats is also in accordance with the Water Framework Directive in Norway. Step 6: planting eggs as part of a population restoration programme according to guidelines is also practically feasible. Step 7: monitoring spawning populations and parr densities is also practically feasible and particularly important in regions with extensive exploitation of aquatic habitats, such as in the Hardangerfjord region. In conclusion, the scientific literature which documents the effects of human activities on anadromous salmonid populations is extensive and growing. Conservation plans for aquatic resources and mitigation efforts must be based on scientific principles and coordinated by national authorities, not by private enterprises whose economic success is based on exploitation or even overexploitation of the natural resources. However, in Norway there is still little funding available for habitat assessments and apart from a small private fund managed by salmon farmers, no funding is available for mitigation efforts to reduce impacts on wild salmonid populations threatened by industrial activities. For comparison, in a previous assessment the costs to restore anadromous populations in the Hardangerfjord alone were estimated at NOK 65 million over a 6-year project period (Skaala et al. 2010). This lack of funding is in contrast to the extensive industrial activities in Norway based on aquatic resources and in contrast to the extensive scientific documentation of impact factors. We therefore call for an immediate initiative to establish a sufficiently large fund under democratic and public control, where predictable funding can be obtained for projects which focus on mitigation efforts and the conservation of salmonid populations.

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