Atlantic salmon fishways: The Norwegian experiences

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Sammendrag

Tilstanden til alle de 344 norske fisketrappene for atlantisk laks ble undersøkt, som en kombinert studie basert på den norske Fisketrappdatabasen og tilleggsopplysninger fra fylkesmennene, samt inspeksjon av 89 utvalgte trappeanlegg for ytterligere informasjon om utforming og funksjon. Denne inspeksjonen indikerte at nærmere 70 % av trappene fungerte godt og at laksetrapper har åpnet ca. 2000 km nye anadrome elvestrekninger. Norske laksetrapper består i hovedsak av støpte kulptrapper i betong, samt en del kulptrapper sprengt i fjell, begge typer med overløpsåpning. Studien viste at typisk vannføring i laksetrappene var mindre enn 0,5 m^3s^{-1}, men samtidig var også vannføringen i elva liten ved trappelokalitetene. I 70 % av tilfellene var årlig middelvannføring i elva ved laksetrappen mindre enn 20 m^3s^{-1}. Det ble ikke funnet noen sammenheng mellom laksetrappenes funksjon og trappens lengde eller høyde. Tvert imot viste studien at noen av Europas største fisketrapper finnes blant godt fungerende norske laksetrapper, og at laksen vandrer gjennom mørke tunneler over flere hundre meters strekning. Middelvannføring i elva var større ved godt fungerende trapper enn ved laksetrapper med dårlig effektivitet. I tillegg hadde laksetrapper ved menneskeskapte hindringer bedre funksjon enn trapper ved naturlige hindre. Dette indikerer at trapper med tilstrekkelig tilsyn, og trapper som administreres av vassdragsregulanter, gjennomgående vedlikeholdes bedre enn andre trapper. Den viktigste årsaken til at laksetrapper ikke fungerte var fysiske skader på trappen og manglende vedlikehold. Studien viser at den norske tradisjonen med kulptrapper antas å være godt egnet for voksen laks, og at godt vedlikehold og tilsyn av laksetrapper er et viktig forvaltningstiltak for framtidig bevaring av mange norske laksestammer.

Summary

The status of all 344 Norwegian Atlantic salmon fishways were explored, combining an existing national inventory with collection of additional information from local river authorities and on-site inspections of 89 selected sites to provide more detailed information on design and functionality. Inspections of 89 fishways indicated that nearly 70 % were fully functional and that the fishways potentially have opened approximately 2000 km of anadromous river reaches. With few exceptions, Norwegian fishways are pool and weir type ladders with surface notches, mostly in concrete but also a number blasted in rock. Fishway

discharge was generally smaller than 0.5 m^3s^{-1}, but at the same time mean annual river flow was small, and smaller than 20 m^3s^{-1} at 70 % of the 344 the fishway sites. No relation was found between fishway height or length and fishway function. Contrarily, some of the highest and most sophisticated constructions in Europe are among the functional Norwegian fishways, and the salmon ascend through long tunnel reaches in complete darkness. River flow was larger at sites with functional fishways than sites with dysfunctional fishways, and fishways at man-made obstacles had better function than fishways passing natural waterfalls. These findings indicate that fishways with sufficient supervision and fishways maintained by hydropower companies receive more attention than those at other sites. The most important reasons for fishway dysfunction were physical damage and lack of maintenance. The study shows that the tradition and development of pool and weir ladders is considered to be well suited for adult salmon under Norwegian conditions, and that maintenance of the fishways is an important management assignment in future conservation of many salmon populations.

Key words: *Salmo salar*, migration barrier, fishways, upstream migration, fishway efficiency.

Introduction

The Atlantic salmon has fascinated humans for thousands of years and is one of the most prized and exploited species worldwide (Aas et al. 2011). Historically, Atlantic salmon was distributed in more than 2600 watersheds on both sides of the North Atlantic (WWF 2001), but now populations are declining within the whole distribution range and numerous anthropogenic impacts contribute to this trend (ICES 2011). Nearly 90 % of the known, healthy populations are now found in four countries (Norway, Iceland, Ireland and Scotland) while 85 % of the populations in the other countries are categorised as critical, vulnerable or endangered (WWF 2001). Based on the number of distinct populations and total occurrence, Norway presently represents the core area for the Atlantic salmon but also here, negative trends are highly noticeable. According to a recent inventory of the originally 450 self-reproducing Atlantic salmon populations in Norway, 45 have gone extinct, 32 are threatened with extinction, 49 are classified as vulnerable and 65 as reduced (Hansen et al. 2007).

The anadromous life cycle of the Atlantic salmon implies a particular vulnerability to anthropogenic threats as it involves migration across several habitats and large areas. The upstream migration in rivers is the foundation for the abundance of salmon, both ecologically and for human recreation and economic output. During the upstream migration, the salmon may encounter obstacles and barriers that delay or block the migration routes (Mills 1989). Constructions of impassable dams are among the most important reasons for the loss of populations across the entire species distribution (Johnsen et al. 2011). Based on the recognition of the critical need for river connectivity (Knaepkens et al. 2007), fishways for Atlantic salmon is topic of increased scientific interest, and occupies several professional societies, including engineers, ecologists and biologists (Katopodis 1992, 2005; Gowans et al. 2003; Larinier 1998; Thorstad et al. 2008).

Construction of fish passage facilities is widely used to mitigate migration barriers (Katopodis 2005). The first documented fish passes in the 18th century (Landmark 1884), were simple constructions and likely used as a measure to increase population size and fishing opportunities. Since then, anthropogenic impacts and industrial development have fragmented river systems in the majority of large rivers around the world (Nilsson *et al.* 2005) and parallel to this development a large number of fish passes of various technical designs have been constructed (Clay 1995). Despite the Atlantic salmon's impressive capability of leaping waterfalls, the migration success through man-made fish passes is often small or involves significant delays (Rivinoja et al. 2001). The reason for this is obviously complex and depends on a set of parameters, both general and site specific.

Adult Atlantic salmon appear to display a high degree of local homing within the river

(Harden Jones 1968; Stasko et al. 1973). Consequently, full recruitment of new production areas only by construction of fish passes may take decades (Berg 1964, 1966), explaining why initial fish pass migration can be deceptively limited. The conditions in the opened reaches, such as availability of spawning and rearing habitats and presence of competitors or predators, will confine the expansion progress of the upstream salmon population and subsequently the migration motivation to these new areas. The ability of swimming and leaping is strongly dependent on water temperature and cold water can delay migration past waterfalls or fish passes significantly (Bell 1973). Local hydraulic conditions around a migration obstacle depend on discharge and fish passing often takes place in certain discharge windows (Jensen *et al.* 1986; Rivinoja et al. 2001). Water quality, turbidity, cloud cover, atmospheric pressure and air temperature are additional factors that can influence migration, and these variables are often related to river discharge (Banks 1969). Intrinsic factors, such as maturation state or energy state may also influence the migration pattern. Such factors are sometimes referred to as "motivation" for migration (Thorstad et al. 2011) and this motivation may increase when spawning time approaches (Gowans et al. 1999; Johnsen et al. 1998).

Hydroelectric dams and their tailrace areas represent particular migration challenges. Rivinoja et al. (2001) reported that only 26 % of migrating Atlantic salmon on the river Umeå in Sweden passed a hydropower outlet through a fishway. Thorstad et al. (2008) found that radio tagged adult salmon stopped at a median value of 20 days (2003a) and at a mean value of 42 days (2005) at two hydropower outlets but the mechanisms are not completely understood.

Increasing research on fishways has revealed that more knowledge is still needed to understand the different aspects around fishway migration and that site specific conditions play an important role (Katopodis 2005), both on a population scale (Thorstad et al. 2008) and down to technical details, such as turbulence impacts in the fishway (Silva et al. 2010). For instance, different physical aspects must be considered in each different case, such as entrance design, water discharges in the fish pass and in the river, and adaption to local dynamics including floods, ice jamming and sediment exposure.

Construction of fishways for Atlantic salmon has long traditions in Norway. The first one was opened in 1872 and is still in use. Since then, approximately 500 fishways have been built, mostly for Atlantic salmon migration (Grande 2010) including a variety of designs, from minor riprap and blasting works to comprehensive combinations of concrete towers and rock tunnels, the tallest nearly 50 meters high (Mathisfossen waterfall, 46.5 m). However, considering the large number of technical solutions worldwide (e.g. Denil, lifts, Borland and vertical slots), Norwegian fishways are almost exclusively pool and weir type ladders with surface notches. Also, they are designed for relatively small discharges (0.2-0.5 m^3s^{-1}) and with a 0.5 meters drop between each pool. Partly, this is a result of a tradition and not scientific based policy, as different designs have demonstrated successful migration elsewhere (Clay 1995). It must be assumed that this category of fishways originally represented a design, manageable to commission in the back country with limited skills, equipment and budget.

Even though fishways are widely used to pass manmade barriers, Norwegian fishways were most often constructed for increasing the fish production and thereby the economic outcome. The Norwegian Directorate for Nature Management is responsible for the management of salmon populations in Norway, including migration facilities (Anon. 2010). The Directorate also governs a national fishway inventory. At the same time, the 19 local county administrations, hydro power companies, anglers clubs and private stakeholders conduct major parts of the supervision and maintenance. As a consequence, information about each fishway, its state and its function is fragmented and an up to date complete overview of the fishways has not been available. Particularly, information is lacking for the many smaller facilities in the smaller river systems.

Except from a few scientific studies (Jensen et al. 1986; Bergan et al. 2003; Thorstad et al. 2003b; Lamberg et al. 2008), verification of migration success and the importance of physical variables (e.g. discharge and entrance design) in Norwegian fishways are scarce and such knowledge is important in future Atlantic salmon management. Unverified studies have suggested that between 20 and 50 % of the Norwegian salmon passes have a limited function or do not work at all. However, most of the information is scattered among many institutions and is often based on individual interpretation. Generally, the functionality problems are described as related to fishway design, entrance location, or connected to the relationship between river discharge and discharge through the fishway. These are all credible explanations but still, a national verification has so far not been conducted.

The present study is a systematic analysis of the actual state, the successes and the challenges for all the 344 Norwegian Atlantic salmon fishways. In addition, inspections of 89 fishways made us able to describe the functionality in details.

Materials and methods

The Norwegian Directorate for Nature Management administrates a national fishway database, which includes brief information about each site, such as the names of each site and river, technical data for the fish ladder and a judgment of its function and technical condition. The database contained 547 fishways and was made available for the present study. It initially became evident that large parts of the information were not updated and a simple questionnaire was developed to update the database. Altogether 17 (of 19) Norwegian counties had fishways for Atlantic salmon.

A list of Atlantic salmon fishways for each of the counties was sent by e-mail to the respective County Governor's Fisheries Manager, (hereafter referred to as the CGFM) who were invited to update the information and add projects not listed. The CGFM's were also requested to provide additional information:

- A judgment of any particular problem for each fishway (and how it occurred)
- An assessment of the potential production above each fishway and catch or enumeration data if available
- Identification of particular vulnerability from physical strain, such as floods, sediment transport and ice jams
- A list of relevant studies, photographs or reports from each site or river

Answers were received from all CGFM's and additional communication was implemented with CGFM's when desired information was missing. Next, the answers were used to update the database and subsequently the updated version was reviewed together with two retired employees at the Norwegian Directorate for Nature Management who had visited most of the sites during their employment and constructed many of the fishways. Finally, based on all the collected information each fishway was qualitatively categorized into four groups: good functionality (1), partly functional (2), not functional (3) and unknown function (4). Group 3 was subdivided into three categories, according to the provided explanation for dysfunction: water intake or discharge problems in the fishway (3.1), lack of maintenance, physical damages or design defects (3.2) and entrance problems related to location or design (3.3). A number of fishways could be placed in more than one group, and final categorization was based on the factor assumed to be most important for dysfunction.

To explore relationships between functionality and physical characteristics of the river at the respective site, the approximate mean annual flow (MAF) in the river at the site was estimated by use of a variety of sources. The Norwegian Water Resources and Energy Directorate (NVE) maintain a large number of gauging stations and many of these could be used directly. NVE has also produced maps of specific runoff for the entire country (in $ls^{-1}km^{2}$) which, in combination with catchment sizes, could be used to calculate MAF values. In addition, relevant data, especially in small rivers, were found in reports and books. For instance, catchment sizes for many of the Atlantic salmon rivers in northern Norway were already calculated by Berg (1964).

To obtain more detailed information on design and functionality, 89 sites from Finnmark county (approximately 71° N, 29° E) to Vest-Agder county (approximately 58° N, 7° E) were visited between 2007 and 2010. The fishways were selected as to represent the entire geographical range of the country, and targeted rivers where a fishway had potentially increased total production. No consideration was given to apparent functionality as classified in the revised database.

The main objective was to verify the qualitative categorization of the fishway under present day conditions and to identify technical details that were not included in the existing database. In most cases the inspections were conducted in company with stakeholders, angling associations or local river authorities that provided relevant local information. In some cases, these institutions or persons were contacted before or after the visits to provide information for the judgment of the functionality of each fish ladder. At each site fishway type, the physical state and characteristics of the constructions, distance from the entrance to the migration barrier, counting system in the fishway and water drop was recorded. In 17 out of 89 fishways, data from enumeration systems in the fishway was collected and compared with official fishery catch data from the respective rivers for 2009 and 2010.

Results

National findings

After the first fishway was constructed in 1872, the number of fishways in Norway increased with a distinct peak in the number of projects between 1960 and 1980. Thus, a majority of the constructions are 30-50 years old, figure 1. Out of 547 listed fish fishways, altogether 203 were removed (never constructed, damaged and removed or not built forAtlantic salmon), leaving 344 fishways for Atlantic salmon for further analyses. Despite some uncertainty associated with verification of anadromous reaches in many rivers, a rough estimate indicate that these fishways potentially have opened 2000 km of anadromous river reaches. Of the 344 fishways, approximately 20 are presently closed as a measure to restrict the distribution of the parasite *Gyrodactylus salaris* (Harris et al. 2011) within the river systems.

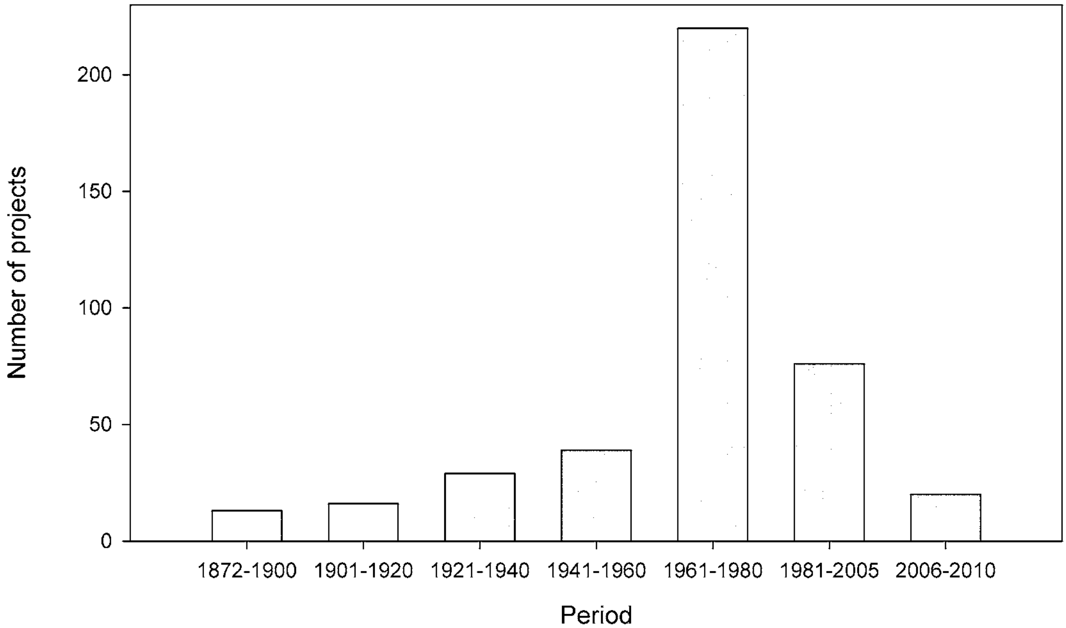

Figure 1. Number of constructed fish ladders in Norway in the period from 1872 to 2010 (Source: Norwegian directorate for nature management).

Distribution and functionality. – The fishways were located along the entire coast, with the highest number in the northern part, table 1. Based on the reports from the CGFM's, 66 % of the fishways had good functionality, while 21 % did not work - most of them due to physical damages or lack of maintenance. 5 % were reported to be partly functional, and 8 % , were reported to have unknown function, table 2. The geographic distribution of dysfunctional fishways was not significantly different from the distribution of the total number of fishways (χ^2-test, P = 0.12). However, the proportion of dysfunctional fishways were higher in the northern district (50 %) compared with the other districts (6-25 %). The large proportion of sites in the northern district, shows that the maintenance challenges in this part of Norway is considerable.

River size and fishway functionality. – More than 70 % of the Atlantic salmon fishways in Norway were located at sites where mean annual flow (MAF) was smaller than 20 m^3s^{-1} while only 11 % of the fishways where constructed at sites with a MAF larger than 50 m^3s^{-1}, table 3. MAF was larger at sites with functional fishways (mean 30 m^3s^{-1}, SD 55.7) than sites with dysfunctional fishways (mean 17 m^3s^{-1}, SD 36.4), (P = 0.02) and sites with unknown fishway function were generally in small systems (mean 6 m^3s^{-1}, SD 17). At sites with reported entrance problems the MAF was not different from MAF at sites with functional ladders (P = 0.99). Among fishways at hydro power dams situated at the ten sites with highest MAF (average MAF = 171 m^3s^{-1}, SD = 101), good functionality was reported at nine, while one was dysfunctional, assumedly because the fishway entrance was located in a bay, far from the tailrace of the plant. Different systems for enumeration of migrating fish (video, mechanical gates, manual enumeration etc.) were found in 63 of the 344 ladders (18 %), 47 of them in fishways reported to have good function.

Fishway design and functionality. – Among the functional fishways, 82 % were concrete pool

District	Number of fishways	Fishways visited
North (Finnmark, Troms and Nordland)	136 (40 %)	32
Middle (Trøndelag and Møre og Romsdal)	81 (24 %)	31
West (Sogn og Fjordane, Hordaland and Rogaland)	81 (24 %)	15
South/east (Agder, Telemark, Vestfold, Buskerud, Akershus, Oslo and Østfold)	46 (13 %)	11
Total	**344 (100 %)**	**89**

Table 1. Geographic distribution of Atlantic salmon fishways, divided into four regions including the corresponding counties for each region listed in brackets.

State	Number of ladders	% of ladders
1 Functional	226	66
2 Partly functional	18	5
3.1 Water intake problem	5	1
3.2 Construction damages	50	15
3.3 Entrance problems	17	5
4 Unknown state	28	8
Total	**344**	**100**

Table 2. Functional state of all Norwegian Atlantic salmon fishways.

Discharge (m^3s^{-1})	Number of ladders	% of ladders
<2	52	15
2-10	127	37
10-20	71	21
20-50	56	16
50-100	18	5
>100	20	6
Total	**344**	**100**

Table 3. Distribution of Atlantic salmon fishways according to river discharge.

and weir ladders while 16 % were pool and weir ladders blasted in rock or simple rock adjustments. For the dysfunctional fishways the corresponding figures were 85 and 13 %. Hence, differences in technical characteristics inside the fishways did not seem to influence the migration success (χ^2-test, $P = 0.41$).

Visited fishways

Distribution and functionality. – The fishways visited were situated along the whole coast, table 1. A total of 66% ($N = 59$) of them were constructed between 1960 and 1980, see below, the period identified as a peak period for constructed projects in Norway, figure 1. Based on the reports from the CGFM's 77 of them (87 %) had good function. After inspections, this number was reduced to 65 fishways, representing 73 % of the sites. Eight fishways were moved from category "1" to "2", one based on low juvenile salmon densities above, one because it regularly got filled up with sediment and the rest because of damages or wear and tear.

River size and fishway functionality. – MAF at sites with functional fishways (mean 33.8 m^3s^{-1}, SD 42.5) was larger than MAF at sites with dysfunctional fishways (mean 12.0 m^3s^{-1}, SD 6.2), ($P < 0.001$) but not different from fishways at sites with reduced function (mean 24.8 m^3s^{-1}, SD 40.7), ($P = 0.49$). These results correspond with the national findings.

Fishway design and functionality. – Length and height of the fishway did not seem to influence fish pass success. Mean water drop at the 89 visited fishways was 7.3 meters and mean water drop size in the dysfunctional fishways ($N = 12$) was not different from the total mean ($P = 0.9$). In fact, some of Europe's highest and longest fishways are found among the functional fishways in Norway. For instance the fishway in Granfossen in River Helgåa and Lower Fiskumfoss in River Namsen which have water drops of 40 and 34.5 meters respectively, work well according to enumeration data. Also, the fishway passing the waterfall Granfossen in River Verdalselva demonstrates that successful migration occur in complete darkness through rock tunnels over approximately two hundred meters.

Of the 89 fishways, 20 are constructed at manmade obstacles, four of them large dams and 16 small weir constructions or intake dams. One of these 20 is partly functional, one is situated in a river without a viable population, while the remaining 18 were judged to have good function.

Altogether 37 fishways were located in regulated rivers. Most of the visited fishways (84 %, $N = 75$) were concrete pool and weir type ladders with surface notches, some of them partly or entirely constructed inside rock tunnels. The other fishways were blasted in rock, rock adjustments and one ladder was a small, wooden gutter pass. The fishways with reduced function and dysfunctional ladders (category 2 and 3, $N = 24$) were all concrete pool and weir ladders. Altogether 69 of the 89 visited fishways had their entrance placed in the immediate proximity of the barrier ("distance to barrier" equal to zero in Table 4).

Among the remaining 20 fishways, only two were dysfunctional. One (Hellandsfoss in River

Modalselva, category 3.3) has its entrance 10 meters from the barrier, but the Atlantic salmon population in this river is regarded as close to extinct. In the other one (Waterfall 1 in River Vestre Jakobselv, category 3.2), the lowermost pool in the fishway has been completely removed by floods. The fishway therefore only works well on large river discharges. Longest distance between barrier and fishway entrance was 65 meters (Lower Fiskumfoss in River Namsen) and this fishway works well. In the other cases, the entrances were placed from two to ten meters from the barrier. Based on the 89 visited fishways, it was not possible to suggest a significant correlation between functionality and distance between fishway entrance and barrier.

Enumeration data. – Systems for enumeration of migrating fish were found in 21 of the 89 fishways. Two of these are presently closed because of the *Gyrodactylus salaries* infection, while one, characterized as dysfunctional because of entrance problems, did not register any passing salmon in 2009 or 2010. A total of 15 of the 21 enumeration systems were placed in fishways in the lower parts of the respective rivers. In 14 of them, the number of fish counted in the fishways was larger than the total fishery catch in the respective river in both 2009 and 2010, supporting the judgment of good function (one fishway was completed in 2010 and enumeration data did not exist for this site in 2009 or 2010). The last three systems were located in the upper parts of the respective rivers and total catch data for these rivers could not be used for verification of fishway function. However, the CGMF's had used the enumeration data for their categorization.

Physical damages on constructions. – Physical damage was reported as the most important reason for dysfunction in fishways at national level, and was also found to be the dominant problem among the dysfunctional fishways of the 89 visited. Signs of such tear were visible for many of the well functioning ladders as well. The age of many concrete ladders implies that maintenance is necessary, even though most of them were located such that physical strain had likely been properly considered. Also, fifty years old concrete constructions do not hold the same quality as modern constructions.

Discussion

In the present study, a total of 344 Atlantic salmon fishways along the coast of Norway were identified and categorized according to functionality. They were almost exclusively pool and weir type ladders with surface notches. A large proportion of the fishways were constructed between 1960 and 1980. According to information from responsible fish management authorities, a large part of them (66 %) had good function, while 5 % were partly functional and 21 % did not work. The remaining 8 % of the passes had unknown function, mainly representing fish passes in small rivers or rivers with weak salmon populations. Additional data were collected by on-site inspections of 89 fishways, most of them selected as having a good potential for increased total salmon production. Before inspections, 87 % (n=77) of these were reported by the different county governors as having good functionality, indicating that the selection represented prioritized fishways. However, the inspections showed that the situation was not as positive as reports indicated, and the proportion of fishways with good functionality was reduced from 87 to 73 % (N = 65). The main reason for this was that a number of fishways were partly damaged by natural extreme events, such as floods or ice runs. Inspection of the remaining fishways would likely reduce the proportion of functional fishways for salmon in Norway.

Most Norwegian fishways are situated in relatively small rivers and more than 70 % of the 344 fishways were located at sites with a mean annual river flow (MAF) smaller than 20 m^3s^{-1}. MAF was larger at sites with functional fishways than at sites with dysfunctional fishways. Migration success at visited sites could not be correlated with distance between fishway entrance and migration barrier. Similarly, no relation was found between migration success and the length or height of the fishway. Contrarily, some of Europe's longest and highest fishways were found among the fully functional Norwegian ladders. Also, pool and weir type ladders constructed inside completely dark tunnels over 200 meters did not seem to delay the migration, which has also been demonstrated in River Lærdalselva (Romundstad 1991).

Problems with the water intake to the fishway were reported at only 1 % of the 344 sites. This might be misleading as fishways in this category also are reported with damages. Moreover, inspections of the fishways indicated that ladders with suboptimal or insufficient water intake could have adequate function in sufficiently long periods of the migration season to be reported as functional. In general, water intake problems can be a challenge with pool and weir ladders. Problems have often been mitigated with submerged intakes or concrete walls to protect the intake or lead ice and debris away. Nevertheless, proven technology from other countries such as vertical slot design and Denil passes, which can involve larger flexibility for river discharge changes and reduction of sediment problems (Katopodis 1992, 2005), should likely be considered in future projects.

Dysfunction of Norwegian Atlantic salmon fishways was mainly (more than 75 % of the cases) related to physical damages and lacking maintenance. Inspected fishways at man-made obstacles had better function than fishways passing natural waterfalls. Morover, dysfunctional fishways were located at sites with smaller MAF than functional fishways. These findings indicate that fishways in smaller rivers and fishways without supervision and funding from hydropower companies suffer from lack of sufficient attention. At the same time, many smaller fishways were constructed in order to limit delays in waterfalls already passable for fish, or to increase the number of passing fish over a larger flow range and hence, maintenance of these constructions may have received less attention than fishways around absolute barriers.

The fact that entrance problems were reported in relatively few fish ladders (5 %) does not imply that the entrance of fishways is not important in Norwegian rivers. Contrarily, the design of entrances has been a main focus since the beginning of the fish ladder era in Norway. Landmark (1884) pointed out the entrance design as a main issue when a fishway is planned. Grande (2010) stated the same after reviewing more than a hundred years of experience in Norwegian rivers. Hence, it is likely that entrance problems have been mitigated by physical adjustments through trial and error over time.

A large number of the Norwegian fish passes were designed by a small number of experts, who eventually collected the requisite experience. The fact that most of the fishways were located at sites with small river discharges, will also allow the discharge in the fishway to constitute a significant part of the total discharge and thereby represent a visible and attractive migration corridor. Accordingly, the entrance challenges in Norway are different from those found at the large dams on the Pacific rivers in North America, with their massive discharges and large number of adult migrating fish (see for example Columbia River Fish Passage Center: http://www.fpc.org).

This study has compiled information about each individual fishway in Norway, including their state and function. The large number of constructions and the many success stories show that fishways for Atlantic salmon is an important and effective measure for conservation of the Norwegian populations (L'Abée-Lund et al., 2006). Consequently, and based on the demand for refurbishment indicated in this study, there is a need for a maintenance program for the fishways on a national scale, including sufficient funding for reconstruction and repair.

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Visited sites/fishways by region

Characteristics of the 89 fishways visited. "Type" refers to fishway design, where 1 is a concrete pool and weir type ladder, 2 is pool and weir type ladders blasted in rock, 3 is ditch blasted in rock, 4 is blasted rock adjustments and 5 is wooden gutter. "Enum. syst." refers to type of enumeration system, where 0 is no enumeration, 1 is automatic enumeration with video, 2 is mechanical counter and 3 is manual enumeration. Judged function is a classification of the fishway, where 1 is functional, 2 is partly functional and 31, 32 and 33 is dysfunctional, where 31 is because of missing discharge in fishway, 32 because of physical damages and 33 because of entrance problems.

North region:

River	Site name	MAF (m^3s^{-1})	Type	Pools	Constructed (Year)	Drop (m)	Distance to barrier (m)	Enum. syst.	Judged function
Langfjordelva(Laggo)	Waterfall 1	8	1	10	1969	4.3	2	0	2
Langfjordelva(Laggo)	Waterfall 2	8	1	6	1969	2.6	5	0	2
Langfjordelva(Laggo)	Waterfall 3	8	1	3	1969	1.8	0	0	31
Langfjordelva(Laggo)	Waterfall 4	8	1	5	1969	2.5	5	0	1
Vesterelva	Waterfall 1	2	1	7	1975	3	5	0	1
Vesterelva	Waterfall 2	2	1	20	1970	8.5	0	0	2
Neidenelva	Skoltefoss	45	1	7	1951	4	0	2	1
Bergebyelva	Waterfall 1	5	1	10	1961	4.5	5	0	1
Bergebyelva	Waterfall 2	5	1	4	1961	2.5	10	0	2
Bergebyelva	Waterfall 3	5	1	9	1961	5	0	0	2
Vestre Jakobselv	Waterfall 1	14	1	9	1970	5	3	2	2
Vestre Jakobselv	Waterfall 1	14	1	11	1961	6	0	0	2
Vestre Jakobselv	Waterfall 3	14	1	8	1961	3.6	8	0	2
Vestre Jakobselv	Waterfall 2	14	1	7	1961	3	0	0	32
Vestre Jakobselv	Waterfall 4	14	3	2	1961	2	5	0	32
Vefsna	Laksfors	148	1	24	1901	14	0	1	2
Vefsna	Forsjordfoss	170	2	5	1974	3.2	0	0	1
Vefsna	Forsjordfoss	170	2	8	1974	5.1	0	0	1
Kongsfjordelva	Waterfall 1	4	1	7	1968	4	0	0	32
Kongsfjordelva	Waterfall 2	4	1	6	1968	3.5	0	0	32
Elvegårdselva (Skjoma)	At weir 1	10	1	4	1977	2	0	1	1
Elvegårdselva (Skjoma)	At weir 2	10	1	3	1977	2	0	0	1
Fusta	Forsmofoss	35	1	13	1886	10	0	0	1
Drevja	Forsmofoss	10	1	11	1927	5.5	0	0	1
Åbjøra	Hårstadfoss	30	2	6	1908	5	0	0	1
Åbjøra	Teinfoss	30	2	6	1908	10	0	0	1
Åbjøra	Teinfoss	30	1	6	2003	5	0	0	32
Åbjøra	Brattfoss	30	2	20	1908	12	0	1	1
Åbjøra	Åbjørvann	30	1	4		2	0	0	2
Åbjøra	Gardsfoss	30	1	4	2001	3	0	0	1
Målselv	Målselvfoss	170	2	44	1910	23	10	1	1

Middle region:

River	Site name	MAF (m^3s^{-1})	Type	Pools	Constructed (Year)	Drop (m)	Distance to barrier (m)	Enum. syst.	Judged function
Hustadelva	At dam	1	1	3	1996	2	0	0	1
Valldøla	Hoelsfoss	25	1	12	1955	4.5	5	2	1
Valldøla	Berlifoss	25	1	12	1970	6	0	0	1
Valldøla	Kyrfonnfoss	25	1	13	1969	6.2	0	0	1
Strandaelva	Verkshølen	15	1	4	1975	3	0	0	1
Strandaelva	Osbrufoss	15	1	9	1975	3.5	0	0	1
Strandaelva	Hjellefoss	15	1	3	1975	2	0	0	1
Strandaelva	Nesfossen	10	4	6	1975	3	0	0	1
Strandaelva	Svefossen	10	4	7	1975	3.5	0	0	1
Strandaelva	Dregefoss	10	1	3	1975	2	0	0	31
Korsbrekkelva	Stadheims	10	1	17	1966	7	0	2	1
Korsbrekkelva	Waterfall 2	10	1	15	1967	7	0	0	32
Korsbrekkelva	Waterfall 3	10	1	15	1968	5.5	0	0	32
Åheimselva	Åheimsfoss	3.5	1	10	1981	6.5	0	0	1
Fyrdselva	Fyrdsfoss	3	1	11	1975	5	0	0	1
Namsen	Upper Fiskumfoss	150	1	20	1976	7	20	0	1
Namsen	Lower Fiskumfoss	150	1	77	1975	34.5	65	1	1
Sanddøla	Up.Tømmmeråsfoss	60	1	31	1964	17	0	1	1
Sanddøla	Low.Tømmmeråsfoss	60	1	4	1967	2	0	0	1
Sanddøla	Møllefoss	30	1	9	1967	5	0	0	1
Sanddøla	Lower Formofoss	60	1	7	1964	4	0	0	1
Sanddøla	Upper Formofoss	60	1	35	1966	14.8	0	2	1
Øiensåa	Berrefoss	12	1	42	1970	17	11	1	1
Helgåa	Granfoss	42	1	78	1990	40	5	2	1
Helgåa	Grunnfoss	45	1	11	1981	5.5	0	0	1
Ogna	Støafoss	18	1	13	1974	6	0	0	32
Ogna	Hyttfosse	15	1	13	1971	5	0	0	32
Ingdalselv	Waterfall 1	2	1	5	1999	3	5	1	1
Orkla	Bjørset	50	1	6	1982	2	0	1	1
Orkla	Bjørset	50	1		1989	2	0	0	1
Stordalselv	Lower Støvelfoss	10	1	7	1970	3.6	0	2	1

Western region:

River	Site name	MAF (m^3s^{-1})	Type	Pools	Constructed (Year)	Drop (m)	Distance to barrier (m)	Enum. syst.	Judged function
Modalselva	Hellandsfoss	25	1	90	1983	34.5	10	3	33
Eidselva	Kviafossen	22	1	17	1966	7.7	0	0	1
Hjalma	Hjalmafoss	4	1	12	1975	6	0	0	2
Gaula	Osfossen	40	2	17	1872	8	0	1	1
Gaula	Alvarfoss	40	2	6	1894	4	0	0	1
Gloppenelva	Evebøfoss south	45	1	9	1930	4	0	0	1
Gloppenelva	Evebøfoss north	45	1	9	1971	4	0	0	1
Gloppenelva	Eidsfoss	45	1	74	1969	34	0	0	2
Lærdalselva	Sjurhaugsfoss	24	1	30	1970	14	0	0	1
Lærdalselva	Husumfoss	15	1	12	1970	5.5	0	1	1
Lærdalselva	Kolgrytefoss	15	1	18	1972	9	0	0	1
Lærdalselva	Svartgjelfoss	15	1	23	1970	13	0	0	1
Lærdalselva	Stuvane power st..	24	1	12	1985	7	0	0	1
Nausta	Hovefossen	19	1	14	1939	3.5	0	1	1
Nausta	Naustadfossen	19	4	7	1978	3.5	0	0	1
Loelv	Lofoss	15	2	19	1955	11	0	0	1

South/east region:

River	Site name	MAF (m^3s^{-1})	Type	Pools	Constructed (Year)	Drop (m)	Distance to barrier (m)	Enum. syst.	Judged function
Sandvikselva	Isi elv	1.2	5	7	1986	2	0	0	1
Sandvikselv	Fransefoss	3.5	2	4	1907	2	0	0	1
Nidelva	Rygene	110	1	15	1979	15	10	3	1
Nidelva	Strufoss	2	1	4	1979	2	0	0	1
Lierelva	Grøttedam	5	1	3	2009	4	0	2	1
Mandalselva	Laudal power st..	5	1			2	0	0	1
Mandalselva	Bjelland	5	1		1980		0	0	1
Mandalselva	Sundsfoss	5	1	3	1975	1.5	0	0	1
Mandalselva	Laksekjær	5	1	7	1975	2.8	0	0	1
Kvina	Trælandsfoss	10	1		1930			0	1
Kvina	At weir	10	1	3		1.5	0	0	1

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