Agenda Item 5.2
For Information

Council

CNL(15)41

Progress in developing best available technology for hydropower generation and other initiatives to improve fish passage in Sweden

(Tabled by the EU-Sweden)

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Hydropower and environmental legislation

In Sweden, hydropower is an important form of electricity production. About 2,100 hydroelectric power stations generate 40% of the total electricity generated in Sweden. Nuclear power accounts for 40% of electricity production and other sources, mainly wind turbines, the remaining 20%. The largest 206 hydropower stations account for 93% of the country´s total hydropower production. Most of the hydropower stations are situated in the south of Sweden, are often small and were constructed between 1880 and 1950. The hydropower plants in the north of Sweden are generally much larger and were built between 1910 and 1970 and often the schemes included construction of very large reservoirs to facilitate production in the hydropower plants downstream.

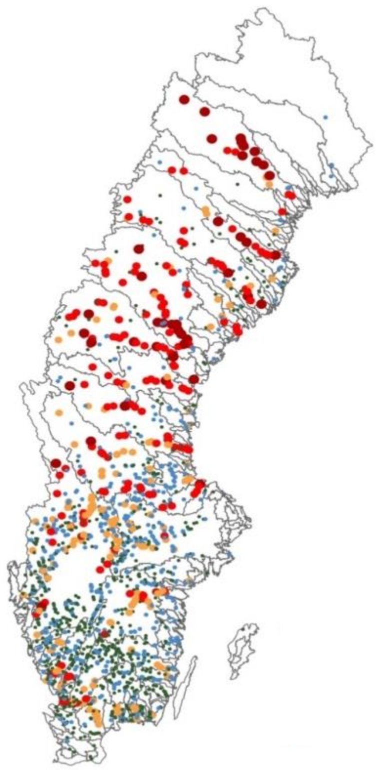
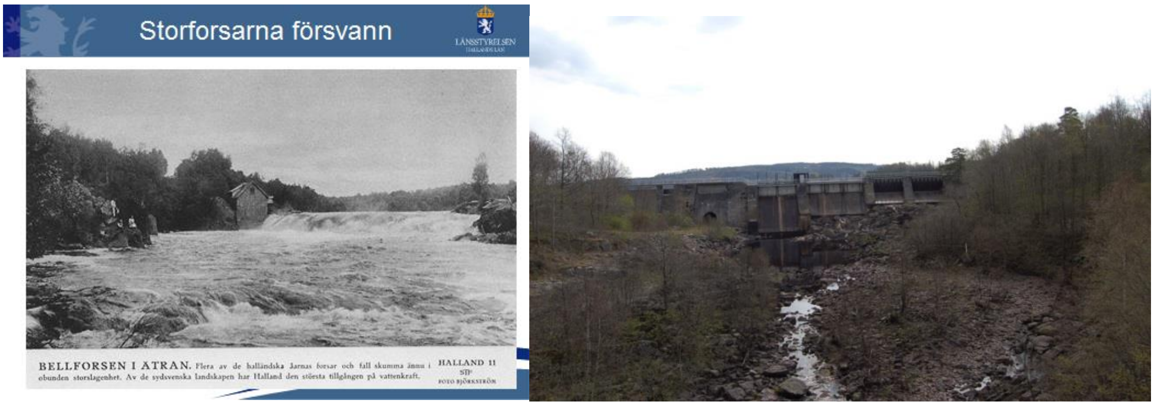


Figure 1*. Hydropower plants in Sweden. Sweden has 2 101 hydropower plants, 206 of which account for 93 percent of the country's hydroelectric power production. The size of the dot indicates the size of the station.*

Prior to the 1960s little was known about the environmental impacts of hydropower, although it was clear that power stations and dams had a huge impact on the migration of salmon and sea trout to their spawning grounds and several large rivers lost their salmon populations (e.g. Rivers Luleälven, Skellefteälven, Ångermanälven, Indalsälven, Ljusnan, Dalälven and Lagan). However, other impacts on biodiversity had not been studied. The main goal for the society was to support the production of electricity to facilitate industrial development and improve communications and standards of living.



The River Ätran before the hydropower station was built in the upper part of the river (left). The hydropower station and dam (right) located in the upper part of the Atlantic salmon's former habitat. Photo by Björkström and Hans Schiblii

In Sweden, all hydropower stations require a court decision regulating the conditions for water use. The first water legislation, dating from 1918, was mainly designed to make it easier to obtain a court decision to allow construction of hydropower plants. During the 1960s, the debate increased regarding the dilemma of hydropower production and safeguarding the aquatic environment. Since 1990, more than 30 rivers, or parts of rivers, have been protected from hydropower exploitation as a result of political decisions. In 1983, new water legislation and other environmental legislation was enacted in Sweden which to some extent made it more difficult to obtain permission to build new hydropower plants. The new legislation gave the environmental courts additional powers to specify conditions for the hydropower generation that took greater account of the environment. Since the 1980s, several larger hydropower plants have been built. Hydropower development is influenced by many factors including development of nuclear power plants, environmental interests to protect watercourses from further exploitation and also to some extent the improved water legislation in place since 1983.

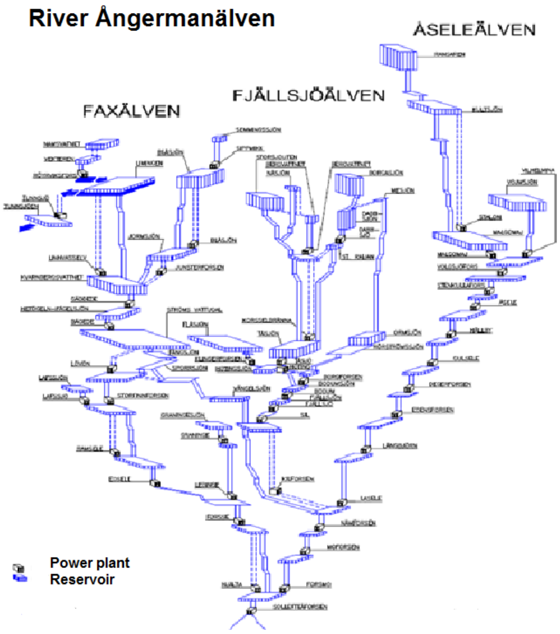


Figure 2. *Schematic map of hydropower plants (black boxes; n=42) and reservoirs (blue boxes) in the Baltic River Ångermanälven. The spawning grounds have been destroyed or made inaccessible. Only one fishway exists. Yearly releases of smolts from hatcheries compensate for part of the lost natural production of salmon and trout.*

The terms imposed by the court for hydropower plants, unlike other industrial activities, are not time-limited. In some cases the court decision includes mandatory building of fishways for upstream migration. If the damage to salmon production is very severe, compensatory releases of salmon smolts from hatcheries has been approved as an alternative mitigation measure.

Renegotiation of terms can be decided by environmental courts at the request of the authorities. However, the authorities are responsible for all legal costs including those of the hydropower companies. As a consequence, few of the old court decisions have been improved; in fact most of the court decisions are according to the law of 1918.

In 2014, a government investigation proposed new environmental legislation, more consistent with the EU Water Framework Directive. This proposed that permits for hydropower plants should be time limited, that the environmental authorities should be able to decide on new terms for the hydropower plants in the same was as for other environmentally damaging industries and that the hydropower plants should bear their own costs for measures to protect the environment. The hydropower industry has strongly criticized this proposal, while the environmental authorities and organisations have endorsed it. The government has not yet decided whether or not to present a proposal for new environmental legislation to the parliament.

Dialogue and national strategy

In 2012, the Swedish Agency for Marine and Water Management was given a government mandate to initiate a dialogue with the relevant authorities and other stakeholders with the aim of building increased consensus on hydropower and the EU objectives for renewable energy and the environmental objectives for biodiversity and water management. One outcome from the dialogue has been a general consensus on the river systems in which hydropower production is most important. Another outcome has been a general consensus that the approximately 1,900 smaller hydropower plants, that produce only 7% of the total hydropower production, have a major impact on biodiversity and the technical measures to restore, for example, salmon production can be implemented relatively easily in many of them.

The Swedish Agency for Marine and Water Management and the Swedish Energy Agency have developed a national strategy for enhanced energy production and biodiversity. The strategy identifies where environmental and energy measures should be focused in order to maximize the total value of biodiversity and energy production.

Best available technology for hydropower generation and other initiatives to improve fish passage

Fish passes are important to maintain biodiversity and restore fish production. As the stocks of Atlantic salmon are often weak, and marine survival is currently low, it is essential that all potential nursery habitat is accessible to salmon and that smolts can migrate freely to the sea. Restricted fish passage can have significant ecological impacts:

- exclusion of salmon from important nursery habitats;
- increased mortality due to predation by fish and birds, increased exploitation by anglers, and increased parasite burdens as salmon congregate at obstacles and move through impoundments; and
- injury or death of smolts and kelts at spillways and sills or passing through turbines during their downstream migration.

When providing fish passage facilities, the focus is often on ensuring free passage for upstream migration. However, it is also vital to improve conditions for downstream passage, especially in watercourses with hydropower plants.

Both upstream and downstream passage can be achieved in four ways:

- removal of hydropower plants, dams and reservoirs;
- opening of dam or sluice gates;
- nature-like fishways; and
- technical fishways.

Fish passes should be built to facilitate as easy passage as possible. Fish passes that require high swimming speed and ability need be very short. Where possible, fish passes should also ensure that all species in the river (not only fish) can pass artificial barriers.

Removal of hydropower plants and dams

In the last twenty years, a number of small, old hydropower plants that produce little electricity and old plants requiring costly renovation have been removed in Atlantic salmon rivers in Sweden. Additionally, the requirement to install costly fishways has resulted in removal of dams as a less costly measure. With financial support from the authorities, it has been possible to finance the purchase of such plants or at least the permit for hydropower production and the removal of the migration barrier.

When a dam or other obstacle is removed (which, of course, requires an environmental permit) a passage is created in the existing channel, normally encompassing the whole watercourse. This is, therefore, the solution that works best for most species and most sizes of watercourse. Removing the dam also means that habitat lost to salmon production may again become available. Furthermore, migrating smolts often suffer large mortalities due to predation when passing impoundments.

Before and after removal of a dam at a hydropower plant in the Atlantic salmon river Rolfsån. The dam was replaced with a rocky ramp. Photo by Andreas Bäckstrand

The work to remove the obstacle is usually followed by work to build up a naturally fast-flowing stretch of river where the obstacle previously stood. In general, these measures do not require maintenance and are relatively cheap to implement. The new rapids often become an important habitat for species that live in fast-flowing water.

In the long-term, the cost of the removal of a dam can be low compared to the other alternatives. For example, there will be no further costs in maintaining a technical fishway. Normally there is no risk that re-starting hydropower production when the station and the dam have been removed. In several cases, the cost of a technical fishway or a nature-like fishway can be so high that it is more cost effective to remove the station and the dam.

Opening of dam or sluice gates

A considerable difficulty in removing dams can be the high sediment load from the old impoundment and issues with the stability of the ground particularly where there are buildings near the dam. One possible solution is to retain the dam and open the sluice gates during peak migration periods to facilitate migration of salmon without passage through the turbines. In some situations this approach has been used even where technical fishways or nature-like fish passes have been built, in particular to allow downstream migration of salmon, trout and eels.

Nature-like fishways

Three main ways to create nature-like fishways are used in Sweden:

- rocky ramps to create rapids over the obstacle (see above);
- nature-like channels bypassing the obstacle within the watercourse (bypass through the dam); and
- natural channels bypassing the obstacle outside of the watercourse (bypass).

These different techniques are often combined:

Rocky ramps, or bottom ramps, are used to raise the water level downstream of the obstacle to migration while still maintaining water levels upstream so that a ramp is created allowing fish passage. This method is often used in smaller watercourses for low head dams.

A bypass through the dam is a natural channel built into the watercourse itself. This is different to an external bypass, which is a channel around the obstacle that is built outside of the existing watercourse. The bypass through the dam can be designed so that it takes a given quantity of water at different levels of water flow. It is suitable for use in situations where the land around the obstacle cannot be used. Since the bypass is built within the watercourse and has a natural substrate bottom, it is easy for migrating species to find and use. It is likely that a bypass through the dam is a more effective than a bypass as the attracting water is generally easier to find.

Bypass through the dam in the Atlantic salmon river Rolfsån. Before (left) and after (right). The former technical fishway did not function properly. Photo by Andreas Bäckstrand

External bypasses are nature-like passes that are built to divert water around an obstacle. They are normally built with a low gradient (1 - 5%) and a stony littoral zone. Many species can utilise an external bypass. One disadvantage with external bypasses is that they are sensitive to variations in the water level upstream. The external bypass tolerates greater water level variation if the inflow is constructed to regulate the flow of water. External bypasses can be built with natural sections of rapids and can thereby also function as rearing habitat for mussels, fish, insects and other invertebrates.

Bypass in the Atlantic salmon river Rolfsån. Photo by Andreas Bäckstrand

In order to achieve a low slope in the fishway, external bypasses may have a meandering path, thus increasing their length. The longest external bypass in Sweden was built in 2013 in the Atlantic salmon River Säveån and is 500m long and cost approximately €6 million. Thirty years earlier the hydropower station was for sale and the cost was then €300,000.

External bypasses are sensitive to erosion when water seeks a way out through the ground and creates new channels leading more directly down the slope. The bottom in Swedish bypasses is often protected with a sealing layer, e.g. a geotextile.

Technical fishways

In general, technical fishways require special expertise for their construction and they require regular maintenance. In 2002, it was estimated that 11% of the fishways in Atlantic salmon rivers in Sweden did not allow fish passage (Hans Schibli, *personal communication*). Most of these fishways had been constructed many years ago.

In Sweden, nearly all of the hydropower plants were constructed more than fifty years ago when knowledge and interest in fish passage issues was limited. Often it is more difficult and more costly to retrofit fishways at old hydropower plants than if the fishways and hydropower plant were constructed at the same time.

It is very important that the entrance to a fishway is easily located by salmon. This problem is most frequent for downstream migrating smolts or kelts when the water flow into the turbines greatly exceeds that through the fishway. Different types of grids (Figure 3, physical screens) installed upstream of the turbines are often used in smaller rivers in order to direct smolts and kelts towards the fishway. In the largest rivers, trials with systems with trash-racks to direct smolts and kelts to the opening of the fishway have been made with varying results since trees and other objects may block the screens.

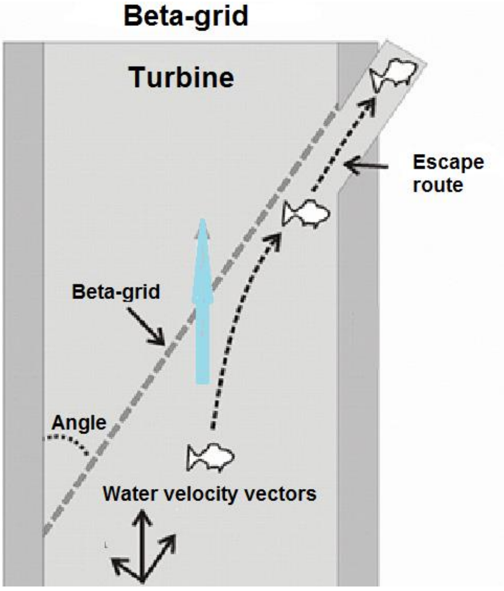


Figure 3*. A beta-grid located upstream of the turbine can direct smolts and kelts into the fishway (Calles et al. 2013).*

Generally three types of technical fishways are used in Sweden or a combination of these types.

The **pool and weir fishway** is the traditional fish ladder. It consists of pools separated by weirs that break the head of water into passable steps.

Pool and weir fishway in the Atlantic salmon River Nissan. Photo by Hans Schiblii

The **vertical slot fishway** typically consists of 30 - 50cm wide vertical slots between pools. The vertical slot has a lower water velocity and turbulence than a pool and weir design. Furthermore, the vertical slot is insensitive to variation in the water level upstream.

The **Denil fishway** is an artificially roughened channel, with baffles pointing upstream extending from the sides. Denil fishways are typically installed at sites with steep gradients (10 - 25%). The fishway itself consists of a relatively narrow flume with U-shaped baffles installed at frequent intervals. It uses more water for its depth and width than any other type of fishway, which is a definite advantage in attracting fish to the entrance. Denil fishways typically require a high degree of operational supervision and maintenance. The fishway must be kept completely free of debris to avoid altering the flow characteristics of the baffles, which would affect fish passage conditions.

Establishing criteria for Best Available Technology (BAT) in Sweden

Establishing BAT is a joint project of the Swedish Agency for Marine and Water Management, the hydropower industry, County boards and Universities. So far four reports have been published.

The project has focused on:

- fishways;
- technical installations to facilitate environmental flow regulation (not ecoflows as such); and
- maintenance and monitoring.

Fishways and upstream migration

The recommendation is that fishways at artificial dams should allow migration for all species and age groups.

Nature-like fishways are preferred (e.g. bypass, rocky ramp, fish slope, bypass through the dam). A maximum slope of 5% (extreme 9%) is used unless passage would be difficult for species other than salmon in which case a technical fishway may be installed.

For technical fishways, the vertical slot design is preferred over pool and weir and finally Denil. The design of technical fishways should also allow weak swimming species to pass. The depth in technical fishways should be at least 1m with a flow of $1m^3/s$ for salmon and large sea trout and depth of 0.5 m and flow of 0.5 m^3/s for smaller sea trout and other species. The attraction flow should be 5% of the flow at the site and the fishway entrance should be in a suitable location.

Sluices and elevators are not recommended.

Fishways – downstream migration

Fish larger than 10 cm (smolt) should always be screened away from the turbines. Physical screens are preferred over behavioural techniques (electricity, sound, light, bubbles etc).

Beta-screens with an angle of 30^o are preferred before alpha-screens and the least preferred solution is other types of screens (e.g. louvre).

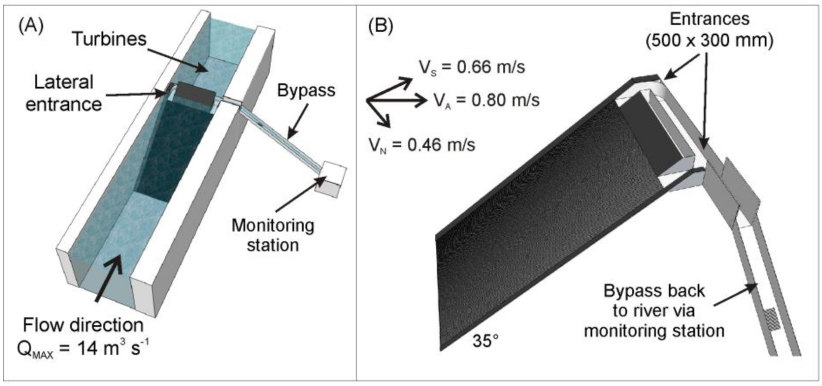


Figure 4*. An alpha-grid upstream from the turbine can direct smolts and kelts into the bypass (Calles et al. 2013). Note that the screen covers the entire depth and width of the channel.*

Screens should be installed from the surface all the way to the bottom with 10 - 18 cm spacing between the bars.

The flow in the fishway should be at least 2% of the flow at the site.

Technical installations facilitating environmental flow regulation

Automatic regulation of flow at dams is preferred, allowing better monitoring and less pronounced alterations in flow.

The outlets from power plants and dams should allow bottom and surface water of different proportions to be used in order to avoid high temperatures and facilitate sediment transport.

Safety installations are required to avoid loss of water in the river bed due to technical failures.

Examples from Swedish rivers with Atlantic salmon

River Ätran

The River Ätran is the most important salmon river on the Swedish west coast. In 1903, a hydropower plant was built close to the mouth of the river in the city of Falkenberg and later a second hydropower plant was built in the same area. Salmon and sea trout experienced great difficulties in passing the dam using the original fish ladder. In 1946, the dam was equipped with a Denil fishway. Salmon immediately started to use the fishway and the population in the river is now of good status. Salmon parr densities have averaged 98 per 100 m^2 since electrofishing monitoring started in 1959. Data from an installed Vaki counter show that 3,000 - 5,000 Atlantic salmon and sea trout passed the power plant annually from 2000 to 2010.

Although the Denil fishway was functioning well for strong swimmers, such as salmon and sea trout, other species were hindered, among these red listed species including eel (*Anguilla anguilla*) and sea lamprey (*Petromyzon marinus*).

The Denil fish ladder built in 1946 in the River Ätran. Photo Hans Schibli.

Furthermore, downstream passage of fish has been a problem in the river. Some approaches to reduce the mortality of downstream migrating Atlantic salmon and brown trout have been tested including trash gates and low-sloped fine-spaced racks. Smolts and kelts were radio-tagged and tracked passing the facilities. An open trash gate proved to have a very low efficiency for smolts (7%) and most individuals passed through the racks and turbines. The efficiency was intermediate for kelts (40%) and several individuals died on the trash racks or remained upstream until the end of the study. The route-seeking time was limited for smolts but substantial for kelts. Using surface spill gates and fine-spaced racks the efficiency in directing smolts and kelts has been improved (Ph. D. Olle Calles, University of Karlstad *personal communication*).

In 2012, the Environment Court granted permission for the removal of Herting dam in the River Ätran. In 2014, part of the dam was removed, opening half of the main stem for free passage of fish and other species. The habitat in this part of the river has been restored and a dam upstream guarantees a minimum flow of 11 m^3/s. The older of the two hydropower stations will operate all year round but the newer power station situated in the main stem, that has been opened for fish passage, will only operate during winter high flows.

The dam has been removed (2014) in one of the two main stems in the River Ätran. A construction directs migrating Atlantic salmon into a fish counter situated in the middle of the main stem.

Concluding remarks

Fishways are never 100% effective so a proportion of the migrating population is lost at each passage. In rivers with multiple passes, this can have a substantial negative cumulative effect as too few spawners reach the nursery areas and few smolts reach the sea. Often fish that do pass are delayed and may experience increased mortality.

The low efficiency of fishways is often related to low attraction flows compared to the main flow through the dam or turbines.

Existing fish passes are often not sufficiently well designed to allow species with weak swimming abilities to migrate, resulting in reductions in biodiversity. This has led to a focus on establishing nature-like fishways instead of technical fishways.

However, several examples exist of fishways that have made access to salmonid nursery areas possible and populations have been sustained by properly working passes.

Careful design, proper maintenance and monitoring of fishway efficiency are crucial to their effectiveness.

Removal of dams should always be prioritised because these solutions enable most aquatic species to pass both up and downstream without delay or mortality. Additionally, an increase in productive habitat for salmon and trout can often be achieved.

Removal of the dams may also result in reduced predation on smolts. In systems with several dams, dam removal is the preferred option compared to other approaches to facilitate fish passage.

The second choice for upstream movement is a nature-like pass mimicking a natural watercourse. Technical fishways are mainly used for large obstacles such as power station dams, where there is a large fall (head) in the water level.

References

Calles, O., Degerman, E., Wickström, H., Christiansson, J., Gustafsson, S. and Näslund, I. 2013. Anordningar för upp- och nedströmspassage av fisk vid vattenanläggningar. Underlag till vägledning om lämpliga försiktighetsmått och bästa möjliga teknik för vattenkraft. Havs- och vattenmyndighetens rapport 2013:14. 114 pp. (In Swedish, title: Fishways for up- and downstream passage, literature survey and recommendations).

Degerman, E. and Russell, I. 2011. Fish passage in rivers. ICES Working Group on North Atlantic Salmon, March 22 - 31, 2011. Working Paper 27. 18 pp.