Swedish Society for Nature Conservation

Running Water

Hydropower development on small waterways – small benefits but large-scale damage

Hydropower has devastated the majority of Sweden's large rivers. The continued exploitation is now aimed at small waterways. In order to facilitate the construction of mini power stations, the Swedish parliament has allocated subsidies to small-scale hydropower[1]. This decision will lead to the impoverishment of the original ecosystems in running water. The Swedish Society for Nature Conservation believes that the continued destruction of Swedish waterways cannot be accepted. There is even within the EU the intention to encourage small-scale hydropower.

[1]When a power station is built on a smaller waterway, it is usually referred to as a mini power station or small-scale hydropower.

In southern Sweden, there are few, if any, waterways that have not been regulated for hydropower or not been affected by other types of physical actions. A small number of waterways are protected against further exploitation. It is really only in the far north, in northernmost Lapland, where the waterways are essentially unaffected by development. But even here, in areas affected by forestry activities, the construction of roads and ditches

Ljung River mini power station under construction on the Ljung River, Bräcke municipality in central Sweden. Capacity 1,200 kW, dimensioned water discharge 9 m^3/s. The concrete dam that will force the water to flow through the turbine of the power station can be seen in the background. The river is hidden behind the cover in the centre of the picture. At the very right the river is visible but covered with ice. Photo: Hans Isgren has lead to the radical disturbance of many smaller waterways.

On a European level there remains a very small number of large river systems in their original condition. One of these is shared by Sweden and Finland. It is not only a matter of national concern to preserve the last remaining free running rivers, but also of international concern. As most of the large waterways have been exploited for hydropower purposes, it is even more important to preserve the many small waterways that make a highly important contribution to the variation and biological diversity in the landscape.

In the summer of 1997, the Swedish parliament decided to provide state subsidies for ”environment-friendly, small-scale hydropower stations”, as they are called in the Government's energy proposition. Builders of power stations can receive subsidies equivalent to 15 per cent of the total required investment. The decision is deeply unfortunate. The extra energy provided by the development of small-scale hydropower is marginal. The Government itself calculates the increase as 0.25 terawatt hours (TWh) within five years. This is the equivalent of less than 0.4 per cent of today's average hydropower production during a year, and less than 0.2 per cent of Sweden's total electricity production. However, even more of the irreplaceable living environments of the plant and animals that inhabit running waters will be destroyed for ever.

In contrast to what many people may imagine, a mini power station is neither small nor ”cosy”. It is the word mini that is misleading. Seen in relation to the size of the waterway, it is not at all smaller than a ”large” power station.

The amount of electricity that is generated by a mini power station is very small. In Sweden there are about 1,550 hydropower stations. Together these give, in a year with normal precipitation, 65 TWh. 63.5 TWh come from the 350 largest hydropower stations. The remaining 1,200 hydropower stations are mini power stations, and electricity production in these only reaches 1.5 TWh per year. Most of the mini power stations are in the south of Sweden.

As part of the drive for renewable energy resources, there is also the intention within the EU to encourage small-scale hydropower. One proposal suggests that small-scale hydropower should increase by 50 per cent during the period 1995–2010.

Red-listed and other sensitive species

The single factor that has shown itself to threaten most red-listed species in Swedish lakes and waterways is the regulation of rivers for hydropower. According to the National Swedish Environment Protection Board's book **Biological Diversity in Sweden**, 177 red-listed freshwater species are under threat from the regulation of hydropower. Thereafter follow over-fertilization (107 species) and increased acidity (80 species).

But it is not by any means only species living in water that are threatened by the regulation of hydropower. Even species that are connected to running water, but that exist above the water line, can be also seriously affected. What these species have in common is that they are dependent on the natural water level fluctuations that occur in a pre-

Reservoirs and dry rapids

Hydropower development requires extensive interference with the natural environment. The original, running water plant and animal life is replaced by lake species. Dams are built on the waterway to force the water to go through the power station's turbines instead of along its natural course. Rapids and waterfalls become dry. Sometimes the power companies are required to release a certain minimum water flow along the original water course. The dams are also used to store water from night to day (short-term regulation) and from summer to winter (annual regulation). Short-term regulation, which is carried out close to the power stations, leads to extensive erosion of the river shores. The annual regulation reservoirs are situated high up in the water system (in Sweden usually in mountain areas). Annual regulation is carried out because electricity demand is greatest during the winter when there is little water in the rivers. The extremely high water volumes during spring floods are reduced and stored for use in the winter months. The variations between different times of the year are therefore less noticeable. But the water flow in the rivers is still like a ”mirror image”, there being high water during the winter and low water in the summer. The height of water levels in the annual reservoirs can vary by 35 metres. Along the shores, enormous sterile areas are formed which are alternatively flooded or left dry and where almost nothing can grow.

Most of the waterways in Sweden are more or less highly fragmented by dams. In the SMHI (Swedish Meteorological Office) dam register there are 5,290 dams registered. The register is based on an inventory of dams that was carried out by county councils at the end of the 1980s.

Examples of other developments that have had great effect on Swedish waterways are clearing for the floating of logs and various forms of digging and straightening. In farming areas, many small waterways have been led through culverts. It has been necessary to use culverts beneath all roads in the countryside. Most of the innumerable road culverts have been laid in such a way that they hinder the passage of animals up and down the waterways. A serious but overlooked problem.

European view: only four large, untouched water systems, of which three are in Russia

Most of the large waterways in Canada, USA, Europe and the former Soviet Union are to a greater or lesser extent affected by regulation and dam constructions. This is shown by a survey that was published in 1994 in the Science journal. In Europe there remain only four large river systems that run freely from source to outlet. Three of these are in northern Russia and the fourth is in Sweden and Finland. The Swedish-Finnish river system is the Torne and Kalix Rivers. The rivers are regarded as **one** river system, as they are connected by the Tärendö River which transfers over half of the waters from the Torne River to the Kalix River quite high up in the river system.

The lower limit for large river systems has been put at an average water flow rate of 350 m^3/s. This average water flow should be achieved somewhere along the river (normally the water flow is greatest at the river mouth, but in desert areas the flow becomes less towards the river mouth). An estimate has been made of how much each river has been affected. This was based partly on the level of fragmentation by dams, and partly on how much the natural water flow has been affected by reservoirs, and use for irrigation.

A survey was carried out for medium-sized river systems (average water flow rate greater than 40 m^3/s but less than 350 m^3/s) in Denmark, Finland, Norway and Sweden. These river systems were shown to be greatly or moderately affected to an even greater degree than the large river systems in Canada, USA, Europe and the former Soviet Union.

Remaining unaffected large river systems in Europe

After Dynesius and Nilsson (1994) Illustration: Björn Möllersten

defined yearly cycle in free-flowing waterways. The plant and animal communities that these species are part of are strongly influenced by water level variations, such as when more common stronger rivals are held back by the high waters of spring floods.

Drastic worsening of the Gunnilbo River

There are very few reports on animal and plant life in a waterway before and after regulation. Developments of mainly animal life in the Gunnilbo River in Västmanland have been documented by a number of coincidences. The result shows the often catastrophic effects of the introduction of hydropower on the animal life of small waterways. The local brown trout population – which was probably genetically unique – disappeared after increased regulation in 1996. Nor has the water shrew been seen there since 1995. The dipper also disappeared at first but has now returned.

The regulation of the water flow that has been carried out in the Gunnilbo River is by no means unusual. The increased regulation of this waterway is typical for what has happened after the upgrading of many mini power stations that have taken place in Sweden during the latest 25 years.

The lakes and waterways in the water system that includes the Gunnilbo River are by no means any virgin environments. Dams built for mining and iron processing have existed at least since the 1600s. At the beginning of the 1940s a mini power station was also built just over a kilometre downstream of the actual Gunnilbo River. But the possibilities of regulating the water flow with existing dams has during recent decades only been partly used, which is why its waters have been allowed to flow relatively freely.

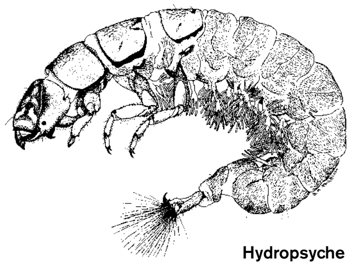
A change of landowner in 1995 marked the beginning of an overall change in the regulation of the Gunnilbo River. The new landowner and the owner of the falls (somebody living near Stockholm) commenced the regulation of the water flow with the aim of maximizing the income from the mini power station. During 1996, the variations in water flow were very sudden and large. At certain times the river was full of water, and at other times large areas of its

Small-scale hydropower in Sweden and the EU

Put simply, a mini power station is a hydropower station that has been built on a small river or large stream. These waterways are very small in relation to the major rivers. And it is clear that a power station built on a stream or small river needs to be a very small one. But a mini power station is in principle a smaller copy of the power stations that have caused such havoc on major rivers. The damage caused is also of the same type, e.g. dams that disturb fish and small animals during their natural movements, ruined spawning grounds and dry rapids and waterfalls. The variation in the water flow can be both greater and smaller than in the major regulated waterways. The original plant and animal life can be wiped out.

Mini power stations are defined in Sweden as power stations with a maximum capacity of 1.5 megawatts (MW). The term small-scale hydropower is defined in the same way. Sometimes the term **micro power station** is used, which refers to power stations with a capacity lower than 0.1 MW.

The definition used in discussions concerning small-scale hydropower within the EU is considerably more generous than the Swedish definition. In EU contexts, hydropower stations with a capacity up to 10 MW are considered to be mini power stations.


Hydropsyche

bed were laid dry. The width of the waterway varied between about 7 metres and 1–2 metres. The difference between the highest and lowest flow was much greater than it would have been under more natural circumstances.

The rich bottom-living fauna (animal life on and in the river-bed) of the Gunnilbo River deteriorated enormously. Of the 198 taxa (biological categories) that were found before 1996, 62 were missing from tests carried out in 1996 and 1997. Many of the animal groups that have disappeared are characteristic of fast-flowing water. The character of the bottom-living fauna of the Gunnilbo River has changed and today consists of typical inland lake species, which come from upstream lakes.

The disappearance of the dipper and the water shrew is explained largely by the extensive reduction in the quality of the bottom-living fauna during 1996. Important food organisms amongst caddis flies and mayflies retreated sharply or disappeared. The dipper is a dedicated bottom-living fauna specialist which prefers to eat caddis fly larvae. Stream-resident

Facts about the bottom-living fauna species that are shown in the diagram

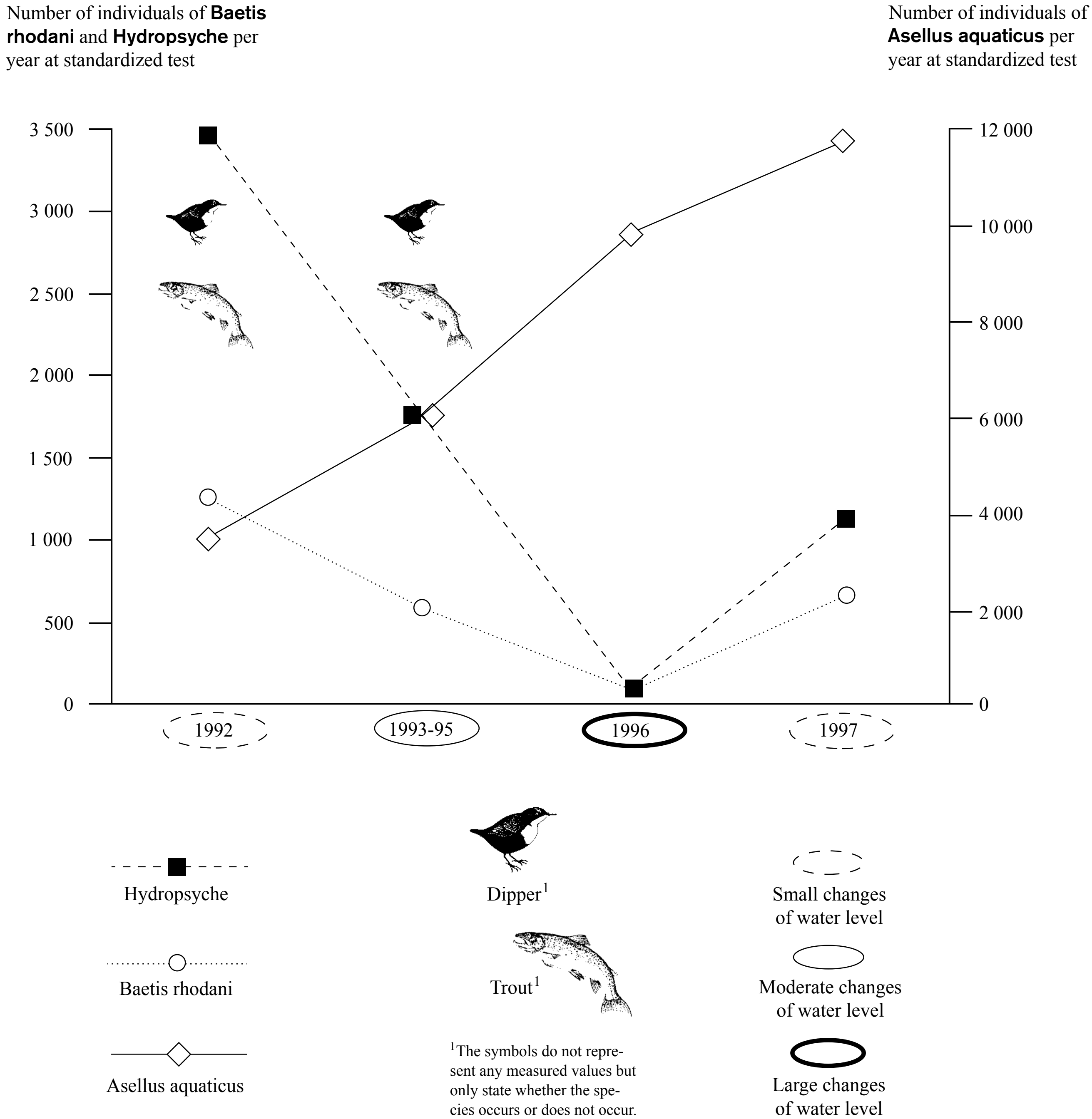
The mayfly **Baetis rhodani** is the most common mayfly in running water in Sweden. It is a fast-swimming species that lives mainly in stony, fast-flowing areas. It lives chiefly on algae. It is seldom longer than 1 cm. The **Baetis** genus is the most important food for growing brown trout and is also commonly found in the stomachs of other fish that live in strong currents. As a winged insect, **Baetis** is an important source of food for many types of small birds. It tolerates various types of environmental changes better than other mayflies. It is however very sensitive to changes in oxygen levels and reductions in water flow speed. In contrast to other mayflies, **Baetis** is not capable of moving its gills to pump oxygen-rich water which is why it must be surrounded by oxygen-rich water with a strong current.

The caddis fly genus **Hydropsyche** are to be found in all types of running water over the whole country except in mountain areas. They grow to a length of between 10 and 15 mm and are the favourite food of the dipper. They build themselves a protective cover for instance between stones, which are by no means the same as the house-building of the caddis flies. The **Hydropsyche** genus spins a web which is about 1 cm^2. It feeds on the animals and pieces of plants that are caught in the web. It requires fast-flowing oxygen-rich water. **Hydropsyche** cannot swim and are therefore marooned on dry shores if water levels go down rapidly. They then die in large quantities. They are sensitive to clouding of the water. If there is extreme cloudiness, their webs can become blocked and the animals are stressed to death in their attempts to keep their webs clear. They belong nevertheless to the most tolerant of species among the bottom-living fauna. The figure shows the following species: **H. siltalai, H. pellucidula and H. angustipennis.**

Freshwater louse **(Asellus aquaticus)** is found in all types of freshwater in the whole country except mountain areas (also in the Baltic Sea). In running water it is usually found in areas where the flow rate is slow. It moves with a slow crawl and eats detritus and dead animals. **Asellus aquaticus** is much favoured by human interference. It tolerates very low levels of oxygen, very high metallic levels, very high nutritive salt levels and very clouded water conditions. It can also survive on dry land for much longer than most other aquatic small animals. The freshwater louse forms an important source of food for fish, as well as for predating larvae of stoneflies, caddis flies and dragonflies.

The taxa (biological categories) that are shown in the figure form a

Regulation effects on bottom-living fauna, dipper and trout



good cross-section of animals living in running water. Their reaction to the altered flow conditions in the Gunnilbo River are typical for how the fauna react in equivalent situations in the whole country except mountain areas. They have been chosen because they are typical, not because they differ in any way.

Facts: Pär-Erik Lingdell and Eva Engblom

Test method: M42

The bottom-living fauna tests in the Gunnilbo River have been carried out using a method known as M42. It is described in the National Swedish Environment Protection Board's handbook for environmental monitoring. Briefly, M42 means that 30 samples are taken from a 50 m stretch of river shore. Each sample contains material that has been collected in a net (diameter 16 cm and mesh width 1 mm) after the bottom within an area of about 0.2 m^2 has been disturbed by kicking it for a period of 5 seconds.

The taking of test samples and identification of species has been carried out by Eva Engblom. Pär-Erik Lingdell was responsible for the analysis of the data.

Classification of the bottom-living fauna and its use as an environmental indicator

Important animal groups amongst the bottom-living fauna are snails, mussels, leeches, worms, crustaceans and insects. Among insects it is above all the larvae stages of some groups that live on and in the bottom. Examples of such groups are stoneflies, mayflies and caddis flies. Among beetles there are several species that live in water even when fully developed.

The bottom-living fauna is usually divided into so-called functional groups according to how they obtain their food. **Shredders** (common among stoneflies) live mostly on leaves that have fallen into the water. **Scrapers** (e.g. many mayflies and snails) eat microscopic growth on stones and plants. **Filterers** (e.g. mussels, blackfly larvae and many caddis flies) filter the free floating bacteria and fine organic material from the water. Among the caddis flies there are many species that spin a special web for catching food. **Detritus eaters** (e.g. midge larvae and many earthworms) eat partly decomposed organic material. **Predators** are found in many groups, e.g. beetles, dragonflies and leeches.

Most small animals that live in water are sensitive to environmental changes. They are therefore ideal environmental indicators. When periodic chemical samples are taken, momentary drops in e.g. oxygen levels or pH values can easily be missed. But such brief environmental changes are often easily revealed by an examination of the bottom-living fauna. There is a strong indication that something of a serious nature has occurred if species that do not tolerate low oxygen levels or pH values have disappeared.

brown trout **(Salmo trutta fario)**, types of brown trout that live stationary in smaller waterways, feed to a large degree on bottom-living fauna. The water shrew eats small aquatic animals.

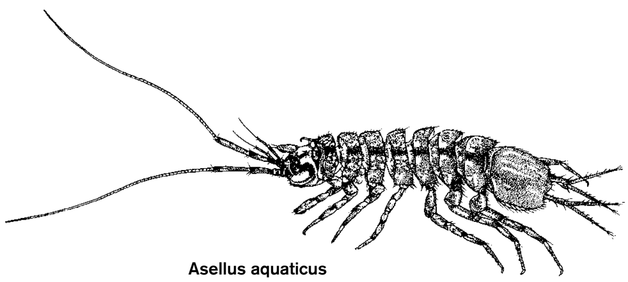
The final death blow for trouts was the occasional very low water levels to which regulation led. During January and February 1996 the slightly raised shingle banks where the trout had laid their spawn during the previous autumn became dry. The spawn froze or perished due to the dry conditions.

Protests from local residents, as well as negative publicity in the local press, led to a more careful control of the water from the middle of 1996. Brief but large falls in water levels have, however, occurred even after the middle of 1996. Brief periods of clouded water have also been noted. A certain degree of recovery has taken place amongst the relatively tolerant species of the bottom-living fauna. Experience has shown, however, that it can take 20 years before the bottom-living fauna has recovered most of what has been lost in terms of species and number of creatures – provided no new disturbances occur. But it would seem that the trout stock has been killed-off for good.

The large increase in numbers of freshwater lice which is shown in the accompanying figure is probably due to the reduced predation by fish and preying insects. This water louse belongs to the small group of organisms that thrive on increased acidity, pollution and other disruptions in the water environment. The freshwater louse has increasingly taken over and is today (winter 2001–2002) the dominating species. The two insects shown in the figure, the mayfly **Baetis rhodani** and the caddis fly genus **Hydropsyche**, are important food organisms for trouts and dippers, respectively. Both are relatively tolerant and recolonize quickly after drastic falls in population levels. The increase in numbers in 1997 was helped by the fact that both the trout and dipper were absent.

There are several interacting reasons behind the drastic changes that have taken place amongst bottom-living fauna. Water level variations are the most important factor. Large quantities of dead small animals have been found on the exposed shores after rapid reductions in the water level. Another factor is periods during which the water has quickly become clouded. The latter is caused mainly by rapid rises and falls in water levels. Increased cloudiness, and the increased deposition of fine silt that the cloudiness leads to, disrupts the foraging and reproduction of many small animals. The cloudiness is also connected with the fact that the content of particle humus (incompletely broken down organic material) has increased markedly since the landowner change in 1995. The more intensive regulation causes the water at intervals to encroach higher up on land than before, and therefore increases the leaching of humus.[1] In addition the depleted oxygen levels of the water, which is an indirect result of low water levels, has had a bad effect on the bottom-living fauna.

Increased cloudiness and humus content also cause problems for trout.



Asellus aquaticus

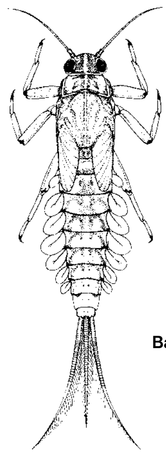
[1]To give a fair picture, it should be mentioned that the situation has been made worse by the opening of an area of peat in the upper reaches of the catchment area during the 1990s and from which humus is carried out.

The river-beds can be so blocked by silt and humus particles that the trout cannot dig its spawning ground. This has occurred in the Gunnilbo River. The survival of the spawn can also be disturbed because the fine silt and humus particles that are laid stop fresh, oxygen-rich water from passing through the shingle beds where the spawn is laid.

”Environmentally friendly” hydropower stations?

Exploitation interest groups like to speak of ”environmentally friendly” power stations. What is meant in general, where small-scale hydropower is concerned, is that the power station is run without the need for a reservoir for short-term or annual regulation. This reduces damage to the environment, but what cannot be avoided is that the water must be passed through the turbines of the power station. This means that the waterway has a dry section by the power station, usually a stretch of rapids or waterfall.

Modern water legislation often requires a minimum release of water. A certain amount of water is required to be allowed to go past the power station along the natural river-bed. As a rule the minimum release is 5–10 per cent of the average water flow of the waterway, in some cases even less. Sometimes the minimum release requirement does not apply to every month of the year. In order for the minimum release to have any effect on fish, it should be between 10 and 30 per cent of the average water flow. If there are salmonids in the waterway, then at least 30 per cent of the average water flow should apply. In addition, attempts should always be made to copy the natural seasonal variations of the water flow. At the same time such minimum release requirements mean that the power station could create a loss for its owner. Every cubic metre of water that is led past the power station represents an economic loss for the



Baetis rhodani

owner. Making a hydropower station environmentally friendly in a meaningful way is therefore difficult or impossible.

It is important to remember that achieving environmental friendliness can never, except in minor ways, compensate for the enormous environmental damage that the regulation of hydropower causes.

Two examples of planned mini power stations without a reservoir are Fallfors power station on the Mo River on the coast of Norrbotten and the Ljung River power station in eastern Jämtland. Fallfors power station would leave dry a 1.5 km stretch of rapids for 10 months of the year (July–April). The bottom-living fauna in the Ljung River has been shown to consist of an exceptionally large number of different species. The Ljung River power station will leave a 500 metre stretch of rapids dry for nine and a half months of the year (middle of July to April). A small compensation is that a water volume equivalent to about 7 per cent of the average water flow will be released into a specially created fish route from 1st April to 31st October.

The Mo River was very recently saved, not because any court found the planned power station incompatible with the Swedish Environment Act, but simply because the county administration decided to buy out the developer. In the Ljung River, the power station is being built right now (see picture on page 1).

Small animals are tricked into flying wrong or are killed in the power station

It is easy to understand that a minimum release equivalent to only 5–10 per cent of the average water flow would have serious consequences for plants and animals in the waterway. Not least the bottom-living fauna, which forms an important food source for e.g. many types of fish, is greatly affected. In the dry part of the Ljung River the bottom-living fauna that are dependent on running water will more or less disappear.

When individual winged species of the bottom-living fauna are on their way up the waterway, they fly. They need to make their way upstreams as the larvae are carried downstream in the water system during their development period. If the animals find themselves in far too small water flows they can become disorientated and fly wrong. The females then lay their eggs in places that are less suitable for the purpose, with the result that many of the eggs perish. Unnaturally low flows as a consequence of power station construction therefore make the natural recolonisation impossible or seriously restrict it.

Many larvae (but also fully developed individuals that have landed on the surface of the water) are carried down the waterway. If we assume that 90 per cent of the water flow runs through the power station, it follows that 90 per cent of the floating small animals also go through the power station. And most of them are killed or injured when they pass through the turbines of the power station. Many of the small animals that live in water are very fragile. During testing of the bottom-living fauna it has proved difficult to gather in the animals in such a way as to not injure them.

Where fish are concerned, many are hacked to pieces in the turbines.

Untouched tributaries are important havens of retreat

In river valleys where there are several power stations and where the slow flowing stretches have been dammed to form reservoirs for the power stations, the smaller tributaries are often the only remaining natural flowing environments. A large number of brown trout stocks (several hundred) have been eliminated or substantially reduced in the regulated rivers. In the counties of Västerbotten and Jämtland almost half of the known stocks of full-grown brown trout are gone. The tributaries that flow into the regulated rivers have an especially important function, as they still have spawning grounds intact and are good environments for fish such as young trout to grow up in. The fish can then grow big out in the power station reservoirs (assuming that there is no large presence of pike which is a very efficient predator).

The still free-flowing rivers' small tributaries (or tributaries of the tributaries) are also important reproduction areas for brown trout. When the sea trouts make their way in from the sea to spawn, they do not by any means all remain in the main waterway. Most of them make their way instead into the smaller tributaries where the sea trouts can find the conditions they require for spawning. The same applies to spawning lake dwelling brown trout, who mostly leave their home lake to enter the smaller tributaries. The salmon, however, spawns chiefly in the large unregulated waterways.

Sixth place in the hydropower league table

Only in Norway, Iceland, Canada, Paraguay and New Zealand is there more developed hydropower per capita than in Sweden. The figures in the table apply to 1996 and are from the Statistical Yearbook for 2001.

Country	Production of hydropower electricity (TWh)	Population (millions)	Hydropower electricity (kWh) per capita
Norway	104.0	4.4	23,636
Iceland	4.8	0.3	16,000
Canada	352.6	30.0	11,753
Paraguay	48.0	5.0	9,600
New Zealand	25.7	3.6	7,139
Sweden	51.5[a]	8.8	5,852
Austria	35.6	8.1	4,395
Switzerland	29.7	7.1	4,183
Venezuela	56.0	22.3	2,511
Finland	11.9	5.1	2,333

[a] In 1996 hydropower production was much lower than normal in Sweden. The average figure is about 65 TWh per year. During a normal year the figure is about 7,400 kWh hydropower electricity per capita.

About 70 per cent of the economically viable hydropower in Sweden has already been developed. In many areas, especially Värmland, Jämtland and southern Lapland, the developed level is over 90 per cent. Only in two major rivers – the Torne and Kalix Rivers in the far north – is the water permitted to run freely from its sources in the mountains to the sea.

More hydropower will not solve Sweden's energy problems. But a single mini power station can destroy parts of the biological diversity that Sweden has promised on an international level to conserve.

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