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# BIOTOPE ADJUSTMENT MEASURES IN NORWEGIAN WATERCOURSES

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*Front cover:*
*Biotope adjustment measures in the river, Letjenna, in May 1993 (photo: Jon Arne Eie).*

*Back cover:*
*An embankment weir in the Eksingedal watercourse (photo: Jan Henning L'Abée-Lund).*

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# Foreword

This presentation marks the formal conclusion of a number of research projects known collectively as the "Biotope Adjustment Programme." The programme began in 1985 as the result of an initiative taken by the Environmental Section of the Norwegian Water Resources and Energy Administration (NVE), which has also coordinated and supervised the programme. The programme is a sequel to the "Weir Project", concluded in 1983 after nearly 10 years of scientific investigations.

This publication was orginally written in Norwegian, as were many of the scientific reports. In order to make the material available to a wider audience, we have decided undertake an English translation. The main text is largely unaltered, but we have excluded many of the citations to Norwegian reports, where possible replacing them with papers written in English. However, much of the detailed literature remains in Norwegian, although most reports do have an English summary. A selection of the these Norwegian sources is given at the end of the report.

Hydropower development is not the only factor that influences the aquatic environment. Road construction, landfills and other human encroachments also have a serious impact. Moreover, embankments and other measures initially intended to reduce or prevent flood damage and/or erosion along watercourses can have adverse effects on the environment. It was therefore important for NVE to identify measures and approaches that would minimise the environmental damage caused by flood protection measures.

This publication is based on a number of projects financed in whole or in part by NVE, thanks to funding received from the Hydropower Licencing Fee Fund. The material has been taken from reports published in the Biotope Adjustment Programme series and in various national and international scientific journals.

The Biotope Adjustment Programme has also provided support for and participated in a number of other research programmes and projects. For example, substantial support was provided for a programme designed to improve conditions for fish in rivers and streams, conducted under the auspices of the Research Council of Norway. The final report from that programme has been published in book form in Norwegian. Further, the Biotope Adjustment Programme contributed scientifically and financially to the "Salmon improvement project in the river, Suldalslågen", implemented by Statkraft Engineering. The Biotope Adjustment Programme also supported a NIVA (the Norwegian Institute for Water Research) project aimed at combating Canadian pondweed in the large lake, Tyrifjord. The final report is available as a separate publication in the NIVA series.

The goal of this report is to provide information about the experiments that have been carried out, and about the positive and negative experience gained from biotope adjustment measures so far. The report has been written for people who are interested in fishery management and freshwater biology, as well as for individuals who work with environmental questions relating to freshwaters.

We have tried to describe the effects of the individual remedial measures. Consequently, the results may be the collective efforts of several different projects and authors. Where necessary, contributors have supplemented programme results with knowledge from other sources. Although this presentation is not annotated, references to relevant reports and articles are provided at the end of the report.

The state of man's current knowledge about the consequences of watercourse regulation was the theme of an important conference organised jointly by NVE and the Water Systems Management Association in Bergen in the spring of 1993. The results were published in "Watercourse encroachments: consequences and remedial measures - a summary of our knowledge," published as No. 13 in the NVE report series (Faugli et al. 1993). This report, written in Norwegian, contains more details regarding the impact of various human activities on rivers and streams.

The research results that comprise the core of this publication are the work of individual scientists. They deserve a large part of the credit for the final result.

This report was written by Jon Atle Eie. Jon Arne Eie headed the project from its beginning until 1993, and John Brittain has served as project co-ordinator and edited the English version. Most of the pictures and illustrations have been taken from NVE's extensive slide archives, although some were borrowed from other sources. Jan Henning L'Abée-Lund also provided valuable assistance and advice, while the Norwegian text was translated into English by Linda Sivesind.

*Haavard Østhagen*
*Section Manager,*
*Environmental Section*

# Summary

This report is a synthesis of the results derived from a vast array of studies conducted under the auspices of NVE's Biotope Adjustment Programme. The term 'biotope adjustment' refers to goal-oriented remedial measures designed to develop or promote the establishment of optimal habitats, often to improve conditions for specific species or groups of organisms. Attempts were made to identify practical measures that require a minimum of maintenance and which, not least, promote natural processes. The projects were conducted by scientists at the universities of Oslo, Bergen and Trondheim, the Agricultural University of Norway, the Norwegian Institute for Nature Research (NINA) and the Norwegian Institute for Water Research (NIVA).

Following two introductory chapters, chapter 3 gives a brief description of the effects of hydropower development on life in regulated reservoirs and rivers. The drawdown zones in power plant reservoirs vary from a few metres in most of the large lowland lakes to 100 metres or more in some of the highland reservoirs. The shore zone is the most productive parts of lakes, and drawdowns of more than 5-6 metres will generally impede biodiversity and reduce the production of food organisms for fish. The brown trout, *Salmo trutta,* is the species of fish that suffers most under such conditions.

Hydrological conditions, such as flow, velocity, temperature, ice conditions and sediment transportation, are altered in regulated rivers. Regulation affects water flow in a variety of ways. In the case of older regulation projects, riverbeds may even be dry for large parts of the year. More recent regulation projects always ensure a guaranteed minimum water flow. However, temperature changes also have a major effect on flora and fauna. Temperatures rise in streams from which melt water is diverted, then drop in the summer months in streams that receive increased discharge.

Chapter 4 is mainly about the habitat requirements of brown trout. One of the objectives of biotope adjustment measures is to identify factors that limit production. For fish, the main limiting factors include water quality, water temperature, food supply and access to spawning and rearing areas. Riverbed conditions are closely related to water velocity, for instance in rapids, the substratum will consist of boulders and coarse gravel, while it will consist of more finely grained particles in calmer waters.

Different sizes of fish prefer different water velocities. Young brown trout prefer shallow stretches of river that feature relatively slow water velocities, 10-30 cm/second. In larger rivers, young fish live along the banks, while larger, older fish prefer deeper, faster flowing waters further out in the river. The lack of deep pools in regulated rivers may limit the number of large fish they can support.

Atlantic salmon *Salmo salar,* and brown trout prefer areas where they can find cover. Both are territorial, and access to a larger number of hiding places means more territories. Common hiding places include shoreline vegetation that hangs out into the river, undercut riverbanks, aquatic vegetation, roots, tree trunks and piles of rocks. The cavities between rocks are especially important for young fish.

In the wintertime, large and small brown trout demonstrate different diurnal behaviour patterns, that is they act differently during the day and at night. When the temperature falls to about 5 °C, small fish spend their days taking refuge in cavities between rocks and in deep, slow-flowing areas where they stop and rest. However, the small fish behave differently at night, leaving their shelters and becoming more active.

Chapter 5 reports on the various remedial measures tested in reservoirs. The objective of one of the experiments was to establish vegetation in the shore zone both for aesthetic reasons and to promote the production of fish and other organisms. The area was fertilised and scientists planted species they believed would tolerate the harsh conditions in the drawdown zone. Finely grained substrate (rooting medium) has to be available in the shore zone if plants are to survive. It is also necessary to implement erosion prevention measures. The experiments showed that it is extremely difficult to get vegetation to grow on the shores of reservoirs that have large drawdown zones.

A weir was built to isolate an arm of the Innerdal Reservoir in central Norway from the rest of the lake. Thus, lowering the water level in the reservoir did not affect the weir basin. The weir basin proved favourable for fish production as well as for bird life, in particular. As a supplement to fish stocking, some experiments were also targeted at improving natural recruitment conditions in small streams that flow into reservoirs.

Chapter 6 deals with biotope adjustment measures in rivers and streams. Extensive channelization was performed in a wetland area, Lesjaleirene, in central southern Norway during the late 1970s to safeguard farm land. In 1990 "islands" of coarse rock were spread out across the river and along the banks. These man-made islands had a beneficial effect on the density and diversity of the benthic fauna, as well as on the fish. Young-of-the-year fish have been observed in the interstices between the rocks, suggesting that brown trout are spawning there.

In times past, many of the rivers used for logging were cleared of large rocks and other obstacles. Boulders were therefore removed in several of the old logging rivers, deep pools were dug and artificial embankments were built. One good example of this is at Letjenna, near Elverum in south-eastern Norway. The riverbed was also narrowed in the reach between the pools to increase water velocity. These remedial measures led to a tripling of fish density.

In the river, Ekso, in western Norway, the use of hatching boxes to stock fertilised Atlantic salmon eggs from indigenous populations met with success.

Weirs are commonly used to maintain water levels in regulated rivers in which the water flow has been reduced. Altogether, more than 1000 weirs made of wood, concrete or rocks and gravel have been constructed in Norwegian rivers. Embankment weirs are the most common type. Weirs increase water retention in rivers with reduced water flow. A large part of the nutrients that come into weir basins drift in as dead organic matter (allochthonous input). Weirs delay the flushing out of this material, which is an important source of food for benthic organisms.

As water velocity decreases and sedimentation increases, there is a succession in the species of benthic fauna that live in weir basins. The fauna eventually comprises a selection of species adapted to lentic waters. The benthic biomass increases rapidly. Experiments have shown that alternating stretches of riffles and weir basins creates greater biodiversity than riffles or rapids alone.

Weirs generally have a positive effect on fish production, but it is important that they not impede migration. "Syvde" weirs are the most commonly used design in salmon and sea trout (anadromous brown trout) rivers. These weirs have long 'wings', while the middle is slightly recessed to allow salmon to pass over easily. In addition, pools are excavated just below the weir basins. Investigations indicate that brown trout dominate in the weir basins, while Atlantic salmon show the greatest density in the outlying riffles. However, weir-building does favour species such as perch, minnows and pike in areas with little water flow. Weirs also appear to be beneficial for ducks and waders.

Weirs are relatively expensive structures. In larger rivers, costs vary from NOK 1 000 to NOK 4 000 per metre. However, costs are closely related to the height of the weirs and access to rock. In connection with hydropower development projects, the authorities are empowered to order regulators to build weirs or to implement other biotope adjustment measures.

Chapter 7 deals with wetland reclamation measures involving drainage to increase farm land. In the Bygd Delta of Myrkdalsvatn, in the Vosso River of western Norway, scientists monitored the development of vegetation, benthic fauna and birds on the excavated areas and man-made islands for several years. Vegetation quickly took root on the denuded areas and changed radically in the early years. It took four years to establish vegetation zones that were largely similar to those that prevailed prior to drainage.

The benthic fauna also changed as time passed. Bird life was reduced after drainage, but new species moved in as plants and insects returned. The construction of earthworks, channels and islets ensured the preservation of important wetlands for birds. The islets were increasingly used for foraging. By building small weirs in the many small channels made in the Lesjaleirene, the accessible water surface area was increased. This made the channels attractive to a wider variety of water birds. Studies in the Søya River, western Norway, showed that when conditions changed radically as a result of cultivation or the removal of riparian woodlands, it was not possible to maintain a favourable habitat for birds.

Chapter 8 explains the Norwegian administrative and legal proceedures for implementing various biotope adjustment measures in watercourses.

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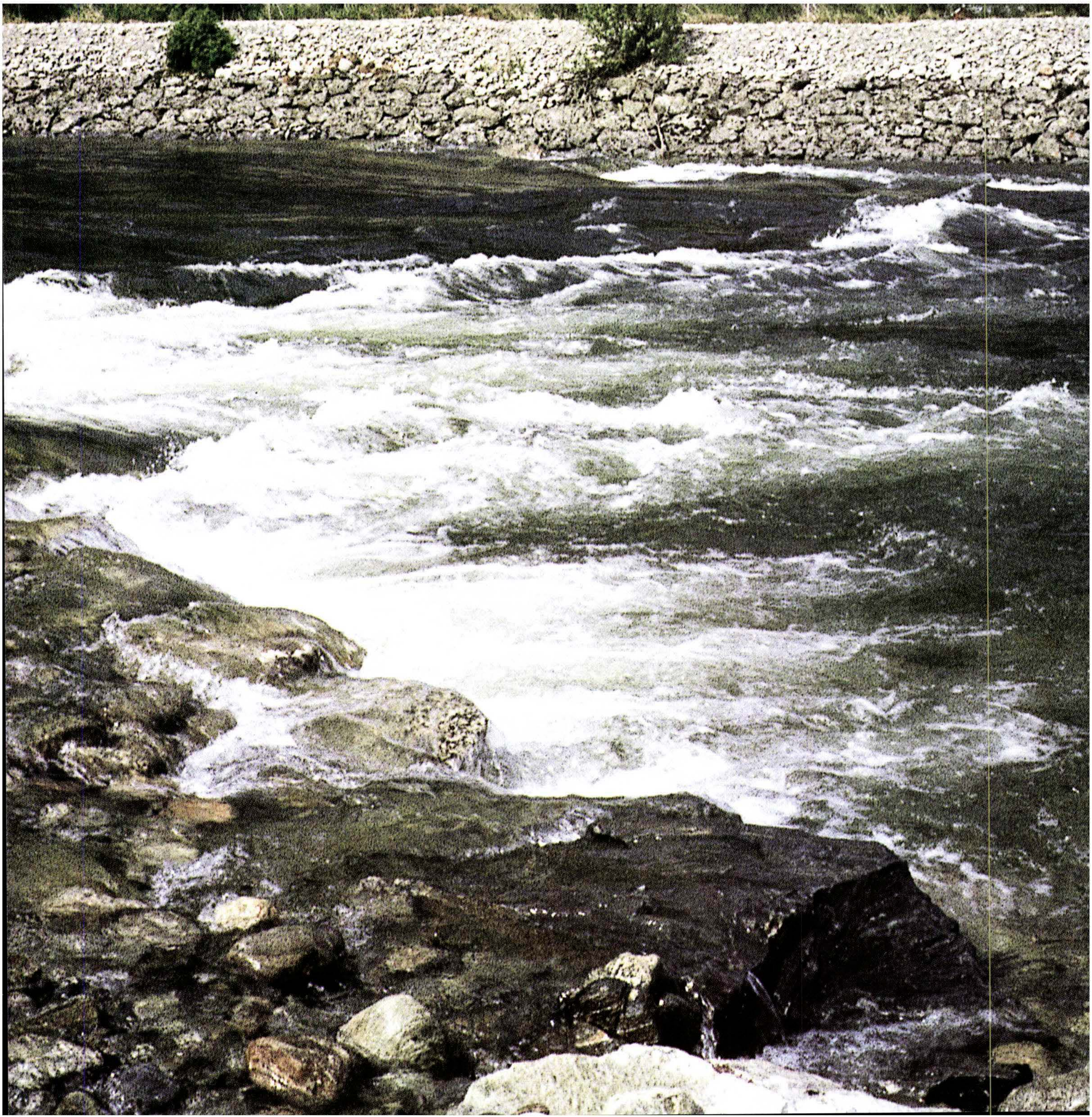


# 1 The Biotope Adjustment Programme

The term "biotope adjustment" refers to goal-oriented measures aimed at developing or promoting the establishment of habitats to improve living conditions for the species or groups of organisms one wishes to encourage. For example, to promote species such as brown trout and Atlantic salmon, two of Norway's most important species of fish, remedial measures must be directed at all stages of their life cycles.

In connection with major encroachments, it is virtually impossible to maintain the natural state or return an area to its pre-encroachment condition. Thus objectives and user interests must be ranked by priority or user interests, then adapted to the relevant stretches of river. In many cases, the goal is to maintain natural biodiversity and reduce the detrimental effects of various technical encroachments. Traditionally, Norwegian scientists have assigned the highest priority to improving conditions for fish.

The Biotope Adjustment Programme is a research and development programme aimed at identifying practical remedial measures. The programme is based on the assumption that the measures had to be technically feasible, preferably requiring little or no maintenance, and, not least, that they should promote natural processes. The programme was also based partly on existing knowledge of various organisms' environmental requirements and partly on the acquisition of new knowledge.

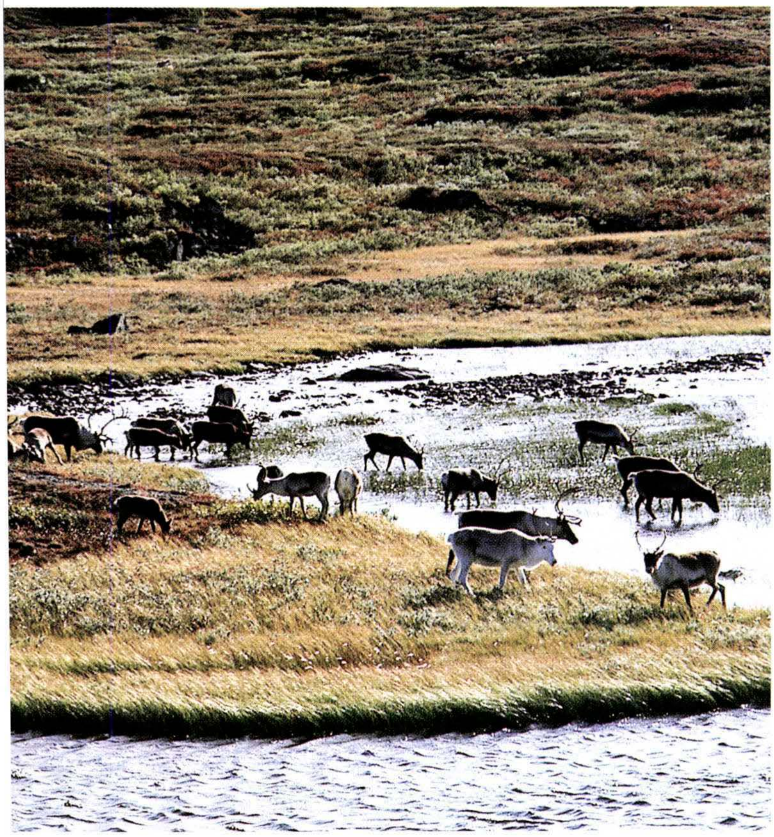
In Norway, all administrative agencies are in charge of environmental protection within their own sphere of responsibility. NVE was well aware of its responsibility in this respect long before the concept was incorporated into the political agenda. The Biotope Adjustment Programme commenced in 1985 as a sequel to NVE's Weir Project, which began as early as 1973.

*A "Syvde" weir in the river, Lærdalselva (photo: Pål Mellquist).*

# 2 The biodiversity of lakes and rivers

Norway features well-diversified ecosystems in and along a number of different types of watercourses. These sites are home to a variety of plants and animals, and we are responsible for preserving these species for future generations. For example, more than 60 species of higher aquatic plants have been registered in Norway. These form a substrate for bacteria, fungi, algae and certain species of invertebrates. The plants are also important sources of food and shelter for a number of animals, including larvae, adult insects and other invertebrates. These, in turn, provide sustenance for other animals such as fish and birds.

*Reindeer in Heimdalen, Valdres (photo: John E. Brittain).*



Invertebrates comprise a large group that includes an abundance of species. At a rough estimate, Norway has about 3000 different species of invertebrates living in its freshwater habitats. Insect groups such as caddis flies, mayflies, stoneflies and midges often dominate, although other groups such as freshwater mussels and water mites may also be well represented. Invertebrates that live on and in riverbeds are crucial to the utilisation and metabolism of organic matter. They are also an important link in many food chains, and they are particularly important as food organisms for fish. Densities from 5000 to 30 000 individuals per $m^2$ are usual, although the figures vary widely.

Norway has relatively few species of freshwater fish, not more than 40 altogether, only five or six of which are found throughout most of the country.

In economic terms, the Atlantic salmon is the most valuable fish in Norway's coastal watercourses, but it has been hard hit by the activities of man. At one time, salmon used to occurred naturally in approximately 600 Norwegian rivers. Today, however, salmon stocks are extinct or endangered in 91 of these rivers. Reasons include acid precipitation, the salmon parasite, *Gyrodactylus salaris,* hydropower development and numerous other types of watercourse encroachments. Fish that escape from fish farms represent a growing threat of genetic pollution. The brown trout is found all over the country and is a favourite with anglers.

The diversity of Norway's riverine habitats has made it possible for a large number of bird species to establish viable populations. Sixty to 70 of the more than 250 species of birds observed nesting in Norway rely on freshwater ecosystems to a greater or lesser extent.

# 3 Watercourse encroachments

## 3.1 Watercourse encroachments through the ages

For centuries, rivers have been essential for the transportation of logs and the provision of power. Norway's waterways were also vital traffic arteries, and they have provided in the form of fish. Yet rivers have also posed a threat to life and settlement, as floods and erosion have wreaked serious damage on farmlands and other areas.

Thus man has exploited the rivers, while trying to protect himself against the dangers and threats the rivers represent. To facilitate logging activities, people built dams so they could increase the water flow of water in the rivers when needed. Many riverbeds were cleared of boulders and other obstacles to facilitate the transport of logs. This caused rivers to lose much of their diversity, putting an end to many favourable spawning grounds and fish habitats.

Over the past 50 years, the natural terrain around Norwegian watercourses has been modified significantly through lowering of lake and river levels, drainage, cultivation, channelization, etc., to prevent flood damage on cultivated fields and/or to reclaim new agricultural land. Encroachments have modified water velocities and the transport of sediments, reducing the danger of flooding. At the same time, these activities have led to removal or modification of riparian vegetation. The encroachments have probably also affected benthic fauna. Spawning and rearing conditions for fish have certainly been affected, and there is less wetland area available to birds, etc. Many watercourses have also deteriorated as a result of road construction and the establishment of industrial and residential zones. Moreover, rivers are susceptible to pollution from agricultural activities, traffic, human settlement and acid precipitation.

Sand and gravel from the rivers have always been important resources. Pressures on these resources have increased considerably in recent decades, yet extracting gravel from rivers can have a strong adverse impact on the environment. We have examples of how riverbeds have been lowered right down to the underlying clay sediment, reducing water quality and entailing serious biological consequences.

Any measure to which a watercourse is subjected, be it channelization, reinforcement, the removal of water or gravel, regulation, road construction, etc., will affect hydrological and biological processes alike. Whether the effects are considered positive or negative depends largely on the "user group". Most measures aim at a particular objective. If that objective is achieved, the result is considered positive. Yet that same measure may entail adverse effects for others. Anthropogenic activities often reduce biodiversity in the ecosystem as a whole.

Reduced biodiversity usually means that species, that require very particular ecological conditions to survive, will loose ground in the face of competition from species with broader tolerances and a greater potential for reproduction. One of the primary political objectives of sound nature management today is to preserve biodiversity. This objective can be achieved by maintaining a large variety of biotopes or niches. Among the most important reasons for protecting biodiversity is the need to ensure genetic variation. This may potentially benefit mankind as it leaves the door open to the discovery of new medicines and useful plants that will prove useful There are also strong ethical groundreasons for not causing species to become extinct.

## 3.2 The effects of hydropower development

### *3.2.1 Hydropower reservoirs*

Power station reservoirs represent major encroachments in Norwegian lakes, rivers and alpine ecosystems. Norway currently has about 800 power plant reservoirs, accounting for a total of roughly 40 per cent of the area covered by freshwater.

The scope of watercourse regulation varies from drawdown zones of a few metres, as is the case in most of the large lakes in eastern Norway, to 100 metres or more in a few of the more extreme cases involving mountain reservoirs. Generally, the establishment of reservoirs with a drawdown zones of more than five or six metres will reduce biodiversity. Most of the more recent reservoirs are located in the mountains, where the drawdown zones are greatest.

The littoral or shore zone is the most productive area of a lake and features the greatest abundance of species. In regulated watercourses, all or part of the shore zone is dry for shorter or longer periods of time, and water level rhythms are different from those that occur in natural lakes. The annual raising and lowering of the water level causes fine material to be washed away from the shore zone and deposited in deeper water.

In regulated watercourses, flowering plants will eventually disappear from the shore zone due to descication and erosion. This in turn limits the production of periphyton and benthic fauna, reducing their availability as food organisms for fish and birds. The trout is the species of fish most severely affected, as it mainly lives on a diet of benthic fauna. The impact is less severe on Arctic char *(Salvelinus alpinus)* and whitefish *(Coregonus lavaretus)*, which feed more more on zooplankton. The adverse effects of shore zone destruction are particularly pronounced in alpine lakes where production is usually considerably higher in the shore zone than the open waters.

The regulation of lakes and watercourses can also affect bird life. Of the 60 to 70 species found in Norway's freshwater ecosystems, 27 are classified as endangered, threatened, rare or of uncertain status. Some of these species have such narrow distribution that hydropower development rarely causes a problem for them. Other species which are in no way endangered may, on the other hand, be strongly affected. This is especially true of loons, most ducks, swans, swallows, wagtails and dippers. As for waders, their living conditions are strongly affected when fairly large wetland areas are submerged as a result of hydropower development. However, intake reservoirs

*The shore zone along the hydropower reservoir, Pålsbufjorden on 20 July 1996 (photo: Jan Henning L'Abée-Lund).*

with fairly stable water levels can have a positive effect on bird life.

## 3.2.2 Regulated rivers

Hydropower development affects hydrological conditions such as water level, water velocity, water temperature, ice conditions and sediment transport. Channelization, drainage, obstacle removal and hydropower development have entailed major and minor changes in the habitats of plants and animals that live in or near watercourses. Depending on their severity, encroachments will usually compromise the complexity of the physical environment, reducing biodiversity. It is therefore important to identify and implement remedial measures that can mitigate the damage caused by such human activities. Insight into how key species adapt to riverine ecosystems is essential if we are to understand the effects of water-course regulation on the flora and fauna, and to determine which measures to apply.

### *Changes in water flow*

The magnitude of changes in water flow will depend on the type of development project in question and the guaranteed minimum discharge. In connection with older regulation projects, some stretches of riverbed may even be dry for large parts of the year. In this context, a distinction is made between two

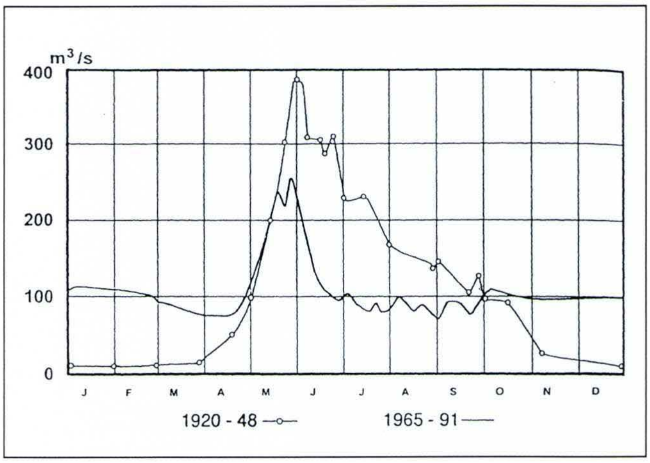



*Fig. 1. Mean water flow before (1920-1948) and after (1965-1991) the hydropower project in the river, Hallingdalselva, downstream from Bromma.*

main types of power plants: run-of-the-river power plants and reservoir power plants. Most river power plants take advantage of the waterflow that exists at any given time. The waterflow is not modified well downstream from such power plants, but can be severely reduced in the riverbed between the intake and the power plant when the power plant is in operation.

Most large Norwegian power schemes are based on mountain reservoirs. In some cases, catchments are partially diverted to other watercourses. Sometimes, several tributaries are led directly into the intake tunnel. The waterflow will be modified in both watercourses, that is less in the one and more in the otherother, where the power plant is located. Tributaries led into the tunnel will also be subject to reduced water flow.

The reservoirs' most important function is to store water from summer to winter, when the demand for power is greatest and inflow least. Reservoirs fill with meltwater in the spring, reducing the magnitude and duration of spring flooding. The result is that the watercourse carries less water in the summer and more in the winter. Overall, regulated watercourses (Fig. 1) have a more stable, steady flow of water.

In addition to seasonal variations, the time of day can sometimes cause significant fluctuations in the water flow of water downstream from certain power

*Low water flow in the river, Mandalselva, downstream from the Bjelland power plant in 1975 (photo: Knut Ove Hillestad).*

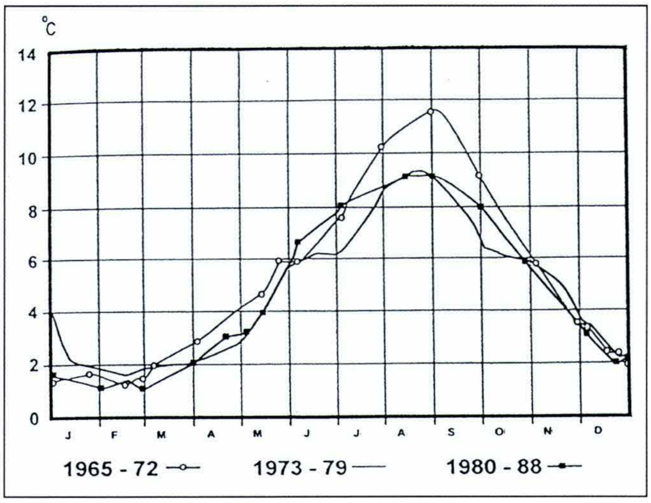



*Fig. 2. Water temperatures in the river, Aurlandselva, at Skjærshølen from 1965-1972 (unregulated), 1973-1979 (1st stage of construction) and 1980-1988 (construction completed).*

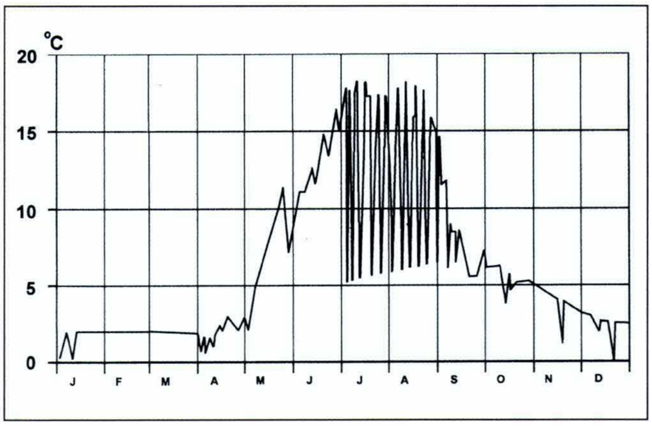



*Fig. 3. Temperatures in the river, Flatdalselva, near Seljord, downstream from the Sundsbarm power plant in 1976. Peaking operations in July and August led to extreme temperature fluctuations.*

plants. This happens if a plant is shut down or operates at reduced capacity to adapt in response to less demand for power (peaking). This type of flow management will probably become more common in future. The biological consequences of such releases could be substantial if the plant discharges into a river. If the power plant empties directly into the sea or a large lake, the effects will generally be minimal.

### *Changes in water temperature*

The most common reasons for water temperatures changes in regulated watercourses are:

1. Water is drawn off from deeper water. In winter, such water will be relatively warm, in summer, relatively cold.
2. Meltwater is added and/or stored in the spring and summer. This leads to higher summer temperatures below the intake point.
3. Significant changes in waterflow. The greater the discharge, the more slowly temperatures change; the lesser the discharge, the more quickly they change.
4. The energy generated by the fall is not converted into heat, but is extracted as electrical energy. A 427 m natural, vertical fall would, for example, heat the water by 1°C.

Several of these factors will usually interact in regulated watercourses. Post-regulatory water temperature changes have been documented in the rivers, Suldalslågen, Orkla, Aurlandselva and Altaelva. The Ulla-Førre development project in south-western Norway caused mean monthly temperatures in the Suldalslågen to drop by up to 1.5°C.

The temperature of the Aurlandselva, western Norway, rose by 1°C in June in a stretch from which a considerable amount of meltwater had been diverted. On the other hand, the mean August temperature dropped by 2.5°C (Fig. 2) in another stretch that received increased water flow due to diversion.

The river, Flatdalselva, below the Sundsbarm power plant in southern Norway, is a prime example of serious short-term temperature variations. The power plant water is drawn directly from deep waters in the Sundsbarm reservoir. Summer operations vary significantly, causing river temperatures to drop by 10 to 12°C almost instantly when the power plant comes on-line (Fig. 3).

### *Changes in sediment transport*

Sediments in and along watercourses comprise the substrate for plants and animals alike. Reducing floods in a watercourse also reduces erosion. If sediments continue to be brought in by tributaries, the riverbed will eventually build up. Example are the Jostedal power plant and the Fortun regulation scheme, both in western Norway. Below dams or in connection with diversion, the opposite process may apply. Increased water flow will increase the transport of sediment, deepening the riverbed as a result. This can cause erosion under riverbanks and any reinforcement structures that might be located there.

# 4 Habitat requirements

*The river, Sømåa, north of Istern, with riffles, pools, large rocks and varied riverbank vegetation. Variation is decisive for promoting biodiversity as well as for providing good living conditions for fish and their food organisms (photo: Jon Arne Eie).*

All organisms have certain habitat-related requirements. Some species can survive under a wide variety of living conditions, while others are extremely discerning. We know quite a bit about the habitat-related requirements of some species, while our knowledge of others remains sorely deficient.

## 4.1 Benthic fauna

The invertebrate organisms that live on and in stream beds and lake bottoms are referred to collectively as the benthos. They can be found in a wide variety of different habitats. Vegetation is extremely important for some groups, while others live on or under rocks and stones. Generally, the highest densities and greatest diversity of species are found in riffles that feature stones and coarse gravel, and where the substrate is covered in moss. The more varied the substrate, the greater the number of species that live there.

Some benthic animals live on detritus (dead organic matter) and/or on plant material on and in the river bottom. This may either be produced in the water, such as algae or moss, or be introduced into the water from the riverbanks, such as leaves of trees and bushes. The benthos also comprises predators and filter-feeders.

Different species of benthic animals require different water velocities. Some need lotic, or swiftly flowing water to breathe or to bring food particles while others are better suited to lentic, or calmer water and would be flushed away if the water velocity were too great. Benthic animals are poikilothermic, i.e., their body temperatures vary in accordance with the temperature of their surroundings. As a result, temperature has a strong effect on their hatching, growth, and activity.

## 4.2 Fish

Salmon and trout are both versatile species, able to adapt to a wide range of conditions. For them, the most notable impact of regulation is on spawning and rearing grounds. Fish are not randomly distributed in a river; they choose the areas that suit them best. It is therefore important that biotope adjustment measures take into account environmental factors that might alter or constrain living conditions. The following factors are of importance to fish: water quality, water temperature, access to food organisms, spawning grounds and access to shelter. In recent years, the Biotope Adjustment Project has added significantly to our knowledge about brown trout habitats, so this section is devoted to that subject.

### *4.2.1 Acceptable water quality*

Among other things, the term 'acceptable water quality' implies that water does not contain toxins in excess of the tolerance limits, such as for acidity. Different species of fish react differently to acidity, and if waters are too acidic, the fish die. Fish also react differently to acidity at different stages in their life cycles. One general rule is that young fish are more sensitive to acidity than adult fish. Water must also contain adequate amounts of oxygen. Different species have different oxygenation requirements as well. For example, among fish, salmonids require more oxygen than cyprinids.

Some species cannot tolerate water that is turbid due to clay or other suspended particles. Salmonids are especially sensitive to turbidity, which can even affect spawning and hatching activities. Suspended particles can also have a strong effect on the production of fish food organisms.

### *4.2.2 Productive areas*

There are two main types of habitats in rivers: riffles and pools, although the two often grade into one another. Numerous investigations have shown that riffles are important production areas for fish food organisms.

Water velocity plays a decisive role in the distribution pattern of aquatic invertebrates. Adaptations such as hooks, suckers, streamlined shape and flatness allow many organisms to live in rapids. Constant access to fresh, oxygenated water ensures good respiration and feeding conditions for many organisms. A water velocity of 0.5 - 1 m/s is optimal for many species.

Bottom conditions are closely related to water velocity, and the substrate is coarser in riffles than in calmer areas. Several investigations have shown that the number of food organisms is reduced when substrate particle size is reduced from stones and gravel to the size of sand. The production of food organisms is greatest where the substrate consists of relatively coarse rocks, as it gives insects a firm surface and the best possible protection against the current. Lotic waters also contains large amounts of "drifting" organisms, that have perhaps lost their hold on the substrate or been washed out of an upstream lake. Some fish diets are largely based on drift, and the amount of drift is affected by the water velocity.

Fish of different sizes live in areas with different water velocities. As juveniles, the smallest brown trout usually prefer shallow waters with low water velocities (10 to 30 cm/s). In larger rivers, young fish live along riverbanks and in backwaters, while the larger fish usually prefer more swiftly flowing, deeper waters further out in the river. In smaller rivers and brooks, older fish are often found in deep, calm waters, especially in pools. The lack of deepwater areas or

pools can limit the number of larger fish that live in small rivers, especially those that are regulated.

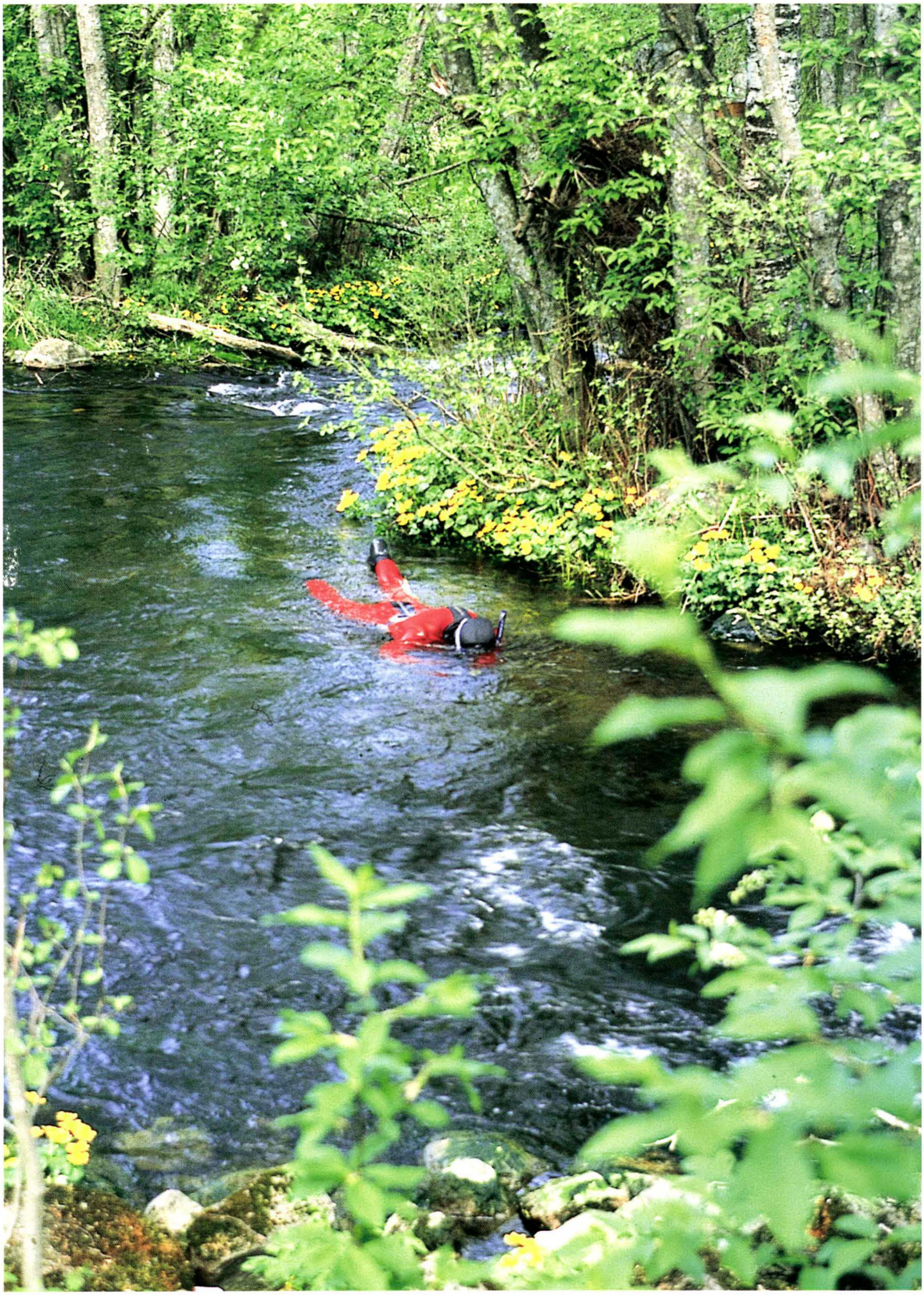
In brooks and rivers, the young juvenile stages of caddis flies, midges, stoneflies and mayflies are among the trout's prey. Blackfly larvae and net-spinning caddis larvae may comprise a significant proportion of the food organisms in rivers flowing out of lakes. Here, the trout may also consume a large portion of the zooplankton that originates in the lake.

*Riparian vegetation along the river, Lierelva, after careful thinning. In some areas, this riverbank vegetation has to be thinned to prevent it from choking the watercourse in the event of floods and causing the submersion of adjacent farmlands. The alternative would have been to clear the area and build stone retainers along the banks (photo: Jon Arne Eie).*

### 4.2.3 Spawning grounds

Most salmon have very exacting requirements for spawning grounds in terms of water velocity, water depth and substrate. A water velocity of 0.2 to 0.9 m/s is considered best for brown trout. The water must be at least 0.2 m deep, and the rocks in the substrate gravel should have a diameter of 0.5 to 8 cm.

Insufficient water flow can prevent or delay brown



*Divers were used to study fish habitat in the river, Hunnselva, in February 1991 (photo: Jan Heggenes).*

*Studies of fish habitat in the river, Hunnselva, May 1990 (photo: Jon Arne Eie).*

trout from reaching their spawning grounds. They lay their eggs in stones and gravel, ensuring a good supply of oxygen during low winter flows. Mortality is considerably lower when eggs are laid in gravel than in sand.

The mortality rate is very low immediately after hatching, as the alevins (the first stage of development) stay down in the gravel. However, the mortality rate rises dramatically when the alevins emerge from the gravel and are ready to eat. This normally happens at a time when there is plenty of food available.

The spawning season is adapted to the life cycles of food organisms and the danger of flooding in the river. Changes in water flow and temperature may have an impact on when the alevins emerge from the gravel. This can result in a large proportion of the alevins emerging at a time when there is not abundant access to food organisms. This may in turn affect recruitment.

### *4.2.4 Cover*

Both Atlantic salmon and brown trout prefer areas that offer shelter or hiding places, partly to avoid being caught by other fish or other predators such as mink and birds, and partly as protection against strong currents. Another reason cover is important is that salmon and trout are both territorial, establishing their own "domains" and defending them against intruders. Where there are plenty of potential hiding places, the number of territories increases, as does the stock of fish.

Common hiding places include riverbank vegetation that hangs down into the water, eroded river banks, aquatic plants, roots, tree trunks, rocks, etc. However, the most important hiding places, especially for small fish, are cavities in the substrate. Fish of different sizes prefer different types of cover. Surface turbulence provides good cover in many Norwegian rivers, reducing the importance of other hiding places. In contrast, in slow-flowing, shallow regulated rivers with finely grained substrate, or in channelized stretches, the availability of cover is probably the single factor that has most often been overlooked but is easiest to remedy.

### *4.2.5 The winter habitat of trout in rivers*

Studies of the brown trout's winter habitat were conducted in the the river, Hunnselva, which offers a wide variety of habitat types. During the four years of the investigation (1989 to 1992), scientists found that groups of trout of different sizes occupied different habitats in the winter, and that their diurnal behaviour patterns changed markedly as temperatures dropped (Heggenes et al. 1993).

Differences in diurnal behaviour patterns were also noted between large and small fish. Relatively speaking, smaller individuals (< 25 cm) tended to stay closer to quick-flowing rapids. As water temperatures dropped from 10 °C to 5 °C, an increasing proportion of the smallest trout "disappeared". At temperatures of less than 5 °C, no small fish were observed in the waters at all, but systematic search of the substrate revealed that that they were hiding in cavities between rocks and aquatic vegetation. The fish were very sluggish, "resting" in a state that resembled suspended animation. The larger trout (> 25 cm), on the other hand, formed shoals in the deep, calm waters of the river and remained more active than the small fish.

Fish behaviour changed at night, when the smaller fish also became active in or above the substrate. This nocturnal component remained stable throughout the winter.

Ice conditions in the watercourse and the danger of being eaten are plausible explanations for the brown trout's winter behaviour pattern. Predators such as mink and fishing ducks are warm-blooded, meaning they are good hunters even at low temperatures. Such species are active during the day and use vision to spot their prey. Thus the trout's nocturnal activity pattern reduces the danger of being eaten. At low temperatures, ice conditions change throughout the day and night, but the changes are most pronounced at night due to heat loss through radiation. In other words, nocturnal activity is also therefore the best way to avoid freezing to death.

The trout's swimming ability is reduced at low temperatures and there is a constant danger of being flushed away, both day and night. It is important to bear in mind that wintertime water levels are low in unregulated watercourses. By way of contrast, in regulated rivers temperatures downstream from power stations in regulated rivers, flows are higher in winter than at other times of the year, increasing the danger of being flushed away.

Since the trout does not move around much in cold water and hides during the day when it would see food organisms best, one might expect the trout to have a very limited intake of food during the winter. How ever, investigations have shown that trout continue to feed all winter, and that they see well, even in very weak light.

Knowledge about the brown trout's choice of habitat is essential for any biotope adjustment measures. Winter is a critical period for the trout. Measures to promote brown trout stocks might include ensuring sufficient access to areas in which the waters are calm at night, such as pools, backwaters and river banks. Such areas can be created by excavating pools and building weirs. There should be plenty of places that offer a coarse substrate with numerous cavities where fish can hide located near areas of nocturnal activity. It is also important to preserve aquatic vegetation, as it provides good cover during the day.

# 5 Biotope adjustment measures in reservoirs

*Natural vegetation in the shore zone of Meltingen, August 1985 (photo: Pål Mellquist).*

## 5.1 The establishment of vegetation in the drawdown zone

Reservoir shore zones may not be particularly attractive, especially before the reservoir is filled in the spring and early summer. Shore zones may also be subject to wash out and erosion. In 1989, experiments were initiated in the reservoir, Meltingen (216 m a.s.l.), in the county of Nord-Trøndelag to test the viability of different plants in the shore zone (Rørslett & Johansen 1996). Meltingen is low in nutrients and its water quality is well suited for plants such as *Myriophyllum* and *Potamogeton.* The drawdown height is 21 m.

### *5.1.1 Species composition*

There were still a few indigenous terrestrial-type plants along the shoreline five years after the reservoir was filled. *Deschampsia cespitosa* ssp. *cespitosa, Calamagrostis purpurea,* and various species of *Juncus* had taken taken root there along with young shoots of *Rumex* spp. and *Salix* spp. Sheltered areas were largely covered by moss. Certain aquatic plants such as *Myriophyllum*

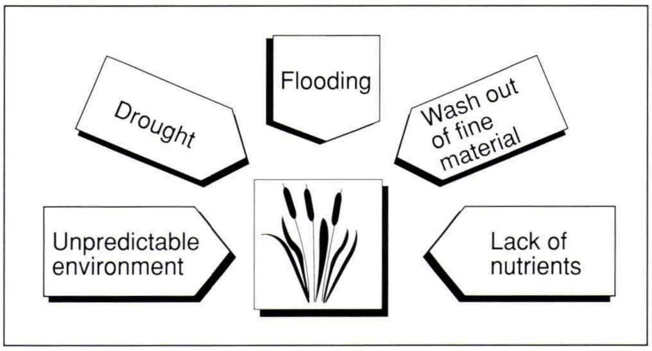


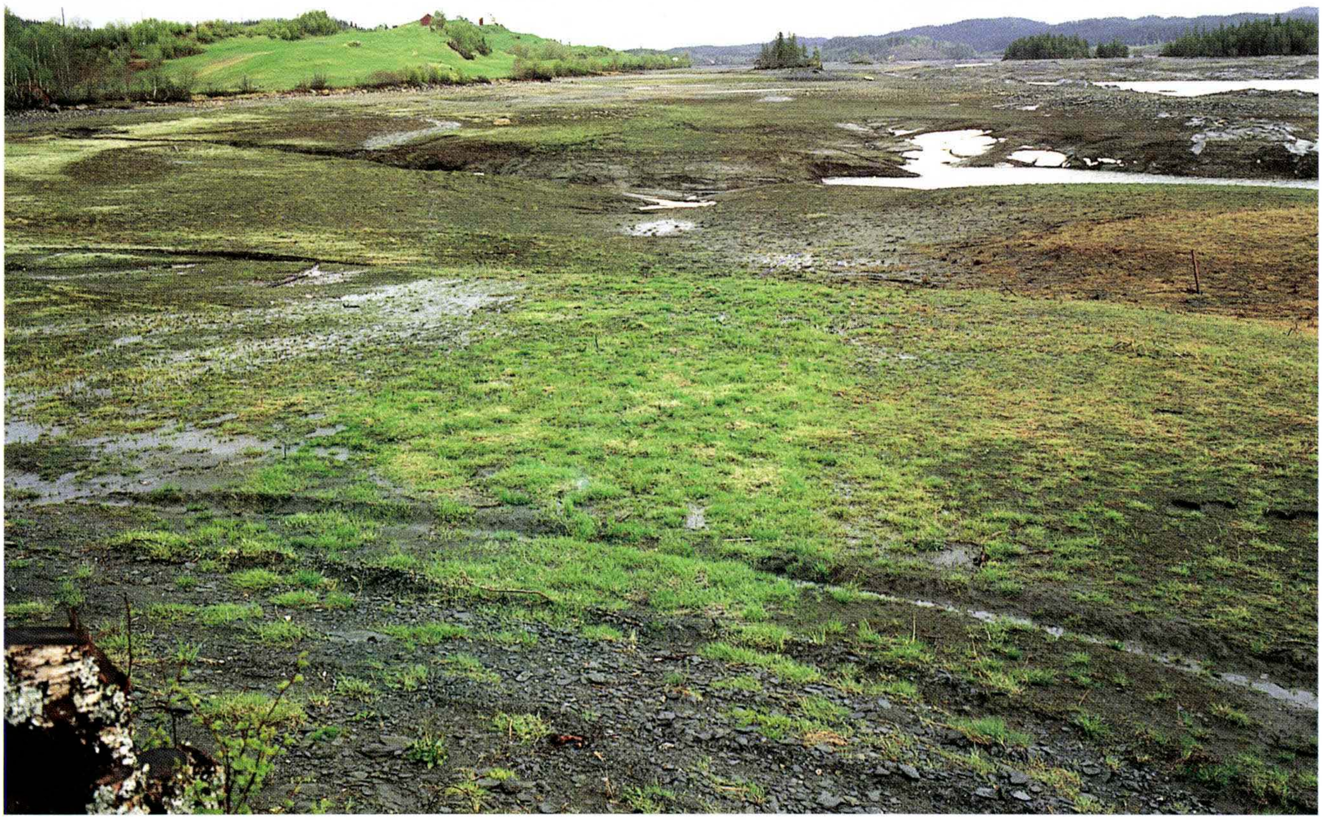

*Fig. 4. The key factors affecting breakdown of plant cover (from Rørslett et al. 1993).*

*alternifolium* and *Ranunculus reptans* were also observed, but all of them were sterile.

The composition of species in the ground cover changed in line with major changes in water levels (Fig. 4). In years with sparse precipitation, the shore and parts of the original drawdown zone were dry during the summer months, but they were flooded for most of the summer in wet years. In wet summers featuring high water levels, terrestrial plants simply disappeared from large areas, and were superseded by aquatic plants. Plants such as *Rumex* would suddenly disappear from areas where they had previously been very viable, to be replaced by aquatic plants such as *Myriophyllum alternifolium, Potamogeton* spp., *Sparganium angustifolium, Juncus supinus* and *Glyceria fluitans.* All these species feature flexible growth strategies that facilitate rapid re-growth.

Once the water receded, aquatic vegetation was reduced considerably in the shore zone. Annual weeds such as *Filaginella uliginosa, Chenopodium album, Spergula arvensis, Juncus bufonius,* other rushes and grass sprouted from the seed bank in the substrate. *Rumex* sprouted on the shoreline once again. Such alternation seems to occur as long as the substrate is finely-grained and contains sufficient nutrients and seeds.

*Fertilisation experiments in Meltingen. The light green vegetation in the foreground was fertilised, while the brown area further back was not (photo: Jon Arne Eie).*



On shore segments that had been submerged 30-40% of the six-year period, most of the tufts of *Deschampsia cespitosa* had died or were severely reduced. In a belt that swept across one particular level, all the *Phalaris arundinacea* had been wiped out by ice and wave erosion. *Ranunculus reptans,* on the other hand, had survived somewhat better. There are strong indications that species with perennial rhizomes are better adapted to surviving long, harsh periods as long as the growth substrate remains intact.

The lake, Meltingen, was the testing site for several measures designed to reduce the wash out of finely-grained particles from the shore zone. Attempts were also made to introduce new plant species.

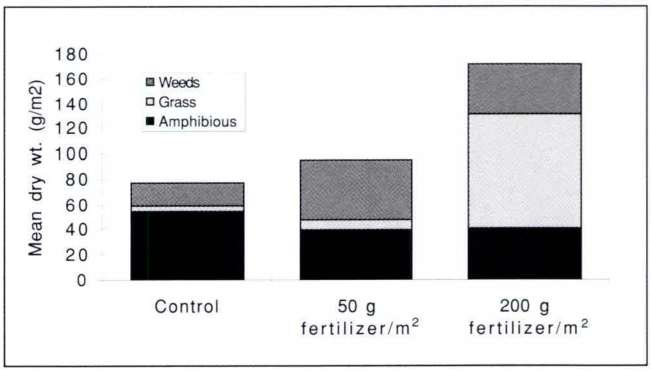



*Fig. 5. The result of fertilisation with fertiliser (nitrogen, phosphorous and potassium) on test areas featuring fragments of natural plant cover (1991). The term "amphibious" vegetation mainly refers to* Ranunculus reptans *(from Rørslett et al. 1993).*

## *5.1.2 Erosion mats and fertilisation*

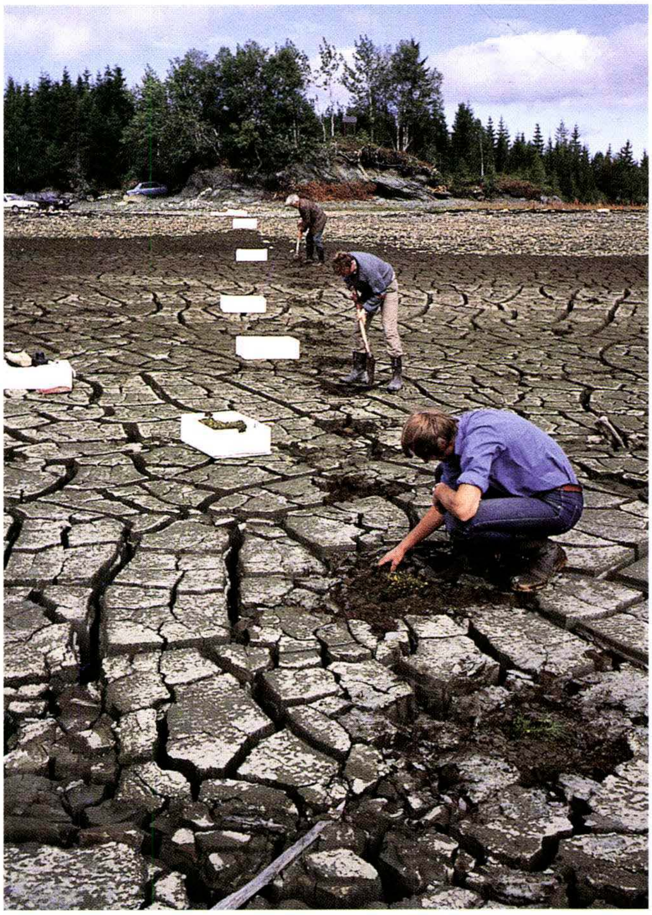
Erosion mats were deployed to curb the wash out of finely-grained matter, and the vegetation was fertilised and lime-enriched peat added to promote growth. Fertilisation was intended to increase root growth so the roots would hold the soil better, thus limiting erosion.

The erosion mats were undermined by wave action and they loosened unless anchored very firmly. It did not seem likely that they would be able to withstand the forces of nature in the shore zone for any length of time.

Fertilisation resulted in rapid growth of vegetation (Fig. 5). Strong fertilisation (200 g/m$^2$) caused terrestrial species of grass, especially *Agrostis* and annual weeds to develop robustly, adding organic matter to the substrate in the form of more roots. The effect was sustained for several growing seasons. Plants sprouted from the seed bank in the substrate, but the species tended to succumb if the shores were submerged for any length of time. Water-milfoil and other aquatic species also gained ground immediately after fertilisation, but the effect did not last long.

Experiments indicated that fertilisation should be kept at a low level to avoid unintended competition between aquatic and terrestrial species. Fertilisation could also have an adverse effect on water quality. All in all, it appears that well-developed root systems can delay, but not prevent the wash out of finely-grained matter.

*Planting* Ranunculus reptans *in Meltingen in August 1985 (photo: Pål Mellquist).*



## *5.1.3 Planting*

The first pilot experiments involving the planting of *Ranunculus reptans,* among other species, were carried out in 1985. Later, five different species were planted, all of which were adapted to a partially aquatic life: *Deschampsia cespitosa* ssp. *cespitosa, Deschampsia*

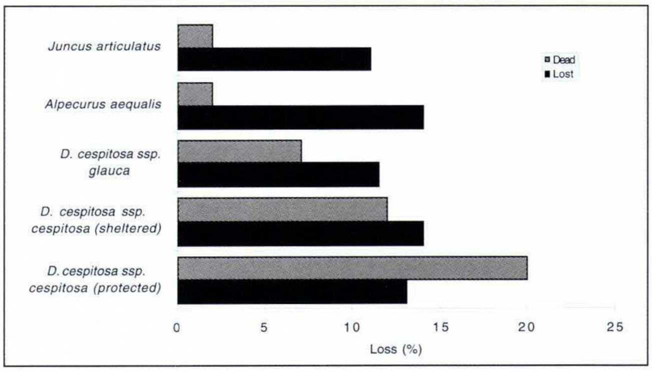



*Fig. 6. Total loss throughout the test period for some of the species planted at Meltingen. Mortality is calculated on an annual basis, but the losses due to erosion and excavation refer to the number of individual plants set out (from Rørslett et al. 1993).*

*cespitosa* ssp. *glauca, Alpecurus aequalis, Juncus articulatus* and *Elocharis acicularis.*

Roughly 10% of all the test plants were lost soon after planting. In addition, there was a certain continuous loss of plants, particularly in the shore zone at a level comparable to the autumn filling level. The loss was mainly due to erosion and sedimentation.

Fertilisation led to improved survival, stronger plants and more seed production. Even when the plants were covered by gravel, viable individuals managed to break through the cover and grow if they had been fertilised. One interesting observation was that fertilisation and the addition of organic matter had different short-term and long-term effects. The addition of organic matter led to the development of strong root systems, increasing the survival rate during the first critical phase after planting, but fertilisation was the only measure that had a proven positive effect on the survival rate after three growing seasons.

*Deschampsia cespitosa* ssp. *cespitosa* was planted in an open area and a sheltered area. *Deschampsia cespitosa* ssp. *glauca* was planted in an open area. The results indicated that the latter subspecies was far better adapted to life along the shoreline. The mortality rate was even lower than for this subspecies planted in the sheltered area (Fig. 6). Little is known about this grass, other than that it grows along the larger rivers in eastern Norway and in the central and northern parts of Sweden. Of the other species, *Alpecurus aequalis* and *Juncus articulatus* had the lowest mortality rates. That was not surprising since the two species occur naturally on shore zones that flood occasionally.

Experiments have shown that the re-establishment of vegetation on a large scale in a hydropower reservoir depends on certain conditions:

- There must be finely-grained substrate in the shore zone, preferably with some organic content. Erosion-prevention measures are necessary if vegetation is to gain a foothold.
- There must be access to seeds, either from a permanent seed bank nearby or from areas not as severely affected by regulation.
- The plants must be given time to develop an extensive root system and to grow strong enough to tolerate harsher conditions. Dry years are needed if amphibious vegetation is to have any chance of surviving in a reservoir in the long term.
- Fertilisation is highly recommended for the promotion of growth on dried up shore zones. Fertilisation will also advance the growth of grass, which will spread roots and thus help stabilise the shore areas in the event of flooding.

Regardless of which measures are employed, reservoirs will inevitably feature imbalanced, changing vegetation. Accordingly, the shore zones will never have an entirely natural appearance, but they can be greener than what is often the case today.

## 5.2 Retaining dams within reservoirs

The annual variation in water levels in regulated lakes means that the finely-grained substrate in the shore zone is washed away, eventually leaving the shore zone covered with stones and coarse gravel. This will lead to a reduction in aquatic vegetation, benthic fauna and aquatic insects in the shore zone, meaning that fewer food organisms will be available to birds and fish.

In some cases, vast tracts of land are submerged, affecting many important animal habitats, particularly bird biotopes. For example, when the valley, Innerdalen, at the upper end of the Orkla watercourse in central Norway, began to be used as a reservoir in 1982, 6.5 km$^2$ of wilderness were submerged. Prior to development, the area was a flat valley that featured an extremely meandering river. The valley was known for its lush flora and fauna.

In an attempt to improve conditions for fish and birds, a weir dam was constructed seven years after the reservoir was initially filled. The weir cut off and stabilised the water level in about 0.4 km$^2$ of the productive south-eastern part of the reservoir (Reitan & Sandvik 1996). The weir prevents the water level from dropping along with the water level in the main basin.

*Completed retaining weir in the Innerdal Reservoir, June 1992 (photo: Jan Ivar Koksvik).*

The weir basin has a maximum depth of 7 m, but the average depth is only 1.3 m. The weir was equipped with a bypass channel built at an angle that allows fish to move between the main basin and the weir basin regardless of water level.

## *5.2.1 Effects on fish*

Since the area was dammed in 1982, scientists have monitored the development of the brown trout stock in the Innerdal Reservoir and compared it with the weir basin.

Prior to regulation, the fish in this river grew just less that 5 cm per year for the first two years, then 5 to 6 cm in each of the next two years (Fig. 7). This is considered average to good growth. When the reservoir was being filled in 1982, the fish experienced exceptionally strong growth, were very fat and had a high condition factor. Two- to four-year-olds grew an average of 9 to 11 cm that year. This extraordinary growth was ascribable to access to additional food, mainly earthworms from the area that was submerged (damming effect) (Fig. 8). Although growth was

*Fig. 7. Average growth in centimetres for young-of-the-year (rhomboids), 2-year-olds (open circles) and 4-year-olds (solid circles) of brown trout in the Innerdal Reservoir in different years (from Koksvik 1992).*

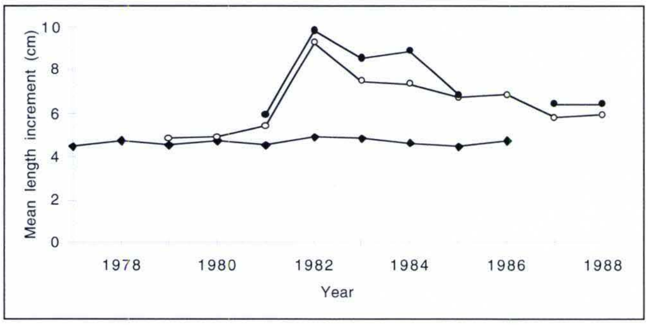
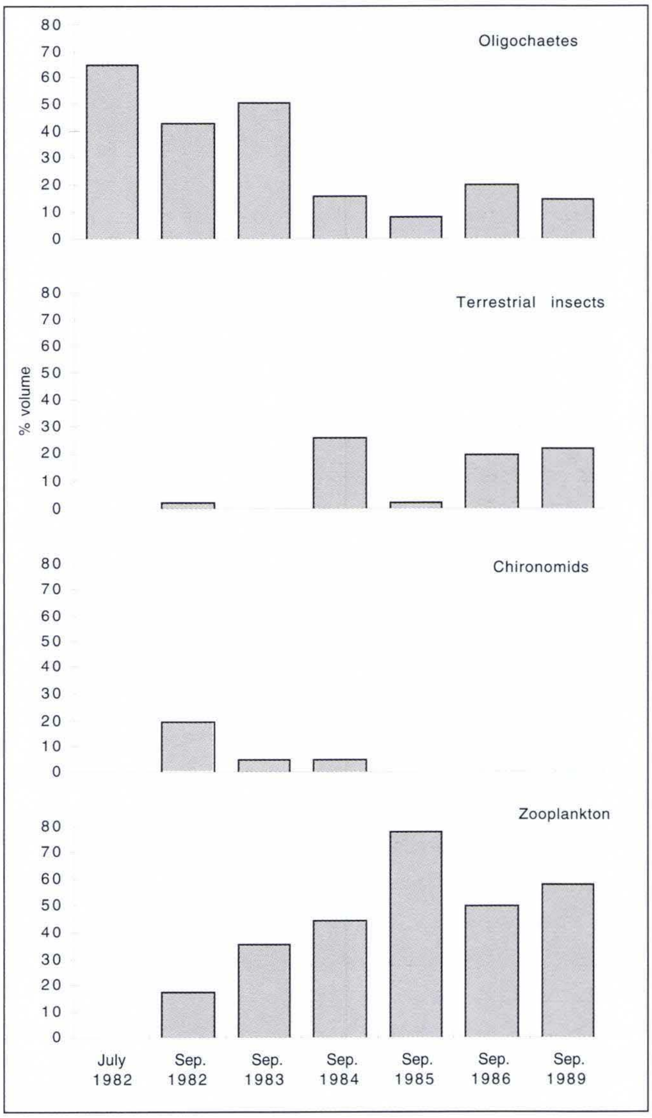



*Fig. 8. Average proportions of the main food organisms found in brown trout stomachs from 1982 to 1989, by volume (from Koksvik 1992).*



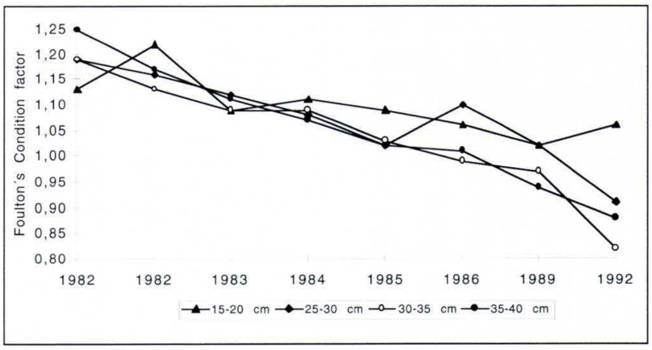



*Fig. 9. Condition factor for brown trout of various lengths in the Innerdal Reservoir, 1982 - 1992 (from Koksvik 1992).*

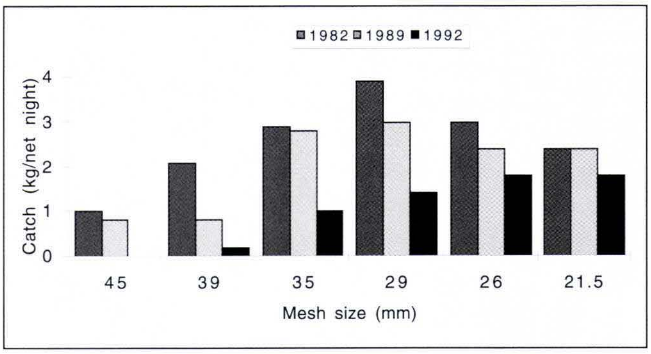



*Fig. 10. Brown trout catch (kg per net night) in nets of different mesh sizes from September 1982 - 1992 (from Koksvik 1992).*

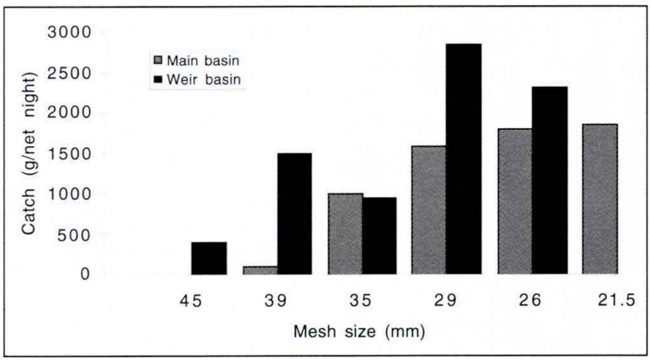



*Fig. 11. Brown trout catch (g per net night) in nets of different mesh sizes in the main basin and the weir basin in Innerdalen, September 1992 (from Koksvik 1992).*

reduced somewhat subsequent to 1983, it must be described as having been good up to 1985. Growth was still above average in 1991.

At the same time as growth slowed down in the late 1980s, scientists registered a gradual decline in the condition factor (Fig. 9). The decline in growth and condition was attributable to less access to food organisms. Plankton, especially species of water fleas, became the dominant food organism. However, earthworms were still among the three most important food organisms in terms of volume.

Throughout the period up to 1989, fishing was good regardless of net mesh size (Fig. 10). The average yield for 26-35 mm nets varied from 1.9 to 3.3 kg per net night. Surveys from a number of other Norwegian lakes show that catches in excess of 2 kg per net night are rare, being registered almost exclusively in hydropower reservoirs subject to a strong damming effect. The 1992 yield was only half as much as the average for the first five years after regulation.

In 1992, the yield per net night was greater in the weir basin than in the hydropower reservoir itself. In the weir basin, there were good catches with coarse-meshed nets (39-45 mm) (Fig. 11). The same year, the average catch in 26 to 35 mm nets was 1.5 kg per net night in the reservoir, compared with 2 kg in the weir basin. The recruitment of small fish (21.5 mm nets) still appeared to be very good at both sites.

Measurements of the condition factor in 1992 showed that fish over 25 cm in length had slightly below average condition. With the exception of fish less than 20 cm in length, in 1992 there was no significant statistical difference between condition for trout caught in the main basin and the weir basin (Fig. 9). Thus the results from Innerdal indicated that the damming effect was significant, but of short duration.

### 5.2.2 Effects on bird life

Prior to development, Innerdal was home to a wide variety of bird life. The construction of the Innerdal Reservoir led to the submersion of many rich bird habitats, leading in turn to a clear decline in the total populations of most of the bird species in the area. One hard-hit species was the rare and vulnerable great snipe. Although the species was well represented in 1976, it has seldom been seen in the Innerdal Valley since the reservoir was built. The birds that nested above the new shoreline also saw a deterioration in conditions after construction.

The new drawdown zone was worthless as a nesting place, not least because the nests were submerged when the reservoir filled during the nesting season. Nonetheless, the drawdown zone was a good place to look for food, especially while it was wet and insect emergence was taking place. The surface of the water in the reservoir was used by only a few species and individual water birds. The only time ducks were observed in the area was during the spring snow melt.

The weir basin proved favourable for many birds.

During the year after construction there was a very pronounced increase in the number of species that used this particular part of the reservoir. Black-throated divers, grey herons, long-tailed ducks, velvet scoters, red-breasted mergansers, curlews, spotted redshanks and wood sandpipers were registered as new, while mallards, red-necked phalaropes, common gulls and terns, especially Arctic terns, increased in number. In contrast, the population of common sandpipers decreased somewhat, probably because the shoreline was shorter.

There were clearly more species of ducks in the weir dam than in comparable areas prior to construction of the weir (Fig. 12). The total number of ducks also increased significantly (Fig. 13). Tufted ducks had the largest increase in numbers, and more nesting pairs were registered in the area. There was also a change in the composition of duck species, shifting from a dominance by dabbling ducks to diving ducks (Fig. 14). Fishing ducks also increased slightly. Prior to weir construction, wigeons and teal dominated, while tufted ducks, long-tailed ducks, goldeneyes and red-breasted mergansers increased significantly after regulation. The reservoir itself and the drawdown zone are still only used by a few species and a low number of individuals.

Subsequent to weir construction, water birds have increased while shore birds have fluctuated. Stabilisation of the water level has had a positive effect on vegetation and benthic fauna, at the same time as it has reduced the danger of nesting grounds being flooded during the nesting season. However, developments since 1992 indicate a decrease in the number of ducks that use the weir dam. The reasons for this are unclear, but the trend shows just how important biotope management is in such areas if the favourable effects are to be sustained.

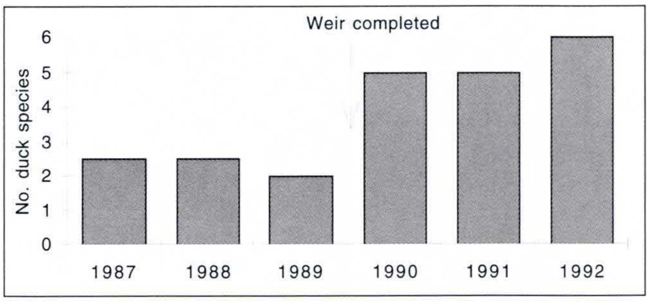



*Fig. 12. Number of species of ducks observed daily in the weir area at Innerdalen from 1987 to 1992. The figures indicate the median number of observations. The weir was built in the autumn of 1989 (from Reitan & Kålås 1993).*

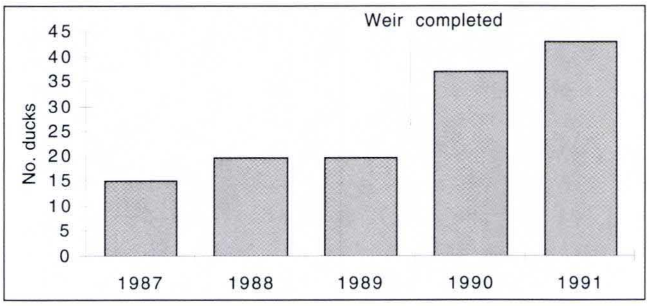



*Fig. 13. The largest number of individual adult ducks observed on a single day in the weir area at Innerdalen during each year from 1987 to 1992 (from Reitan 1993).*

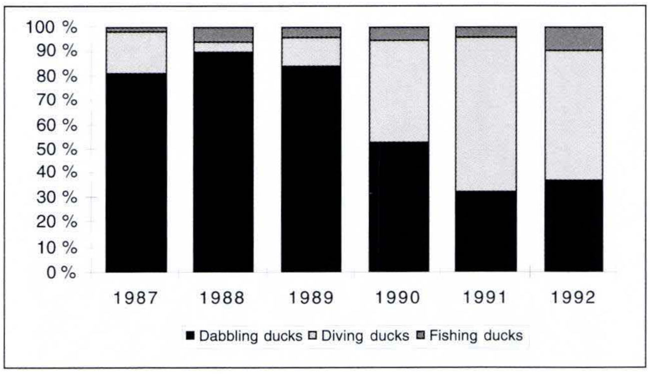



*Fig. 14. Composition of the duck community in the weir area in Innerdal from 1987 to 1992, expressed as a percentage of the total number of ducks observed each year (from Reitan & Kålås 1993).*

## 5.1 Habitat adjustment measures in reservoir tributaries

One of the main problems facing brown trout in hydropower reservoirs is the deterioration of former spawning grounds in inlet streams. To make matters worse, spawning grounds in outlet streams are almost never available. The answer has generally been to compensate for the loss of spawning and rearing grounds by stocking fish. Accordingly, Norwegian power companies have been required to stock about 2.8 million juvenile brown trout and 1.6 million juvenile Atlantic salmon each year. Yet stocking also has its disadvantages: a high mortality rate, the risk of spreading diseases, parasites and undesirable fish species.

Recent research has documented genetic differences in stocks of species such as Atlantic salmon, brown trout and Arctic charr. Stocking fish with a different genetic history from that of the existing population will usually lead to a change in the genetic make-up of

*The weir basin in the Innerdal Reservoir, June 1992 (photo: Jan Ivar Koksvik).*

the indigenous population. Experience suggests that such genetic changes are not of a positive nature.

As a supplement to stocking, the authorities are now focusing more on biotope adjustment measures to improve natural recruitment. One measure is to improve natural spawning conditions or to create new spawning grounds, and to ensure the availability of suitable rearing areas. In the Tesse Reservoir in the county of Oppland, for instance, deep pools and other hiding places have been incorporated into an inlet stream. The work began in 1986, when fish traps were used to catch spawners as they were migrating upstream. The goal of the project was to determine recruitment potential. Techniques such as using fish traps to capture parent fish and electrofishing indicated little recruitment potential and a low density of young fish prior to enhancement measures.

To improve recruitment, a new culvert was put in under a road to make it easy for the ascending fish to pass. Waterflow was ensured during the winter and in dry periods by piping in water from a neighbouring brook. Further, the upper end of the stream was lowered to prevent ice from choking the channel in the winter, cutting off the water flow downstream. Rocks were placed in the stream to give young fish more cover, and boulders were placed along the banks to establish hiding places there. The cover along the river-banks are very important to young fish and spawners alike. The ground along the banks was in the process of eroding, and the rocks served to shore up the banks, preventing further erosion. The measures have had a positive effect.

In recent years, a co-operative project known as "Improving the utilization of fisheries resources in regulated watercourses in Oppland County" has implemented some similar biotope adjustment measures, as well as providing financial support to fishing and landowners' associations for their implementation. The measures range from simple clean-up operations to the removal of barriers to fish migration. At Geitrygga, obstacles were blasted away in a stream that runs into the Tisleia Reservoir to open it to fish migration and facilitate access to new spawning grounds. The streambed was also modified to promote water flow during periods in which there is little natural water flow. Simple weirs were constructed to make migration easier for spawners. Similar measures have been carried out in streams that run into the reservoir, Vangsmjøsa, in the stream, Nordre Rjupa a tributary of Vinsteren, as well as in the Buaråne that runs into the lake, Flyvatn. It is expected that these measures will enhance natural recruitment.

The measures are relatively reasonably priced and can be carried out by local contractors under professional supervision. Total costs have come to roughly NOK 15 000 - 30 000 per measure, in addition to some voluntary efforts.

# 6 Biotope adjustment measures in rivers

*The small riffle to the lower left of the picture illustrates how small rocks have been used in the river, Søya (photo: Jon Arne Eie).*

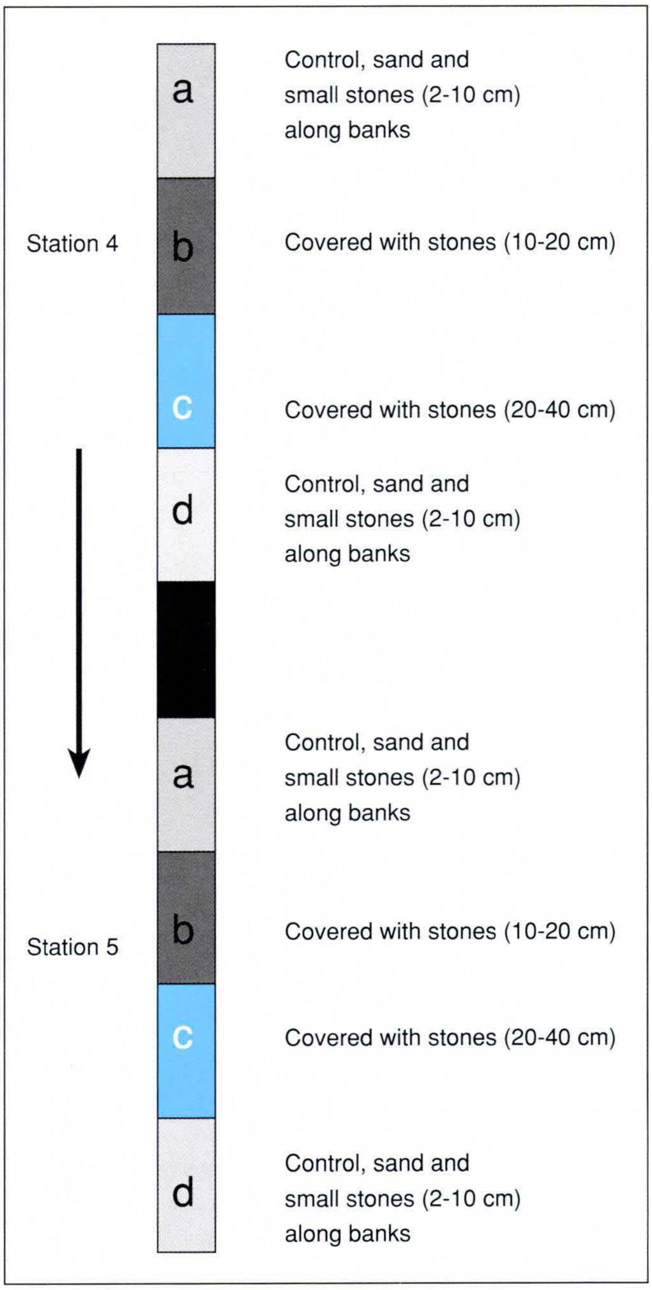
## 6.1 The deployment of rocks

People build dykes, straighten rivers and reinforce riverbanks in an effort to win new farmland and prevent erosion. The channelized stretches of river are often quite monotonous, having no sharp bends where sediment builds up in the inside curves or is washed away from the outside curves. Moreover, much of the riparian vegetation is removed, and re-growth takes time. Riverbank areas are frequently rezoned for agriculture, transportation or industrial purposes. Such conditions translate into limited access to hiding places, spawning substrate and food for fish.

Comprehensive biotope adjustment experiments have been performed under the auspices of the programme, including the deployment of rocks to alter habitats in the the rivers, Gudbrandsdalslågen,

*Deployment of rock piles at Lesjaleirene in the winter of 1990 (photo: Jon Arne Eie).*

*Fig. 15. Schematic diagram of the control areas and the areas in which various types of substrate were added in the Søya.*




Søya, Gaula and Teigdalselva. Other measures were also carried out in the rivers, Moelva and Brumunda. The goal was to improve living conditions for the fish that live in rivers that have been altered radically through regulation, reinforcement, channelization, etc.

Based on general knowledge of the brown trout's habitat preferences, conditions in these rivers were not particularly favourable for trout immediately after channelization. This was true of all stages in the trout's life cycle. The finely grained, sandy substrate and the monotonous profile of the stream bed in the rivers, Gudbrandsdalslågen, Søya and Teigdalselva, offered little cover. Additionally, an unstable substrate and finely grained sand lead to poor production of food organisms and few opportunities to spawn.

### *6.1.1 Placement patterns*

The rocks have been placed in the water in different patterns. Fairly coarse rock, ≥15 cm in diameter, was placed in the Gudbrandsdalslågen at the Lesjaleirene (Brittain et al. 1993). The rock was placed in piles measuring about 8 x 5m, with 11 rock piles per station. The rock piles were deployed in regular patterns, that is, in three rows across the width of the river, taking no account whatsoever of flow. In connection with low flow in the autumn and winter, several of the piles were left high and dry, making them inaccessible to the fish. However, they are accessible at high flow in the spring and summer, when they support a certain level of benthic production.

A somewhat different design was used for rock deployment in the Søya River (Hvidsten & Johnsen 1992). Here, two flat weirs (fields of rocky substrate covering the whole riverbed) were built, each of which consists of tailings (blast rock) from 10 to 20 cm in diameter, grading into tailings from 20 to 40 cm in diameter. Each of the fields was 30 m long and spanned the full width of the river (Fig. 15). In Teigdalelva, rocks were lined up across the river in rows in an effort to create more hiding places for fish.

### *6.1.2 Vegetation takes root*

A significant amount of new aquatic vegetation took root within six months after deployment of the rock piles in the Gudbrandsdalslågen. Vegetation was especially evident on rock piles in deeper waters, where some of the plant drift had become stuck under and between the rocks. Although the vegetation was dominated by river mosses, *Ranunculus peltatus, Callitriche hamulata* and *Chara* spp. were also observed. In contrast to the vegetation on the silty substrate close to shore, vegetation on the stable rock substrate tolerated a stronger flow and a substantial bed load.

### *6.1.3 Effects on the benthos*

The rock piles had a positive effect on the benthos in both the Gudbrandsdalslågen and the Søya, and a benthic community was established quickly. In the Gudbrandsdalslågen, positive changes in the benthos were registered just six months after the rock piles were deployed. Density and biodiversity were considerably greater in the rock piles than on the sandy substrate surrounding them. The rock piles further out in the river had a lower benthic density than the piles along the riverbanks (Fig. 16), which in turn had a lower density than the boulder-reinforced riverbanks. Samples taken a year later indicated that biodiversity was still increasing in the rock piles.

The fact that benthic animals have a strong propensity for colonising new areas quickly was also proven in a newly excavated side channel to the Søya River. Just a year after the project was completed, the biomass and diversity of benthic species in the upper part of the channelized zone were comparable to conditions in an untouched river.

There were appreciable differences in the incidence of benthic fauna on the various types of substrates in the channelized zone in the Søya River following the deployment of the rock piles and natural rearrangement. The sandy substrate at the lower end of the channelized zone had the lowest benthic biomass. Then followed the areas with small round river stones (2 - 10 cm). The fields that featured larger rocks (10 - 40 cm tailings) supported the largest biomass of benthic invertebrates (Fig. 17).

Over a four-year period, scientists registered a total of five species of mayfly, eight species of stonefly and three species of caddisfly in the rock deployment fields in the Søya. This was the roughly the same diversity as on the riverbed covered naturally with small stones (Fig. 18). During the same period, a small number of specimens of only two species of mayfly and four species of stonefly were found on the sandy bottom in the lowest part of the channelized zone.

### *6.1.4 Effects on fish*

The deployment of rock piles had a positive effect on fish. Already during the first full summer, fish density around the rock piles in the Gudbrandsdalslågen rocks was considerably higher than it had been in the years

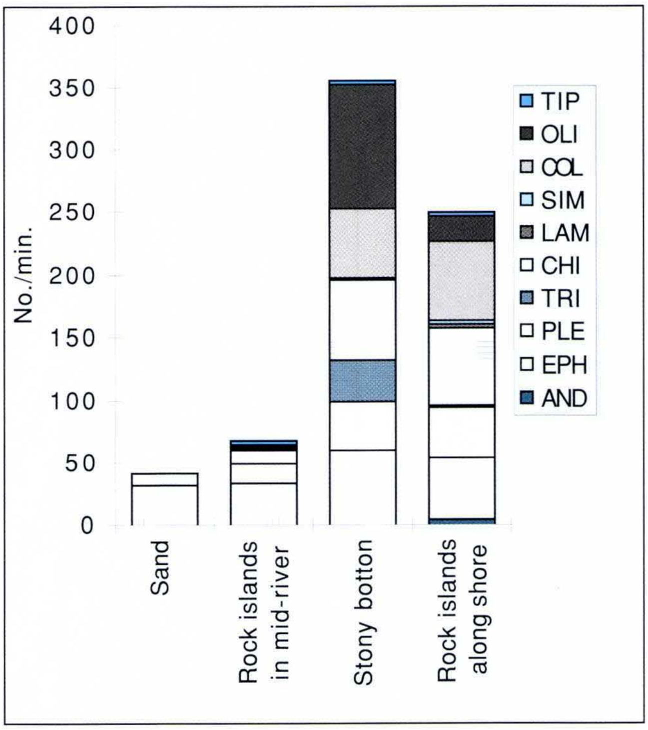



*Fig. 16. Density of benthic species in various types of habitats at Lesja in August 1990 (from Brittain et al. 1993). TIP = craneflies, OLI = oligochaetes, COL = water beetles, SIM = blackflies, LAM = mussels, CHI =chironomids, TRI = caddisflies, PLE = stoneflies, EPH = mayflies, AND = others.*

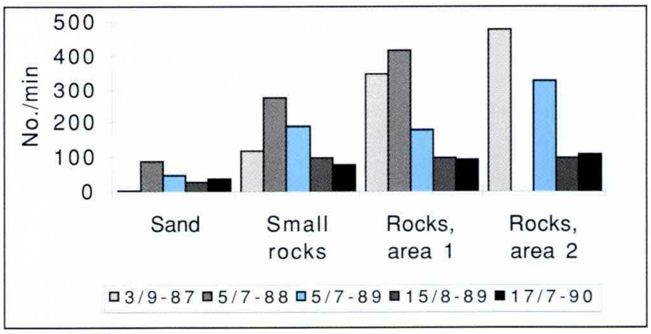



*Fig. 17. Density of benthic fauna (numbers per minute kick sample) on various types of substrate in the Søya 1987-1990 (from Arnekleiv 1993).*

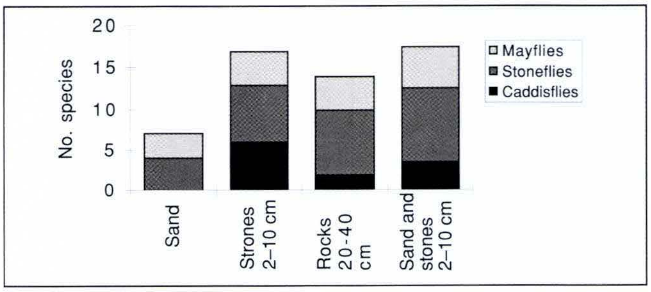



*Fig. 18. The number of species of mayflies, stoneflies and caddisflies on various substrates in the Søya from 1987 to 1990 (from Brittain et al. 1993).*

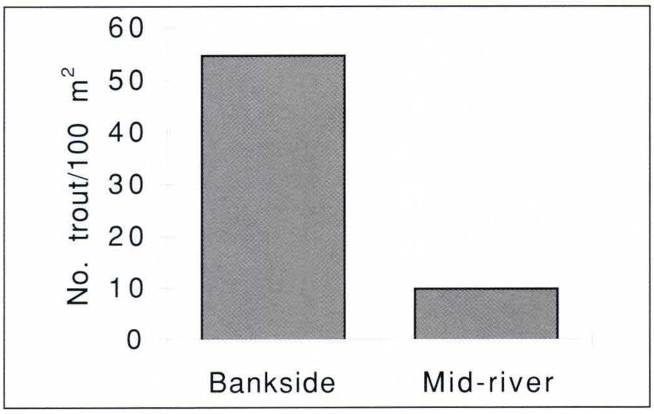



*Fig. 19. The density of brown trout, estimated by electrofishing at deployed rock piles near the banks and out in mid-river in the Gudbrandsdalslågen at Lesja, summer 1990 (from Brittain et al. 1993).*

prior to deployment. Densities were greatest around and between the rocks/boulders placed along the riverbanks and lowest around the free-standing piles of rocks (Fig. 19). This may be because the fish preferred not to move across the open sandy substrate between the piles of rocks. Since benthic density was also relatively lower among the piles of rocks out in the river than in the rocks along the riverbank, there are strong indications that the fish densities around the rock piles were optimal. Young-of-the-year were observed at several of the piles, indicating that brown trout spawn on or near them. The rock piles also channelled the currents to promote the natural excavation of pools downstream, providing invaluable winter habitats for large fish.

In the Søya River, covering the riverbed in the upper part of the channelized zone with rocks led to a considerably higher density of juvenile fish than had previously been registered in this part of the river. The density of young Atlantic salmon increased in particular. The density of young trout was the same as in areas in which rock had only been placed along the sides of the river. It therefore appears that tailings placed on the riverbed provide an excellent habitat for young salmon.

The rocky patches were also important spawning grounds for the anadromous brown trout (sea trout), and the redds were largely concentrated in these areas. Hence, it appears that an appropriate spawning substrate for sea trout can be created by covering the riverbed with rocks ranging from 2 to 5 cm in diameter.

The rocks deployed in the upper part of the Søya tended to collect sediment. To prevent this, boulders measuring up to 1 $m^3$ were placed in one of the areas. The boulders were intended to enhance the effect of the current and prevent sedimentation in the cavities.

*The rock piles deployed at Lesjaleirene at high water level (photo: John E. Brittain).*

*Habitat studies at one of the rock piles deployed at Lesjaleirene, August 1991 (photo: John E. Brittain).*

The boulders had the desired effect, as salmon density increased more there than in areas in which no boulders had been deployed. The density of juvenile trout increased as well, probably because areas with lower current velocity were established further out in the river.

Using boulders to reinforce riverbanks also had a positive effect. The reinforcement resulted in good hiding places for salmon and trout. Placing rocks on the riverbed increased the rearing areas for salmon and had somewhat the same effect for trout. The deployment of boulders (> 50 cm in diameter) appears to have made the measure more effective for a longer period of time than the deployment of smaller rocks.

Estimates of fish density in and around the rock piles placed in the river, Teigdalselva, indicated that young fish had visited all the rock piles. On average, there were 58 fish/m$^2$ around the rock piles, while no fish at all were registered in the control areas between them. Thus the rock piles provided an attractive habitat for the fish. Densities registered in such areas are comparable to densities in natural stretches of water that provide ample shelter for fish.

The fishery administration authorities have now abolished the stocking requirement that applied to the Teigdalselva, replacing it with biotope adjustment measures. Now the regulator is building a weir to ensure the rock piles always remain submerged, enhancing their beneficial effects even more.

## 6.2 Hydropower management regulations - guaranteed minimum water flow

Power plant management can have a significant influence on the production of fish in a watercourse. Rapid reductions in flow can leave fish stranded, while strong flows and rapid increases in discharge can dislodge and flush out juvenile fish, benthic invertebrates and organic matter essential for fish growth.

With support from the Biotope Adjustment Programme, an Atlantic salmon improvement project is currently in progress in the river, Suldalslågen. Experiments include reducing water flow in the spring, a measure likely to improve salmon production. A separate series of reports are being published to disseminate information from the project.

The Suldalslågen was originally an extremely good salmon river with a well-developed stock of Atlantic salmon. The river also contains sea trout. Following the Ulla-Førre hydro development, the density of young salmon decreased despite the fact that the river had a relatively large residual flow. It has been suggested that the power plant management regime is one of the causes of the low fish density.

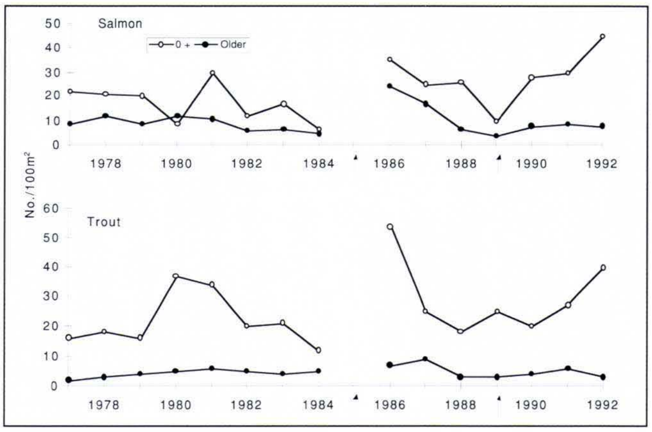



*Fig. 20. The density of Atlantic salmon and brown trout fry in the Suldalslågen, registered in September/October from 1977 to 1992. The arrows indicate the reduction in water flow to 3% hour in 1985 and a locking gate accident in 1989 (from Saltveit 1993).*

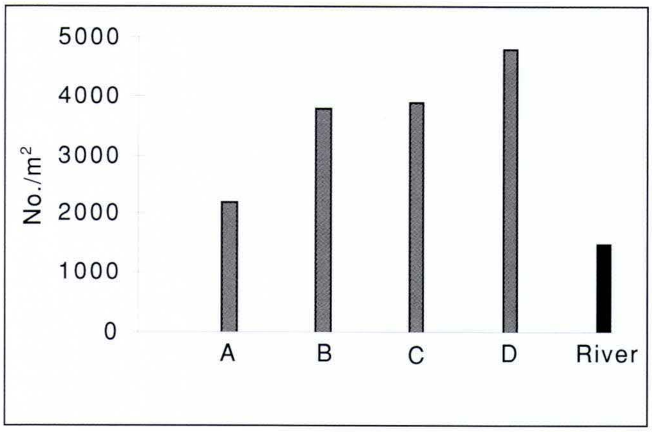



*Fig. 21. Density of food organisms in four production channels (grey columns) and in the Suldalslågen (black column) (from Kaasa 1993).*

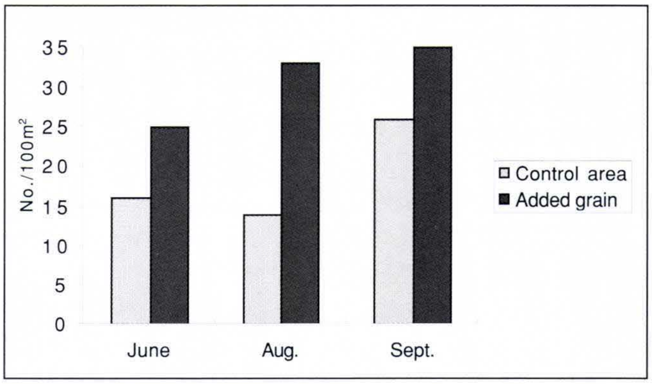



*Fig. 22. The density of Atlantic salmon fry in the Suldalslågen in 1992 in areas with and without the addition of grain (from Kaasa 1993).*

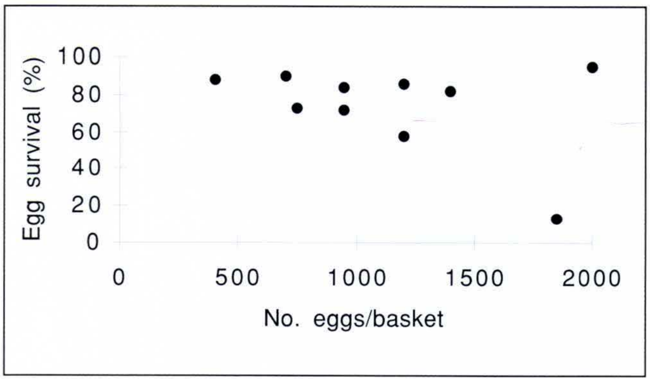



*Fig. 23. Survival of Atlantic salmon eggs in baskets with varying numbers of eggs stocked in the Ekso River (Raddum & Fjellheim 1995).*

The Suldalslågen is poor in nutrients. It is a cold river in which salmon fry grow very slowly the first summer. There is high mortality the first winter, probably because the young salmon are too small when the cold weather sets in. It was expected that more organic matter on the riverbed would increase the production of food organisms and thereby improve conditions for salmon.

It also involves striking a flow balance which neither brings too much cold water into the river nor flushes away food organisms and organic matter into the sea. A limit of 3% per hour was placed on the flow reductions, causing fish density to increase already the next year (Fig. 20). The marked decline of salmon fry in 1989 was due to an accident that resulted in an extremely rapid reduction in water flow.

Other experiments involve the addition of energy-rich organic matter (grain) to an experimental channel and to experimental areas in the river. This has increased the volume of food organisms for the fish (Fig. 21). In fact, fish density also increased considerably in one of the experimental areas (Fig. 22) (Raastad *et al.* 1993).

## 6.3 Stocking salmon eggs from an indigenous strain of salmon

Major variations in water flow can have an adverse effect on Atlantic salmon production in some rivers. In the salmon reaches of the river, Ekso, in the valley, Eksingdalen, in the county of Hordaland, for example, the flow velocity varies from 150 $m^3/s$ during floods to less than 1 $m^3/s$ when water levels are low. As a result, spawning grounds dry up during periods of low water flow, leading to a shortfall in recruitment.

In an effort to maintain the production of naturally hatched salmon smolt in the Ekso, an experiment was initiated in 1990, involving the stocking of fertilised salmon eggs from an indigenous strain (Raddum & Fjellheim 1995). By placing the eggs in appropriate locations so that they were were protected from frost and desication, scientists hoped to reduce egg and fry mortality.

The first year 1010 fertilised salmon eggs were placed in hatching boxes. The mortality rate was relatively high, although no higher than for naturally spawned eggs. In 1991 and 1992, the eggs were set out in baskets of gravel, which were buried in the riverbed. In 1991, the number of eggs in each basket varied from 500 to 2000. It turned out that the density of eggs in the baskets had no effect on hatching success (Fig. 23). In 1992, a total of 17 000 fertilised salmon eggs were set out in 14 baskets. The survival rate in the baskets averaged 80%, varying from 73 to 97%. This was the same rate as scientists observed in 1991. Some of the alevins stayed down in the gravel until July, although most of them were registered as fry above the gravel. Immediately following the yolk sac stage, the alevins mainly stayed in the hatching area. Eventually, there was a certain downstream movement, but very little migration against the current. The young salmon were not distributed along the entire study area (Fig. 24) until the second year.

Twenty per cent of the salmon fry survived the first growing season, and the survival rate for the first winter was estimated at 13%. This is high compared to natural conditions. The growth rate was extremely

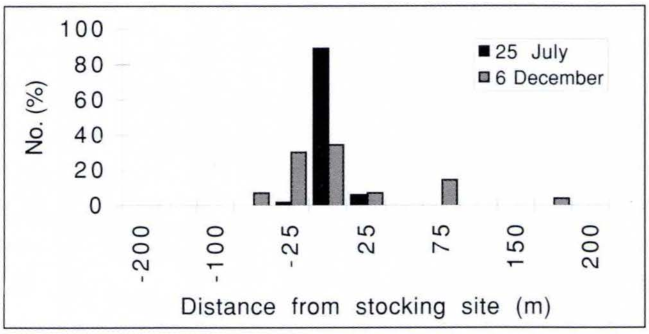



*Fig. 24. Distribution of Atlantic salmon fry from the stocking site in the Eksingedal watercourse. Negative values are upstream, positive values downstream (Raddum & Fjellheim 1995).*

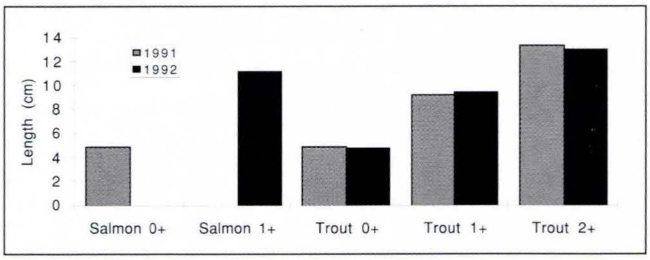
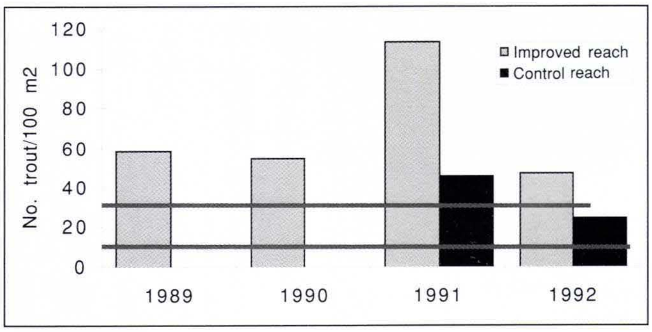



*Fig. 25. The length of Atlantic salmon and brown trout juveniles in the Eksingedal watercourse (from Raddum 1993).*

*Rearing channel for salmon fry in the river, Suldalslågen, December 1990. The rearing channel was made by diverting water into a dried up old riverbed (photo: Jon Arne Eie).*

*Experimental channel in the Suldalslågen, September 1991. Grain was added to the left side, while the right side was a control zone (photo: Jon Arne Eie).*

***Fig. 26.*** *A comparison of the density of brown trout in an improved area and the control area. Minimum and maximum values for densities prior to improvements are indicated by the horizontal black lines (from Linløkken & Solvang 1994).*




good. In November 1991, both salmon and trout fry measured an average of 5 cm and, at the end of October 1992, salmon parr (1+) measured an average of some 11 cm, having grown more than 6 cm. The largest individuals were close to 13 cm long, so it was assumed that most of the population would smoltify as two year olds (2+) (Fig. 25). Trout parr measured an average of 9 cm. In other words, trout grew a little more slowly than salmon. In 1991, the density was calculated to be 0.18 fish/m$^2$ for salmon and 0.25 fish/m$^2$ for trout in the area under investigation.

## 6.4 Pools and current concentrators

Pools serve several important functions for fish. They are important places for the fish to be in the summer when there is little water flow, and they are refuges against freezing in the winter. Access to pools is also decisive to the size of the fish that can live in a watercourse.

Measures related to log floating and channelization have reduced the number of natural pools in many rivers. Pools often form downstream from boulders due to natural excavation from the currents flowing around them, but to facilitate log floating, riverbeds were frequently cleared of boulders.

Letjenna, 12 km north of Elverum in the county of Hedmark, was a typical logging tributary river where trout and grayling migrated up from the main river, the Glomma, to spawn in a 2 km stretch of river. Biotope adjustment measures have been implemented along a 200 m reach. Pools were excavated and current concentrators built upstream to increase current velocity and enhance the natural excavating effect. A total of four pools were dug and four rock groynes were built in the river, and the riverbed was narrowed in the stretches between the pools in order to increase current velocity to keep the pools clear. The pools were up to 1.5 m deep, but have partially filled in over time. Boulders were deployed between two pools, and smaller pools were excavated further downstream. An area above the adjusted reach was used as a control.

The measures led to more than a tripling of the trout density in the adjusted reach compared with the density in the same stretch prior to improvements (Fig. 26). Before the measures were implemented, trout density varied from 10.5 to 27.5 fish/100 m$^2$, with an average of 18.3/100 m$^2$. Subsequent to the improvements, the average was 68.8/100 m$^2$ (1989-

*Letjenna in June 1993 in the control area above the site where the biotope adjustment measures were carried out shows an evenly sloping stream with little variation (photo: Jon Arne Eie).*

*Biotope adjustment measures in Letjenna in May 1993. In the middle of the picture, there is a pool that has been excavated and current concentrators above and below it create riffles (photo: Jon Arne Eie).*

1982). In the control stretch, which remained unchanged throughout the period, the density was 36.1/100 m² from 1986 to 1992, slightly more than half of what was found in the adjusted stretch. The decline from 1991 to 1992 in the adjusted stretch was probably due to a low level of summer water flow.

The habitat adjustment measures also led to changes in distribution of trout length. Prior to the adjustments, small trout (<10 cm) were most common in the lower stretch, and bigger trout (>15 cm) in the control stretch. Following the adjustment measures, the distribution of length was relatively similar in the large pools and the control stretch, while there were few trout longer than 15 cm in the stretch with the small pools.

Fish production also increased following the formation of new pools in the River Toåa in the county of Møre og Romsdal. After a Syvde weir was built (see section 6.5) in an ordinary stretch of riffles, a large, deep pool developed downstream from the weir. The pool covered an area of about 600 m² and was 4 metres deep when surveyed for the first time in 1987, but it has continued expanding downstream, and covered an area of about 1 000 m² in 1994. Compared with three riffles located close by, fish density was more than four times higher in the pool than in the riffles (145 and 35 fish/m², respectively). The high proportion of juvenile Atlantic salmon in the pool (56.8%) indicates that the pools are suitable rearing areas for salmon as well, as brown trout.

In different parts of eastern Norway in recent years, a number of restoration measures have been implemented in what used to be used as logging rivers, but the projects have not always been followed up to determine their effects. The measures were largely initiated by local fishermen's associations with the assistance of the fisheries management authorities and some financial and technical assistance from NVE. One of the largest river restoration projects of this kind was carried out in the the river, Flisa, in the county of Hedmark. Through close cooperation with the relevant landowners, the Åsnes Hunting and Fishing Association, NVE, the municipality of Åsnes and the Water Environment Project, restoration work has been planned and/or carried out over a 55-km stretch of river. The efforts involve excavating deep areas to collect water, excavating pools and holes, installing current concentrators, groups of boulders, embankments, and river reinforcement measures, as well as reducing obstacles to migration. The cost of such measures varies significantly, depending on conditions in the river. NVE has paid an average of NOK 10 000 to 20 000 per kilometre of river for the excavation work.

*Biotope adjustment measures in the Letjenna in April 1989. Rocks have been deployed to form a riffle. A deep pool has formed below the riffle (photo: Jon Arne Eie).*

Biotope adjustment measures have met with success in small and medium-size watercourses. In stretches in which a river had previously been cleared for log floating, the measures have led to a tripling of the brown trout population. These are lasting measures which are a reasonably good means of increasing fish production in the long term.

## 6.5 Weirs in watercourses with reduced water flow

Weirs are mainly built to improve biological and aesthetic conditions in a river following development. However, weir building often has other positive effects, including the collection of water for agriculture and livestock, the establishment of recreational areas, and the preservation of the river as a natural barrier for livestock. Obviously, weir building can improve the appearance of a regulated river, but it has never been equally clear how such measures affect the plant and animal life in a watercourse.

The term 'weir' refers to relatively low dams that have no regulatory devices and are built across riverbeds. The goal of weir construction is to maintain a certain water level even when there is little water flow. Today, weirs are one of many environmental improvement measures implemented in connection with hydropower development. A total of more than

*Concrete weir with a fish ladder in the the river, Sandvikselva, April 1996 (photo: Jan Henning L'Abée -Lund).*

*Biotope adjustment measures in the river, Brumunda, August 1989. The substrate was made more variable (photo: Jon Arne Eie).*

*Biotope measures in a river in river, Umeälven, Sweden, with reduced flow. Pools have been made and rocks deployed to create riffles and cover for fish. June 1992 (Photo: Jon Arne Eie).*

one thousand weirs have been built in Norwegian watercourses.

Weirs can be made of different materials and they may be shaped differently from the examples shown in the pictures. Some are made of concrete, some of wood and others of moraine materials (gravels, stones and rocks). The last type is the most common. As regards form, a distinction is made between weirs with a straight crest (a full-width weir) and weirs in which the crest is v-shaped, with wings diagonal to the centre section (a Syvde weir). Full-width weirs have no effect on current velocity, and water flows all across the crest. The Syvde weir, on the other hand, concentrates water towards the middle and has a current enhancing effect. This type of weir is also used in connection with reinforcement work in unregulated rivers. Syvde weirs tend to suppress energy and to reduce the pressure on the rocks deployed along the shore.

To clarify how weir construction affects the biota of lotic ecosystems, a special weir project was carried out from 1975-1985 under the auspices of NVE. Although most of the project's resources were allocated to the Eksingedal watercourse, investigations were also conducted in other streams and rivers. The results were presented in "Life in Regulated Streams - the Weir Project" (Mellquist 1985). The long-term effects of the weirs in the rivers, Ekso, Toåa, Nea and Skjoma, have been followed up under the Biotope Adjustment Programme.

### *6.5.1. The physical environment in the water basin*

Compared with unregulated rivers, streams in which weirs are constructed experience a sharp reduction in water flow. Weir construction can bring the submerged area back up to the size it was prior to regulation, but water turnover will be reduced. The water will stand longer, affecting both physical and biological conditions.

One important result noted by the Weir Project is that most nutrients come into the weir basin as drift in the form of allochthonous input. Much of this matter is utilized when benthic invertebrates eat the leaves and the microorganisms that live on the leaves. One very important function of weir basins is to delay the transport of organic matter downstream. In this

Summer in a weir basin (photo: Knut Ove Hillestad).

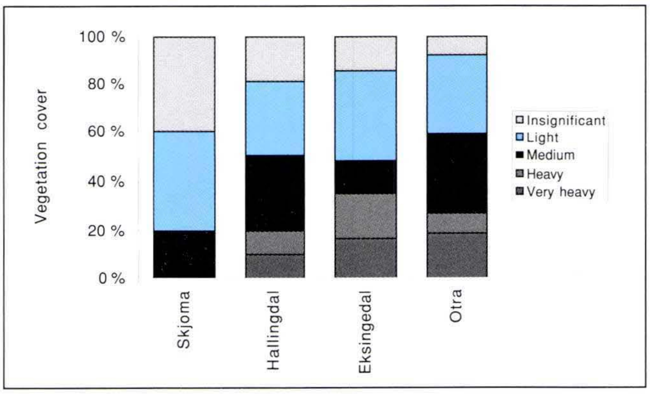
respect, the basins act like natural pools. Without pools or weir basins, most nutrients would be flushed out before they could be exploited.

## 6.5.2 Vegetation

Few botanical investigations have been conducted in weir basins, so there is limited material to draw upon. Nonetheless, in general, it must be said that when a river is more or less dried up, weir building has a positive effect on the vegetation in and around the river. Thorough botanical investigations have been made in watercourses with weirs in four regions: Hallingdalselva (South-Eastern Norway), Otra (Southern Norway), Ekso (Western Norway) and Skjoma (Northern Norway).

Rivers with a low guaranteed minimum water flow, where the weir basins are long and shallow and feature finely grained sediments, will favour the type of vegetation associated with slow-flowing waters (Rørslett & Johansen 1996). In some watercourses, this has led to increased algal growth, an abundance of moss and the growth of a few higher plants. Enough algal growth to be described as overgrowth has only been registered in a few of the basins (Fig. 27). Although it can be dense and robust, most of the new vegetation is limited to small areas of the weir basin.

*Fig. 27. Degree of vegetation cover (percentage distribution) in weir basins in regulated watercourses (from Rørslett et al. 1990, Brandrud et al. 1992).*



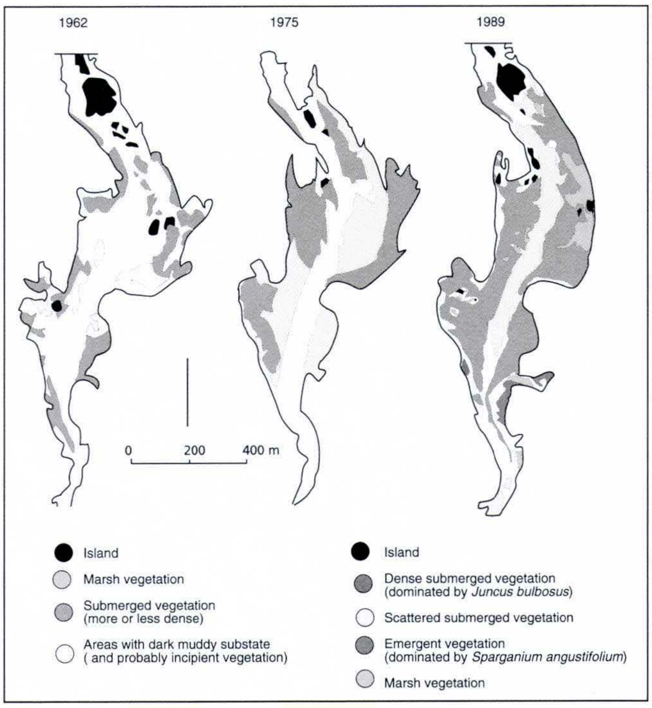



***Fig. 28.*** *Vegetation map for the Harstad weir basin in the river, Otra, near Valle (1962-1989) (from Rørslett et al. 1990).*

*The Nea downstream from the Heggsetfoss power plant before the construction of a weir (photo: Knut Ove Hillestad).*

Overgrowth is a phenomenon caused by different plants in different watercourses. In the basins in the watercourse, Hallingdalselva, overgrowth is dominated by *Myriophyllum alternifolium,* while *Juncus supinus* dominates in the Otra and, to some extent, in Eksingedalselva. *Juncus supinus, Sparganium angustifolium, Callitriche hamulata, Myriophyllum alternifolium,* together with the aquatic mosses such as *Fontinalis dalecarlica* and *Sphagnum auriculatum* are considered problem plants. *Juncus supinus* seems to be the species that profits most by the reduction in "winter stress." In extreme cases this plant can grow more than 3-metres long, highly compact groups of shoots over a period of 5-10 years. It is assumed that the increased growth of *Juncus supinus* and some of the other plants is also related to increased acidification and other conditions not related to weir construction.

The shallow weir basins offer particularly favourable living conditions for aquatic plants. The light regime promotes abundant plant growth. Provided the riverbed substrate is finely grained and does not contain too much organic matter, and the water temperature is favourable, aquatic plants have relatively good access to nutrients. Fig. 28 shows the development of aquatic vegetation in a weir basin in the Otra which suffers from considerable overgrowth.

Lower summer flows and higher winter flows, as is the case in many regulated watercourses that have weirs, results in stable water levels. A stable water level entails less stress on the environment and on the plants, thereby increasing submerged vegetation. On the other hand, if both winter and summer flow are reduced, there can be a marked decline in the occurrence of aquatic plants and mosses due to desication.

The growth of moss and other plants in rivers is beneficial for biodiversity and production. Increased plant growth may also have a positive effect on fish, as the vegetation provides more food organisms and more shelter. However, in the event of massive overgrowth, biodiversity will decrease at the same time as the vegetation creates problems for swimming, fishing and other activities. Overgrowth can also cause operational problems for power plants further downstream. In the Otra, *Juncus supinus* and *Sparganium angustifolium* were removed by reducing the water flow in the river for a few days during a period of cold winter weather. The plants simply froze. After freezing, water was discharged into the river again and the ice carried the plants away. This was an effective way of removing undesirable vegetation from the weir basin. However, such a measure can lead to problems further downstream when the material washes up on beaches, gets stuck in nets, etc.

*A Syvde weir in the river, Lærdalselva, October 1986 (photo: Jon Arne Eie).*

*The Nea downstream from the Heggsetfoss power plant after the construction of a weir (photo: Knut Ove Hillestad).*

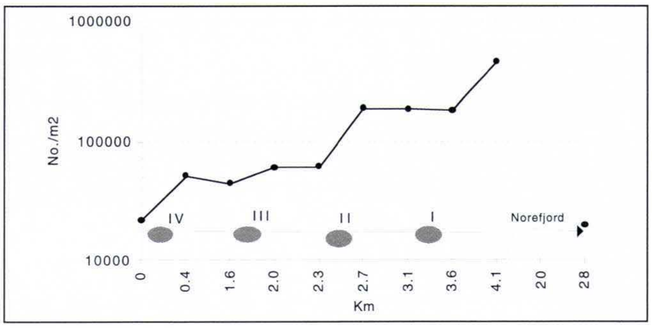



*Fig. 29. The distribution of benthic species (chironomids, blackflies, mayflies and other benthic invertebrates) in the Numedalslågen, 12 July 1977 from Rødberg to Mykstufoss. The Roman numerals indicate weir placement (from Raastad 1979).*

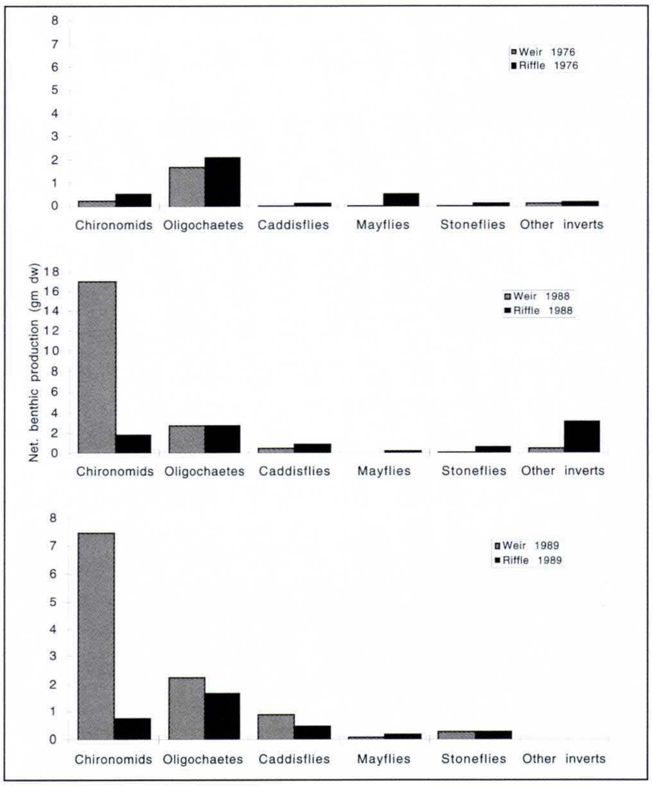



*Fig. 30. Average net production of important benthic species in weir basins and riffles in the Eksingedal watercourse from 1976 to 1989 (data from Bækken et al. 1984, Fjellheim et al. 1989).*

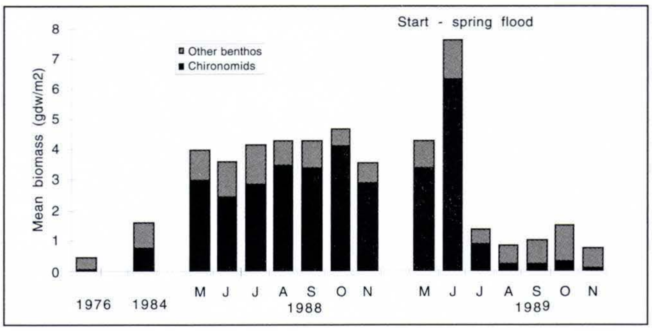



*Fig. 31. Average biomass in the weir basin at Ekse from 1976 to 1989 (Fjellheim & Raddum 1996).*

### 6.5.3 The benthos

Among the important species of benthic fauna in weir basins are: oligochaetes, mayflies, stoneflies, caddisflies, chironomids, blackflies, craneflies and water mites. The number of species in each group varies from just a few to 10 or more.

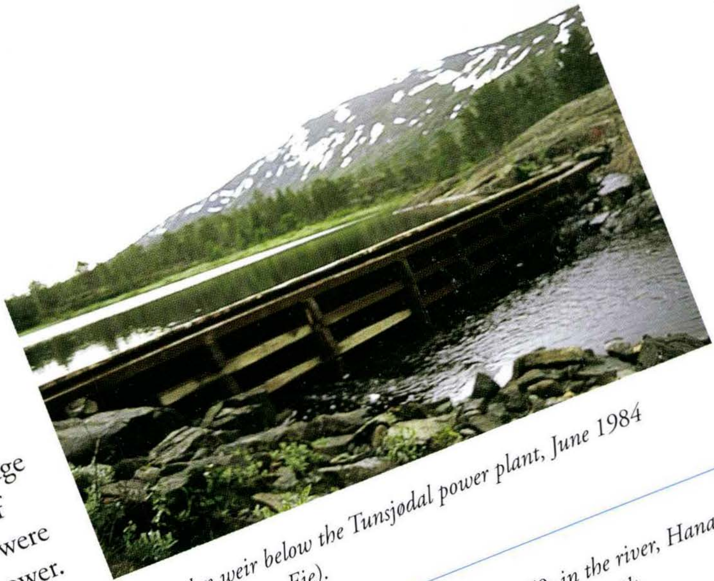
Of all the main groups of insects in riverine fauna, the blackflies are the only ones not found in lentic waters. Thus they are particularly sensitive to changes that affect water flow, such as watercourse regulation. Owing to the briefness of its life cycle, the blackfly benefits from the presence of weirs. Blackfly density can be especially high on weir crests where the water velocities are favourable and there is plenty of food available.

The total volume of benthos in a watercourse appears to be strongly influenced by the presence of weirs. A comparison of weir habitats in the Numendalslågen from Rødberg to Mykstufoss below Norefjord (Fig. 29) indicated a clear tendency towards higher benthic densities towards the lower end of the watercourse. The effect was most obvious for blackflies.

Benthic communities in weir basins are dynamic and they will be a succession, mainly as a result of the reduction in water velocity, which leads to the sedimentation of particles (Fjellheim *et al.* 1989). In the river, Ekso, oligochaetes comprised the dominant group inside and outside the weir basin immediately after the weir was built. The mayfly biomass was high in the lotic waters outside the weir basin, while the production of chironomids was largely the same inside and outside the weir basin (Fig. 30). Eventually, there was a strong increase in the production of chironomids and oligochaetes in the weir basin and, 12 years after the weir was built, the chironomid biomass was nearly 30 times as high as it was prior to construction.

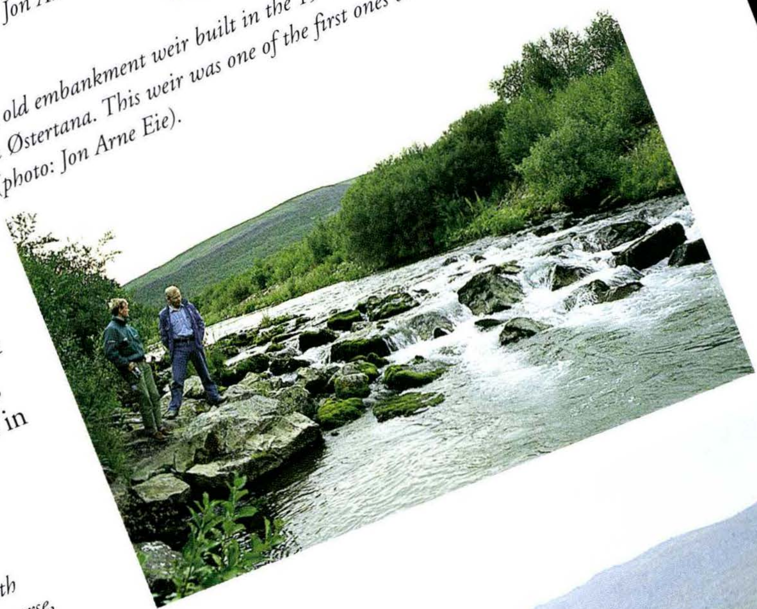
The benthic community changed from one consisting of species adapted to life in lotic waters to species adapted to lentic waters. For example, large, burrowing species of chironomids, mainly belonging to the genera *Stictochironomus* and *Micropsectra*, came to dominate the benthos, although there had been very few of them before the weir was built.

Parallel to the changes in the pattern of species, major changes took place in the total benthic biomass (Fig. 31). Three years after the weir was built in Eksingedalen, the total biomass decreased drastically in riffles, at the same time as biomass in the weir basin increased strongly by 420% and 240%, respectively, at two sampling stations. This happened because the weir g as a sedimentation trap where organic ed. As time passed, this created an excel- or burrowing species of benthic fauna and pted to slow-flowing or still-standing waters. n years after weir construction, the benthic ity underwent yet another transformation m *et al.* 1993, Fjellheim & Raddum 1996). nter of 1988-89 was particularly wet, and huge ants of snow accumulated in the mountains of tern Norway. At the same time, temperatures were ld in the lowlands, reducing the demand for power. arge volumes of water had to be discharged from the regulation dam into the Eksingedal watercourse, increasing water flow through the weir basin by nearly a factor of five, compared with a normal year. The after-effects of the increased water flow appeared very quickly (Fig. 31). The benthic biomass was reduced dramatically, and major changes were effected in the balance between the species. The large, burrowing midges were flushed away, along with huge volumes of sediment, and the benthic community quickly transformed to a type of benthos more similar to that found in swiftly-flowing waters. As the years passed, the species and groups will once again adapt to life in slow-flowing waters.

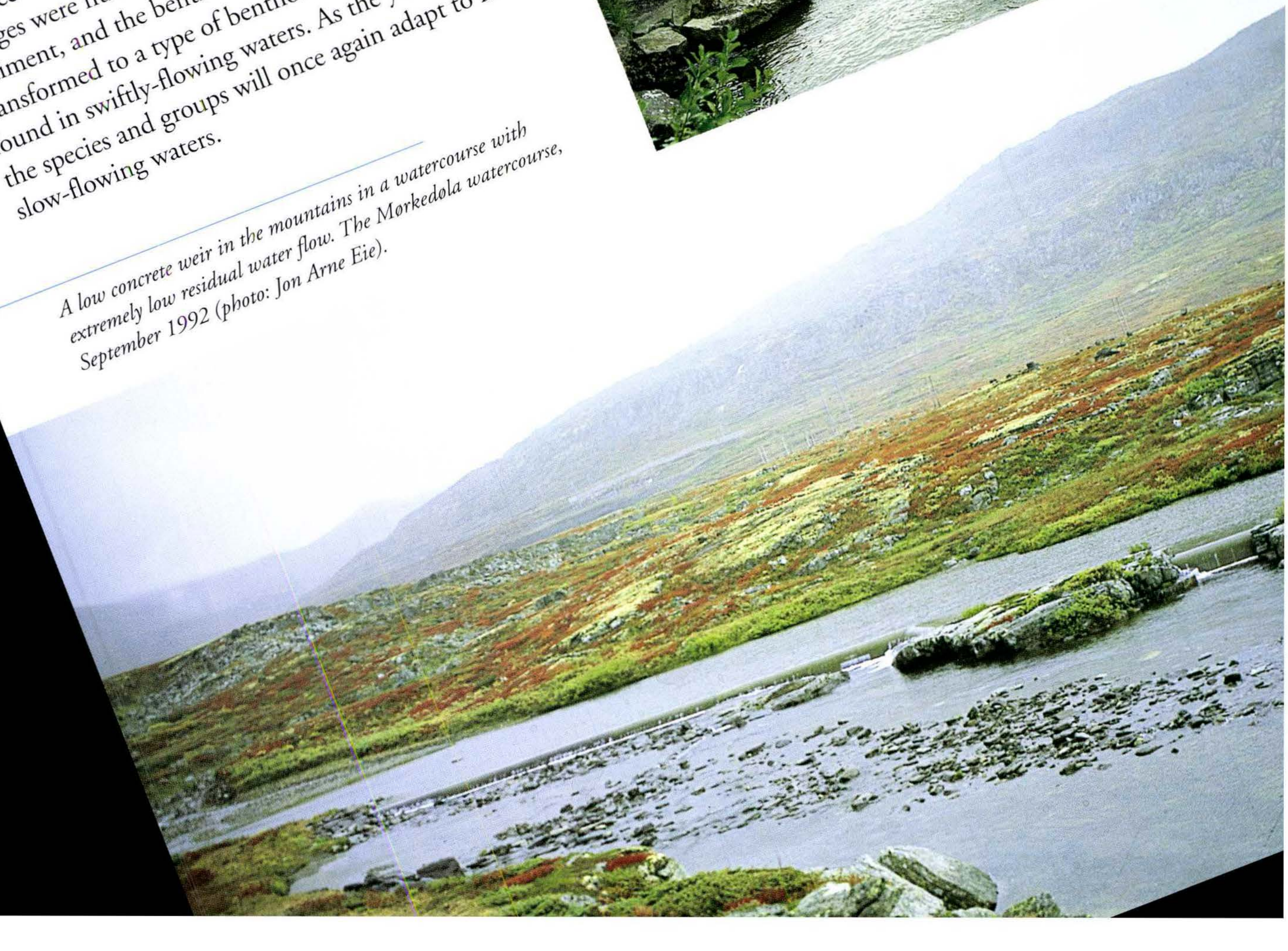


*A wooden weir below the Tunsjødal power plant, June 1984 (photo: Jon Arne Eie).*

*An old embankment weir built in the 1960s in the river, Hanaelva, in Østertana. This weir was one of the first ones built (photo: Jon Arne Eie).*



*A low concrete weir in the mountains in a watercourse with extremely low residual water flow. The Mørkedøla watercourse, September 1992 (photo: Jon Arne Eie).*



*Excessive growth of* Juncus supinus *in the Otra River, May 1987 (photo: Jon Arne Eie).*

*The overgrowth of* Juncus supinus *has occasionally caused problems for power plant operation (photo: Tor Erik Brandrud).*


Studies of weir basin fauna indicate that the benthos found in such systems changes significantly over time. Normally, the fauna will be similar to the type that prevails in still-standing water. Alternation between stretches of lotic (rapids and riffles) and lentic waters (weir basins) will create far greater biodiversity than would occur in lotic waters alone.

### *6.5.4 Fish in the weir basin*

Reduced flow in rivers and streams can have particularly strong adverse effects on larger fish. Weirs are an appropriate measure for increasing water volume, but they also have a number of other indirect effects.

**Fish colonisation in weir basins**

How long does it take from the time weirs are completed until fish have colonised the weir basins? An attempt was made to find the answer to this question in the Nea River by comparing fish densities in weir basins of different ages. Test fishing using standard gill net series resulted in bigger catches in old than in new weir basins. This applied to all the net mesh sizes tested. The results also showed that while the brown trout had already colonized a new weir basin after just six months, the establishment of a stable, sizeable stock took time. The condition factor was also higher in old weir basins than in new ones for all lengths of fish, suggesting that there was better access to food organisms in the older weir basins.

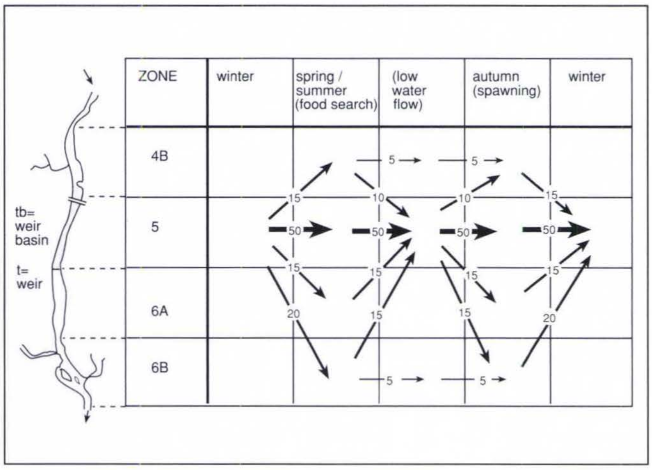



*Fig. 32. Brown trout migration in the weir basin at Ekse (from Evensen 1984).*

Juncus supinus *in Eksingedalen at Eikemo, 1991 (photo: Tor Erik Brandrud).*

**Migration**

Brown trout can migrate long distances, but most of the stock is relatively stationary. Watercourses of a certain size will usually contain several trout stocks that may demonstrate fairly significant differences in their migratory patterns. In most cases, building weirs in regulated rivers will improve opportunities to migrate, although that requires the correct choice, placement and design of weirs.

In the Glomma, large brown trout migrate great distances. Migrations of distances of up to 80 and 120 km have been registered in the main watercourse. In the large lake, Storsjøen, indigenous brown trout graze the entire lake for food, although their spawning and rearing grounds are in the Mistra River, which flows into the northern end of the lake. There is a stationary river stock in the river, Søndre Rena, from which a number of immature fish emigrate and spread out across Storsjøen. This sort of widespread emigration from spawning and rearing grounds is fairly common, and has also been registered in the Søre Osa, where the resident brown trout migrate up in the late autumn to reach the lake, Osensjøen.

Two brown trout stocks have been registered in the Nea watercourse: one resident, river-residing stock and a stock of large trout in the large lake, Selbusjøen. Although the migratory pattern of the stock of large trout in Selbusjøen has in no way been charted thoroughly, it has been shown that the Nea is an important spawning and rearing river. 1992 marked the beginning of an experiment in which radiotelemetry was used to increase knowledge of the migratory routes of the large trout.

Fish production was reduced drastically in the Nea watercourse after hydropower development. In one of the stretches of river investigated, flow was cut from roughly 80 $m^3/s$ to less than 2 $m^3/s$. Several weirs were built to concentrate the residual water flow. The effects have varied. Weirs had a positive effect on the resident trout stock, but made it difficult for the large trout to migrate upstream except during floods. This was because the weirs had been built with straight crests so the water was evenly distributed across the entire structures. When water flow was low, the water filtered between the rocks all across the wide river, making migration difficult. In fact, when water flow was low, the weirs themselves impeded the migration of large trout. The extensive weir construction programme also entailed the loss of several stretches of rapids that had once been important spawning grounds, and spawning conditions were extremely poor in the wide riverbed.

The migratory pattern of the resident brown trout was studied in detail in the Eksingedal watercourse (Fig. 32) (Evensen 1984). Weirs have had no adverse effects on fish migration there. The stock of fish in the weir basin was made up of older, sexually mature fish and older, sexually immature fish. Young fish were outcompeted in the weir basin. In spring, the older, sexually mature fish migrated out of the weir basin. It is assumed they were on a quest for food. The trout reach a critical period in late winter when they have an energy deficit. To re-establish their energy balance, they move up smaller streams to areas where insect emergence takes place slightly earlier. In autumn, the older, sexually mature fish move upstream through the rapids again, but this time their objective is to spawn.

*Weir basin and embankment weir at Ekse in the Eksingedalen watercourse (photo: Jon Arne Eie).*

This paves the way for the immigration of young fish (3 to 4 years old) into the weir basin, facilitating a renewal of the fish stock. The older, sexually immature fish are extremely stationary and generally stay in the weir basin all year round.

**Food**

The brown trout's choice of food organisms was studied thoroughly in Hallingdal and Hemsedal from 1973 to 1980. The investigation showed that the benthos was an important source of food organisms for trout. In the course of a single season, benthic fauna can account for 70-80% of a trout's diet in terms of weight. Terrestrial insects comprised 10-20% of the trout's diet. Among the benthos, mayflies, caddisflies, stoneflies, blackflies and chironomids were the most common groups.

Samples taken in the Ekso from the benthos and the drift showed that stoneflies, mayflies, caddisflies and a number of other groups were likely food organisms for the trout. Chironomid larvae and aquatic oligochaetes accounted for the majority of the food organisms found in the samples taken from the benthos. Analyses of the content of fish stomachs indicated that chironomid larvae were the most important food organisms. It was also interesting to note that there were no significant differences in the stomach contents of trout caught in weir basin and those caught in riffles.

In 1983-84, the brown trout stock in a weir basin in the Ekso looked as though its members were suffering from malnutrition despite the fact that a study of the benthos that same year indicated a continuous increase in biomass and production since 1976. In an effort to improve the situation, a large number of trout were removed (Raddum *et al.* 1989). The trout in the weir basin subsequently showed signs of better growth and condition. A new study of the benthos in 1983-84 indicated a continued increase in the production and biomass of benthic fauna. This would indicate that large parts of the benthic fauna in the weir basin, which consisted of burrowing species at the time, were not accessible to the trout.

Serious flooding reduces benthic fauna considerably, as the animals are dislodged and flushed away. Weir basins tend to mitigate the flushing effect, thus contributing to gradual stabilization of the species composition and biomass of the benthic fauna. In the light of the preceeding discussion, it is hard to tell how positively this will affect the fish stock.

It appears that the functional unit is not the weir basin alone, but also the lotic stretches above and below it. Rapids are also an important part of the fishes' food supply. Many of the food organisms that drift into the basin come from rapids, and trout forage on them. The weir basins represent areas with stable environmental conditions that ensure survival during winter and in dry periods. This shows the importance of a varied environment.

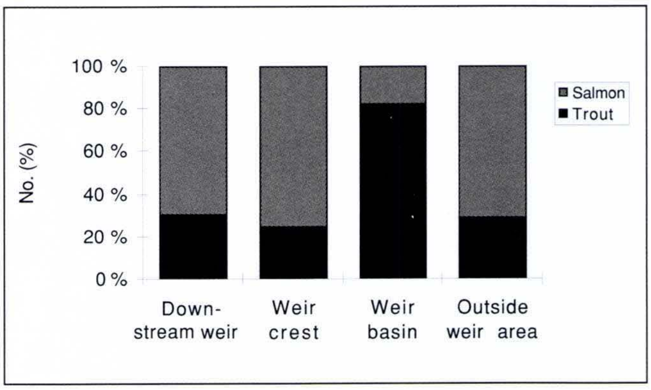



*Fig. 33. Distribution of young brown trout and Atlantic salmon in weir areas in the Skjoma River (from Heggberget et al. 1993).*

**Competition between salmon and trout**

In watercourses with low flows, groups of fish of different sizes are forced to exploit the same habitats, resulting in competition with each other. This increases mortality. Weirs can reduce competition between age groups and have a positive effect on the stock as a whole.

In unregulated trout and salmon rivers, the two species have different habitat preferences. The brown trout prefers calmer waters than the Atlantic salmon. This is also true in regulated rivers. In the areas between weir basins, salmon live mainly in the most swiftly-flowing parts of the river, while trout prefer the slower-flowing waters close to land, especially if there are boulders there.

The same habitat preferences are evident in the weir basins. Investigations in a number of watercourses have shown that trout density is greater in weir basins than in rapids, and that salmon and trout are fairly clearly separated. Trout dominate in the basins, while salmon have the highest density in the stretches of rapids outside the basins (Fig. 33).

*Fishing in the weir basin at Ekse in the Eksingedalen watercourse May 1989, (photo: Jon Arne Eie).*

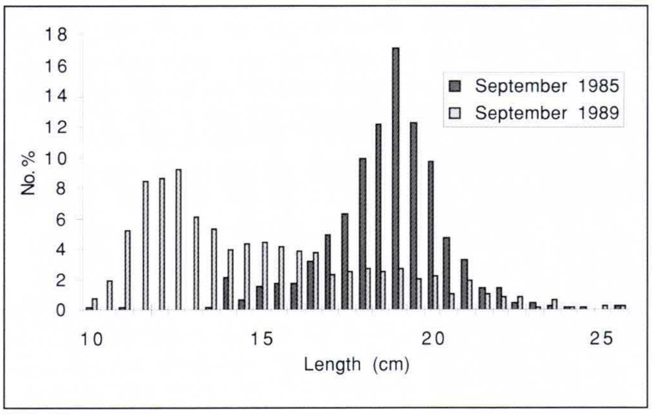



*Fig. 34. Distribution by length of brown trout caught in the weir basin in the river Ekso in 1985 and 1989 (from Raddum et al. 1989).*

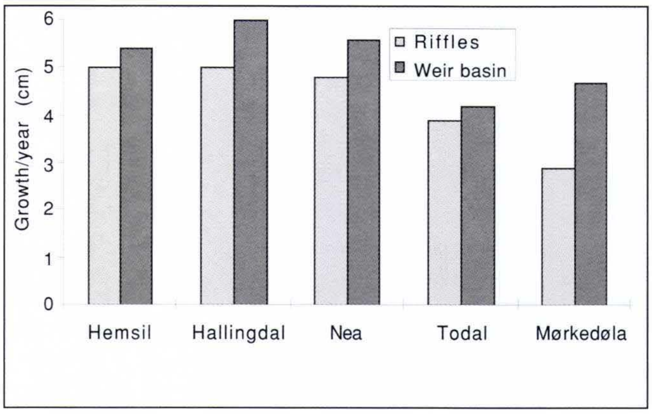



*Fig. 35. Annual growth in length (cm) of brown trout in the weir basins and outlying riffles in different watercourses (from Borgstrøm 1981, Aass 1983, Korsen 1984, Arnekleiv 1988).*

However, the distribution of salmon and trout in weir basins depends on the type of weir. In basins created by full-width weirs, the distribution of the two species is similar. There are, however, differences in distribution in the basins created by Syvde weirs. In connection with a weir area in the river, Todalselva, juvenile trout had the highest density along the banks of the basin and in the downstream stretches, while juvenile salmon were more abundant in the middle of the basin, and they dominated completed in the area around the crest of the weir and in the swiftest-flowing downstream areas. A reduction in water flow followed by weir construction will favour trout and thus affect the distribution of salmon and trout in the watercourse.

Pools form below Syvde weirs. In one such pool in the river, Toåa, salmon consistently opted for deeper water and faster currents than trout. Older fish preferred deeper water than younger fish. Juveniles and yearlings of both species generally stayed in shallow water, while two and three year olds tended to move into deeper water. The investigation also showed that younger fish are more likely than older fish to be dependent on the substrate. Young-of-the-year stayed under and between the rocks in the substrate. Salmon and trout yearlings stayed 6 to 15 cm above the riverbed, while two and three year old salmon remained 17 to 25 cm above the bottom. Two and three year old trout were least dependent on the substrate, maintaining positions 46 to 55 cm above the riverbed.

**Salmon and trout density**

Most investigations have found that weirs increase fish density, and that the population density in the weir basins is far higher than in riffles outside the basins. In a 1.5-km stretch of the Ekso River, the density of brown trout larger than 8 cm increased six-fold over 15 years: from 2.5 fish/100 $m^2$ prior to weir construction to 15 fish/$m^2$ after. In the Nea, the density of 1- to 3-year old trout increased from 5.7 to 83.5 fish/100 $m^2$ in the established weir basins. The highest density (183 fish/100 $m^2$) was found in an old weir basin.

One important change that takes place when water velocity is reduced to less than 5 to 10 cm/s, is that salmon no longer exhibit territorial behaviour. They tolerate close proximity to other species, allowing the fish density to increase. Lentic waters that feature pools may therefore have high densities of young fish, as was discovered in a pool just below a Syvde weir in the Toåa, where fish density was about four times as high as the mean density in lotic waters.

Weir basins do not automatically generate an increase in fish density. Basins that have finely-grained sand bottoms with virtually no rocks may have a lower density of fish than what would be found in stretches of rapids. If the banks of a weir basin are reinforced with large stone boulders, the fish density may be far higher than in rapids.

To promote fish density in weir basins, the basins must be deep enough to ensure good winter survival rates (see Chapter 4.2.5). Further, the riverbed substrate must offer good shelter and hiding places, and there must be sufficient access to food organisms. Under such conditions, large and small fish will live in separate habitats, reducing the competition between age groups and species, and thus reducing the mortality rate.

### Growth

It is well documented that fish often grow significantly more quickly in weir basins than in stretches of rapids (Figs 34 and 35). There are three reasons for this. Water temperatures in lentic waters are somewhat higher and this has a positive effect on fish metabolism. Fish also expend less energy in staying in place in lentic waters. Nor do salmon exhibit territorial behaviour there. All in all, this means that more energy can be devoted to growth.

Despite the fact that the density of Atlantic salmon in the investigated pool in the Toåa was far higher than in the stretches of rapids, the pool-dwelling salmon were clearly larger, 3 to 11% longer and 6 to 40% heavier, than fish from the rapids. The same was true of brown trout. Those living in the pool were 7 to 17 per cent longer and 24 to 56 per cent heavier. In the Skjoma, too, the salmon and trout living in the weir basin showed a strong increase in growth. Since regulation and weir construction, salmon now spend nearly a year less in the river before turning into smolt. Another example is from Mørkedøla, where six-year-old brown trout reach a given length nearly two years earlier now than they did prior to weir construction.

### Predation

Compared with regulated rivers with little water flow, weir basins that offer deep areas and a varied substrate furnish fish with better protection against predators such as mink. Mink have been shown to wreak havoc in fish populations.

### Producing young fish for stocking in reservoirs

As fish density increases, the danger of overtaxing the food base increases as well. This happened for example, in the Eksingedal watercourse resulting in smaller fish that did not grow well and had a low condition factor.

Further up the watercourse in the regulated lakes, Askjelldalsvatn, and Store Volavatn, there were very small populations of brown trout, and spawning conditions were poor. One-summer old hatchery fry from a fish farm used to be stocked there, but as the goal was to preserve the local fish population, it was decided that it would be more prudent to use indigenous fish from further downstream for stocking.

*The largest and most expensive embankment weir in Norway: the Glomma River at Lyngen (photo: Jon Arne Eie).*

*The banks of the channelized stretch are terraced to make the river more accessible for fishing both at low and high water levels. On the left, a fishing path for use when the water level is low. When the water level is high fishermen stand up on the earthworks. The riverbanks have been sown. The river, Hareidselva, October 1985 (photo: Jon Arne Eie).*

To improve the quality of the fish in the weir basins and procure young wild fish, 1500 specimens were taken from the weir basin and stocked in Askjelldalsvatn and Store Volavatn (Fjellheim & Raddum 1994). A small residual population of spawners was kept in the weir basin. The experiment was a success, resulting in the large-scale immigration of small fish into the weir basin, most of them two- and three-year-olds (Fig. 34). This size of fish is ideal for stocking and, in subsequent years it was possible to catch 10 fish per 100 $m^2$. The few larger fish that were left enjoyed a better quality habitat and were more sought after as food fish. In Store Volavatn, the fish were in better condition and multiplied many times over in terms of weight. The same thing happened in Askjelldalsvatn, although after several years of overstocking, growth and condition trends took a downward turn once again. An adjustment in the density of the fish stocked resulted in a tangible improvement in fish quality. It appears that brown trout populations in regulated waters are extremely dependent on correct stocking numbers.

**Conclusion**

Without exception, the investigations all indicate that weirs have a positive impact on brown trout production in regulated rivers. In the rivers, Eksingedalselva, Todalselva, Mørkedøla and Skjoma, trout densities were higher in the weir basins than in the riffles outside the basin areas. The picture is somewhat more complex for young Atlantic salmon. Salmon and trout often segregate in weir areas. Trout dominate the weir basins, while salmon have the greatest density in the riffles outside the basin. Weirs in regulated salmon and sea trout rivers will favour the trout, but there are indications that the production of salmon smolt increases as well. The most important factor for increasing smolt production seems to be a reduction of winter mortality. Nevertheless, weirs can also favour other, less desirable fish species such as burbot, pike and minnows, where these occur.

### *6.5.5 Birdlife in the weir area*

Investigations in the river, Hallingdalselva, showed that different species of waterfowl are distributed differently between lentic and lotic waters. Four species could be considered typical of these stretches of the Hallingdalselva in the nesting season. Two of them, the mallard and the goosander, showed a clear preference for weir basins. The dipper preferred rapids, while the common sandpiper had no obvious preference. Goosanders fished in the shallow parts of the weir basins, where the fish were larger and the populations were more dense than in the rapids. Swallows, house martins and sand martins also used the weir basins far more frequently than the rapids when seeking food.

Bird censuses taken in the weir areas in the river, Eksingedalselva, before and after regulation indicate that the nesting populations of many species of waterfowl have increased in recent years. This was particularly true of the lapwing, the common sandpiper and the redshank. The other species of waterbirds were fairly evenly distributed among the various sections of the river. A few individuals belonging to other species of waterfowl were observed during migration or grazing. Of those species, the teal and the goldeneye indicated a clear preference for the weir basins.

In Hallingdalselva and in the weir area of Eksingedalselva, there were strong indications that the bird life in and around the watercourses has become richer and more productive since the weirs were built. This phenomenon is ascribable to the marked increase in benthic production in the river.

### *6.5.6 The cost of building weirs*

Practically all Norway's weirs have been built either in connection with watercourse regulation or flood prevention projects. NVE has had the authority to order regulators to build weirs for the past 20 years or so, and has often performed a large part of the planning and administrative work involved. The regulator has either hired local contractors or employed NVE's River Engineering Section to do the job.

The costs of construction vary considerably, depending on the width of the river, the accessibility of the site and the distance tailings, etc. have to be transported. Long-distance transport increases costs substantially. Sand and gravel are often taken from the river itself when there is a relatively modest change in water flow and good access to boulders.

Wooden weirs have often been used in small, out-of-the-way watercourses in Trøndelag County. Costs vary considerably. The same is true of the concrete weirs built on bedrock on sites that are fairly accessible by road. A large weir built in the Namsen in the 1970s cost NOK 1.7 million, while it costs little to bridge small natural gaps.

Embankment weirs are the most common type. Costs ranged from NOK 1 000 to NOK 4 000 per metre for the weirs built in the Orkla and the Nea and now, more recently, in connection with the Meråker development project. Costs depend largely on the height of the weir and the distance materials have to be transported. Weirs built of tailings are the most expensive ones. Even though tailings are already blasted, the sorting, loading and transport costs add up. Costs can be kept down if sand and gravel can be taken from the river itself. All weirs are sealed with watertight facing. Located just below Hanestad in the Glomma River, Norway's longest embankment weir cost a total of NOK 3.5 million. However, conditions were particularly difficult there and tailings had to be transported from quite some distance away. The project also called for extensive modelling experiments to test stability.

### *6.5.7 Evaluating weirs*

Weirs built in rivers with reduced water flow increase water surface area and volume. This has obvious aesthetic advantages, as well as a number of biological benefits. Weirs create richer, more diversified habitats in regulated rivers.

When evaluating the effects of weirs on biological communities, one must examine the advantages entailed by the individual weir and the overall effect of weirs on a watercourse. By choosing the right type of weir, locating it in the right place, and giving it the right design and engineering, it is to some extent possible to "recreate" certain types of rivers in regulated watercourses, even though the river in question would be a new one. Some of the original uses can continue, however, and the alternative, in many cases, would be far less water surface area and modest fish production.

There is little point in building weirs in rivers with steep gradients. The weir basins would be small, meaning many weirs would have to be built to increase

*Weirs in the river, Hareidselva, below the lake, Grimstadvatn. The weirs were built to prevent lowering of the level of the protected Grimstadvatn and to safeguard the abundant bird life when the river was going to be channelized for agricultural purposes (photo: Jon Arne Eie).*

water surface area significantly. The stream would also look strange, and the cost/benefit ratio would be low. On the other hand, regulated rivers with a moderate gradient, not too much water flow and a mixture of lotic and lentic waters, usually lend themselves well to weir building. Even in those cases, however, the use of weirs is limited in terms of technology, aesthetics and, not least, finances.

Problems such as the development of undesirable vegetation and overgrowth have been documented in certain weir basins. These problems may be related to the increasing accumulation of organic matter combined with other environmental changes.

Weirs are measures generally designed to remedy the disadvantages of watercourse regulation projects that reduce water flow. Weir building calls for strong professional insight into hydrological and technical conditions. In Norway, permits must be obtained from the authorities before weirs can be built. A description of the process is given in Chapter 8.

# 7 Biotope adjustment measures in wetlands

Wetlands include swamps, bogs, shallow ponds and lakes, estuaries, sea meadows, and shallow bays and inlets along the coast. They are often highly productive areas, supporting a rich flora and fauna. For years, wetlands have been subject to pressure from road construction, agriculture, industry, etc., until they are now an endangered type of natural habitat. As Norway has little experience of restoring wetland biotopes, there is a great need for more knowledge. Accordingly, the main emphasis of this chapter is on a restoration programme after lowering the water level in the lake, Myrkdalsvatn, part of the Vosso watercourse.

## 7.1 The importance of the wetland mosaic

In connection with the restoration of wetlands, it is essential to look at the relevant area as a whole, rather than focusing on individual species. Furthermore, it is crucial to preserve the diversity of plant life, especially in wet/dry transition zones, to be aware of the stratification of vegetation and to ensure that wetland areas are not fragmented.

Variations in the environmental conditions in wetland areas are important because different plants have different degrees of significance as food resources for insects and birds. Many wetland birds build nests in the transition zones where various types of vegetation overlap. In addition, the transition zones between water and land offer a shoreline effect that is very important to waterfowl. All in all, variations in water levels and a mosaic of well-diversified vegetation set the stage for a wide variety of animal life. The value of wetlands as natural habitats will deteriorate if conditions become too homogenous, as when riverbanks and shorelines are levelled out and water flow becomes virtually constant.

## 7.2 Islands and channels as restoration measures

The Bygddelta is located at the north end of the lake, Myrkdalsvatn, in the municipality of Voss. It is one of western Norway's largest inland deltas. In its natural state, it was an important regional wetland area. The richness of the delta's native flora and fauna was one of several reasons the Vosso watercourse was permanently protected from hydropower development. However, the delta has been used for growing hay for quite some time and, these days, the original vegetation is limited to the odd patch here and there on the delta flats.

A variety of plants used to grow in the higher areas. Along the edges of the cultivated fields, there were dense areas of *Phalaris arundinacea, Calamagrostis purpurea,* and a band of *Salix myrsinifolia. Rubus idaeus* and *Deschampsia cespitosa* dominated the highest areas, where there was also a tree/bush layer featuring *Alnus incana, Salix myrsinifolia* and *Prunus padus.* Another belt featured different herbs, including *Geranium sylvaticum, Valeriana sambucifolia, Filipendula ulmaria* and *Angelica sylvestris.* The fern, *Mateuccia struthiopteris,* dominated in shallow depressions. Wet meadows were dominated by *Deschampsia cespitosa* and *Agrostis stolonifera,* accompanied by *Cirsium palustre* and various species of *Carex.*

The last major encroachment on the Bygddelta was made in 1987 when the water level in Myrkdalsvatn was lowered by 1.4 m to claim new farm land. The mouth of the river was widened, and the tributary was channellised and reinforced to protect farm lands from flooding. As a result, vast areas of shallow wetlands that had been used by birds dried up and serious flooding was brought to an end. However, a number of measures were implemented to mitigate the negative effects of the encroachment. Among other things, man-made islands were built in the shallow channels to increase the available shore zone and create new nesting places for birds.

### *7.2.1 The development of vegetation on exposed sediment*

The delta was examined for the first time approximately one month after the water level was lowered. Although the original belts of vegetation were still intact, they were above the waterline in most cases. Vast expanses were exposed in the flattest areas (Fig. 36).

Several cross-sections of vegetation were established. Two examples are illustrated in Fig. 37. The lowest zone consisted almost exclusively of silt, with occasional tussocks of *Callitrichaceae palustris* and *Subularia aquatica.* This zone blended into a densely covered mat containing the same species in addition to *Pholia*

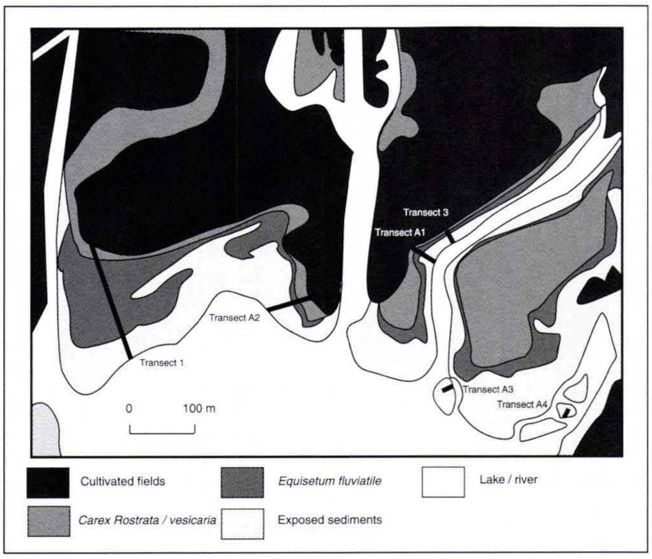
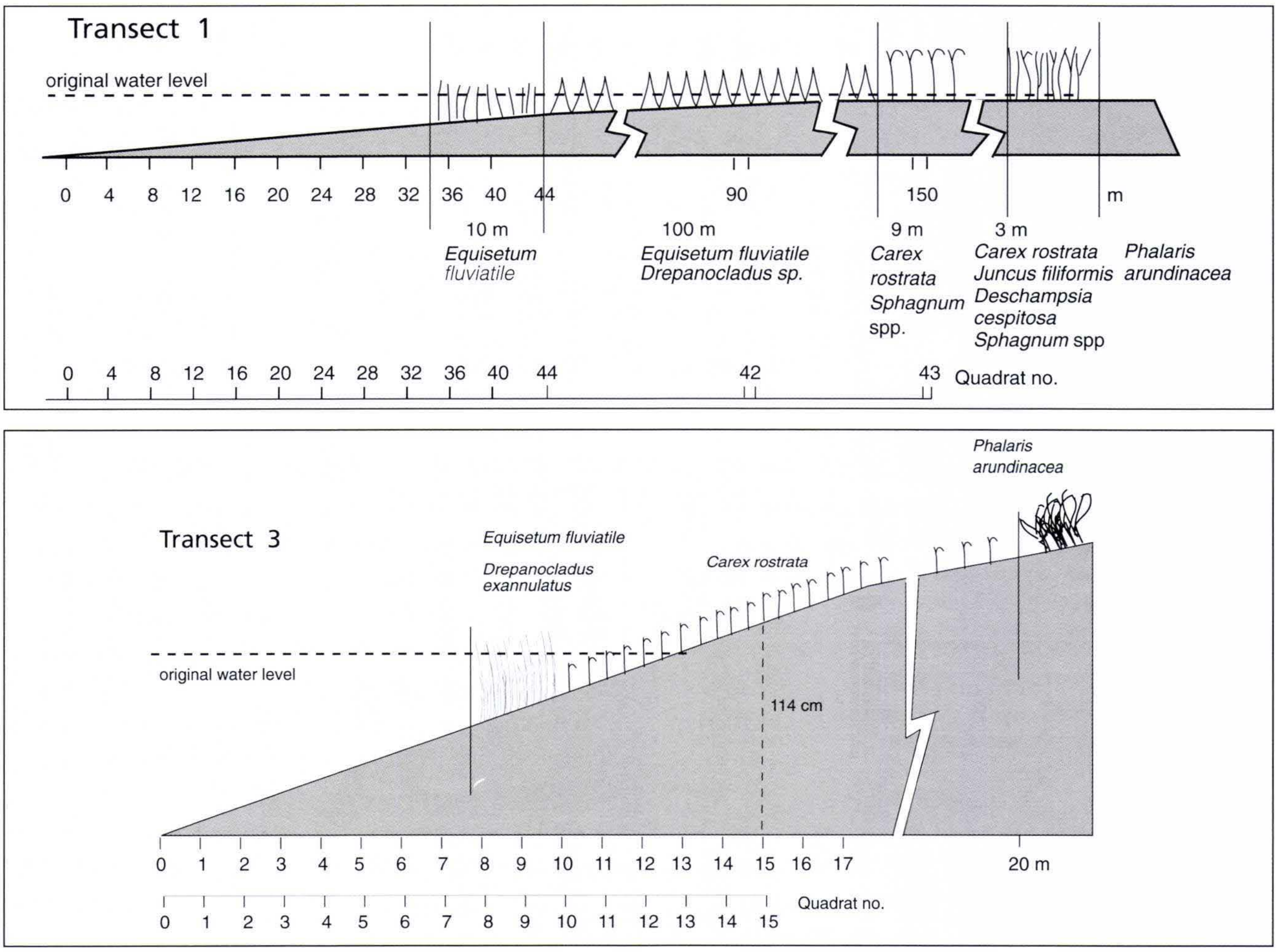



*Fig. 36. Map of the vegetation in the outer parts of the Bygddelta in the lake, Myrkdalsvatn, after it was lowered in 1987 (from Raddum 1993).*

*Fig. 37. Cross-section of the vegetation zones in transects 1 and 3 after the lowering of the lake, Myrkdalsvatn (from Odland 1992).*



View of the outer part of the Bygddelta, Myrkdalsvatn, in the Vosso watercourse, May 1989. The area was channelized and the water level lowered to claim new farmland and prevent the flooding of existing agricultural areas. Among other things, man-made islands were built to reduce the adverse effects on bird life (photo: Jon Arne Eie).

mosses. Above that was a belt of the original *Equisetum fluviatile*, which could be subdivided into a *Pholia* zone and a zone of *Drepanocladus exannulatus*. The penultimate belt was approximately 10 m wide and dominated by *Carex rostrata, Equisetum fluviatile* and *Sphagnum terres*. The upper edge of the shoreline itself featured numerous stands of *Phalaris arundinacea*.

In 1988, a year after the water level was lowered, the *Callitrichaceae-Subularia* zone had expanded further down, leaving only a two-metre wide band of clay with occasional tussocks of *Callitrichaceae palustris* and *Subularia aquatica*. From above, the *Callitrichaceae-Subularia* zone was subject to pressure from *Deschampsia cespitosa, Juncus filiformes* and *Carex rostrata*. These species had managed to establish a homogenous zone 16 m long during the course of the first year after the water level was lowered. *Juncus filiformes* had also managed to establish itself in the zone below. A number of non-native species had gained a foothold in the *Equisetum* belt, particularly *Calamagrostis purpurea*. There were few changes in the *Carex rostrata - Equisetum -Sphagnum* belt.

In the second year (1989) after the water level was lowered, *Subularia aquatica* and *Callitriche palustris*, now mixed with *Ranunculus reptans*, colonised the exposed river bottom right down to the water's edge. Nonetheless, the total amount of vegetation in this zone had declined. From the top, the homogenous *Deschampsia-Carex* vegetation had expanded seven metres further down, managing to establish sporadic tussocks of *Deschampsia cespitosa* and *Carex rostrata* throughout the entire *Subularia-Callitriche* zone. Above the *Deschampsia-Carex* zone, there was a well developed ground cover the moss, *Blasia pusilla*. A number of changes had taken place in the innermost belt by that time. *Deschampsia cespitosa, Calamagrostis purpurea* and *Agrostis stolonifera* had gained a foothold at the expense of *Sphagnum teres*.

The *Deschampsia-Carex rostrata-Carex vesicaria* belt continued to expand in a downward direction for the next two years, as the *Subularia-Callitriche* zone narrowed and became considerably thinner. The expanding belt was itself pressured by other species, and *Phalaris arundinacea, Juncus filiformis*, and *Ranunculus repens* managed to establish regular colonies. From the

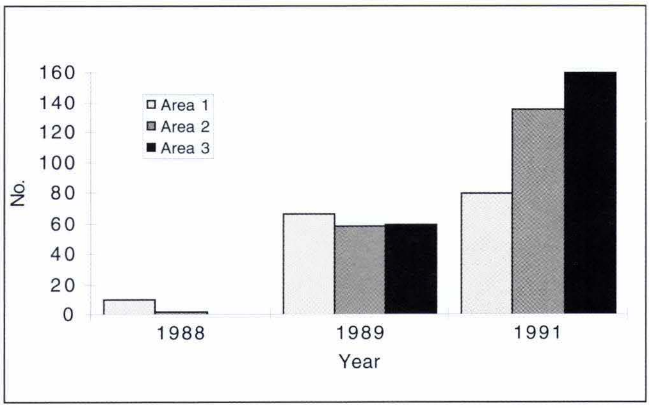



*Fig. 38. Numbers of mayflies, stoneflies and caddisflies per 5-min. kick sample in the Bygddelta, Myrkdalsvatn (from Raddum 1993).*

top, the *Equisetum* belt had expanded in a downwards direction. As time passed, a transition zone consisting of *Equisetum fluviatile, Carex rostrata* and *C. vesicaria* developed. The original *Equisetum* zone remained more or less intact, although it was eventually mixed with quite a bit of *Deschampsia cespitosa* and a number of other species of grasses and sedges. The *Carex rostrata-Equisetum-Sphagnum* belt continued to remain more or less intact, while *Deschampsia cespitosa, Phalaris arundinacea, Rumex acetosa* and some species of sedge increased markedly. *Equisetum* and *Sphagnum* continued to loose ground.

## *7.2.2. The development of vegetation on excavated sediments*

Vegetation developed differently on excavated and non-excavated sediments. It took a year longer for new vegetation to take root on excavated sediments than on non-excavated sediments. The explanation is that digging around in the sediments removes the upper "seed bank layer", meaning new seeds have be introduced when water levels are high. Comparing the various phases of development of vegetation on the excavated and non-excavated sediments, one finds important differences both with a view to the selection of species and dominance. This is probably due to differences in the particle composition of the sediments.

One year after the water level was lowered, sparse, homogenous pioneer vegetation had taken root on the excavated sediments. Species of moss dominated strongly. Liverworts, *Pholia* and other species of mosses dominated completely the first year, while seedlings of birch, *Betula pubescens* and *Salix* spp. were found spread throughout the area. *Callitriche palustris, Juncus filiformis* and *Subularia aquatica* also occurred here and there, although not in the highest areas.

Two years after the water level was lowered, there had been a rapid expansion of grass and small willow bushes. The vegetation was not particularly differentiated, but one could nonetheless distinguish between the *Subularia-Callitriche* vegetation at the bottom and a zone of birch and the moss, *Blasia pusilla*, at the top.

Three years after the water level adjustment, the vegetation was still fairly homogenous, largely due to the domination of *Deschampsia cespitosa*. The lower areas were covered by *Subularia aquatica* and *Alopecurus geniculatus*, while *Agrostis stolonifera, Carex canescens* and *Agrostis canina* dominated the higher areas.

Four years after the measure had been implemented, the lower areas were dominated by *Alopecurus geniculatus* and *Ranunculus reptans,* although *Deschampsia cespitosa, Juncus filiformis, Agrostis stolonifera* and *Phalaris arundinacea* were also present. The lower level was dominated by liverworts. By then, the higher areas were covered with *Salix caprea, S. myrsinifolia, Betula pubescens* and *Carex rostrata*, with an undergrowth of *Polytrichum* moss.

There has been a gradual shift from the original wetland ecology. Generally speaking, one might say that *Carex rostrata* and *Carex vesicaria* were replaced by *Deschampsia cespitosa, Calamagrostis purpurea* and *Phalaris arundinacea*, while *Equisetum fluviatile* was replaced by *Carex rostrata* and *C. vesicaria*. However, the vegetation on the delta is still evolving. No new *Equisetum* belt has developed, but the process is moving forward and over the next five to ten years, it is assumed that this important element of a wetland ecosystem will be re-established.

Over the five-year period, the vegetation zones that developed in the man-made wetlands were quite similar to those found prior to lowering the water level. There was no *Equisetum* belt here then either, although, as of 1994, such a belt was in the process of becoming established. The survey showed that by excavating channels and building man-made islands, it is possible to encourage the native wetland species to re-establish over the course of a few years.

## *7.2.3. The development of benthic fauna*

To chart the consequences of the encroachments and follow developments in the years subsequent to them, the benthos was surveyed at several locations in the Bygddelta. Apart from the channelized stretch, all the areas saw a major increase in density (Fig. 38) and a shift in the composition of the species (Fig. 39) subsequent to restoration. The increase in the number of mayflies was particularly notable.

Since the water level was lowered, there has been a change in the composition of mayfly species. Several species have increased, some have decreased and others have almost disappeared. Stoneflies were primarily found in the channelized tributary. Stoneflies no longer occurred in areas previously covered by running water but in backwaters. Caddisflies were found more sporadically and not in large numbers.

The distinctions registered between the species in terms of density are unusual for western Norway. Strong representation by groups/species that are normally far less common indicate that the ecosystem is unstable. Further, the generally strong increase in density indicates that a number of previously untapped resources have become available. Figures 40 and 41 show how the total density of benthos on soft bottoms developed in the delta after the water level was lowered.

In the non-excavated sediments in the new shore zone (0.5 m deep), the fauna seemed to suffer a one-year setback after lowering (Fig. 40). Benthic density continued to decline, until, in the fourth year after the water level was lowered, there was an increase in the benthos. In the two first years, the benthos contained a strikingly large proportion of oligochaetes and nematodes, and relatively few chironomid larvae. Chironomids are ordinarily the most common group of invertebrates found in oligotrophic lakes. When the total amount of benthos increased during the fourth year, the amount of insect larvae increased as well, although the incidence of oligochaetes and nematodes was still abnormally high.

The excavated sediments on the shore zone showed a gradual recolonisation. Oligochaetes dominated there the first year as well, then chironomids increased relatively rapidly, before decreasing somewhat in the past year. The results up until 1991 show that the benthos in the "new shore zone" on the excavated sediments still had an abnormal composition, featuring relatively large numbers of oligochaetes and roundworms. However, by 1992 the density of insect larvae had increased to levels commonly seen in western Norwegian lakes.

At a depth of two metres, benthic density showed different development patterns (Fig. 41). In untouched sediments, there was a reduction in density, while there was a gradual increase in density in the excavated sediments. Densities were high both places,

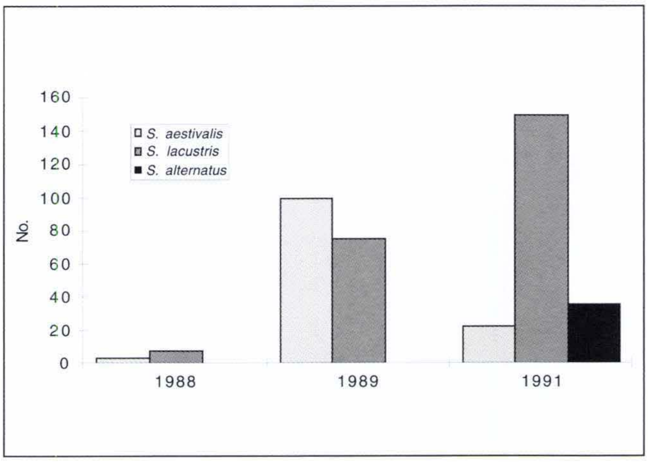



*Fig. 39. Presence of mayfly species belonging to the genus* Siphlonurus *in excavated and non-excavated sediments in the Bygddelta, Myrkdalsvatn (from Raddum 1993).*

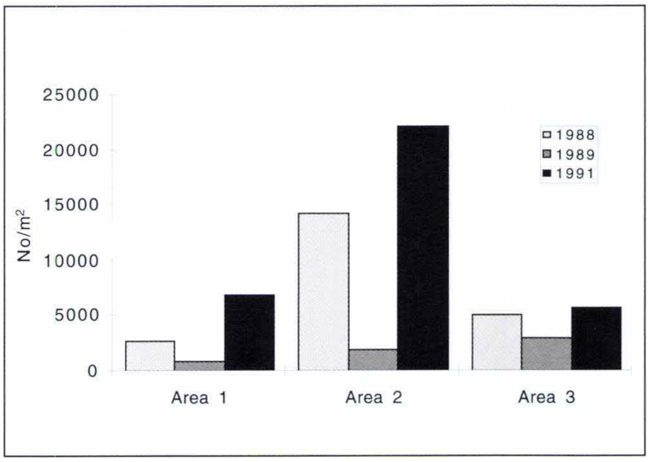



*Fig. 40. Total density of benthic invertebrates in the shore zone (0.5 m deep) on non-excavated sediments (areas 1 and 2) and on excavated sediments (area 3) in the Bygddelta, Myrkdalsvatn (from Raddum 1993).*

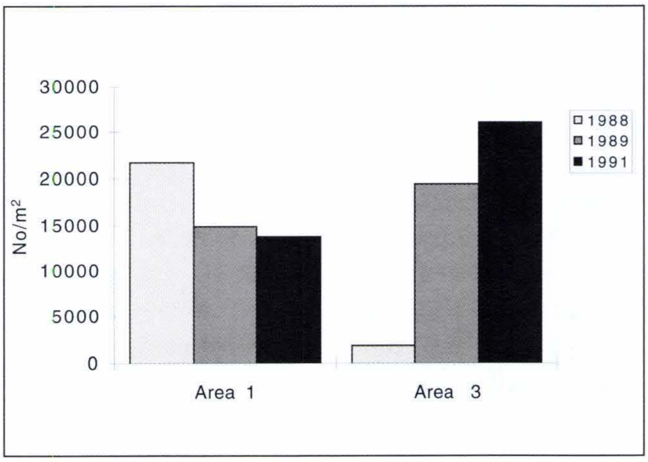



*Fig. 41. Total density of benthic invertebrates at a depth of 2 m in non-excavated sediments (Area 1) and in excavated sediments (Area 3) on the Bygddelta, Myrkdalsvatn (from Raddum 1993).*

*The excavated islands in the Myrkdalsvatn delta in the Vosso watercourse (photo: Jon Arne Eie).*

and there were huge numbers of oligochaetes. As in the shore zone, there was also a relative increase in the number of oligochaetes at a depth of two metres, although development was somewhat delayed.

The ratio of oligochaetes to chironomids showed values typical of eutrophic locations. Myrkdalsvatn is nutrient poor, so one would expect relatively higher proportions of chironomids than oligochaetes. The chironomid fauna is often reduced in situations where there is a rich supply of nutrients. Lowering the water level may have led to some rearrangement and the exposure of organic matter in shallow areas. The fauna has probably reacted to this, adopting a composition reminiscent of eutrophic conditions. This is probably temporary; the original habitat in which nutrients are in short supply is likely to return gradually. In 1991, the composition of fauna indicated changes were still taking place, and it was still too early to say anything definite about the final consequences that lowering the water level will have on the benthic communities in the area.

**The development of a channelized stretch of river**

Investigations conducted from 1969 to 1971 on the tributary that runs into Myrkdalsvatn indicated an abundance of animal life. This area was somewhat further up river than the area investigated after the lowering, so the results are not necessarily comparable. The first investigation registered nine species of stoneflies and four species of caddisflies. In the channelized section, four to seven species of stoneflies and two species of caddisflies were registered. Compared with previous investigations in the tributary and comparable investigations of rivers that have not been channelized, there are very few species and individuals in this area. All in all, it appears that the biodiversity and density of animal populations have been altered in the channelized tributary. Further studies can determine whether or not the situation is permanent.

### *7.2.4 The development of bird life*

Ornithological studies have focused on three main groups of wetland birds: ducks, waders and wetland passerines. It was expected that birds that prey on large aquatic insects would have more food organisms available in 1991 than in 1988 due to the increased amounts of these insects. Mayflies, especially the large species, are probably important food organisms both

*Aerial photo of the Lesjaleirene in 1991 after the completion of flood prevention measures (1976-1984) and the initiation of cultivation (photo: Per Jordhøy, Biofoto).*

as larvae and as adults. Oligochaetes and nematodes are probably less important food organisms as they are generally small and contain less nutrients than larvae and adult insects. They are also far less accessible.

Nine new bird species were registered in the area from 1987 to 1989: the greylag goose, the merlin, the oystercatcher, Temminck's stint, the wood sandpiper, the blackcap, the whitethroat, the siskin and the jay. As of 1989, a total of 85 bird species had been registered in the delta.

The number of established pairs of dabbling ducks, mallards, teal and wigeons, changed little. The survey indicated that there were fewer clutches of duck eggs laid, but there is little data to support this. The fact that the extensive sedge and horsetail meadows are now generally gone, severely reduces the delta's value as a moulting area. Dabbling ducks now used the delta very little during the moulting season, compared with previously. Diving ducks such as tufted ducks, red-breasted mergansers and goosanders were still few and far between, as was the case prior to lowering. It was positive that the goldeneye had moved into the area.

Lowering the water level led to a reduction in the nesting population of waders that prefer marshy meadows and verdant shore zones. The nesting population of redshanks dropped from ten to three or four pairs, and the nesting population of the common snipe was reduced by half to six or eight pairs. In the channelized section of the tributary, the volume of insects was reduced in terms of both species and individuals. Species such as the dipper probably found less food available after the encroachment. The same would be true of birds that normally catch insects at the water's edge. The population of waders such as lapwings and curlews increased somewhat. As for passerines, pied and white wagtails and bluethroats increased somewhat, while the population of whinchats was unstable. There was a slight decrease in reed buntings.

The construction of small-scale weirs in the area had undoubtedly created important lagoons for several species of ducks and waders. Common gulls began using one of the small man-made islands already the first year. As vegetation gains a foothold, other waders will probably also find these little islands good nesting places. The 1.5 to 2 m deep channels around the man-made islands reduce the risk of the birds being eaten by predators. With each passing year, the small islands have been increasingly used for feeding. For most birds, insects fauna is most accessible during emergence and as adult insects. High biodiversity, for

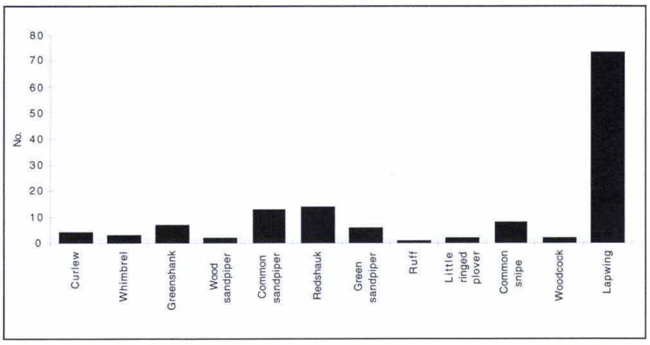



*Fig. 42. The number of registered territories for waders within a 10 km² area of study in Lesjaleirene during 1990 (from Jordhøy & Kålås 1992).*

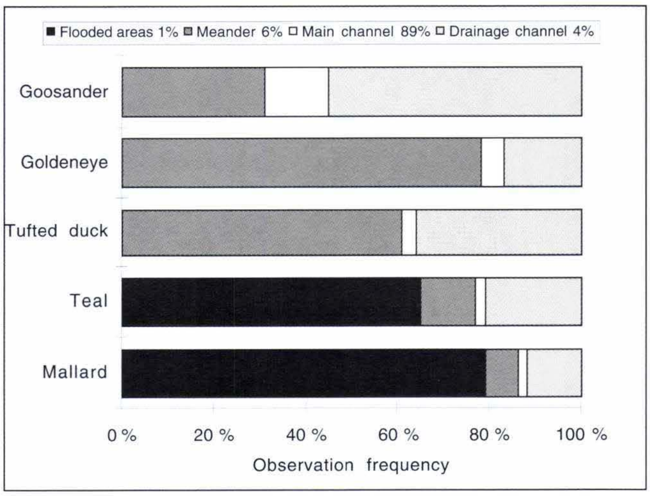



*Fig. 43. Calculated observation frequency per unit of shore and shallows area for some species of ducks in various types of watercourses (percentage of area) at Lesjaleirene during the period April-June 1986-1988 (from Jordhøy & Kålås 1992).*

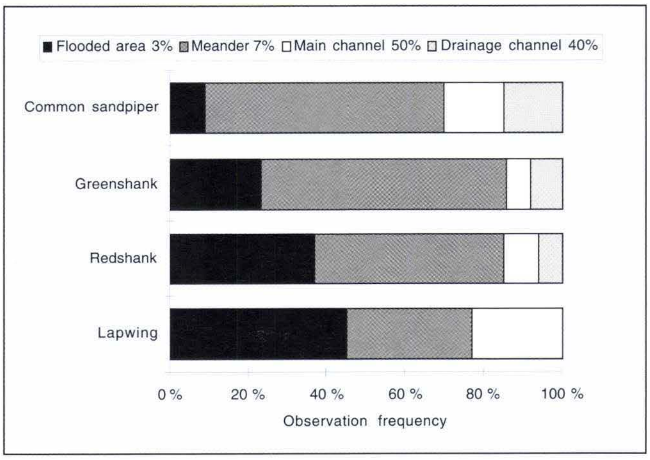



*Fig. 44. Calculated observation frequency per unit of water area for some species of waders in four different types of watercourses (percentage of area) at Lesjaleirene during the period April-June 1986-1988 (from Jordhøy & Kålås 1992).*

example many species of mayflies and stoneflies, means that there will be emergence of one or the other of these species at almost all times. This will stabilise the availability of food resources for the birds.

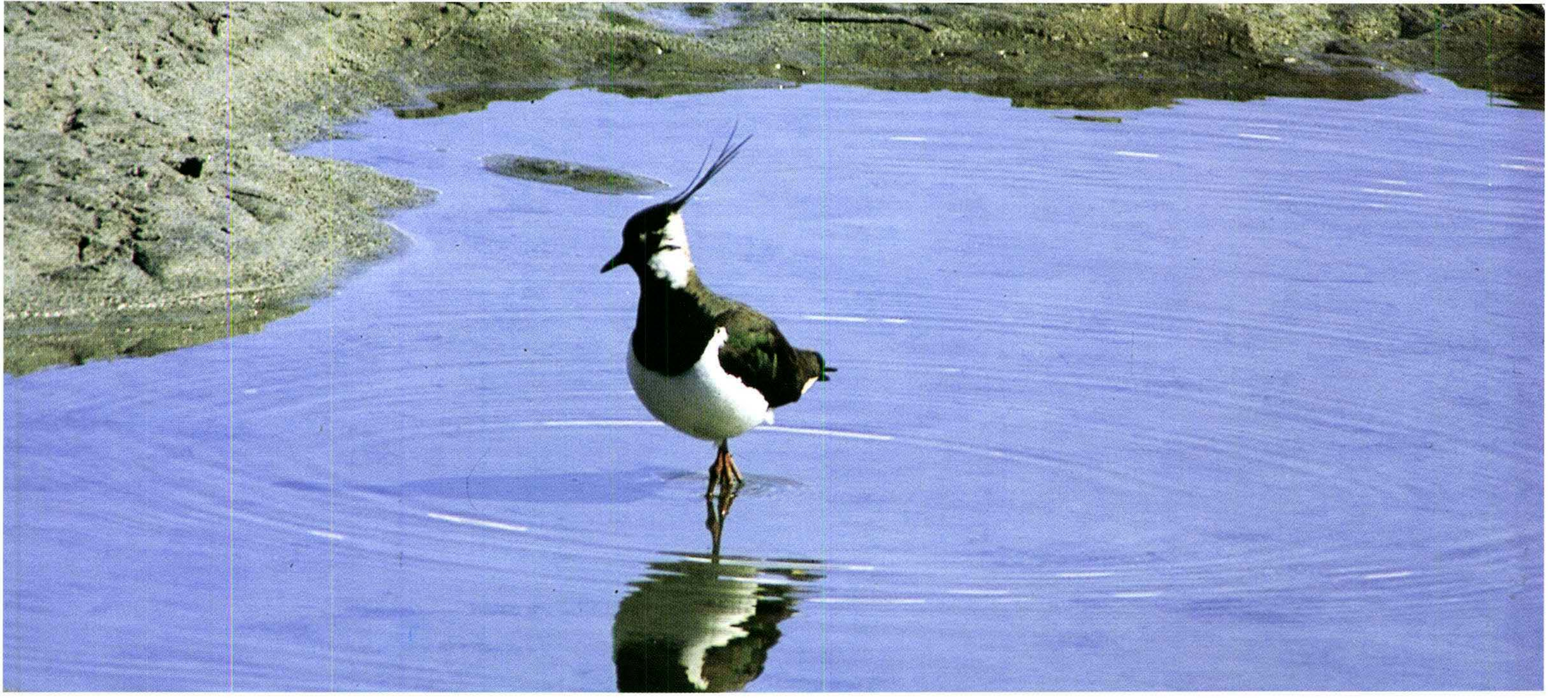
### 7.2.5 The situation at Lesjaleirene

The Lesjaleirene are a low-lying cultivated valley in the mountains that contains extensive habitats for game birds (see also Chapter 6 and Jordhøy & Kålås 1990). The area used to be given high priority as a bird conservation area and it is an important resting place for birds during their spring migration. In April, cultivated fields, particularly those that have been flooded, are important resting and feeding places for among others, ducks and geese. At that time of year, most watercourses are still covered by ice and snow and thus inaccessible to waterfowl. As May progresses and most of the later migratory birds, largely waders, arrive, and the ice has melted in most of the watercourses. Birds spread their autumn migration activities over a far longer period of time than their spring migration. However, water levels are extremely low in several watercourses at that time. Ducks especially dominate at this time.

As it stands today, Lesjaleirene has undergone major changes since the 1800s. The area was originally covered by a lake called, Siemsvatn, which was drained in the period 1857-1865. In recent years, the river has been channelized and the wetlands cultivated for hay production. Since 1963, vegetation typical of heather heaths, grazing meadows, wetlands and open habitats with low vegetation has lost a lot of ground. Deciduous, mixed and coniferous forests have changed little, all in all, but the area under cultivation has increased dramatically, from 4.7 to 46.5% of the total area. Channelization has eliminated the positive effect of flood waters on the remaining wetlands, and several old tributaries and meanders have been isolated. To obtain data on the consequences of drainage and cultivation on the population and diversity of nesting waterfowl and waders, scientific investigations were carried out and biotope measures from 1986 to 1991.

Bird life generally varies in accordance with the types and diversity/height of the vegetation. When vegetation changes, the bird life will also change. In the study areas at Lesjaleirene, 20 species of nesting passerines were registered during the period in question. Of those species, 10 were classified as commonly found in forests and five as commonly found on heaths.

None of the most common nesting species showed



*The lapwing is a common sight in the Lesjaleirene (photo: Per Jordhøy, Biofoto).*

a preference for cultivated fields. It was also interesting to note that shelter belts were not often used by passerines birds for nesting purposes. The decline in the total number of nesting passerines has probably been small as the forest areas have not changed much so far.

As for waders, it seems clear that the drainage and cultivation of wetland areas has led to an increase in density, but a decrease in the number of species. Twelve species of nesting waders were registered on the Lesjaleirene (Fig. 42). Altogether, these species comprised 40-50% of the total nesting population in the area under investigation.

The increase in agricultural area has had a favourable effect on the lapwing and, to some extent, on the redshank and curlew. These three species have increased in number, and the lapwing and redshank are by far the two most abundant species. As for the other waders, typical of wetlands and moors, there has been a decline in populations. Wetland and heath areas have been reduced by approximately 50%. The common snipe is common on the remaining wetland areas, but is rarely seen in cultivated areas.

There were clear differences among the three most common species of waders with regard to how they used the different types of waters (Fig. 43). The common sandpiper resorted less to flooded lands than the lapwing and redshank. Waders used the main watercourse somewhat more frequently than the some species of duck (Fig. 44), but the waders also used the closed meanders and tributaries most frequently.

Further cultivation would, in all likelihood, reduce biodiversity, since many of the residual populations are small. The ruff and wood sandpiper are particularly threatened, as they prefer marshlands and old, partially overgrown watercourses.

Ducks and other birds closely associated with watercourses per se, comprise a relatively large proportion of the total number of nesting birds in the Lesjaleirene. A total of 42 different species have been observed. The most common are the grey heron, the mallard, the teal, the tufted duck, the goosander, the lapwing, the redshank, the greenshank and the common sandpiper.

Various types of wetlands are good nesting and rearing areas for several species of birds. Ducks have strong preferences for different types of watercourses. Over the course of six years, it was found that dabbling ducks prefer flooded lands, while diving ducks such as the goldeneye and tufted duck use the closed meanders and tributaries, and goosanders prefer the drainage channels (Fig. 44). Thus the water content of the soil and watercourse structure exert a strong influence on the number of ducks in an area.

The isolated channels and meanders are the most productive areas. With a view to ensuring the best possible habitat for as many species of ducks and waders as possible, these areas are the most interesting in connection with biotope adjustment measures.

Following a local initiative, two weirs were built in the autumn of 1988 to maintain Lesjaleirene as an important wetlands area. One of the weirs was built in a meander channel and one in an isolated drainage channel. The weir in the channel increased the surface area of the water by about 100%. The weir in the meander stabilised the water at a higher level than previously. The result is that the two watercourses with weirs are now used by more waterfowl during their

*The little ringed plover is a rare species in the Lesjaleirene (photo: Per Jordhøy, Biofoto).*

*Weir basin in one of the channels in the Lesjaleirene (photo: Per Jordhøy, Biofoto).*

spring migration. These measures are expected to have an even more positive effect for nesting waterfowl, as the construction of weirs will result in more stable summer water levels.

*Flood prevention dykes along the Surna River in October 1992. To the left, earthworks intended to prevent the flooding of cultivated fields. The dyke is recessed slightly to retain the riverbank vegetation. Earth has been brought in to promote the establishment of new vegetation. Riparian vegetation is important for the addition of organic matter to the river, and thus for the production of fish food organisms in the watercourse (photo: Jon Arne Eie).*

## 7.3 The construction of bird biotopes in old meanders

Vasts areas of wetlands have been altered in recent decades and important bird biotopes have been lost, so it has been necessary to protect certain key habitats.

Numerous bird habitats were destroyed when the protected Søya watercourse in Nordmøre was channelized in 1987. Bird life in the 3.1 km$^2$ area around the mouth of the stream, Fossåa, where it flows in the Søya River, was surveyed prior to channelization and 81 species of birds were recorded. Of that number, 32 were definitely nesting and 28 were probably nesting.

The most important areas consisted of deciduous forest and a variety of different types of wetland areas. Passerines had the highest density of all the bird communities in the alder forests. There was also a large population of ducks in the river. Almost 90% of the duck observations were made in sheltered areas or small bays in the river. Several fairly rare species were observed in the region: the green sandpiper, Tengmalm's owl, the sedge warbler, the lesser whitethroat and the bluethroat. As for endangered species, the common crane and the white-backed woodpecker were seen more or less regularly.

One year after channelization and the cultivation of the adjacent areas, new surveys showed that six species had disappeared from the area: the goldeneye, the common crane, the kingfisher, the lesser spotted woodpecker, the yellow wagtail and the lesser whitethroat. The occurrence of ducks had been reduced by 36%. The mallard and the red-breasted merganser had the most severe reductions, while the teal, which utilizes ditches, had increased. The wader population remained stable, probably because the groundwater level in the marsher had remained the same.

In an attempt to create new habitats for birds and fish, an old meander that was in the process of becoming overgrown was excavated, and the Fossåa was diverted into it in order to increase water throughflow and prevent overgrowth. Although the measure did not have the intended effect, many other events took place in the area. For example, much of the alder forest was cut down and the area adjacent to the meander was put under the plough. The studies indicated clearly that if conditions are altered too radically, it will not be possible to maintain satisfactory habitat for many bird species.

*A meander in the Søya River soon after it was excavated in May 1987. Attempts were made to improve conditions for birds and fish by deepening the old meander and building man-made islands (photo: Jon Arne Eie).*

*The same meander in the Søya River after the forest was cut and fields cultivated. The area was no longer a good habitat for bird life (photo: Jon Arne Eie).*

# 8 Administrative and legal procedures for initiating biotope adjustment measures in Norway

Any type of measure or encroachment in a watercourse should never be undertake without contacting the authorities first. Different groups of users usually have different interests in watercourses. Even though one group may have the very best intentions, their actions can damage or cause inconvenience for another group, such as the landowner or the general public.

The following is a description of what should be done in Norway before initiating a biotope adjustment measure. As such measures are still relatively new, clear, co-ordinated guidelines are still lacking.

Biotope adjustment measures for fish include placing rocks/boulders in the watercourse, digging pools, building weirs, etc. Such measures call for professional evaluation. Among other things, it must be determined whether the planned measure will have a positive effect on the overall production of fish. The county governor's environmental protection section, either the watercourse manager or the fisheries manager, must be contacted early on in the planning stage. They are able to provide advice and guidance about whether the measure should be implemented and, if so, how it should be done. Many municipalities have environmental experts available for consultations.

Measures to adjust watercourse biotopes will almost always require technical assessment, for example, to determine whether the measure might have a damming effect, particularly during floods, or whether it could put an area in danger of a landslide or cause increased erosion that might cause wash out and affect areas further downstream. Ice conditions must also be taken into account in many watercourses. The Norwegian Water Resources and Energy Administration (NVE) has considerable expertise in such questions, and either their head office in Oslo or one of their five regional offices can be contacted.

During the planning stage, it is therefore necessary to establish cooperation between NVE, the county governor and the municipality. Although this may sound like a difficult, cumbersome process, these agencies contribute useful advice and points of view with regard to the measures in question.

Pursuant to the Act of 1992 related to Salmon Fishing and Inland Fishing, Norway's Ministry of Environment has issued regulations about technical fish-promoting measures and watercourse encroachments. There are general prohibitions against:

a. Physical measures that could cause demonstrable deterioration in the production conditions for fish or other freshwater organisms.
b. Measures in and along watercourses, including the construction of weirs, excavation of pools and deployment of boulders, that could increase the catch of fish at a site or shift the longitudinal distribution of fish in the watercourse.
c. Technical measures intended to alter one or several species' production, population or distribution.

The prohibitions mentioned under a. and b. apply regardless of the objective of the measure.

In most cases, the Watercourse Act does not require that one has a permit for biotope adjustment measures. However, the county governor is the authority that recommends whether or not a measure requires a permit pursuant to the Watercourse Act. If the planned measure is comprehensive, it may be necessary to obtain a permit, in which case NVE is the issuing authority. NVE has drawn up guidelines for applications to make minor changes in watercourses. Before deciding whether an encroachment requires a permit pursuant to §§104-106 of the Watercourse Act, NVE will review the advantages and disadvantages of the measure. It is worth noting that permits are usually required to implement measures in watercourses that are protected from hydropower development.

# SELECTED REFERENCES

Arnekleiv, J.V. 1993. Fish stocks in new and old weir basins in the Nea. In: Brittain, J.E. & Eie, J.A. (Eds). The Biotope Adjustment Programme - status 1992. NVE publication No. 15: 16-19. (In Norwegian)

Bækken, T., Fjellheim, A., Larsen, R. & Otto, C. 1981. Vegetational energy budget of a weir basin in western Norway. Arch. Hydrobiol. 91: 351-365.

Bækken, T., Fjellheim, A. & Larsen, R. 1981. Seasonal fluctuations of physical and chemical parameters of a weir basin in a regulated west Norwegian river. Nordic Hydrol. 12: 31-42.

Bækken, T., Fjellheim, A. & Larsen, R. 1984. Benthic animal production in a weir basin area in western Norway. In: Lillehammer, A. & Saltveit, S.J. (Eds). Regulated Rivers. Universitetsforlaget, Oslo. pp. 223-232.

Brandrud, T.E., Mjelde, M. & Lindstrøm, E.A. 1992. The overgrowth of aquatic vegetation in weir basins in the rivers, Eksingedalselva, Hallingdalselva and Skjoma. Scope, causes and measures. NIVA report 0-90136. (In Norwegian)

Brittain, J.E., Eie, J.A., Brabrand, Å, Saltveit, S.J. & Heggenes, J. 1993. Improvement of fish habitat in a Norwegian river channelization scheme. Regul. Rivers 8: 189-194.

Brittain, J.E. & L'Abée-Lund, J.H. 1995. The environmental effects of dams and strategies for reducing their impact. In: Santbergen, L. & Van Western, C-J. (Eds). Reservoirs in River Basin Development, Balkema, Rotterdam. pp. 129-138.

Brittain, J.E., Saltveit, S.J., Arnekleiv, J.V., Hvidsten, N.A. & Johnsen, B.O. 1993. Rock deployment in rivers and streams; effects on the benthos and fish. In: Faugli, P.E., Erlandsen, A.H. & Eikenæs, O. (Eds). Watercourse encroachments, consequences and measures - a summary of knowledge. NVE publication No. 13: 511-533. (In Norwegian)

Eie, J.A. & Brittain, J.E. 1994. Making hydroelectric projects fit their surroundings. Hydro Rev. Worldwide 2(1): 20-23.

Evensen, T.H. 1984. Migration of brown trout (*Salmo trutta* L.) at a weir basin in a regulated river in western Norway. In: Lillehammer, A. & Saltveit S.J. (Eds) Regulated rivers. Universitetsforlaget, Oslo. pp. 321-327.

Faugli, P.E., Erlandsen, A.H. & Eikenæs, O. (Eds). 1993. Watercourse encroachments: consequences and remedial measures - a summary of our knowledge. NVE publication No. 13. 639 pp. 2 vols. (In Norwegian).

Fjellheim, A. & Raddum, G.G. 1996. Weir building in a regulated west Norwegian river: long-term dynamics of invertebrates and fish. Regul. Rivers 12: 501-508.

Fjellheim, A., Raddum, G. G. & Schnell, Ø. A. 1989. Changes in benthic animal production of a weir basin after eight years of succession. Regul. Rivers 3: 183 - 190.

Fjellheim, A., Håvardstun, J., Raddum, G. G. & Schnell, Ø. A. 1993. Effects of increased discharge on the yearly productivity of benthic invertebrates in a regulated river. Regul. Rivers 8: 179-187.

Fjellheim, A. & Raddum, G. G. 1994. Stocking experiments with wild brown trout (*Salmo trutta*) from a regulated river in two mountain reservoirs. In: Cowx, I. G. (Ed). Rehabilitation of inland fisheries. Fishing News Books, Blackwell Scientific Publications, Oxford. pp. 268 - 279.

Heggberget, T.G., Hvidsten, N.A., Jensen, A.J., Johnsen, B.O. & Saksgård, L. 1993. Fish in salmon rivers. In: Faugli, P.E., Erlandsen, A.H. & Eikenæs, O. (Eds). Watercourse encroachments, consequences and measures - a summary of knowledge. NVE publication No. 13: 262-279. (In Norwegian).

Håland, A. 1993. Birds. In: Faugli, P.E., Erlandsen, A.H. & Eikenæs, O. (Eds). Watercourse encroachments, consequences and measures - a summary of knowledge. NVE publication No. 13: 311-349. (In Norwegian)

Heggenes, J., Krogh, O.M.W., Lindås, O.R., Dokk, J.G. & Bremnes, T. 1993. Homeostatic behavioural responses in a changing environment: brown trout (*Salmo trutta*) become nocturnal during winter. J. Anim. Ecol. 62: 295-308.

Hvidsten, N.A. & Johnsen, B.O. 1992. River bed construction: impact and habitat restoration for juvenile Atlantic salmon, *Salmo salar* L., and brown trout, *Salmo trutta* L. Aquacult. Fish. Mgmt. 23: 489-498.

Jordhøy, P. & Kålås, J.A. 1990. Effects on passerine bird communities of changed land use at a high altitude area in Central Norway. Proc. 20th Int. Congr. Ornithol., Christchurch, New Zealand.

Kaasa, H. 1993. The effects of fish improvement measures in salmon streams. In: Faugli, P.E., Erlandsen, A.H. & Eikenæs, O. (Eds). Watercourse encroachments, consequences and measures - a summary of knowledge. NVE publication No. 13: 591-606. (In Norwegian).

Koksvik, J.I. 1992. The trout in Lake Innerdal from 1982 to 1989. In: Berg, G. & Faugli, P.E. (Eds). R. & D. project in Orkla. Meeting to summarise the project. NVE publication No. 2: 157-175. (In Norwegian).

Linløkken, A. & Solvang, H. 1994. The effect of biotope adjustment measures in the Letjenna at Elverum. Report from the Glomma Project, No. 13. (In Norwegian).

Mellquist, P. 1985. Life in Regulated Rivers. NVE, Kraft og Miljø 10. 58 pp.

Nilsson, C. & Brittain, J.E. (Eds). 1996. Remedial strategies in regulated rivers. Regul. Rivers 12: 345-561.

Odland, A. 1992. Delta vegetation sucession from from 1987 to 1991, following permanent drawdown of Myrkdalsvatn lake, Voss, Western Norway. NINA Report 113: 1-36. (In Norwegian; English abstract).

Odland, A. 1993. The restoration of wetlands and vegetation. In: Faugli, P.E., Erlandsen, A.H. & Eikenæs, O. (Eds). Watercourse encroachments, consequences and measures - a summary of knowledge. NVE publication No. 13: 534-546. (In Norwegian).

Qvenild, T. & Linløkken, A. 1989. Glomma - fish and regulation. Final report from the Glomma Project. (In Norwegian). 62 pp.

Raastad, J.E., Lillehammer, A., Lillehammer, L., Kaasa, H. & Eie, J.A. 1993. Effect of habitat improvement on Atlantic salmon in the regulated River Suldalslågen. Regul. Rivers 8: 95-102.

Raddum, G.G. 1993. Weir investigations in the Eksingedalen Valley. The production of salmon smolt in strongly regulated stretches of river featuring a weir dam. In: Brittain, J.E. & Eie, J.A. (Eds). The Biotope Adjustment Programme - status 1992. NVE publication No. 15: 9-13. (In Norwegian).

Raddum, G. G. & Fjellheim, A. 1995. Artificial deposition of eggs of Atlantic salmon (*Salmo salar* L.) in a regulated Norwegian river: hatching, dispersal and growth of the fry. Regul. Rivers 10: 169-180.

Raddum, G. G., Fjellheim, A., & Sægrov, H. 1989. Removal of brown trout (*Salmo trutta* L.): changes in population dynamics in a weir basin in western Norway. - Regul. Rivers 3: 225 - 233.

Reitan, O. 1993. Biotope adjustment measures in the Innerdal Reservoir. Bird studies. In: Brittain, J.E. & L'Abée-Lund, J.H. (Eds). Biotope Adjustment Programme - Status 1992. NVE publication No. 15: 34-38. (In Norwegian).

Reitan, O. 1997. Responses of birds to habitat disturbances due to damming. Dr. scient. thesis, Department of Zoology, Norwegian University of Science and Technology, Trondheim.

Reitan, O. & Kålås, J.A. 1993. The restoration of wetlands areas - birds. In: Faugli, P.E., Erlandsen, A.H. & Eikenæs, O. (Eds). Watercourse encroachments, consequences and measures - a summary of knowledge. NVE publication No. 13: 547-568. (In Norwegian).

Reitan, O. & Sandvik, J. 1996. An assessment of retaining dams in hydropower reservoirs for enhancing bird habitat. Regul. Rivers 12: 523-534.

Rørslett, B., Brandrud, T.E. & Johansen, S.W. 1990. Overgrowth in weir basins in the Otra River near Valle. An analysis of the problem and proposal for remedial measures. NIVA Report 0-88033. (In Norwegian).

Rørslett, B. & Johansen, S.W. 1996. Remedial measures connected with aquatic macrophytes in Norwegian regulated rivers and reservoirs. Regul. Rivers 12: 509-522.

Rørslett, B., Johansen, S.W. & Singsaas, S. 1993. The establishment of vegetation in drawdown zones. In: Faugli, P.E., Erlandsen, A.H. & Eikenæs, O. (Eds). Watercourse encroachments, consequences and measures - a summary of knowledge. NVE publication No. 13: 569-590. (In Norwegian).

# Reports from the Weir Project and the Biotope Adjustment Programme


1) Mellquist, P. 1976. The weir project - general information. 47 pp.

2) Michaelsen, J. & Ree, V. 1976. Census of the bird fauna along the Hallingdalselva during the period 1 May - 1 August 1975. 39 pp.

3) Råd, O. & Angell-Jacobsen, B. 1976. The bird fauna in weirs along the Eksingeldal watercourse during the summer of 1975. 18 pp.

4) Borgstrøm, R. 1976. The trout population in the river Mørkedøla before the construction of weirs. 29 pp.

5) Heggberget, T.G. 1977. Population of young salmon and trout in the river Skjoma before building of weirs. 42 pp.

6) Larsen, R. 1977. Migration, population size, growth and nutriment of brown trout (*Salmo trutta* L.) in the river, Eksingedalselva, western Norway, before regulation of the river. 31 pp.

7) Aass, P. 1978. Age, growth, stocking and yield of brown trout in river, Hallingdalselva, at Gol, east Norway. 42 pp.

8) Raastad, J.E. 1979. Investigations of the bottom fauna of regulated rivers, with special emphasis on black-flies, (Diptera, Simuliidae). 62 pp.

9) Langeland, A. & Haukebø, T. 1979. Trout, burbot and bottom invertebrates in the river Nea, central Norway, before building of weirs. 56 pp.

10) Bækken, T., Fjellheim, A., Larsen, R. & Otto, C. 1979. Input and output of organic materials to the weir basin at Ekse, Eksingedalen. 38 pp.

11) Fredriksen, K. S. 1980. A survey of vegetation in the upper catchment area of the river Eksingedalselven, western Norway. 28 pp.

12) Evensen, T.H. 1981. Migration of brown trout (*Salmo trutta* L.) in the upper part of the river Eksingedalselva. 37 pp.

13) Bækken, T., Fjellheim, A. & Larsen, R. 1981. Benthic studies in the Eksingedalen river at Ekse after regulation and weir-building. 47 pp.

14) Bækken, T., Fjellheim, A. & Larsen, R. 1981. Drift of benthic animals into and out of the weir basin at Ekse in the river, Eksingedalselva. 37 pp.

15) Bækken, T., Fjellheim, A. & Larsen, R. 1981. Benthic production in the Eksingedalen river at Ekse after regulation and weir-building. 32 pp.

16) Bækken, T., Fjellheim, A. & Larsen, R. 1981. Physical and chemical parameters at the inlet and outlet of the weir basin at Ekse, Eksingedalen. 33 pp.

17) Borgstrøm, R. 1981. The population of brown trout (*Salmo trutta* L.) in the river, Mørkedøla during and after construction of weirs. 25 pp.

18) Aass, P. 1981. The brown trout fishery of the river Hemsil, eastern Norway, 1979. 50 pp.

19) Heggberget, T.G. 1982. Presmolt Atlantic salmon (*Salmo salar* L.) and brown trout (*Salmo trutta* L.) after hydro-electric development and building of weirs in the river Skjoma, north Norway. 70 pp.

20) Hagala, Y. 1983. Egg production, density, mortality and growth of brown trout younger than 3 years (*Salmo trutta* L.) at Ekse, in the river, Eksingedalselva. 47 pp.

21) Andersen, T. F. 1983. Density and mortality of brown trout (*Salmo trutta* L.) older than 2 years, at Ekse, in the river, Eksingedalselva. 54pp.

22) Aass, P. 1983. The brown trout of the rivers,

Hallingdalselva and Hemsil, eastern Norway: age, growth, food and migration. 48 pp.

23) Raastad, J.E. 1983. The effect of weirs on macrobenthos in regulated rivers, with special emphasis on black-flies (Diptera, Simuliidae). 98 pp.

24) Korsen, I. 1984. Atlantic salmon (*Salmo salar* L.) and brown trout (*Salmo trutta* L.) in the river Todalselva, west Norway, after hydro-electric development and building of weirs. 38 pp.

25) Lid, G. & Schandy, T. 1984. The occurence of goosander *(Mergus merganser)* and its choice of food in the river Hallingdalselva near Gol. 30 pp.

26) Navrud, S. 1987. Economic evaluation of recreational fishing in the river, Hallingdalselva. 121 pp.

27) Fjellheim, A., Karlsen, L.R. & Raddum, G.G. 1987. The bottom fauna in the river, Eksingedalselva at Ekse: a comparison of the conditions 3 and 11 years after building of weirs. 46 pp.

28) Arnekleiv, J.V.1988. Fish populations and benthos in the river Nea after construction of weirs. 35 pp.

29) Andersen, T. & Kleiven, E. 1988. Changes in the trout population at Ekse from 1976 to 1983. 48 pp.

30) Karlsen, L.R. 1988. Food consumption by brown trout (*Salmo trutta* L.) in relation to the available food in the regulated river, Eksingedalselva. 51 pp.

31) Eie, J.A. & Brittain, J.E. (Eds) 1989. Eksingedalen: hydropower development - research - management, past, present - future. 155 pp.

32) Bremseth, G. & Berg, O.K. 1991. Studies of young Atlantic salmon and brown trout in the deeper parts of rivers. 73 pp.

33) Fjellheim, A., Håvardstun, J., Raddum, G.G. & Schnell, Ø.A. 1992. The effects of increased discharge on the benthic animal community of the river, Eksingedalselva, western Norway. 36 pp.

34) Jordhøy, P. & Kålås, J.A.. 1992. The effects of flood prevention measures, drainage and land reclamation on the bird fauna of the wetland area, Lesjaleirene. 80 pp.

35) Raddum, G.G. 1993. Studies of the benthic fauna of the delta of the lake, Myrkdalsvatn, after lowering of the water level. 23 pp.

36) Brandrud, T.E.. & Mjelde, M. 1996. Studies of aquatic vegetation in the Lesjaleirene, Oppland county, 1989-94. 15 pp.

37) Bremnes, T. & Sloreid, S.E. 1997. Development of the oligochaete community in a weir basin in the river, Eksingedalselva, Hordaland. 68 pp.

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