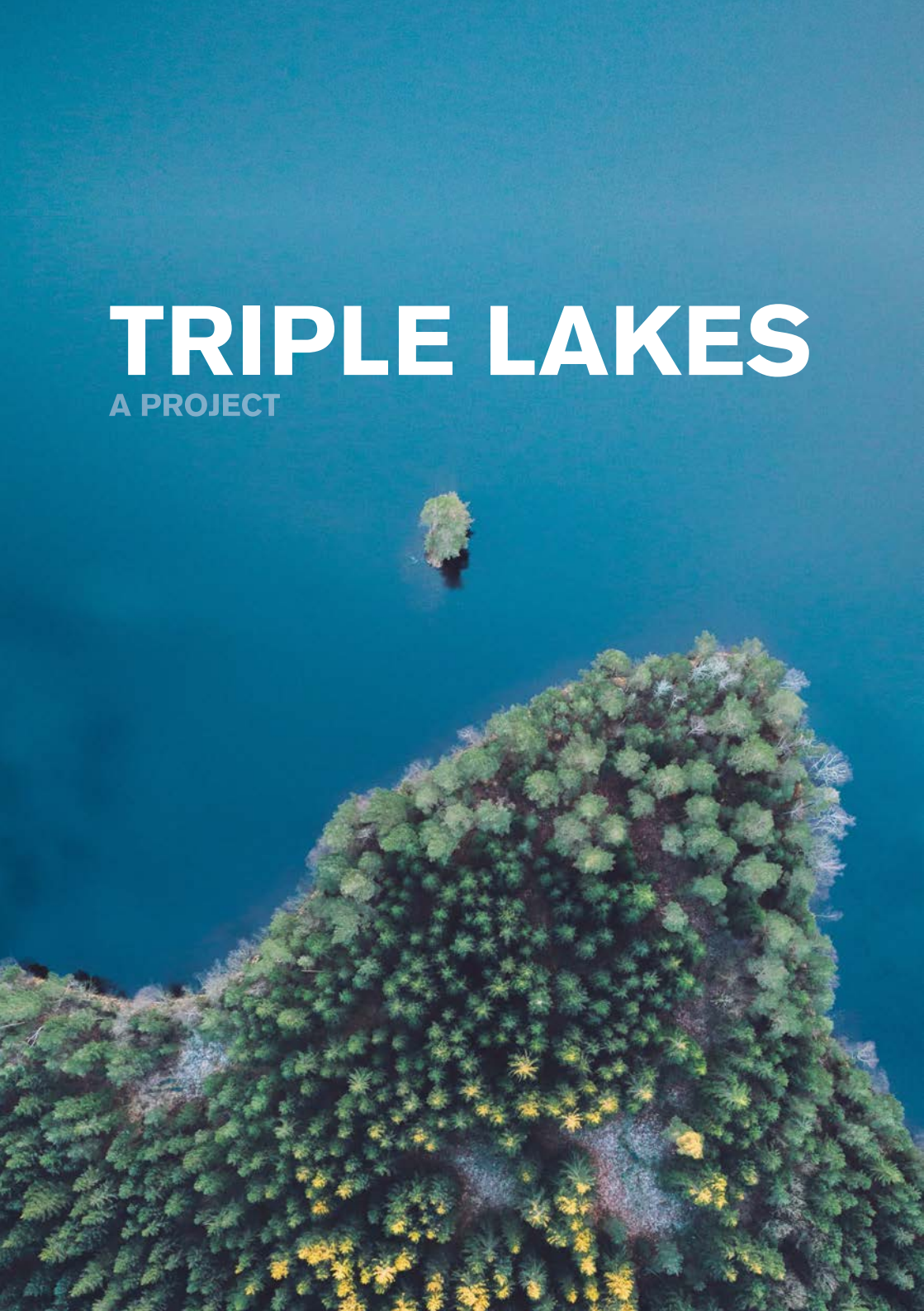
# TRIPLE LAKES

A PROJECT



**PUBLISHED BY:** Länsstyrelsen Jämtlands län, 2019
**RESPONSIBLE:** Malin Bernhardsson
**TEXTS:** Gunnar Öhlund, Lennart Henriksson, Ingemar Näslund, Ingemar Näslund och Per Byström, Ann-Kristin Eriksson, Pierre Samuelsson and Malin Bernhardsson
**PHOTO:** Lars Häreblad, Mikael Sundberg, Ingemar Näslund, Nils J Nilsson /Jamtlis fotosamlingar, SLU - Historiska skogsbilder, Johannes Poignant, Magdalena Thorsbrink, Fjellfotografen, Gettyimages, Shutterstock and Länsstyrelsen Jämtland
**ILLUSTRATIONS:** Lotta Ström, Tobias Flygar, Bo Persson, Martin Holmer
**GRAPHIC DESIGN:** Idermark och Lagerwall Reklam
**PRINT:** TMG Tabergs, 2019
**SERIAL NUMBER:** 2019-38
**DOWLOAD PUBLICATION:**
lansstyrelsen.se/jamtland and triplelakes.se

# CONTENT:

A project for cleaner water ..... 5
The Arctic char lakes of the forest ..... 10
Water - the mirror and conscience of the landscape ..... 20
Fishing in the past and in the present ..... 32
Forest and water belong together ..... 46
Lakes and climate change - what is happening? ..... 62
Management and protection of Arctic char ..... 76
The future ..... 84

# A PROJECT FOR CLEANER WATER


For several decades, the County Administrative Board of Jämtland has been working to strengthen and look after the aquatic environments in the county. Efforts have included both substantial restoration work after the damage caused by log driving and extensive liming and environmental monitoring. This work has been conducted in a dispersed fashion throughout Jämtland county, based on the availability of funding for the various measures. Consequently, we have not often been able to take a holistic approach to several environmental problems in a larger area, such as an entire aquatic system.

At the same time as we were considering more systematically working with the environmental problems affecting our water, we were made aware by those working with fishery conservation areas, as well as other stakeholders, of signs of reduced or changing fish populations, clogging of lakes and other problems. It was not long before questions were asked as to whether these changes were a response to the cumulative effect of various sources or whether it was the impact of a warmer climate that caused the problems.

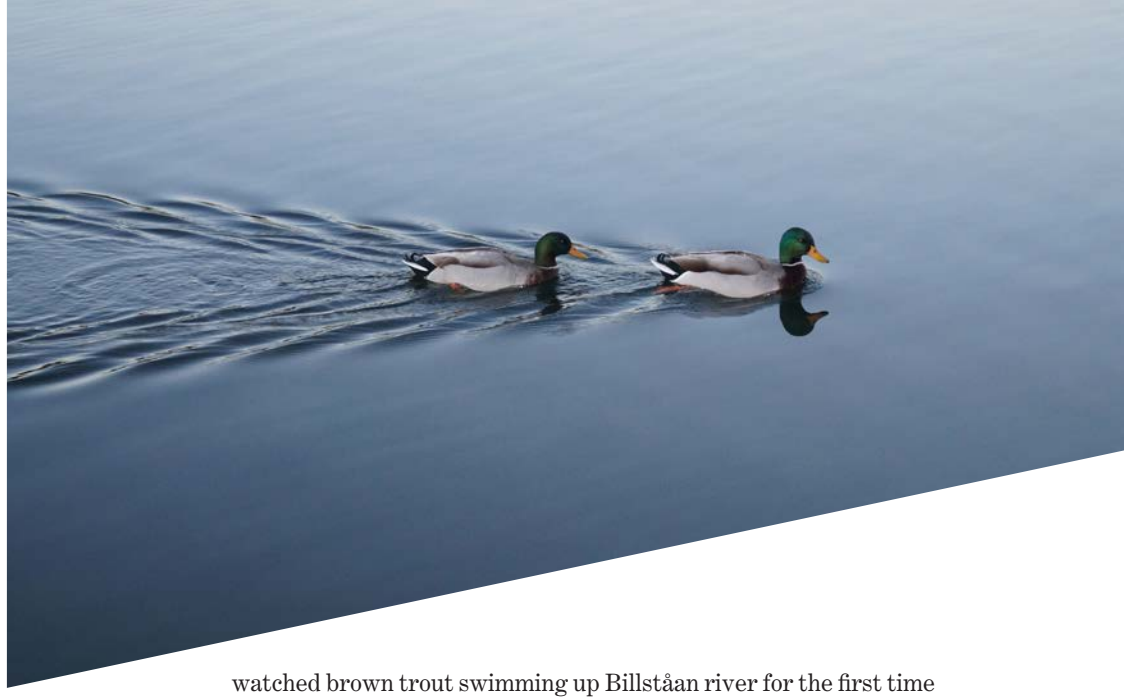
This is where our thoughts on a larger, more extensive water conservation project started to take shape. By bringing together many stakeholders with an interest in or impact on the water with-

in a watershed, we wanted to improve the aquatic environments from a holistic perspective.

Of all the county's lovely lakes, our thoughts finally came together around three of the finest gems - Näkten, Locknesjön and Revsundsjön. The actions, which encompassed both traditional restoration of watercourses as well as enhancing the population of Arctic char, and measures at dams and on land in the watershed, meant that we were forced to look beyond our traditional funding framework.

So we set our sights on the EU's funding programme for the environment, LIFE, and after a long application process, the European Commission accepted our application in 2014. The Triple Lakes project was thus conceived. It aimed at reducing both the historical and present environmental impact through concrete, physical improvements of the habitats and different species' circumstances, as well as dialogue around the need for water conservation in land use. It was time to reverse the negative trends and maintain and strengthen the ecosystems of our lakes and their tributaries for the long term.

We commenced the work in autumn 2014, with ambitious goals and a broad spectrum of actions with which to work. Now looking back over five years of work, we can see that we have achieved a lot. We have restored the habitats of some thirty watercourses,



watched brown trout swimming up Billståan river for the first time in a hundred years, contributed to better purification of sewage and actually succeeded in raising the awareness of the importance of clean water and good habitats for fish and other animals in watercourses and lakes.

It is often the case that when learning new things in a particular area, one's awareness and humility about how much one does not know increases. In the same way, as we have gone deeper into this project we have discovered more areas and possible ways of working towards better water. Sometimes, the flexibility of the project has allowed us to include new approaches into the project work, but sometimes we have also had to leave things be, either due to the scope of the project, the County Administrative Board's scope or conflicts of interest. There are plenty of conflicts of interest when it comes to water, which demonstrates how important water is and what a huge significance it has for us.

In the county we live in, we are spoiled beyond all limits when it comes to water. There is an excessive abundance of it. And we have used it through the ages, in whatever way was possible at the time. However far back we go in our history, we have always lived

near water in this part of the world. It is no coincidence that the relics of old settlements remain scattered along the rivers. Rivers provided drinking water, fish, a means of travel, and over time energy for mills, sawmills, textile stamping mills and so on, until today's modern power stations.

But by using water we have also affected it. Both the chemical composition of water and the physical shape of the watercourses have been affected by humans and how we have used watercourses in particular. In chapter three you can read about how we investigated the water quality of the three lakes we worked with. The results show that we have great and valuable water, but there are also signs that we should not take them for granted.

It may be that awareness that we should not take our water for granted could go a long way towards making sure we retain clear, clean water in our lakes well into the future. Sometimes it doesn't require more effort than that. Planning forest felling a little differently, or leaving deciduous trees along waterways because leaves are important for fish are some examples of ways to consider water in the forest. In chapter five, Lennart Henriksson writes about this and much more on forests and water and how we humans can reduce our impact.

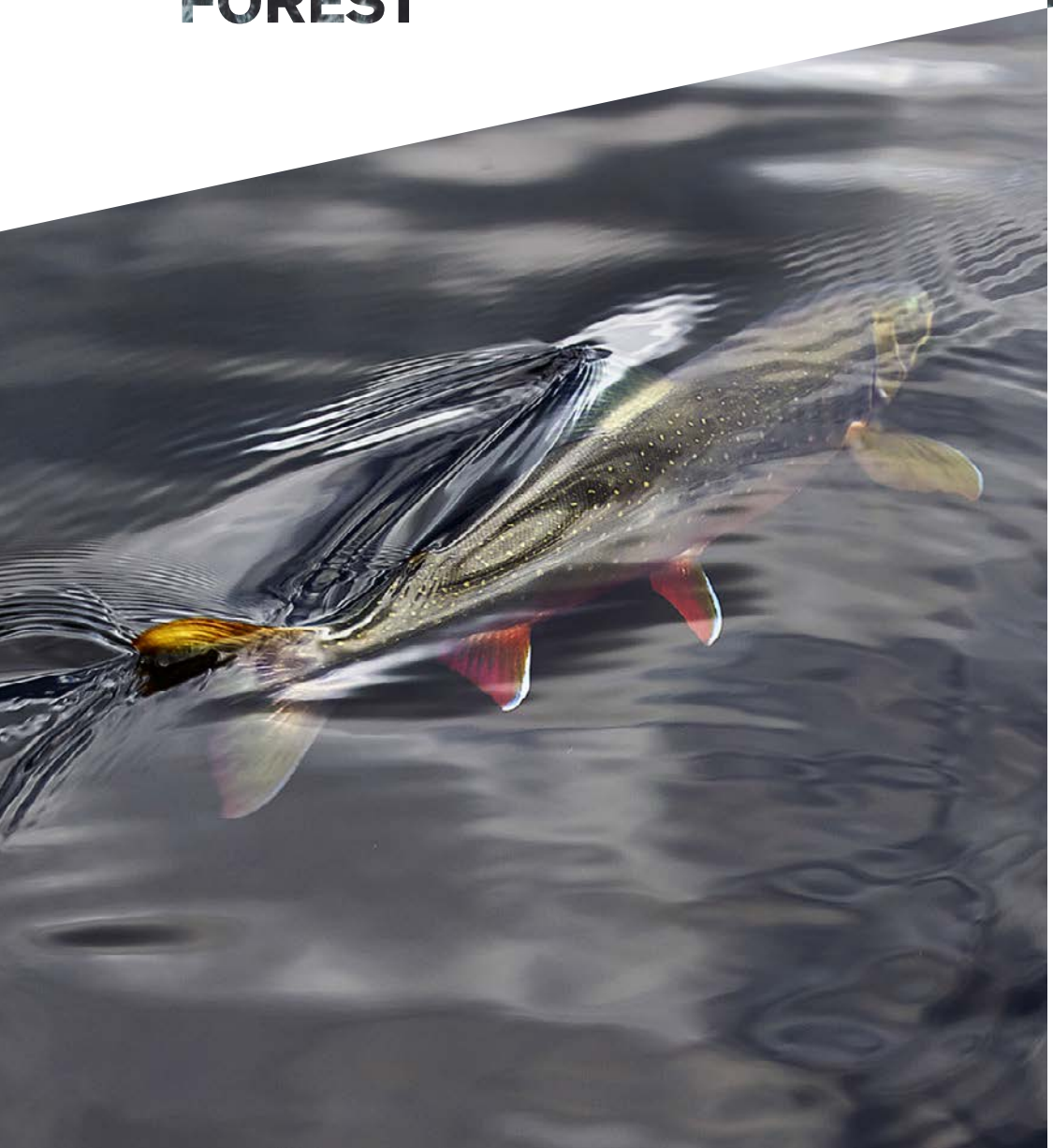
That there is fish in our lakes is also something we often take for granted. The Arctic char ended up playing a central role in the Triple Lakes project. It is a species that has always been important in Näkten and Locknesjön, our two Arctic char lakes. Both for the fishing, which Ingemar Näslund writes more about in chapter four, but also as an important part of the lake's own ecosystem. How different species interact with each other below the surface, why there is even Arctic char in these forest lakes, and why the pike comes into the picture like some kind of dark horse is what Gunnar Öhlund writes about in chapter two.

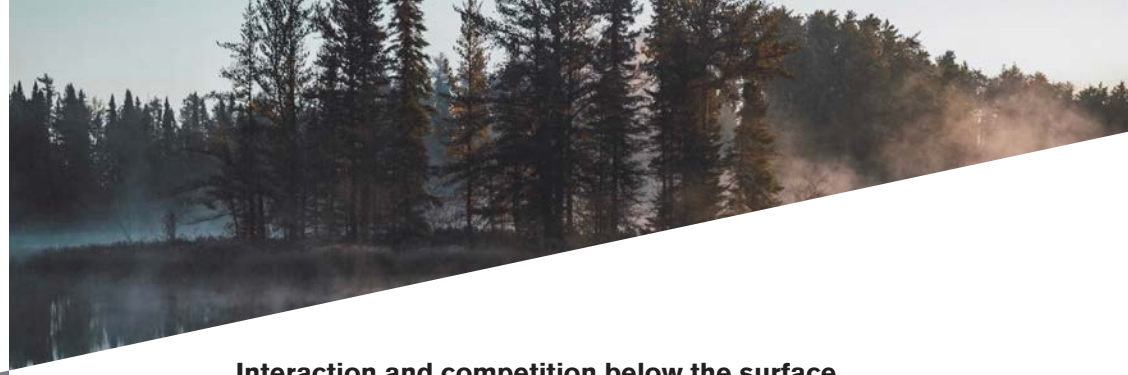
The majority of the project's work can be linked to the Arctic char - even though other species have been the target of several activities. As an example, restoring watercourses slows down the water, which reduces the transportation of nutrients and organic material to the lakes, where the Arctic char needs clear water to be able to hunt. But the future of the Arctic char also depends on how the climate develops. As a cold-water fish, it does not thrive in higher temperatures and with current developments, the Arctic char's future looks uncertain. In the seventh chapter of the book we go through what we know about how the ecology and interaction between species in our lakes are likely to be impacted by higher temperatures.

Understanding the Arctic char's place in the ecosystem, its needs and how it is impacted by fishing, regulation and other activities in and around the lake, is essential if we are to manage the population in the best way, also from a climate perspective. The form such management may take in the future can feel somewhat vague since many fishery conservation areas have a hard time running their operations as the number of residents in the area is falling, as is involvement in non-profit and voluntary work. Ingemar Näslund reflects more on this subject in the last chapter of the book.

Work towards better water is ongoing, but through this book we are putting the final touches to project Triple Lakes. The book gathers the experience from the work of the project and issues that have arisen during the process. Based on the ambitions of the project to reverse negative trends and maintain and strengthen the ecosystems of our lakes and their tributaries for the long term, we believe we have actually made good progress. As mentioned however, the work constantly gives rise to new questions and highlights the fact that there is more work to be done. So, we wish you happy reading! We hope you find the book interesting and that it also awakens an interest in you to experience the waters that we have had the honour of working with.

# THE ARCTIC CHAR LAKES OF THE FOREST





## Interaction and competition below the surface

For many people, it's Easter ice-fishing trips, which in all honesty often deliver more hours of sunshine than Arctic char catches. For others, it's perhaps their childhood net fishing moments with grandfather in his mountain village, or summer hikes to that tarn full of Arctic char high up in the mountains. Irrespective of how we may have come across the Arctic char, for most of us it has a strong connection to mountain lakes. But there are exceptions; those low-altitude forest lakes where the Arctic char not only thrives, it actually grows really large. Why are those fantastic big Arctic char swimming around in Näkten and Locknesjön lakes? How do they get by amongst the pike and perch, and in a changing climate? In this chapter, we summarise what we know and do not know about northern Sweden's boreal lakes that are home to large-sized Arctic char.

## Distribution/classification

The Arctic char is an incredibly multi-shaped fish that can appear in completely different forms depending on where and how it lives. Certain Arctic char populations are extremely small and live exclusively on zooplankton or small benthos, while others become distinctive predatory fish that can reach a maximum weight of more than 10kg. Additionally, in some lakes there are several types of Arctic char with different spawning grounds, choice of food and growth patterns. Early genetic studies suggest that this diversity in shape reflects the immigration history of the Arctic char - i.e. that the different types of Arctic char we see today represent different sibling species that have immigrated at different time

periods following the Ice Age. Today, the majority of researchers believe that the Arctic char's diversity in shape largely arose after their immigration, in response to the local conditions of the lakes in which they live. Whatever the reason, what we do know is that the rare forest Arctic char often grows very large in size and this is because they switch to a fish diet to a greater extent than their relatives in the mountains.

This can seem somewhat confusing at first. The fact that the Arctic char grows well should mean that boreal lakes are suitable Arctic char environments, so why hasn't the Arctic char spread to more lakes then? To understand it all, we first need to take a closer look at how the Arctic char co-exists with other species of fish.

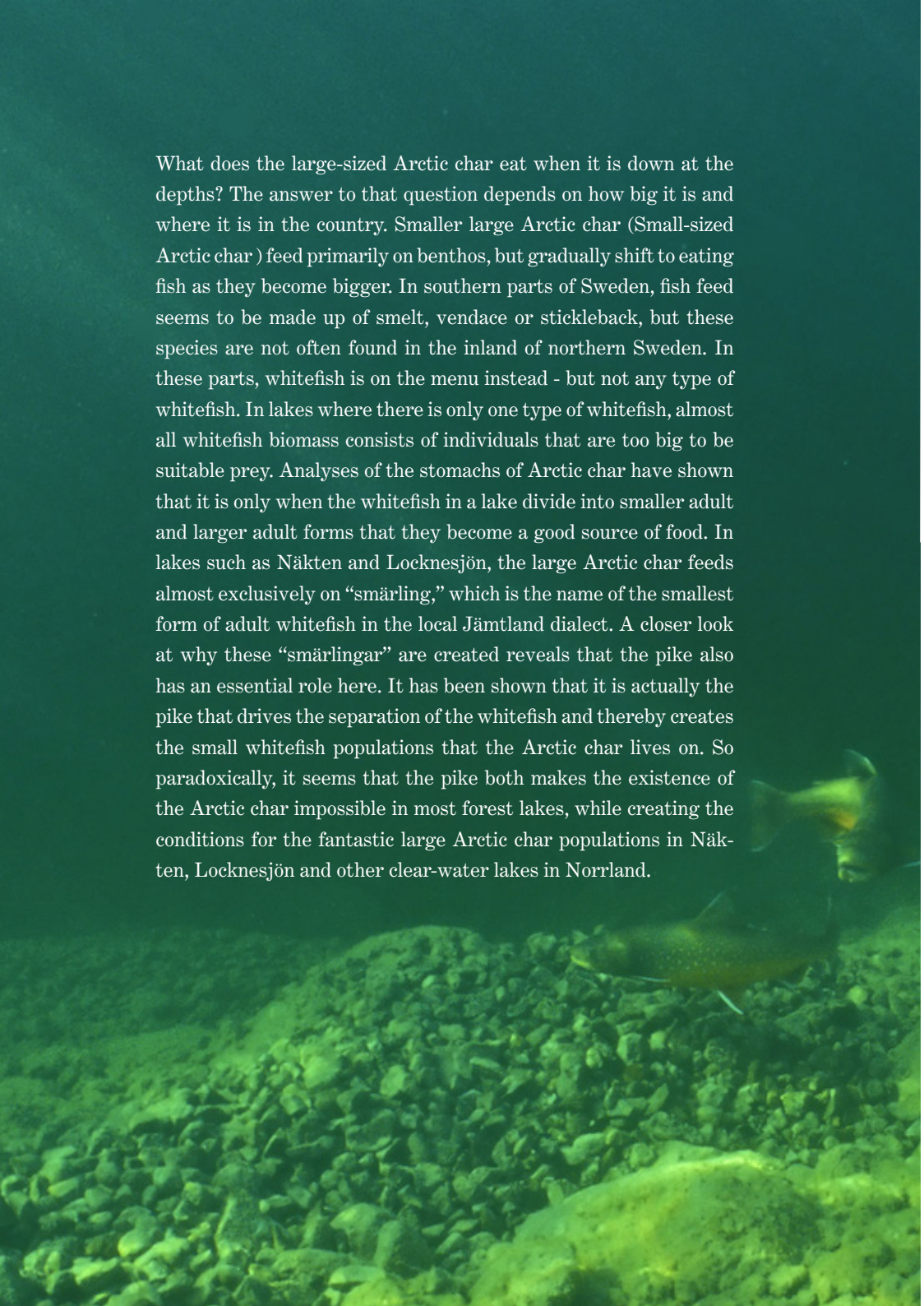
### The Arctic char and the pike

The Arctic char is often linked to the species-poor mountain lakes as it is not deemed to be good at competing with other species for food. However, analyses of where the Arctic char exists in forest areas suggest that predatory fish are an important factor when it comes to limiting the distribution of the Arctic char in our aquatic systems. Above all, the Arctic char has difficulties living alongside the pike and there are many examples showing that the proliferation of pike has led to the disappearance of Arctic char populations within just a few years. The tense relationship between these two species means that many of the Arctic char populations in forest areas exist in isolated tarns and lakes where there are no pike. In these lakes, the Arctic char often lives alone, or together with some combination of the perch, trout, whitefish and minnow species. In many ways these Arctic char resemble their relatives in the mountains; they live mainly on benthic fauna and zooplankton, and do not grow especially large. If we want to find that really big Arctic char, we need instead to search in the lakes where the Arctic char has nonetheless managed to live side by side with the pike. It is in fact possible, but the lakes need to be large and deep. Further, the



water must be very clear, which in practice means that the lakes that contain both species are almost always high up in their watersheds. It is no coincidence that the Arctic char can cope with the pike in the large higher altitude Locknesjön and Näkten lakes, but cannot manage further down in Gimån and Indalsälven rivers.

It is not really strange that the Arctic char benefits from being in large, deep lakes. Large lakes generally have more space for several species, and if they are also deep it means constant access to cold ground water all year round. It is these deep, colder parts of the lake that are the favourite hide-outs of the cold-water Arctic char. In addition to the cold water giving the Arctic char a competitive advantage, tests have also shown that the pike's ability to hunt salmonid fish deteriorates in cold waters. The deep, cold-water layers can thereby work as an ecological refuge for the Arctic char, but obviously only in clear lakes. Why that is the case is not known for sure, but a reasonable explanation is that clear water allows sunlight to penetrate to significantly greater depths. This in turn can facilitate biological production and improve the Arctic char's hunting opportunities in the cold-water layers that it depends on.



What does the large-sized Arctic char eat when it is down at the depths? The answer to that question depends on how big it is and where it is in the country. Smaller large Arctic char (Small-sized Arctic char ) feed primarily on benthos, but gradually shift to eating fish as they become bigger. In southern parts of Sweden, fish feed seems to be made up of smelt, vendace or stickleback, but these species are not often found in the inland of northern Sweden. In these parts, whitefish is on the menu instead - but not any type of whitefish. In lakes where there is only one type of whitefish, almost all whitefish biomass consists of individuals that are too big to be suitable prey. Analyses of the stomachs of Arctic char have shown that it is only when the whitefish in a lake divide into smaller adult and larger adult forms that they become a good source of food. In lakes such as Näkten and Locknesjön, the large Arctic char feeds almost exclusively on "smärling," which is the name of the smallest form of adult whitefish in the local Jämtland dialect. A closer look at why these "smärlingar" are created reveals that the pike also has an essential role here. It has been shown that it is actually the pike that drives the separation of the whitefish and thereby creates the small whitefish populations that the Arctic char lives on. So paradoxically, it seems that the pike both makes the existence of the Arctic char impossible in most forest lakes, while creating the conditions for the fantastic large Arctic char populations in Näkten, Locknesjön and other clear-water lakes in Norrland.

## Competition with other species

While it is clear that the pike has a key role in the story of the large Arctic char, we currently know less about the significance of competition from other fish species. As previously mentioned, the presence of Arctic char is naturally linked to lakes that are located furthest up in the aquatic system. Since these lakes have relatively small inlets and outlets, they often offer limited reproduction areas for the current-spawning trout. It is therefore possible that low densities of small-whitefish-eating trout could be one of the factors that benefit Arctic char in mountain lakes. There are examples indicating that large trout releases seem to have led to a rapid and drastic reduction in the amount of small whitefish, due to which the Arctic char has consequently suffered from starvation. Even though we are still unable to draw any general conclusions, we should apply caution in decisions regarding trout releases into lakes with a decreasing population of large Arctic char.

Competition with whitefish, as an example, has often been described as negatively impacting the Arctic char, which is specialised in zooplankton and benthic fauna. It is less clear to what extent this experience can be applied to whitefish-eating large Arctic char. Competition from other species could lead to a bottleneck which would mean that the smaller Arctic char would have difficulties growing to the size where it becomes an effective whitefish hunter. Another possibility is that pike, burbot and large perch are so effective at reducing fish populations in the relevant lakes that the small Arctic char experiences relatively limited competition for food. This may sound somewhat complicated, and it is. So complicated in fact that we need more knowledge to assess with certainty how competition with other species impacts the long-term development of large Arctic char populations.

## What is happening to the Arctic char?

If we go back a hundred years in time, there were significantly more large Arctic char populations in Sweden than there are today. Above all, many of southern Sweden's populations have either disappeared or been heavily decimated. The situation looks better in northern Sweden, but even here the larger Arctic char strains have declined. Unfortunately, most things suggest there is a risk that this development will continue. The Arctic char is the most distinctive cold-water fish species in the Swedish fish fauna and it will undeniably suffer when climate change makes our lakes warmer. Further, a warmer and wetter climate leads to increased transport of humic matter, which slowly turns our lakes browner. Given what we have just learnt about the distribution of Arctic char in forest areas, warmer and browner water constitutes a particularly bad combination.

In addition to the quantity of Arctic char decreasing, there are also signs that the role of the Arctic char as a large predatory fish is changing. In lakes such as Flåsjön, Storuman and Hornavan, the largest fish-eating types of Arctic char have drastically diminished or completely disappeared, while the small, deep-water-living types of Arctic char seem to have managed better. Even in lakes where there has only been one large type of fish-eating Arctic char, there are reports that the Arctic char has become smaller in size. The trend seems to be that Arctic char are becoming both fewer in quantity and smaller in size, and there is a range of different processes that may have contributed to this development. One factor might be that lake regulations have impacted the large Arctic char's spawning areas, which constantly seem to have been in shallow waters. Another may be that increasing predation is slowly changing the behaviour of the Arctic char and its possibilities for growth. There is a lot of data showing that pike has increased in northern Sweden's lakes, probably as a result of the effect of increasing water temperatures. We also know that warmer water increases the efficiency of individual pikes in feeding on salmonid fish. Since the pike mostly lives in the shallows, this may be a reason for the Arctic char staying hidden in deeper water, and giving up the strategy of hunting in the whitefish shoals in somewhat shallower water. A further factor that has changed the ecology of our lakes is that the crustacean Mysis relicta has been introduced to most of our regulated lakes. This has led to there being a completely new food source along the deeper lake beds, and just how this will affect the whitefish-eating Arctic char's life story over time is as yet unknown. To complicate the picture further, we also know that in certain situations, Mysis can negatively impact the population of small whitefish. So, it is currently difficult to say with certainty what has caused the changes that have occurred so far in our large Arctic char lakes. One thing that is certain is that the lakes will continue to change and that more research initiatives are needed for us to understand how this will impact the Arctic char.

The preservation of our large Arctic char faces significant challenges, but this does not mean that we should give up. On the contrary, it means that we must increase our efforts to preserve these fantastic fish for future generations. To succeed, we need to be prepared to adapt how we manage fishing and prioritise the preservation of the lakes and their surroundings. Further, researchers need to create better knowledge about this type of Arctic char and its ecology, so that we implement the right rules and carry out the right actions. If we succeed in this, then even in the future we will be able to take our children to watch the Lockne Arctic char playing at Börön, or perhaps hope for a new personal Arctic char record during our summer fishing trip on Näkten lake.

## Reading tips


Byström, P., Karlsson, J., Nilsson, P., van Kooten, T., Ask, J., and Olofsson, F. 2007. Substitution of top predators: Effects of pike invasion in a subarctic lake. Freshwater Biology 52(7): 1271-1280

Filipsson, O., och Svärdson, G. 1976. Principer för fiskevården i rödingsjöar. Information från Sötvattenslaboratoriet Drottningholm. No. 2.

Hammar, J. och Lind, O. 2005. Nordlunds röra och andra ryktbara rödingar i Frostvikenfjällen. Svenska fjällklubbens tidning Fjället. Nr 1.

Hein, C. L., Öhlund, G., and Englund, G. 2012. Future Distribution of Arctic Char Salvelinus alpinus in Sweden under Climate Change: Effects of Temperature, Lake Size and Species Interactions. AMBIO 2012, 41 (Supplement 3): 303-312

Jonsson, T. and Setzer, M. A freshwater predator hit twice by the effects of warming across trophic levels. Nature Communications 6, Article number 5992.

Malmgren, J. 2016. Fiskares uppfattning om förändring i status hos ett rödingbestånd i en Jämtländsk sjö. Kandidatarbete, SLU Uppsala.

Öhlund, G., Bodin, M., Nilsson, K. A., Öhlund, S-O., Mobley, K., Hudson, A. G., Peedu, M., Brännström, Å., Bartels, P., Praebel, K., Hein, C. L., Johansson, P. and Englund, G. 2019. Ecological speciation in European whitefish is driven by a large-gaped predator. bioRxiv doi: 10.1101/543744


# WATER - THE MIRROR AND CONSCIENCE OF THE LANDSCAPE

*A resource to use and protect*

## Many reasons to examine the quality of water

Lakes are often described as mirrors in the landscape. This is where the effects of the different activities within the watershed are usually visible and leave traces in the quality of the water. Working with the quality of water therefore involves both examining the quality of the water through sampling and analysis, and also working with the activities that take place on land that can influence the water.

Water quality work in Sweden is largely controlled by the many different EU directives that exist. One of these is the Directive of the European Parliament and of the Council (2000/60/EG) on the establishment of a framework for community measures in the area of water policy, also referred to as the water directive.

The three lakes of Revundssjön, Näkten and Locknesjön are classed as Natura 2000 sites, meaning that they are part of the EU's network of valuable nature conservation areas. The objective of the Natura 2000 network is to preserve plant and animal life for future generations by letting natural habitat types and species grow to viable populations. An important aspect of this work includes the efforts towards good water quality in these areas.

## All water must attain good or high ecological status

The water directive has clearly underlined that it is how plants and animals are affected by different activities that should decide the status of the water, also referred to as the ecological status of the water. However, measurements of the different chemical pa-

rameters are also carried out and used as support in the assessment. The status classification is built on an estimated value for how the quality of water would have been without any human influence (also known as the reference value), which is then compared against the measured value. If there is a large difference between how the quality of water looks today compared to if it had not been influenced by humans, the water is classed as moderate, inadequate or poor status. If the difference is minor, the water is classed as having high or good status.

However, it is difficult to know how the quality of the water would have been without any human influence. Methods for estimating how the water quality would have looked without human influence have been developed over a long period of time, however it is difficult to identify one method that suits all of the country's waters. Since the reference value is estimated in relation to the measured value, a small discrepancy in the estimated reference values can easily lead to an incorrect classification of the status of the water, when low measurement values are used.

### Lakes with clear water

All the three lakes in the Triple Lakes area are classed as lakes with clear water. To be classed as a clear lake, the water must have a colour score of less than 30, according to the national method for status classification (Swedish Agency for Marine and Water Management). Of the three lakes, Locknesjön has the lowest colour score, which is usually at 4 or lower during measurements, the highest value observed during the measurement period being a colour score of 7. The water in Näckten and Revsundsjön lakes has a somewhat higher colour score than Locknesjön, varying between 7 and 17 and 8 and 29 respectively during the measurement period.

One explanation for the result is that the colour of the water often comes from the content of humic matter that comes into the water from contributory forest streams. Locknesjön lake gets



most of its water inflow from the ground water repositories below the lakebed. Thus Locknesjön lake receives a very small addition of humic matter. Näkten and Revsundsjön lakes both have a larger inflow from contributory streams.

## No impact from acidification, but variances in alkalinity

None of the lakes were assessed as being affected by acidification as they had a pH level of over 7.3 (IVL 2016). There are however differences in the alkalinity levels of the different lakes. Alkalinity is an indicator of how well the water can resist acidification. Locknesjön lake is classed as high-alkaline, while Näkten lake is classed as low-alkaline. That means that Locknesjön lake is more resistant to acidification than Näkten lake. In Revsundsjön lake, the alkalinity varies between different parts of the lake. At the western sampling spot, the water has a low alkalinity, but at the eastern sampling area the water is classed as high-alkaline.

Also in this regard Locknesjön lake differs from the other lakes because it is affected far more by a limestone-rich bedrock and inflow of ground water. The other lakes are more greatly affected by a granite bedrock and inflow of surface water.

## Good or high ecological status considering nutritive substances

To determine the ecological status, every year a water sample was taken from which the total biomass, i.e. the quantity of living matter (plankton) in the water sample, was measured. Additionally, all the species found in the sample were identified. Through the species composition of plankton it is possible to assess how they are affected by different environmental factors. The species composition of plankton is affected by natural properties such as alkalinity, water colour and altitude of the lake, but also by human influences. As an example, certain plankton species do not react at all to nutrient enrichment, while others will be out-rivalled by plankton species that thrive off nutrient enrichment (Drake, 201X).

Analyses of the total biomass indicates high or good status of all three lakes during the entire measurement period.

The level of chlorophyll, the substance that gives plants their green colour, is also measured. The levels of chlorophyll measured indicate a high status every year, with one exception. In Näkten lake, the status was classed as moderate at one of the measurement points in 2015.

The basis used for assessment is constantly being developed within water management and in 2018, the method used to estimate the impact of nutrient enrichment on species composition changed from the previously used Trophic Plankton Index (TPI) to the mutual EU system European Plankton Trophic Index (PTI) (Swedish Agency for Marine and Water Management, 2018).

The TPI Index of the lakes indicated large variations from 2015 to 2017. All water achieved high status in terms of phytoplankton in 2016. During 2015 and 2017, however, Locknesjön lake was classed as good, Näkten as moderate and Revsundsjön lake as unsatisfactory.

Under the new PTI index, however, all the lakes were classed as having a high status in terms of phytoplankton.

## High chemical status in terms of nutritive substances

A calculation of the amount of over-fertilizing substances in the water can be made based on the total level of phosphorus measured compared with an estimated reference value (Swedish Agency for Marine and Water Management, 2018). At all sampling locations throughout all the years when measurements have been taken, the calculation of the status based on the average annual values has indicated a high status, apart from the eastern sampling spot in Revsundsjön lake which showed a good status in 2015. Based on the calculations of the reference value, in one year or another all

lakes show even lower phosphorous levels than expected based on the estimated reference value. The reference value is calculated using a regression analysis of the measurements in lakes throughout the entire country to identify a common method for calculating the reference value (Fölster et al, 2018).

As mentioned to begin with it is clearly difficult, if not impossible, to find a method that is suitable for all lakes. When the levels are naturally low as they are in these waters, small differences in the reference value can lead to large differences in the classification. That is why it is difficult with the current methods to provide an exact picture of how we humans have influenced the water quality in these three lakes. Nonetheless, the analyses show that the waters are less impacted by humans in terms of nutrient enrichment than in many other lakes in Sweden.



## The characteristics of the water vary in the different parts of the lakes

The waters in the lakes are not one homogeneous environment. That is why the quality of the water has been measured at two different locations in every lake. In this way, the differences in the various parts of the watershed can be captured as well as any impact on the water quality from the various activities.

Even though the water is classed as clear in both of the sampling locations in Revsundsjön lake, the colour score is somewhat higher at the eastern sampling location. The concentration of total organic carbon is also higher, which indicates that addition of organic material/humic matter contributes to giving the water colour.

In Locknesjön lake there are also differences between the two sampling locations. At the northern sampling point, the levels of chlorophyll and turbidity were higher during the period when water sampling was carried out. Turbidity is a measure of how murky the water is, in other words, the amount of particles in the water. Other types of substances bind to the particles, such as nutritive substances.

At the northern sampling point in Näkten lake, the alkalinity, total concentration of organic carbon, and concentration of total nitrogen and total phosphorous were higher than at the southern point. One explanation for this could be that the bedrock in the area around the northern part of the lake is primarily made up of limestone-rich rock, while the area around the southern part is dominated by granite rock types. One explanation for the higher levels of carbon, nitrogen and phosphorus at the at the northern sampling point could be that around that part of the lake there is a greater proportion of agriculture and a denser built-up area than the southern part of the lake.

## Measures taken to improve the water quality of the three lakes

There are many reasons to follow up the quality of water in the three lakes. Not only because the water itself is an important resource, but also because it constitutes the habitat for the species worth protecting that live in the lakes. At the end of the day, the activities that take place on land around the three lakes will impact their water. A continuous follow-up of the quality of the water provides a measurement of how much the activities affect the water, and an indication of where there is a need for environmental improvement actions. As a step towards improving the quality of water, the municipalities participating in project Triple Lakes have surveyed the individual sewers. The objective of the survey was to identify sewers that were not functioning adequately and thereby reduce the addition of poorly purified waste water in to the three lakes. Berg and Östersund municipalities have worked together to create a water protection area around Näkten lake. Within the water protection area there are regulations that place requirements on different activities, and also control the handling of products that could negatively affect the water. As such, the lake is now formally protected and has a higher status as a protected place.

Another initiative involves illustrating different examples of consideration shown in forestry. The Swedish Forest Agency and SCA have together created a demonstration area showing several examples of environmental care in forestry. The forest industry has worked together to identify targets for environmental quality, and it is these targets that are demonstrated in practice and discussed during excursions and training.

In summary, all three lakes have good quality water and the level of impact from human activity around the lakes is deemed to be low. However, it should be noted that the assessments are made based on the methods available today, and like all general methods of assessment, they include a certain level of uncertainty. We cannot therefore say with certainty how the water in the lakes would have been if we humans had not lived and worked around the lakes.

Nonetheless, we can state that we have three lakes with clear, nutrient-poor water that we have the privilege of using in many different ways. We also observed signs indicating that we should not take them for granted, and instead keep up efforts for fewer emissions of contaminated substances, greater consideration in land usage and a broader awareness of what an asset clean water is.

Evening primrose at Pån

## References

### Legislation


Havs- och vattenmyndighetens föreskrifter om klassificering och miljökvalitetsnormer avseende ytvatten (HVMFS 2013:19: HVMFS 2015:4 samt HVMFS 2018:17)

Vattendirektivet: Europaparlamentets och Rådets direktiv 2000/60/EG av den 23 oktober 2000 om upprättande av en ram för gemenskapens åtgärder på vattenpolitikens område

Habitatdirektivet: Rådets direktiv 92/43/EEG av den 21 maj 1992 om bevarande av livsmiljöer samt vilda djur och växter


### Literature


Fölster, J., Djodjic, F., Huser, B., Moldan, F., och Sonesten, L. (2018) Bedömningsgrunder för fysikaliskkemiska kvalitetsfaktorer i sjöar och vattendrag - Förslag till revidering av föreskrift HVMFS 2013:19, Vatten och miljö: Rapport 2018:10, SLU

Havs- och vattenmyndigheten (2018) Växtplankton i sjöar – vägledning för statusklassificering, Havs- och vattenmyndighetens rapport 2018:39

IVL Svenska miljöinstitutet (2016) MAGIC-biblioteket Besökt 2019-08-26 http://magicbiblioteket.ivl.se/ (senast uppdaterad 2016-06-26)

Lindegarth, M., Carstensen, J., Drakare, S., Johnson, R. K., Nyström Sandman, A., Söderpalm, A., Wikström, S. A. (Editors). Ecological Assessment of Swedish Water Bodies; development, harmonisation and integration of biological indicators. Final report of the research programme WATERS. Deliverable 1.1-4, WATERS report no 2016:10. Havsmiljöinstitutet, Sweden.

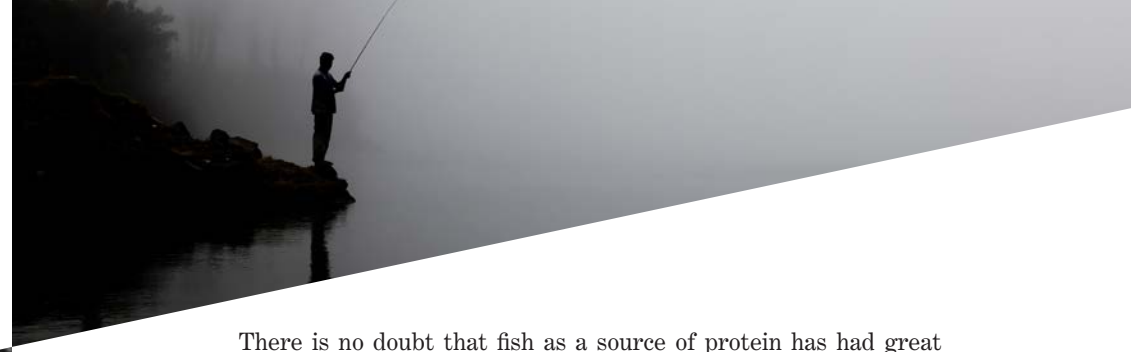
Münzner, K. (2019) Gonyostomum semen i svenska sjöar –förekomst och problem, Uppsala universitet

Naturvårdsverket (2007) Bedömningsgrunder för sjöar och vattendrag, Bilaga A till handbok 2007:4

Sassenhagen, I. (2015). Physical and biological dispersal barriers in invasive, bloom-forming microalgae. Department of Biology, Lund University

SLU (2018) Vattenfärg - absorbans Besökt 2019-08-28 https://www.slu.se/institutioner/vatten-miljo/laboratorier/vatten-kemiska-laboratoriet/detaljerade-metodbeskrivningar/absorbans/ (senast uppdaterad 2018-09-08)


# FISHING IN THE PAST AND IN THE PRESENT



There is no doubt that fish as a source of protein has had great significance for the people who have lived and worked around the lakes of Locknesjön, Näkten and Revsundssjön throughout history. It would appear that the first representatives of the hunting culture arrived in the area more than 9,000 years ago. The inland ice was gone, the landscape had been shaped and the climate was more favourable than it is today. The forests contained quite a few precious deciduous trees. Hunters moved across large areas, but it is clear that in the places where they stayed for longer periods there were particularly favourable conditions. Even as early as these times, lakes and watercourses played an important role for the people in the area. Settlement areas were always close to the lake shores. Travel was by water, and it is likely that access to game was greater by the lakes and streams. This is evidenced by the many hunting pits. But fish was certainly also important. After all, it was the most predictable source of food. If hunting luck ran out, there was always fish available.

It is likely that fish was a source of food that these hunting communities relied on. As a result of the warm climate, production in the water was probably significantly higher than in today's lakes. That meant that the odds of catching fish were higher. The simplest way was to fish at spawning time with some form of fixed fish trap. Well into modern times, humankind has built basic rock barriers in streams and traps from branches and twigs in lakes. They were directed upstream, in the direction of migration of the fish. The narrow opening in the centre allowed the fish to swim through. In lakes it ended up in some sort of cage. In flowing water the opening was closed and the trapped fish were lifted up. In lakes, the so called "katsa" trap was also common. This consisted of "palings" of

wicker forced down into the lake beds in the shallower areas. They were round and labyrinth-like, and were constructed such that the fish was gradually led into narrower passages, and gradually ended up in a small section where they could be pulled up. Another common fishing method was fish trapping in spawning streams. It worked by concentrating the flow of water with the help of stone barriers pointing downstream. Thus, after spawning when the fish swam downstream, they were forced to swim through a narrow passage into a fish trap. This is an ancient method of fishing but it was practised as late as the 1900s. It is unclear whether the fishing targeted fish after spawning rather than before in consideration of fish reproduction, but it is not impossible. Otherwise, we have to assume that rudimentary pots of weaved wicker branches were used, and later simple nets and hooks made of bone and wood. We may think that the hunting methods of the time were somewhat primitive compared to the methods used in modern times. But with knowledge of fishing locations, fish migrtion and tools developed over many thousands of years, fishing techniques most certainly became sophisticated anyway. People were dependant on fishing for survival and that is often a strong motivation for progress.

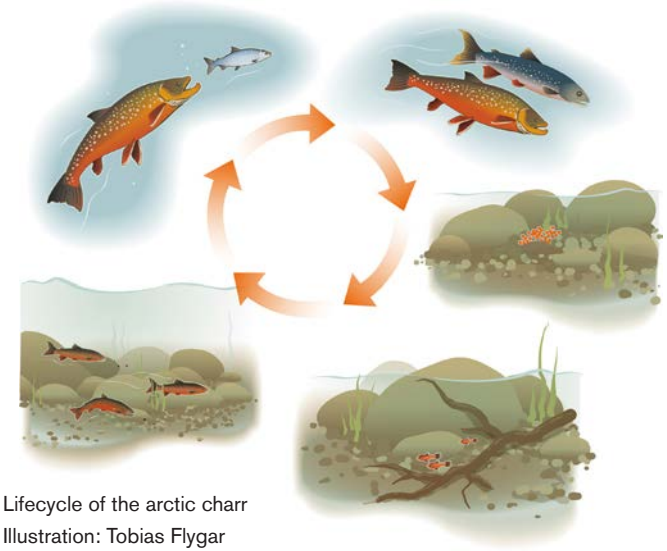
One important question is whether the hunting culture of former times in any way led to a changing in the water ecosystem. It is most probable that the intensity of fishing was so low overall that there was no issue of overfishing. Of course this is speculation, but fish production was high, the human population low and above all, settlements were not permanent. Usage was not as intensive. We therefore assume that human impact on the water ecosystems of the time was relatively modest.

## Agricultural age

Time passes, and after the climatic high point of 9,000 years ago temperatures became gradually cooler. Warmer periods have in fact occurred from time to time, but overall the climate has been similar to what we have today. Somewhere around the beginning of time as we know it, the first farmers came to central Jämtland. Farming culture is calculated to have been established from approximately 200 AD. This most often involved individual dwellings in places that would later develop into villages. Fishing and hunting were probably still significant then, even though people also grew crops. In addition to putting meat on the table, hunting provided hide to sell or use oneself. But most things indicate that fishing was a very important source of protein. The first farmers took advantage of the fish populations and fishing continued to be important where settlements were established. However, there was a big difference that came with the arrival of farming - settlements became permanent. This in turn meant that fishing became more intensive in the nearby waters. With the increasing human population, in particular towards the end of the Iron Age, pressure on fishing waters also increased. Competition for fishing, and along with that, who would get to fish where and how, bears witness to usage increasing substantially. Much points to the availability of fish not being sufficient, at least not with the fishing methods of the time.

The first documented sources that describe conflicts over fishing date back to 1300s (Edvard Bull, Norwegian historian). These state that controversy existed over what was referred to as the Rödbergs fishing in Näkten lake. The fishing had ancient traditions and was based on easily caught Arctic char that was concentrated along the shores during the spawning time in autumn.

Further conflicts are documented in other literature. Skruck-Sjul was the name of the priest that served the parishes of Revsund and Berg during the 1600s. He was expected to deliver the Sunday service every other week in each church. When he did not show up for the church service several times, the local people became upset and started to investigate. It turned out that in transit between the churches he stopped at Näkten lake to go Arctic char fishing. And



Lifecycle of the arctic charr
Illustration: Tobias Flygar

thus never arrived for the church service in time. So they asked the queen for permission to kill the priest. And so it was done one October day, when he was fishing at Monäset on Näkten. He was stoned to death and buried on site. It is unclear though whether it was really because he did not do his job properly or whether those who had the fishing rights there wanted to get rid of an illegal competitor. Nonetheless, Arctic char fishing sealed his fate!

In the village of Kloxåsen there was a farmer with fishing rights on Locknesjön lake. One of his sons inherited the homestead and the other inherited the Arctic char fishing. The second son became an affluent man because the fishing went well and provided income. But things were tough for the homestead owner. In the end the farmer killed his luckier brother. Once again, Arctic char fishing led to an evil death.

In literature about fishing in the area in older times, it is predominantly Arctic char that is mentioned. It would appear that Arctic char was highly appreciated, not only because it was easy to catch during spawning, but also due to its quality. In particular, the "Rörbergsrören" is mentioned. This is the Arctic char fished at Rörberg in Näkten lake (Fale Burman's notes about Jämtland). Another good, famous fishing spot was found in Revsundsjön lake's outlet at Stavre. The fish was mentioned in 1666 and is described as being known since time immemorial. The Stavre currents were known as an important spawning area, and thereby fishing place, for grayling and whitefish, but strangely not for brown trout. There were also several kinds of eel traps in the currents there too. Another traveller to Jämtland, Abraham Hulphers, writes about Locknesjön lake in 1775: "It has quite an abundance of fish, and the healthiest water in the area." He also states that the people of the villages around the lake believe that it is connected to the sea via the "Deep hole" (eight cubits in diameter and a depth that nobody had been able to determine). Proof of the lake's connection to the sea was provided in the form of the capture of two herring during the 1500s. These were depicted on the door of Lockne church and subsequently on the parish seal of Lockne.

During the 1700s the population in the area grew. More and more people settled there and new villages were established, which would have increased the pressure on the fish population. One of the main reasons for the conflicts about fishing was that the fishing rights were often owned by the farmers in the oldest villages. Those who arrived in the area first naturally fished where the results were best. Something called the fishing tax was created, which involved according the fishing rights in a body of water and paying an amount to the state for the rights. These were created as early as the 1600s. It meant that the population of later settlements did not always have the right to fish in the water closest to their farms, which was considered very unfair. Many of the conflicts that arose can be attributed to this fact.

Whitefish fishing on Locknesjön lake was well known and very fruitful. It culminated with the whitefish spawning time in late November/early December. Whitefish bred close to land in very shal-

low water. It is likely that the influent ground water at the shores provided particularly favourable conditions for the eggs. The concentration of fish was very high and it is said that when one rowed through the spawning sites the fish would be pulled up out of the water by the oars. If there were storms and onshore winds, one could even pick up fish that were blown on to land. Fishing had great financial importance for the farms that had fishing rights. In 1847, a classification of the fishing was done to clarify where the borders were between the different farms' fishing. Limits were also set on the number of nets that could be put out, which is evidence of clear insight that this was a limited resource. Fishing with nets was done in the dark and there were three fish per kg, at least up until the 1930s. The Lockne whitefish was very popular due to its quality and was sold both on the square in Östersund and in the farms around the lake and in town. However, the spawning whitefish gradually became smaller in size and by the 1940s-1950s there were 5-6 whitefish per kg. The number of whitefish in the breeding grounds has also decreased significantly and today, no such fishing for spawning whitefish exists. The reasons behind this decline are unclear.

Arctic char fishing on Locknesjön lake is not as well documented as the fishing at Röberg on Näkten lake. Maybe the population of large Arctic char was not as big in Locknesjön lake. Additionally, fishing in the spawning areas was more difficult on Locknesjön lake as the shores were steeper and the fish spawned in deeper water than in Näkten lake. But people of course fished a lot during spawning time, both for their own food and for sale. However, during the 1900s discussions were ongoing about how intensively people could fish without damaging the fish population and about the value of fishing during spawning. It was deemed that spawning fish was low in quality. Consequently, different forms of restrictions were established and in the end during the 1990s, Arctic char fishing with nets was forbidden during the spawning time. Today, even fishing with a rod is not permitted during this time. Fishing for Arctic char with a lure during early summer has been a normal method of fishing ever since the 1800s. The catches were not large, up to 3-4 fish per day, but during the first decades of the 1900s, people paid well for the fish. It was possible to get 3-4 Swedish kronor per kg at the restaurants in Östersund, where Arctic char was served like salmon. This meant that one "couldn't afford" to eat Arctic char in the farms surrounding Locknesjön lake.

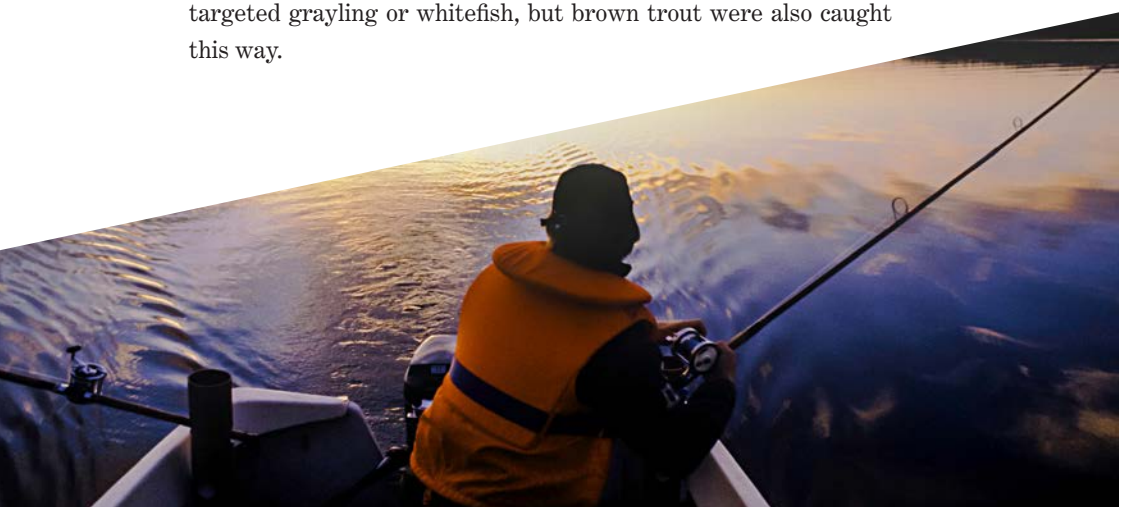
In some cases, conflicts over fishing in the three lakes have continued even until recent times. Autumn fishing for spawning whitefish in Lälån river, a tributary to Revsundsjön lake was very rewarding and thereby attractive. The villages nearby shared the fishing and fished every other week, but poaching attempts were countless. It became so bad that during the 1940s a guard box was built where every night during the autumn fishing season, a man would sit armed with a Browning revolver. Rumour has it that he fired a couple of shots when it got dark and then went to sleep, after which the poaching would start. Still today there are differing opinions about how and when fishing should be permitted. Discussions are mostly around fishing with nets, but even trolling is sometimes questioned.

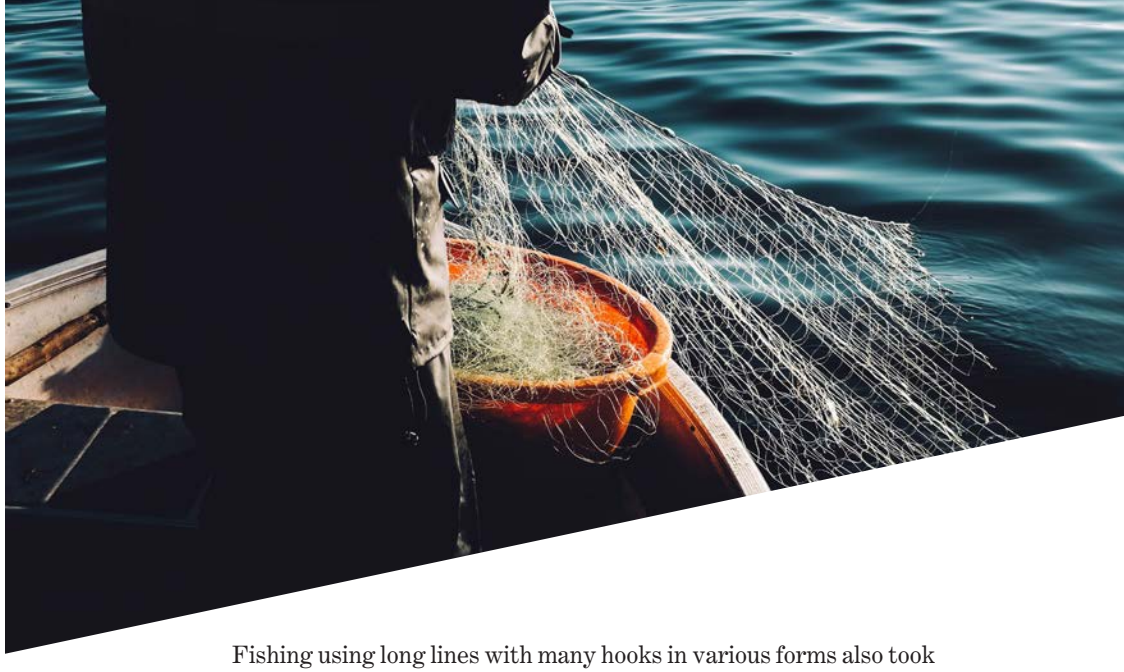
When it comes to the environmental impact of former times, is it primarily log driving that was the major concern. In Stavre, fishing was deemed to be good until 1915 when the extensive log driving business led to "the riverbeds being completely covered by bark, timber logs and log-driving waste." It is hard to know exactly how serious the bark depositions were, but it is clear that in many places it was seen that fishing deteriorated at the time, and people connected this to layering of bark. Over time this led to a requirement that logs should be de-barked before driving. Other early environmental impacts would have come from subterranean drainage activities, increasing releases from individual sewers, and with time the effects of large-scale forestry.

## More effective equipment

The well-known Arctic char fishing in Näkten lake took place, as far as we know, during the 1600s and 1700s and probably much earlier than that, using what are known as cast nets. These were rather simple nets that were placed along the shores and then pulled up onto land. They were sufficient for catching spawning Arctic char. But fishing methods gradually improved and during the end of the 1800s, the seine became generally more popular. Fishing in shallow bays became much more efficient with it than with other methods. Pressure on fishing thus increased significantly, both for Arctic char and the easy-to-catch whitefish. People also became less dependent on fishing during fish spawning times. The seine also worked at other times of the year. Many things suggest that it was a large step towards harder exploitation of the fish population. In the lakes of the Triple Lakes project, it has mostly been used in Locknesjön and Revsundssjön. Näkten lake's stony and uneven bed makes it difficult to fish effectively using a seine.

A few decades later saw the arrival of cotton nets (approx. 1920s) and finally nylon nets (1950s). Nets meant that fishing became simpler and was possible to do efficiently even during winter. In addition to the development of new nets, new more efficient trolling methods arrived early in the 1900s. This involved pulling fishing bait attached to the fishing line from a boat or from land, using a special wooden construction. This kind of fishing mainly targeted grayling or whitefish, but brown trout were also caught this way.



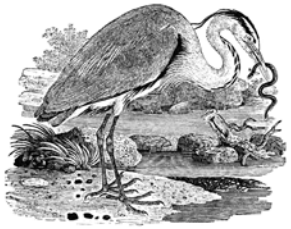


Fishing using long lines with many hooks in various forms also took place in all lakes. Burbot was largely fished, but also brown trout, pike and sometimes even eel and Arctic char. Long-line fishing took place during the first decades of the 1900s but then decreased and completely stopped around the end of the 1950s.

## Fish conservation

Overall, pressure on fishing increased substantially during the 1700s and 1800s, and people started to talk about depletion of fish populations. This fact and technical progress led to the growth of fishing conservation in various forms. For many years, fish had been moved to empty waters, or species of fish were moved to waters where they had not previously existed. This often gave obvious results in the form of more catchable fish. But then at the end of the 1800s, techniques were developed for fish farming. This meant that large quantities of young fish could be bred that were then released into natural waters. Suddenly it was possible to distribute substantially more fish to new water. In the beginning, releases of pike were given highest priority, but during the 1900s focus turned more and more to salmonids. Whitefish was introduced into waters where the species had not previously existed. This resulted

in far-reaching consequences in many brown trout and Arctic char lakes where the original species were out-rivalled. Mostly though, fish releases were done to strengthen the populations of wild fish. Later in the 1900s, releasing brown trout and Arctic char became common, as did introducing north American species such as rainbow and brook trou‘



Cultivation and release of fish was extensive during the entire 1900s, even in the lakes of the Triple Lakes project. Countless releases of pike, whitefish, brown trout and Arctic char were carried out, both directly into lakes and into their inflowing watercourses. The effects have seldom been fully evaluated and the outcome is often uncertain. Of course, in some cases certain species have successfully been strengthened, thus benefiting the fishing, but in many cases efforts have been wasted. There was no pike in Lockesjön lake before the 1940s. It is somewhat unclear how it arrived in the lake, but it likely that the populations of the native fish species changed in some way as a result of the establishment of the pike (see chap 2?). In terms of salmonids, insight has grown about the fact that releasing non-native strains can have negative effects on the genetic composition of the populations native to the lakes or rivers. Overall this has led to a reduction in releases during recent years, and targeting of species, sizes of fish and environments where releases can be most beneficial. Focus has instead turned to conserving the wild populations and their habitats.

During the 1900s other ways to protect fish were also introduced. Bans on fishing during certain periods (spawning) or in certain areas became more common. Limitations on usage of certain equipment also started to be introduced. As an example, a person could only use a certain number of nets. During the 1960s, two types of crustacean were also introduced to Näkten lake, the Mysis relicta and the Pallasea quadrospinosa. The idea was that the Arctic char in particular would take advantage of them for nutrition. Establishment of the Mysis was successful and there are still large quantities today in Näkten lake, and they are part of the Arctic char diet. Later it has been observed that the Mysis is not only a source of food, but also competes with the young Arctic char to eat zooplankton. Thus it could also have a negative effect on the Arctic char population. In the case of Näkten lake, it not yet known whether Mysis will be a plus or a minus for the Arctic char.

There are many other examples of fish conservation initiatives. In Lockesjön lake there were early attempts to put out spawning gravel for Arctic char. In Revsundsjön lake, great efforts have been made using measures in watercourses to enhance brown trout fishing. Overall, many measures have been implemented in the different lakes to conserve and strengthen the fish populations and thereby benefit the fish. Methods and intensity have varied over the years. Not all the measures have been successful, but they demonstrate a collective will to conserve a natural resource and the ecosystem service that the lakes and fish populations provide.

## Fishing today

Up until the 1960s, fishing in the lakes of the Triple Lakes project was dominated by net fishing, mostly for whitefish, Arctic char and to some extent, brown trout. People who owned leisure homes and residents alike fished using nets. Fishing was extensive and there was no ambitious limitation to this fishing. Fishing was targeted at any edible fish and varied in intensity and focus, based on the season. Arctic char was fished all year round, not only during spawning. Ice-net fishing became established from the 1950s onwards

and was most intensive during the 1960s and 1970s. Fishing with nylon nets placed at the bottom of the lake probably culminated in the latter part of the 1960s. At that time sales of the fish had approached almost commercial levels. Towards the end, limitations on the number of nets were introduced for certain categories of fisherman, but it would have a limited effect.

Other traditional methods of fishing that were used until this time were long lines, pike traps, salmon traps and net fishing for whitefish. These types of fishing decreased with the growth of net fishing using nylon nets. Only net fishing remained to any greater extent.

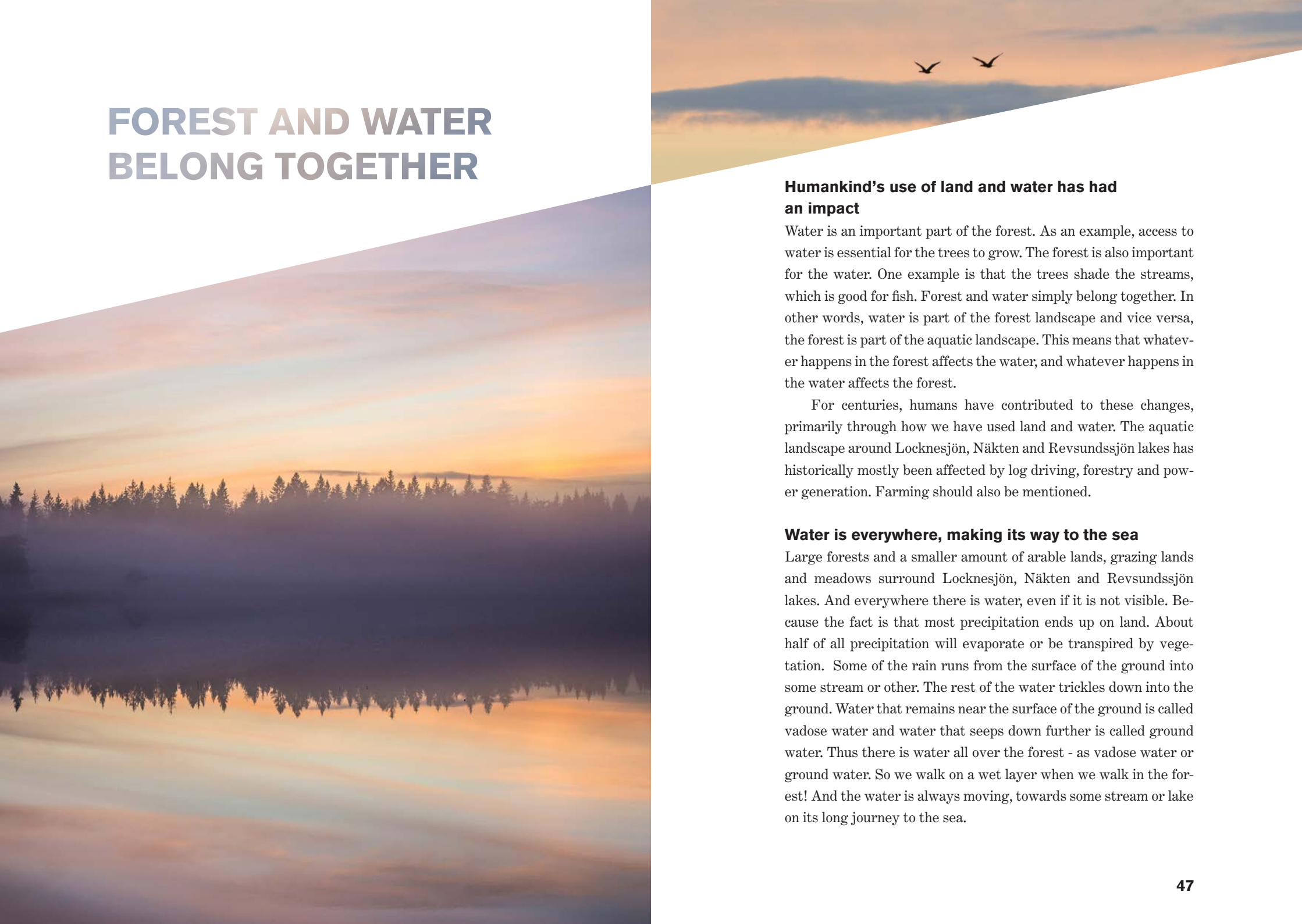
Many types of angling were also becoming more popular. In particular on Näkten lake, ice-fishing for Arctic char grew from the 1960s and reached its peak during the 1970s and 1980s. Ice-fishing was also intensive on Locknesjö, especially for spawning whitefish at Musviken, even though that type of fishing has decreased in later years due to a reduction in the availability of fish. In Näkten lake there had long been a combination of fishing for food needs as well as angling for Arctic char. Large, heavy lures were used in deep waters using copper lines from a reel. A simple form of trolling fishing that was common and effective long into the 1960s. Until that time, the availability of Arctic char was said to be very good. Modern trolling fishing, whereby fishing is done with a rod pulling a bait behind a larger motor-driven boat, often with a sonar and many rods, increased gradually from the 1970s. Fishing became wholly focused on predatory fish such as Arctic char, brown trout and pike. Trolling fishing now takes place in all three lakes, is said to continue to grow and is now the most popular form of recreational fishing, along with ice-fishing in wintertime.

Overall, from the 1980s onwards the intensity of fishing should have decreased. A lot of fishing still goes of course, but mostly with angling equipment. The exception is the net fishing that still takes place, such as the rather extensive net fishing under the ice which



is common in Locknesjön lake. But on the whole, fishing has undergone very large changes over time. From the time when the inland ice disappeared and the first humans colonised the area, mankind has also fished for survival. Fish was a necessary and in many cases decisive part of food gathering. When the human population around the lakes gradually increased, competition for fishing grew. Conflicts arose and fishing was given enormous economic significance. Partly because it became important to own fishing rights in the sections of the lakes that had good fishing conditions and thereby ensure food provision, and partly because there was money to be made in selling fish. During the end of the 1800s, fishing conservation ideas started to emerge. Different efforts, often determined by the fishing right owners' associations, were carried out to strengthen the fish populations. This situation of an overall high pressure on fishing, a direct economic importance of fishing and fish conservation efforts endured long into the 1900s. Only in "modern times", from the 1970s onwards, have attitudes changed radically. Today fishing takes place less for bringing in food to the household. Instead it is dominated by pure recreational fishing. Fishing has thereby a continued economic value, but more in the form of an experience. Value consists primarily of accommodation, service and equipment sales rather than fish meat. However, an interest remains in protecting the aquatic environment and the value that fish and fishing has. This was something evidenced in the initiatives carried out as part of the Triple Lakes project.

# FOREST AND WATER BELONG TOGETHER



## Humankind's use of land and water has had an impact

Water is an important part of the forest. As an example, access to water is essential for the trees to grow. The forest is also important for the water. One example is that the trees shade the streams, which is good for fish. Forest and water simply belong together. In other words, water is part of the forest landscape and vice versa, the forest is part of the aquatic landscape. This means that whatever happens in the forest affects the water, and whatever happens in the water affects the forest.

For centuries, humans have contributed to these changes, primarily through how we have used land and water. The aquatic landscape around Locknesjön, Näkten and Revsundssjön lakes has historically mostly been affected by log driving, forestry and power generation. Farming should also be mentioned.

## Water is everywhere, making its way to the sea

Large forests and a smaller amount of arable lands, grazing lands and meadows surround Locknesjön, Näkten and Revsundssjön lakes. And everywhere there is water, even if it is not visible. Because the fact is that most precipitation ends up on land. About half of all precipitation will evaporate or be transpired by vegetation. Some of the rain runs from the surface of the ground into some stream or other. The rest of the water trickles down into the ground. Water that remains near the surface of the ground is called vadose water and water that seeps down further is called ground water. Thus there is water all over the forest - as vadose water or ground water. So we walk on a wet layer when we walk in the forest! And the water is always moving, towards some stream or lake on its long journey to the sea.

## Water in the landscape is not in any rush, at some point it will arrive at the sea

Water is always moving, flowing towards the sea. Streams and brooks are in no rush, they will get there in the end. Small trickles create brooks and many brooks create a big stream, as the saying goes. Brooks and streams meander their way through the landscape. If the watercourse is completely straight, then something is wrong because “children and streams seldom move in a straight line”. It is usually because the stream or river has been straightened. Water also moves in lakes, even if it does so slowly. It could be said that streams and rivers rest in lakes. When water leaves Näkten lake, it has a long journey via the Indalsälven river before it reaches the sea. Locknesjön and Revsundssjön make their way via the Ljungan river to the Baltic sea.

Illustration: Tobias Flygar

## Ground water becomes stream water in discharge areas

Both vadose water and ground water follow the angle of the terrain down towards streams. A portion of the ground water runs up through the stream bed. Another portion comes up to the surface of the land right at the stream. You can see this when the ground is usually wet and the vegetation is different. Such wet land is called the discharge area. This is where vadose and ground water become stream water and chemical processes create the quality of the water. A large number of plants grow in discharge areas, significantly more than at other places along the stream. Discharge areas are therefore important for both the quality of water and biodiversity. Also, they are sensitive and therefore driving is forbidden in these areas.

## Water is the best solvent

Water is a good solvent, in fact it is one of the best solvents there is. Substances that exist in the ground will therefore dissolve in it. As an example, if there is a lot of lime in the ground, the water will become very hard. Water also brings soil particles with it, from microscopic to larger in size. The ground contains the remains of dead plants, called humus. Microscopic humic particles dissolve in water, turning it brown in colour. Most humic matter is found in water from marshlands. In these areas, water can be almost the same colour as coffee. Thus the quality of water changes as water moves through the ground.

## Anything that happens with the land changes the quality of the water

When we affect the land, such as when hunting or mushroom picking, the water quality changes.  Naturally, the impact is so small that no change can be measured. However when a forestry machine or mounder drives by, the change can be obvious. And there

is an even greater impact from farming of course, where the processing of land is more intrusive. The conclusion is that when we use the land we affect the quality of the water. But this does not always need to be a big problem.

### Wetlands are nature's own purification plants that slow down the water

When streams run through a wetland or lake, the water is purified. Particles that make the water murky sink to the bottom and the water thus becomes clearer. Some of the nutritive substances such as phosphorus and nitrogen also diminish after a wetland or lake. We therefore understand that wetlands are nature's own purification plants - completely for free! Which is why we should take care of wetlands. Water is slowed down in wetlands and when it rains a lot, the water level in these wetlands rises. Thereafter the water is apportioned out to the streams. In this way, wetlands reduce the risk of floods further along in the aquatic system.

### Rocks make the stream sing and provide the brown trout hideouts

A forest stream can be heard from a long distance. The stream sings. There's an African saying that goes like this, "when the stream sings it is because of the stones." The stones make the stream murmur or gurgle. And not only that, the stones also slow the water down, make it flow in a different direction for a short stretch. All this creates different stream beds, some with larger and some with small stones, and some with gravel or sand. Thus, there are many suitable places for all sorts of small animals with different desires on how the stream bed should be. Researchers usually say that stones create a wider variety in the aquatic environment which leads to more kinds of animals in larger quantities. Behind larger stones, shelters are created, places where the water flows very slowly. This is exactly where the brown trout rests, and



Illustration: Bo Persson

when a mayfly larva appears floating in the water, the brown trout flips its fins and shoots out into the current to take the mayfly. Or perhaps it is the angler's fly-fishing lure that floated by. Thus the brown trout does not use as much energy compared to if it were to stay out in the current. Stones also mean that gravel and sand remain where they are. Without the stones, this material would be transported downstream with the water.

### Dead wood in streams creates an abundance of life in the stream

When you walk along a stream in the Russian wilderness, where there has never been any forestry, you are struck by the number of dead trees there are in and on top of the streams. And amongst all this mess it is just teeming with fish. Just like stones, dead wood creates a great variety of habitats. Vegetation also grows on the wood, which becomes food for caddis fly larvae and stonefly larvae. Where a tree trunk lies in the bottom of a stream, the sediment arranges itself such that the thicker material remains upstream and the finer material ends up downstream of the trunk. Upstream of the log, the stream bed becomes suitable for brown trout and mussels, and downstream it is good for lamprey. During the next

high waters, the log will move a little and the sediment once again arranges itself in a new place. Thus patches that are good for animals are recreated over and over. The bed of a stream therefore undergoes constant change on a smaller scale. Researchers call this internal dynamics.

### The riparian zone is important to the water and the water is important to the riparian zone

Even if the forest as a whole affects the water, it is the forest closest to the water - the riparian zone - that has the greatest significance. The functions of the riparian zone in terms of the biodiversity of the water are mainly that it:

- shades, keeping the water temperature down
- filters the water after felling, from particles and some nutritive substances
- supplies food in the form of leaves, other vegetation and small insects such as spiders
- supplies dead wood which provides a rich, varied aquatic environment

Examples of the functions of water in terms of the biodiversity in the riparian zone (overflow areas) are:

- water creates a cool and moist local climate, which is favourable to moss
- regular flooding benefits the plant and animal communities on land
- water produces food (insects) for birds and bats

Riparian zones should be considered part of the water and there should therefore be riparian zones along all streams, rivers and lakes. Leaving riparian zones alone or establishing new ones is one of the most important water conservation measures a forest landowner can take.



### Leaves become fish

Deciduous trees and bushes are common along water courses in forests where there have never been any forestry activities. Leaves that fall into the stream become food for various small animals. Fungi, bacteria and other microscopic organisms will colonise the leaf first. Thereafter, the stonefly larvae, wood lice and others will eat parts of the leaf so that it decomposes into smaller pieces. The pieces float in the water currents and further downstream, the caddisfly as an example, will have built more or less advanced nets that catch the smaller fragments of leaf, which become food. Small pieces of the leaf will also end up at the bottom of the stream where the mayfly larvae can find and eat it. A leaf that ends up in the stream will thus be “processed” by animals that are decomposers, filters and scavengers. These small animals may later be eaten by fish. That is how leaves become fish! And it is why forest landowners should favour leaves in the riparian zone.

### The brown trout’s favourite stream - an ideal picture

Animals and plants in our forest waters have lived without forestry for thousands of years. Biodiversity has thus adapted to what can be called a natural landscape. Brown trout is a common fish in the flowing waters of the forest. If there is plenty of trout, then there are also plenty of other animals. Which is why it is interesting to know which conditions the trout wants. This is what the brown trout’s favourite stream looks like:

- flowing water with natural fluctuations
- clean water - no acidification, over-fertilization or poisons
- cool water
- clear water - no murkiness, not too brown in colour
- clean river beds for spawning (no silt) with stones and gravel
- a lot of stones and/or dead wood - large variation and hideouts

- a riparian zone that shades well, takes care of silt, and provides leaves and dead wood
- plenty of food - insect larvae, snails, crustaceans
- surrounding area and landscape containing plenty of deciduous trees
- open migration paths

This can be an ideal picture of how forest streams should be. Forest landowners can keep the brown trout's favourite stream in mind when planning water considerations.

## Log driving - a smart way to transport timber but bad for the brown trout

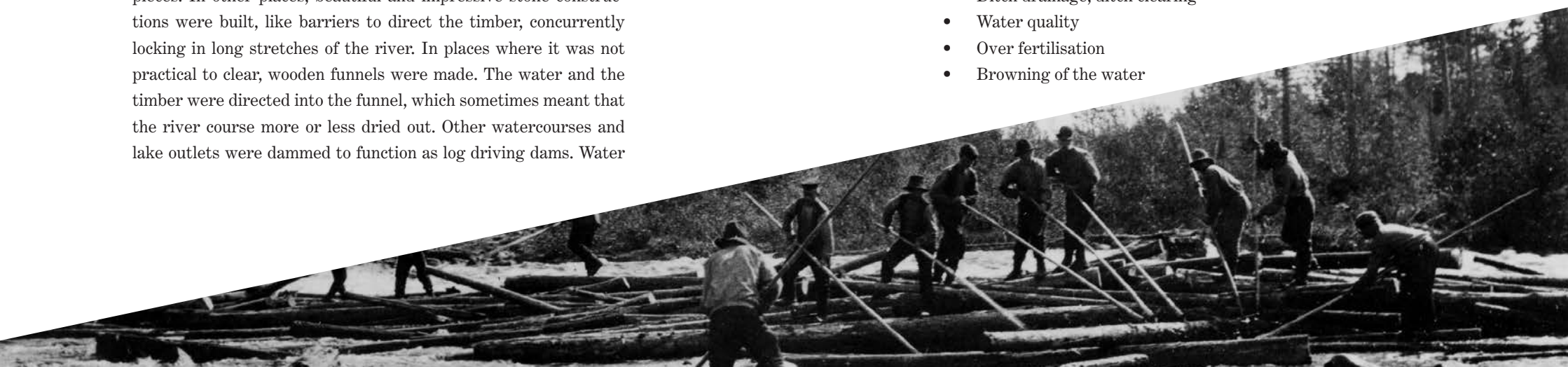
Log driving was an outstandingly smart way to transport timber - no diesel, no emissions - and completely free. Timber was able to be driven in many flowing waters, free of obstacles all the way down to the sawmill at the coast, thanks to thousands of hours of physical labour and simple tools. But for timber to float freely and not get stuck, dead trees and rocks were cleared from the watercourses and edge zones. This commenced at the end of 1700s and by the mid-1900s the clearing had become dramatic. In some places, people drove tracked vehicles from one bank of the river to the other, and moved all the stones up on land. Large rocks were blasted into pieces. In other places, beautiful and impressive stone constructions were built, like barriers to direct the timber, concurrently locking in long stretches of the river. In places where it was not practical to clear, wooden funnels were made. The water and the timber were directed into the funnel, which sometimes meant that the river course more or less dried out. Other watercourses and lake outlets were dammed to function as log driving dams. Water could be saved here and released into the floating channels as needed. The dams became effective barriers to fish migration.

All this re-shaping of streams or rivers has seriously damaged the watercourses. They have been transformed from rich, varied environments to simple gullies in the forest where the water flows faster. There are fewer species of benthos and fewer individuals. The volume of food for the fish decreases. Brown trout, grayling and other biodiversity has been negatively impacted. Today, the stones are being put back into many watercourses. This is often called biological resetting.

## Forestry and farming have an impact - silting is the largest problem

Earlier we said that all changes on land affect the quality of water. Farming and forestry therefore obviously have an impact. Farming has the biggest effect as it involves heavier and more intensive land impact and because remains from fertilisation, nutritive substances, discharge into the streams.  The effects of forestry on streams, rivers and lakes are:

- Silting
- Felling of riparian zones
- Barriers to migration
- Ditch drainage, ditch clearing
- Water quality
- Over fertilisation
- Browning of the water



## Consideration for water has improved in recent years

It is important to point out that during the last two decades the forestry industry has realised the importance of taking care of the forest's water. Damage from driving, which was a huge problem 15 years ago, is significantly less common today. Certain forestry actors have even introduced something called a land care guarantee. Over time a form of "general water consideration" has developed, including:

- Reduction in the risk of driving damage, for example in the form of better planning of driving routes, temporary bridges over watercourses, land protection across wetlands.
- Riparian zones, either retaining them along the water or establishing new ones if the existing riparian zone was cleared due to it being non-functional, for example if it contained similar aged productive forests with only fir trees.
- Adding dead wood. There is room for improvement here though.
- Elimination of migration obstacles in the form of incorrectly placed culverts.

**This table shows the problems and how they can be solved.**

| How forestry can affect streams, rivers and lakes. | Risk | What can be done to reduce the impact |
|---|---|---|
| Silting; fine particles clog up the river beds, particles carry phosphorus with them which can lead to over-fertilising. All bare soil constitutes a risk area, such as forest clearings. Land preparation, tracks from driving and ditch clearing constitute a risk for silting and over-fertilisation | Substantial | Reduce tracks left after driving - plan driving. Cautious land preparation. Riparian zones. Ensure that that silt from ditch clearing does not flow out into streams. |
| Felling of riparian zones; water habitat deterioration | Substantial | Retain a riparian zone of 5 - 15m, wider if the land slopes a lot to the stream. If the edge zone contains only large pines (= an unnatural and non-functional riparian zone) it can be felled and thereafter a new riparian zone established. A functional riparian zone should shade, act as a filter for particles, provide leaves and provide dead wood. A good riparian zone therefore has different species of trees with plenty of leaves, trees of all ages and bushes. |
| Barriers to migration; incorrectly placed culverts, dams | Big | Switch to half-culverts or bridges when renovating the road. Tear down the dam if possible, otherwise create a "detour" (a small stream that passes around the dam). This can be funded by a grant. |
| Ditch drainage, ditch clearing; faster water flow, risk of flooding downstream, silt that clogs up the stream bed. | Big | Do not drain ditches. Make sure that silt does not run into streams when clearing ditches. Many ditches do not improve the production of the forest. Fill in the ditches and recreate wetlands/man-made waters. |
| Over-fertilizing; too much phosphorus (which binds to particles) | Moderate | Keep or create riparian zones, that absorb the soil particles. |

Forestry naturally affects the water quality, even if the impact from forestry is relatively small compared to that of farming. After a final felling, there is leakage of both phosphorus and nitrogen. The phosphorus, which binds to soil particles, is what risks over-fertilization of the forest water. From a biological perspective, the nitrogen does not have a significant impact on the forest waters, but it does when the water later reaches the sea.

Forest water has become browner during recent decades. Researchers call this brownification. It involves the brown humic matter, that is the degraded remains of vegetation. Brown water is unfavourable in a variety of ways to both plant and animal life. It is not entirely clear why brownification has occurred. More rain and less sulphuric rain (acidification) may be some of the reasons. New research suggests that forestry may be largely responsible though. The increasing proportion of fir tree forests create run-off water that is rich in humic matter.

## Siltation - the most serious problem from forestry

The absolute largest effects occur as a result of silt ending up in streams. The risk of siltation is in fact by far the largest water conservation problem. This also applies to water from farming. It involves small, almost microscopic particles (smaller than a millimetre) that clog up the river beds. This affects the eggs of the brown trout which rest in the demersal material and need fresh, oxygenated water to flow through the bed. Similarly, the small half-millimetre young mussels also suffer. When they are released from the brown trout's gills they fall to the stream bed. They cannot remain on the top of the stream bed but need to make their way down into the gaps between the stones and shingle. If the silt has blocked up the gaps then there is no space for the young mussels. Even if they manage to make their way down, there can be a lack of oxygen if there is too much silt. The riparian zone has important ecological functions for the watercourse and it is therefore to be expected that if the riparian zone is felled, the conditions for the aquatic life will dramatically change.



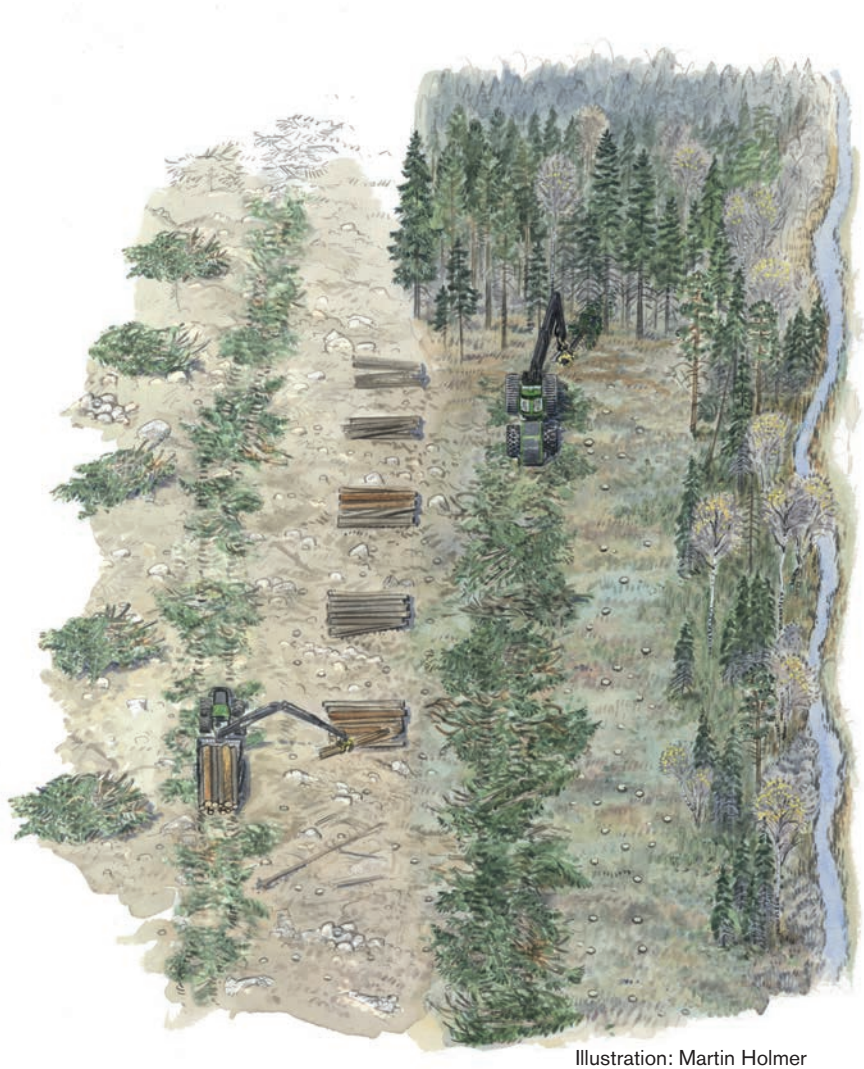


Illustration: Martin Holmer

**Reducing the risk of damage from driving**

The illustration shows a method of driving which spares the ground during forest felling near the water. If both the harvester and the forwarder use the full reach of the crane, the forwarder can remain at a fairly large distance from the sensitive riparian zone. In this example, the heavy forwarder can move on firm ground and thereby not cause damage from driving as easily. The forestry sector's shared vision for good environmental consideration.

## Ditches speed up the flow of water in the landscape

As previously mentioned, water moves slowly through the forest but also, the speed of water increases in cleared log-driving channels. Different kinds of ditches - such as road ditches, forest ditches, ditches in arable land - also increase the speed of the water flow. This is of course why they are created, in addition to drying out wetlands. In the whole of Sweden, there is actually one and half times more ditches than natural water courses (900,000 km vs 600,000 km). It is no wonder that water flows faster through the landscape today and creates floods after a lot of rain. Not only do ditches speed up the run-off, they also transport humus, sand, gravel and nutritive substances which negatively impact the water. Many of the ditches never did lead to better forest production. Estimates show that today in Swedish forests, such ditches are the equivalent of the area of half a million football pitches. These are unnecessary ditches that simply create environmental problems. In this respect, the forest landowner can implement good environmental measures without any impact on production - fill in unnecessary ditches and recreate wetlands or man-made waters.

## Ditch clearing - always damages the water and is not always profitable

Over time, many ditches lose their draining function. Branches stop the flow of water and silt decreases the depth of the water. The ditches therefore need to be cleared. Clearing of course involves lots of materials being flushed out into some stream or lake. The risk of silting becomes very significant. Which is why ditch clearing must be carefully planned - which sections really need to be cleared, how can ditch water be released so that silt can be cleaned out before it reaches a stream? Ideal scenarios exist today that advise, for example, on how sedimentation can be captured. Unfortunately, it has to be said that there are currently no effective ways to reduce the transportation of the very fine particles that clog up river and stream beds. It is often not clear if the clearing is really economically profitable - there is no Swedish research in the matter. Finnish studies are often referred to, but there is much ambiguity about whether the results can be applied to Swedish forests.

## Obstacles to migration fragment the aquatic system

We all know that brown trout migrate. Other animals do too, but not to the same extent. Log driving dams and dams at mills, sawmills and hydropower stations of course block the animal's migration. In addition, culverts have been placed so high that fish and other animals cannot pass through them. The aquatic system becomes chopped up by migration obstacles, which is a very big problem when we want a working aquatic landscape.

## Closing comments

The forest is a large asset for the forest landowner, the general public and the entire Swedish society. Forest landowners and the Swedish government benefit economically, the general public uses the forest for recreation, forest production binds carbon dioxide which reduces climate change. And of course, the forest is home to rich biodiversity, with many fascinating species, and species that provide what we call ecosystem services. There is therefore all reason to manage the forest in a smart way, both economically and environmentally. That way we will have fresh, living forest water for everybody's enjoyment. There is water everywhere in the forest - forests and water belong together.

# LAKES AND CLIMATE CHANGE - WHAT IS HAPPENING?

Discussions about what is happening with the world's climate are intensifying. The 2015 Paris climate accord stated that the countries of the world need to do everything they can to maintain temperature increases globally to below two degrees, compared with pre-industrial times. Increases should preferably stop at 1.5 degrees to avoid all too drastic consequences. In Jämtland, Sweden, the average air temperature has already increased by two degrees since the 1950s (Frösön meteorological station). This is a lot, and it is already affecting both humans and nature. Today there are many indications, from the mountains, lakes and forests, that show that changes are taking place in the plant and animal world. Trees are growing further up the mountains, forests are growing at speed, glaciers are melting faster during the summer season, winters are getting shorter, and so on.

These ongoing changes affect all the world's ecosystems, and not least lakes because the physical, chemical and biological processes in lakes are to a large extent controlled by temperature and precipitation conditions. The fastest and strongest relative warming is also expected to take place at northern latitudes.

For the lakes in the Triple Lakes area, higher air temperatures and different patterns of precipitation would mean changes in the ecosystem and the functions of the lake, From a global perspective, the changes are less dramatic than melting glaciers, forest fires

and rising sea levels. However, we want the ecosystem services that the lakes provide, for example in terms of fishing and drinking water, to remain and we want our surrounding nature to continue working as close to unchanged as possible.

## Basic terms

What can we expect to happen with the fish populations and lake environment? Will the production of fish increase if the water becomes warmer? Might it become so bad that we get algal bloom? In an attempt to describe what is already happening and what we might expect to happen, we will report on the current knowledge level and reflect on possible future consequences for the ecosystems of lakes. To limit and facilitate this reasoning, we will focus on northern lakes of the kind that are part of Triple Lakes. All three lakes in the project are large, relatively deep lakes, with low food value and clear water. Despite being located in forest areas, they are more like mountain lakes than the brown-coloured lakes otherwise found in the area. The fish population is dominated by different forms of whitefish, but there are also salmonids such as brown trout, Arctic char and grayling. There is also perch, roach, pike, burbot and other species. Overall, it is relatively rich in fish species and has a more complex ecosystem than the mountain lakes.

In lake ecosystems we refer to *food webs*. They describe how different groups of organisms relate to each other and how the *flow of energy* moves between them and in the system as a whole. Algae that grow in shallow lake beds and the small, microscopic algae in the body of water are the producers of the basic energy in the lake. They are then eaten by benthos animals or zoo plankton, which in turn become fish food. At the top of the food web is where predatory fish are found. *The energy is thus transformed from algae to invertebrates and then to fish and predatory fish.*

In principle all the organisms in the food webs of lakes are *cold-blooded*. This means that their body temperature is determined by the temperature of their environment. Their body temperature in turn controls the *metabolism* of the organism (the basic energy needs of the body's cells) and how quickly and effectively the food is converted to energy. The temperature also determines how much of the energy content from the food is left over for other essential survival processes such as growth and reproduction. *In other words, warmer water means higher energy needs to maintain the body's functions and for it to be able to grow and reproduce.* For cold-blooded organisms, therefore, the surrounding temperature is often the most important factor in deciding the energy needs of the organism and how much food it takes in.

When the water temperature rises and the ice-free season lengthens, the energy needs of all the consumers in the food web will increase, from zoo plankton, to benthos animals and all the way up to the predatory fish. They need to eat more, which in turn increases the negative effects on the food resources (algae, or prey) upon which they feed. Increased consumption quite simply leads to a greater impact on the food supply. *In simple terms, one can say that changes in the lakes' production of energy due to an increased water temperature directly determines the consequences that a warmer water climate has on the ecosystem.*

## Light, nutrition and algae

In the lakes that were included in the Triple Lakes project, algae growth on the lake beds is the single most important base production. It involves small, microscopic algae on the sediment layer, and larger leaf-shaped algae. The latter include green algae which are characteristic of Locknesjön lake, for example.

Up to 80% of the animals further up in the food chain (demersal animals and thereafter fish) in these types of clear-water lakes receive most of their energy needs from these demersal algae. The production of these is affected primarily by access to light. The algae get their nutrition from the nutritious demersal sediment.

Changes in factors that affect the demersal algae are already happening now as a result of our new climate. As an example, since the 1980s the amount of time that Storsjön lake is covered with ice has reduced. Every winter, the lake is iced over for approximately one less month. This is a very big change. Longer ice-free periods, with increased light penetration for a longer time create the conditions for a higher production of algae. If more light reaches deeper lake beds for a longer period, algae production would reasonably increase.

In this way the productivity at the base of the food web as whole increases as a result of climate change. But whether this is happening and whether it is leading to more fish is far from certain. In this case, the basic production would have to increase more than the increased energy needs of the fish as a result of an increased temperature. One important difference between the energy needs of algae and animals is that the temperature does not have the same importance to algae production as it does to the production of fish and demersal animals. Light and nutrient salt are equally as important factors for the algae to grow. If algae production is to increase then more than warmer water is needed. The algae must also have access to more nourishment in the form of the most important nutrients for fresh water, phosphorus and nitrogen.

Another prerequisite is the colour of the water, or rather, that the transparency of the water does not decrease. One hypothesis regarding climate change is that the increased growth and degradation of organic material from vegetation on land has led to the water becoming browner. More organic material is being flushed into lakes from land environments. This "brownification" would be further strengthened by the expected increase in precipitation. Browner water decreases the amount of light reaching the demersal algae, which leads to reduced algae production. Studies in southern Sweden have also registered a "brownification" of lakes during the last few decades, resulting in a reduced depth of visibility. The reasons are not completely clear, but it is believed that climate change is having an effect. We are not seeing this development in our northern lakes yet. Here the water colour remains the same or else is somewhat reduced. But even here in the North, the growth of on-land vegetation is increasing. Why more organic material is not being flushed out into the lakes is unknown. Perhaps it is all in a state of flux from which we have not yet seen the final results. Perhaps there needs to be a larger change in land vegetation and soil conditions before water also turns brown here.

Lakes also contain small free-moving algae in the mass of water. These phytoplankton become food for zoo plankton, which is in turn eaten by fish. In contrast to demersal algae, they are completely dependent on access to nutritive substances in the water, primarily phosphorus and nitrogen. During recent decades, the quantity of phosphorus in northern water has decreased greatly. In many aquatic systems the quantity of phosphorous has halved compared to the levels of the 1980s. Even here the reasons are partially unknown. It is believed that there is link to climate change and its impacts on vegetation and ground chemistry, but more research is required. What is clear is that reduced levels of phosphorous should mean lower biological production in lakes. No clear and direct effects have yet been able to be identified in northern waters. Perhaps production in the large, clear lakes discussed here is so greatly dependent on demersal algae that the decreased production of zooplankton hardly has any impact.

However, most researchers believe that in the future the significance of plankton production in the wider mass of water will increase compared to the algae production on the river beds. This is partly due to the brownification of the lakes as light penetration decreases. It is also partly due to nutritive substances such as nitrogen and phosphorus being flushed out into the lakes with organic material. This adds to an expected increase in phytoplankton. In comparative studies of clear and brown waters, a pattern appears

that shows a bell-shaped relationship between the total base production in lakes, the quantity of fish and how brown the lake water is (Figure?) An increasing total productivity has been explained by an initial increase in production within the free mass of water since the availability of nutrient salt increases the production of phytoplankton. This initial positive effect is countered by less light reaching the lake beds, which negatively affects the algae production. Overall, the final result might be that production decreases in spite of the warmer climate.

## Fish and water temperature

A rise in the air temperature affects the aquatic environment in several ways. The most obvious is that the water becomes warmer. Research based on measurements in a large number of lakes shows a general increase in the surface water temperature of 0.3 degrees per decade since the 1980s. While this variation is large, it is evident that clear lakes heat up more than others. Further, water temperature actually increases more relative to air temperature. If it becomes one degree warmer in the air, the water temperature increases by 1.7 degrees. The two-degree increase in the air temperature that we know has already happened in Jämtland therefore means an annual average increase of 3.4 degrees in the surface water temperature. This is a big change.

For the animals in the lake, fish and invertebrates alike, an increase in the water temperature means more energy is required to maintain their basic energy needs for metabolism and swimming activities. On the other hand, metabolism and, if there is enough food, growth also goes faster. The fish has the chance to grow for a longer period and in a higher water temperature. In that way it can reach a certain size and maybe even sexual maturity faster . This is very important for the life pattern of fish. For example, it means that fish can become larger prey sooner and grow beyond the period of time when it is at risk of being prey for predatory fish such as pike and brown trout.



The prerequisite for increased growth and/or reproduction of fish, however, is that the amount of prey animals keeps pace when the water gets warmer. There needs to be a greater quantity and for a longer part of the season in order for there to be a positive effect on the growth of the fish. This can be problematic as many insects, which are of course important prey animals, have fixed growth and hatching periods. A longer growth season can however mean that certain insects have time to have two generations per year, instead of only one. Zooplankton, which is important for whitefish and young fish, also has seasonal cycles during which species alternate their dominance in the relationships during different periods of the year. Large species of zooplankton dominate most often during spring and autumn, while smaller species are more common in the summertime. If these patterns remain, or if hatching takes places earlier in spring, this can lead to less food resources later in the season as small zooplankton provides inferior food. Thus, the outcome of temperature increases might not be as extensive in terms of fish growth. Then, understandably, species composition of insects and other invertebrates change if the temperature increases. Some disappear, some are added. Maybe some of the new species will become dominant while some of the original species will reduce in quantity. It is difficult, however, to predict the consequences on fish food availability in advance.

One basic rule is that small fish need relatively less food than large fish to still be able to grow well. If the temperature increases, young fish can grow faster even if the total production of food does not increase, or increases less than the energy requirements for the entire population. An increased production of young fish can thereby mean that overall competition for food increases, which is unfavourable for the larger individuals. As a result of the increased competition, the fish population may end up being dominated by a large population of adult individuals that grow slowly - referred to as a dwarf population. It is not even certain that the large pred-

atory fish benefit since, before they shift to a fish diet the young predatory fish have more competition if there is more prey fish that eats the same food as the younger predatory fish

### Shifting of fish species

Warmer water will benefit certain fish and be detrimental to others. The outcome will depend on the lake's characteristics and the size of the temperature increase. Many of our most popular species of fish, such as Arctic char, brown trout, grayling and to a certain extent whitefish, thrive best in relatively cold water. There are differences between the species of course, but these salmonids grow best in the range between 13 and 18 degrees. If the temperature goes above 20 degrees over the long-term, then the Arctic char and brown trout will have a problem growing and maybe even surviving.

Warmer water leads to increased metabolism and increased energy consumption when fish swim. This means that hunting for food also costs more energy. When the cost of swimming is greater than the income in the form of the prey's calorific content, the fish loses out. They then generally stop eating and keep a low profile instead, which has consequences on muscle growth and sexual reproduction. As it happens, the large northern lakes that we are discussing here actually have large depths containing cold water, even under warmer spells. That means that the fish have a place to escape to and avoid the warm water. But some areas of the lake become inaccessible for feeding. Summer 2018 was extremely dry and warm, and studies show that in Näkten lake the temperatures as far down as 40 metres deep were as high as 13 degrees. Often, the areas where temperatures become too high coincide with the shallow areas where production of demersal animals is greatest. This limits the options for the fish and thereby their growth.

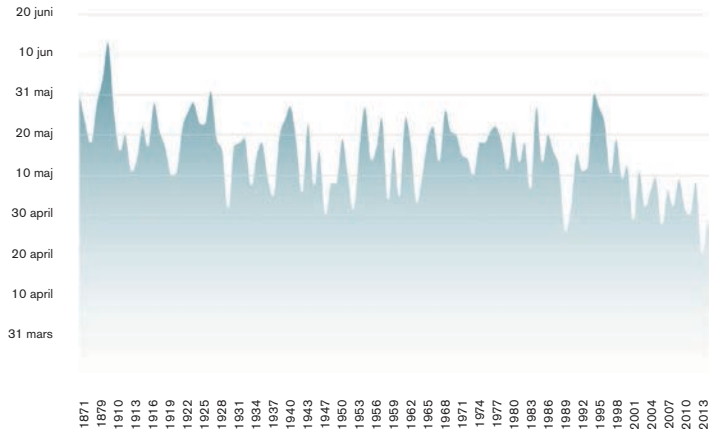
Differences in temperature preferences between various species are even greater if we include other fish than salmonids in the discussion. Roach, perch and pike will benefit if the temperature rises. They do not have anything against waters of 20 - 25 degrees. Much suggests that these species will increase in quantity and make use of more areas of the lakes if the temperatures rise. One important factor here is the winter survival of the juvenile fish. As an example, the juvenile perch eats nothing or very little during winter. That season becomes a bottleneck for perch recruitment. The most important factor behind the increase in perch in many lakes close to the mountains is probably that winter survival of the juvenile has increased. This is strongly linked to the length of the winter and the size of the juvenile perch when the lake freezes over. The larger the juvenile perch is before winter, the longer the period of starvation it can take. A longer growth season and warmer water means both a larger size of juvenile perch and shorter winter period of starvation. Overall, this may lead to salmonids being pushed back, becoming fewer and being displaced.

One must nonetheless remember that the population dynamics of fish are often much more complex. Many factors impact the size of the fish population and the individual fish. Temperature, depth conditions and the physical environment also play their part, as does availability of prey and internal competition within both the age group and in the species in general. Further, competition from other species and predation from predatory fish have an effect. The outcome of an increase in water temperature can therefore be difficult to predict. We have received several indications thus far from different northern bodies of water, that may have bearing on the lakes of the Triple Lakes project. Perch appears to be widely on the increase, both in terms of quantity in cold lakes near the mountains, and in terms of size in many of northern Sweden's lakes. From a point when the temperature limited the growth of perch, the rise in temperature has now increased the growth potential of the perch. From many waters where kilo-sized perch had never been caught there are now reports of frequent catches of

large fish. Even in studies carried out in Näkten lake, those who fish all agree that the availability of perch is growing, as it the average size. Even pike is increasing, and it is expanding its areas where it can, westwards towards the mountain ranges. When it comes to the pike, it is clear that in the lakes where it has managed to establish itself, the effects on the brown trout and Arctic char have been dramatically negative.

Several of the species that benefit spawn in spring. This includes perch, roach and pike, in contrast to brown trout, Arctic char and whitefish that spawn in autumn. It is probably easier for spring-spawning fish to adapt to a warmer climate. They have a much faster development time for their eggs and the opportunity to adjust their spawning time based on the prevalent spring water temperature. Thus the juvenile hatches under favourable conditions in terms of food availability. Fish that spawn in autumn have a much longer development time for their eggs, depending on how low the water temperature becomes. Warmer winters will cause larger differences in the hatching times and generate a risk that the juvenile will hatch in unfavourable conditions. The grayling is the odd-one-out as it is both a salmonid and spawns in spring. This fish also has great flexibility in terms of spawning earlier if the seasonal conditions change. Many things indicate that the grayling would survive a shift to earlier snow-melting and higher spring temperatures. There are also signs from certain northern lakes that the population of grayling has increased during recent decades.

Arctic char is reported to be on the decline, perhaps not higher up in the mountains where it is the only species, but in shallow, lower-altitude lakes located in forestlands. In lakes where the Arctic char and brown trout both exist, the pattern in most lakes is that the proportion of Arctic char in the catch is decreasing, relatively. Even in Näkten lake, the people who fish there report that the population of Arctic char has declined in recent decades. Small whitefish is also on the decline, which can have a big effect in lakes where small whitefish are the main prey for large brown trout and Arctic char. As an example, the reduced population of large Arctic char in Vättern lake has been linked to the reduced population of vendace as a result of warmer winters. Catching small whitefish in spawning areas during autumn has completely ceased in many places due to the shortage of fish. It is of course uncertain whether all this has to do with climate change, but it is clear that large changes are taking place in many lakes. The things that are happening are taking place below the surface, however, somewhat gradually and slowly, which means that it is difficult to detect.




The graph illustrates the dates on which the ice melted on Näkten lake during the period 1871 - 2013. At the end of the period of measurement, the ice melted on average somewhat earlier than at the beginning of the period of measurement.

## And finally

Cause and effect are not always simple to understand. This certainly applies to lake ecosystems. The relationship between the physical environment and biology in the form of plants and animals

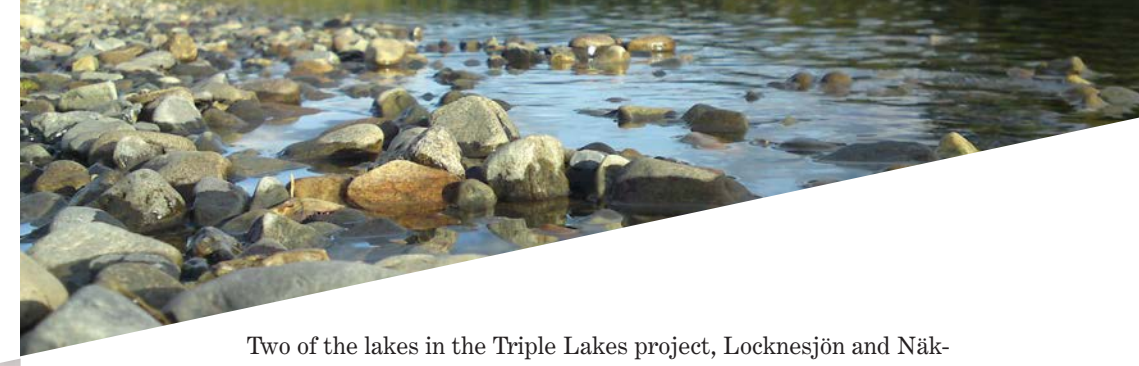
is complex. Much of the discussion we have presented above lands in uncertainty both in terms of what is happening and why. Many things suggest that we have only seen the beginning of the changes that a warmer climate brings. Perhaps we are in a phase when the ecosystem of the lakes is gradually changing, but where new, more stable states have not yet unfolded. Further changes are thus to be expected during the coming decades. We have also omitted the changes in hydrology that occur as a result of a different precipitation patterns. Perhaps dry years with low water will become more common, along with floods and heavy rain. We clearly need more knowledge about specific waters, such as the Triple Lakes project, but also research that can describe and lay out more general overarching trends.

We can also ask the question of whether the lakes' animals and plants have the ability to adapt to the new conditions that higher temperatures bring. For example, are there genes in certain Arctic char individuals and to such an extent that they can survive and grow in warmer water? If so, can natural selection prioritise fish that have these genes such that the entire population becomes more tolerant to the warmth in the long term. A very difficult question. One important factor will be the speed at which the climate and temperatures change. If it goes too fast and maybe also in spurts, which many things suggest, natural selection will not keep up. This means that the ability of the ecosystem to adapt will be limited if that is the case.

In closing, there is not much we can do about climate change that is having a local impact. Whatever happens in the lakes in the coming decades will happen no matter what. What we need to do is try to limit other environmental impact as far as possible. We simply need to manage our water in the best way possible. Ecosystems that are "healthy and strong" to begin with evidently cope better in a warmer future.



# MANAGEMENT AND PROTECTION OF ARCTIC CHAR



Two of the lakes in the Triple Lakes project, Locknesjön and Näkten, are famous for their large Arctic char. Not only is it a beautiful fish, but as previously mentioned, an important resource for people that lived by the lakes. During the application process for the project, a concern was raised, primarily regarding Näkten's population of large Arctic char. A survey of recreational anglers that was carried out in Näkten lake in 2016 showed that people deemed that the size of the Arctic char catches had reduced, that the fish size had decreased and that the total Arctic char population had shrunk.

One possible reason given was that the regulation of the lake during extreme years might have had an impact on the spawning areas located in the shallows, if water levels dropped before the eggs had hatched. Historic over-fishing during spawning was another reason. As was the introduction of Mysis and other non-native strains of whitefish that would eventually compete with the Arctic char for food. Given that other species, such as perch and pike, have increased during recent decades, climate change can also be suggested as a potential cause of the negative trend for the Arctic char in Näkten lake.  But no obvious singular determining factor has been found.

### Historical events in Näkten

The first report we have of a decreasing population of Arctic char comes during the latter part of the 1800s when the population is described as exceedingly weak, thus all fishing for Arctic char was to be stopped. During the first half of the 1900s, the famous spawning declines in the northern part of the lake, and then disappears completely. Fåker's dairy (built in 1920) is suggested as a culprit

early on, but there is no clear evidence for this. During the 1940s the lake is regulated for power generation and water management changes, which may have impacted the spawning areas in the shallower parts of the lake. Between 1948 and 1957, maraena whitefish and Sällsjö whitefish are released to compensate for the regulation. This new type of whitefish may have increased the competition for smaller Arctic char. In 1968, the crustacean types Mysis and Pallasea are introduced. A strong, surviving population of Mysis is noted in 1970 and it cannot be ruled out that Mysis competes for the same food as the smaller Arctic char, and does not only act as a source of nutrition, as was intended. During the latter part of the 1900s, spawning also declines in the western part of the lake, and today is so small that it can hardly be detected.

## Climate change

As mentioned earlier in this book, the Arctic char is a distinctive cold-water species. There is no doubt that we are currently facing climate changes. How and when the effects of a warmer climate will occur is difficult to predict. In earlier studies of Arctic char spawning, it appears that a delay of 2 - 3 weeks has occurred in the spawning, compared to the 1970s. Compared to the beginning of 1990s, this shift is almost a month. Data from ice-melting shows an approximately one-month shorter period of ice cover on Näkten lake, calculated from the 1870s. During the extreme summer of 2018, for a long period the water down to 6 - 8 metres was dangerous or even fatal for the Arctic char to remain in for any length of time. And as deep as 20 - 23 metres, temperatures of around 15 degrees were recorded during some periods, which materially reduces the size of suitable Arctic char habitat in Näkten. At such depths, even these deeper basins become isolated from each other, and it is difficult to say how this impacts the Arctic char. It happens that the Arctic char does not completely avoid these warmer areas of the lake, and still searches them out for food, if only for shorter periods of time. Hopefully we will get some answers on how the Arctic char moves about in the lake through the results of the current telemetry study, currently ongoing in Näkten lake.



## Land use

Water that ends up in Näkten lake is formed during its journey solely by forest land. Today there are no measurements that show the size of the impact from ongoing land use, such as forestry. But as earlier chapters have explained, it is important to reduce all unnecessary impact.

Forestry measures that occur in the watershed should be implemented in accordance with the targets for water conservation that the Swedish Forest Agency and the industry have developed. Reducing transport of particles and nutritive substances to the lake will decrease the overall impact on the quality of water, which in turn is likely to allow for other effects, such as those from climate change. In addition to affecting the Arctic char, changes in the quality of water can also negatively impact other species. This might include siltation of the spawning beds or, in extreme cases, shortages in food sources due to reduced visibility.

## Fishing and fishing management

for Arctic char in Näkten lake has been banned more than once due to a drastic decrease in the population. We also know that how we fish has changed dramatically in the last 50 - 70 years. We cannot confidently say what this change means for the Arctic char population though. Fishing during Arctic char spawning periods still exists today, although in a much-reduced manner. The level at which it is believed to take place today is likely to have only a limited effect on the Arctic char population, biologically and numerically.

Vättern lake, which has a population of large Arctic char, has also experienced similar trends to Näkten lake, with a diminishing population and smaller fish sizes. Vättern has different problems

and circumstances to Näkten, but there are similarities. Investigations have been carried out in Vättern over a relatively long time, such as fish sampling. These types of investigations are lacking in Näkten lake, so we cannot rely on any statistics to demonstrate changes and trends in the lake's biomass. The limited fish sampling carried out in Näkten during the project shows that Arctic char that reaches the size at which it eats fish, should not have a problem finding food. Smärlingen, the small type of whitefish which is the most important source of food for larger Arctic char, were plentiful in these fish sampling tests.

Fishing in Vättern lake has been regulated on various occasions to protect both the Arctic char and other existing species in the lake. In 2004, the Fisheries Authority introduced new regulations to strengthen diminishing Arctic char and whitefish populations. The most dramatic measure taken was protecting three larger areas from all fishing (apart from fishing for crayfish). Follow-up fish sampling shows that this fishing ban seems to have had a large, positive effect on the Arctic char population. Based on how anglers in Näkten lake describe the development of the Arctic char, this may possibly be one approach to take in Näkten to reduce the pressure on the fish-eating part of the population. Trolling anglers that have not been as active in their fishing for Arctic char in Näkten in recent years, this year experienced that there has been a positive development during this period. It may be an effect of the population not being so intensively fished for a few years.

To be able to effectively manage Näkten's fish population in the future, follow-up of the measures taken is needed to find out which measures work and which are most cost-effective. One step would be to continue the fish sampling that has been done to create a series of samples for comparison of developments.

The conclusion has to be that a long-term management plan is needed including both follow-up and measures to be able to continue work with the conservation of Näkten lake's large Arctic char.

"Smärlingen" the small type of whitefish, is an important source of food for the Arctic char. Large quantities were caught during a fish sampling test in Näkten lake in 2018.




## Biotope preservation for Arctic char

The measures discussed so far are more general management in nature. Within the Triple Lakes project, we have also worked with specific initiatives to improve the conditions for the Arctic char. Early in the Triple Lakes project planning phase, Näkten's fish conservation area requested that restoration of the Arctic char spawning beds be part of the project. One of the problems identified was that many of the former known spawning beds in parts of the lake had been abandoned. One possible measure to compensate or restore spawning in these abandoned places was to recreate good spawning conditions.

As mentioned earlier, Arctic char spawning in the northern and western parts of the lake has diminished so much that it is not even possible to confirm that it exists in these parts any longer. The spawning that is known to exist today takes place in shallow waters in the southern part of lake, to the east.

We prioritised efforts in the western and southern parts as the impact here should be less than in the northern part of the lake. There are several reasons for this. Firstly, spawning disappeared from here later than it did in the northern part. Spawning was documented here at least as far as the mid-1900s, compared to the beginning of the same century in the northern part of the lake. Secondly, these areas are closer to the functioning spawning beds in the eastern part.

When the new spawning beds were to be constructed, we chose to start from the places we knew Arctic char had spawned in the past. Several investigations were carried out to ensure that the new spawning beds would be set up in those locations with the best conditions for spawning.

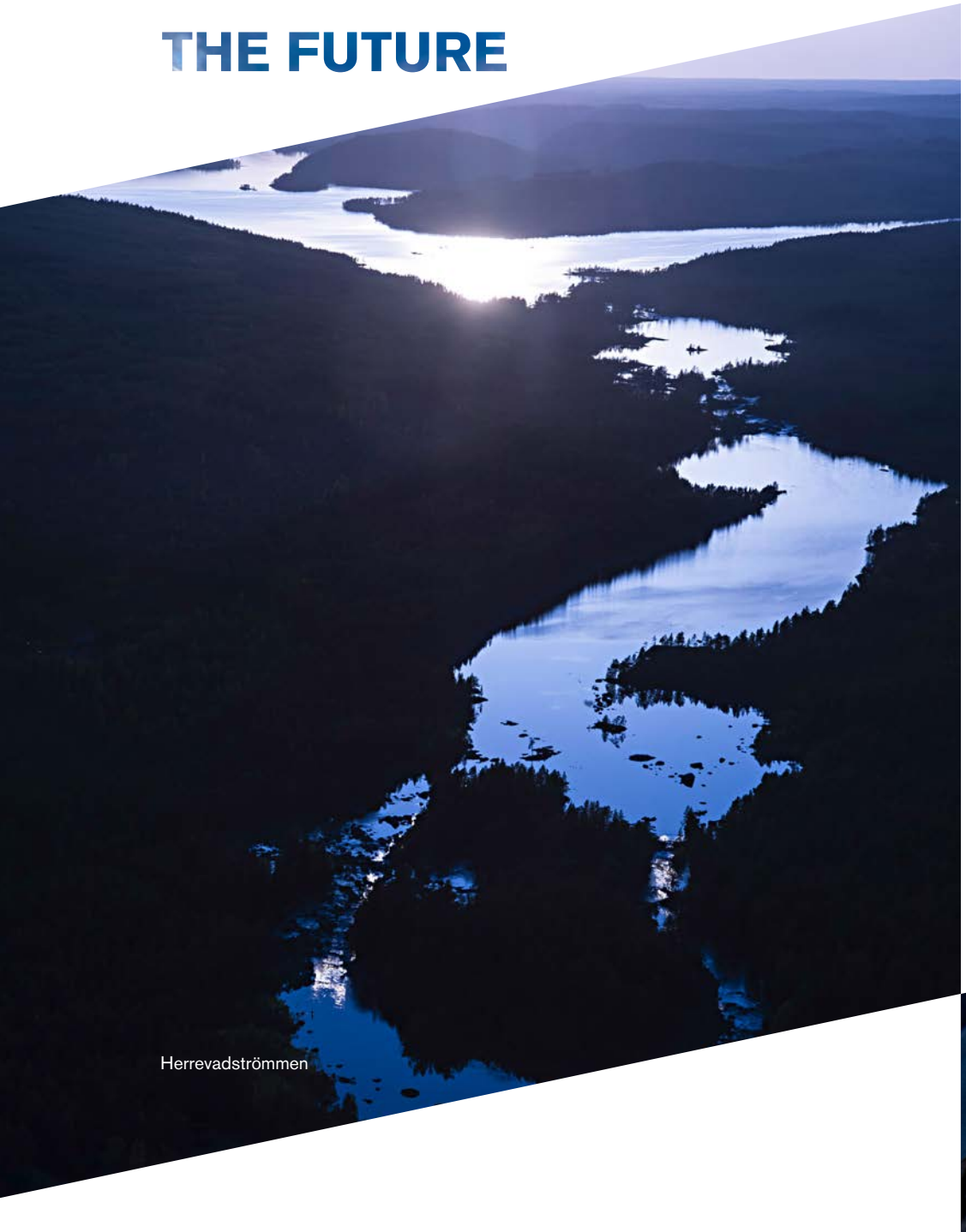


The first used Näkten's normal water level and low water level to determine the most suitable depth,based on the lake's regulations. After that, we used a "minimum depth" that we calculated and visually inspected the locations with suitable spawning substrate. It turned out that sedimentation was not usually an issue and that the current conditions in many places were very good.

Since the physical conditions looked good, attempts at hatching were carried out. Brood fish from areas on the eastern side were spawned and the eggs were fertilized. Once the eggs had expanded they were placed in plastic hatching baskets containing small artificial spawning beds. The baskets were put in some of the proposed places as well as in a couple of working spawning areas. It is worth noting here that we did introduce any fertilized eggs. This meant that the entire test could be done at once on the same day, from the spawning of the net-caught Arctic char to putting out the test baskets. After the ice had melted, the baskets were removed to check the hatching. The result showed equally good or better hatching in the locations where there is currently no breeding.

I Näkten lake we chose to create the new beds in a pyramid shape, primarily with a view to being able to put the fish eggs effectively where they would be able to remain protected. This was done by helicopter. As the work was carried out on top of the water without any natural reference points on the surface, floating frames of drainage pipes were used to be able to form the spawning beds. The material used was natural stone with a fraction of 20 - 200mm. On Näkten lake, 600 tonnes of material was flown out to 14 areas. After construction, swollen eggs have been introduced to the new beds every year. It will take another few years before any results from these annual releases will be seen.

# THE FUTURE



Herrevadströmmen

In the previous chapters we have seen that the environmental situation in many of our lakes in many ways is good, and that within the scope of this project we have implemented further improvement initiatives. We have also seen that the lakes have always and still do have great significance for people and society, from several perspectives. They provide drinking water and take care of our waste water. They are an important component of the physical landscape and help make living in the area attractive, and provide great opportunities for outdoor recreation. Fish populations and fishing is important in many ways. They provide those that live in the area a possibility to catch fish to eat. They also provide visiting anglers the opportunity for fishing experiences. Fishing tourism is small-scale and not particularly extensive, but it benefits the local economy.

But how does the future look? Will the lakes continue to have a central role in the countryside? Will they look the same as they do today, the same aquatic environment, same fish populations? Of course we do not know, but we can be fairly certain that changes will happen. Already now we can see a number of future challenges we need to consider. Below we take the liberty of speculating about these. How will things be in 50 years? How will the lakes of the Triple Lakes project look then? How will they be used and how will we manage them?

## A warmer climate

One of the premises for the TL project has been that we would take steps to solve as many of today's environmental problems as possible so that the lakes and their ecosystems would be in a good condition. We hope that this in turn enables them to be better able to resist or "adapt" to a new situation. Adapt is written between speech marks as the lakes themselves do not adapt. Rather, the ecosystem's structure can change while its function remains. This means that they can continue to deliver the ecosystem services we demand (drinking water, purification of sewerage, fishing, recreation, etc) even though the external circumstances change.

In terms of drinking water and waste water management, it is difficult to predict the effects a warmer climate could bring. One concern is that the warmer water will allow the establishment of new organisms in the lake. In the worst-case scenario, this may involve those that negatively impact the water quality. This in turn would mean that water purification would need to be developed to respond to new demands. Similarly, one can speculate that the addition of nutritive substances from sewerage in a warmer climate might lead to other, more negative consequences for the aquatic environment. Today there is already a problem of increased clogging and water beds that have become land. They may deteriorate further and incur consequences that could be so serious that purification techniques and management would need to change here too.

So what needs to be done to safeguard the future? Obviously, we need environmental and external monitoring so that we can identify any threats and actual negative changes early. Monitoring programs perhaps need to be reviewed and developed to respond to the demands of such a perspective.



## Fish management

As we already established in the historical review, a changing fish population and shifting between species is nothing unusual. This can sometimes be linked to how we have fished and thus affected the fish population. Changes in the composition of the populations has also occurred though as a result of environmental changes, sometimes due to human activities, sometimes as a result of natural events.

We usually tend to link the changes we see today, such as period of ice-cover and water temperatures compared to the 1980s, to the climate. What is clear is that whatever is happening with the climate, irrespective of cause, is already affecting ecosystems. We are also seeing changes in fish populations. Shifts are occurring between the species. Many things point to the changes being extensive, even in the large and somewhat slow lakes of the Triple Lakes project. As an example, perch is on the increase and there are also indications that the pike will benefit. All evidence suggests that the Arctic char has regressed and there are a few question marks about the development of the whitefish. The smaller sized whitefish have dramatically decreased.

What can we do about it then? Normally, we would choose to handle the situation by changing fish management to try to adapt fishing and withdrawal activities so that the negative consequences can be buffered or prevented from happening. We would protect certain species and perhaps fish others harder. The problem is that today fishing has very little impact on the fish populations. Fishing for predatory salmonids and to some extent pike seems to garner most interest. The majority of that fishing is based on fish restocking. The large populations of perch and whitefish are fished to a much lesser degree. Based on today's levels, changes in the

focus of fishing or the pressure of fishing will not materially affect developments. We simply lack the administrative tool that fishing and withdrawals can achieve.

So what can we do? Perhaps it would be relevant to actively increase the interest in fishing, and catching fish for food or possibly even for selling. The resources exist in the form of large, healthy fish populations. There is currently an increasing interest in locally produced food and various forms of self-sufficiency. Perhaps we can encourage and create an interest in more lake fishing primarily for perch and pike for food, and perhaps whitefish and grayling to some extent. The scarcer populations of brown trout and Arctic char should of course be exempted from fishing. In this case, the intention would be to raise interest in fishing amongst both those that live near the lakes and also attract tourist anglers. The latter idea would require service development in the form of boats, accommodation and guiding, which would benefit local growth.

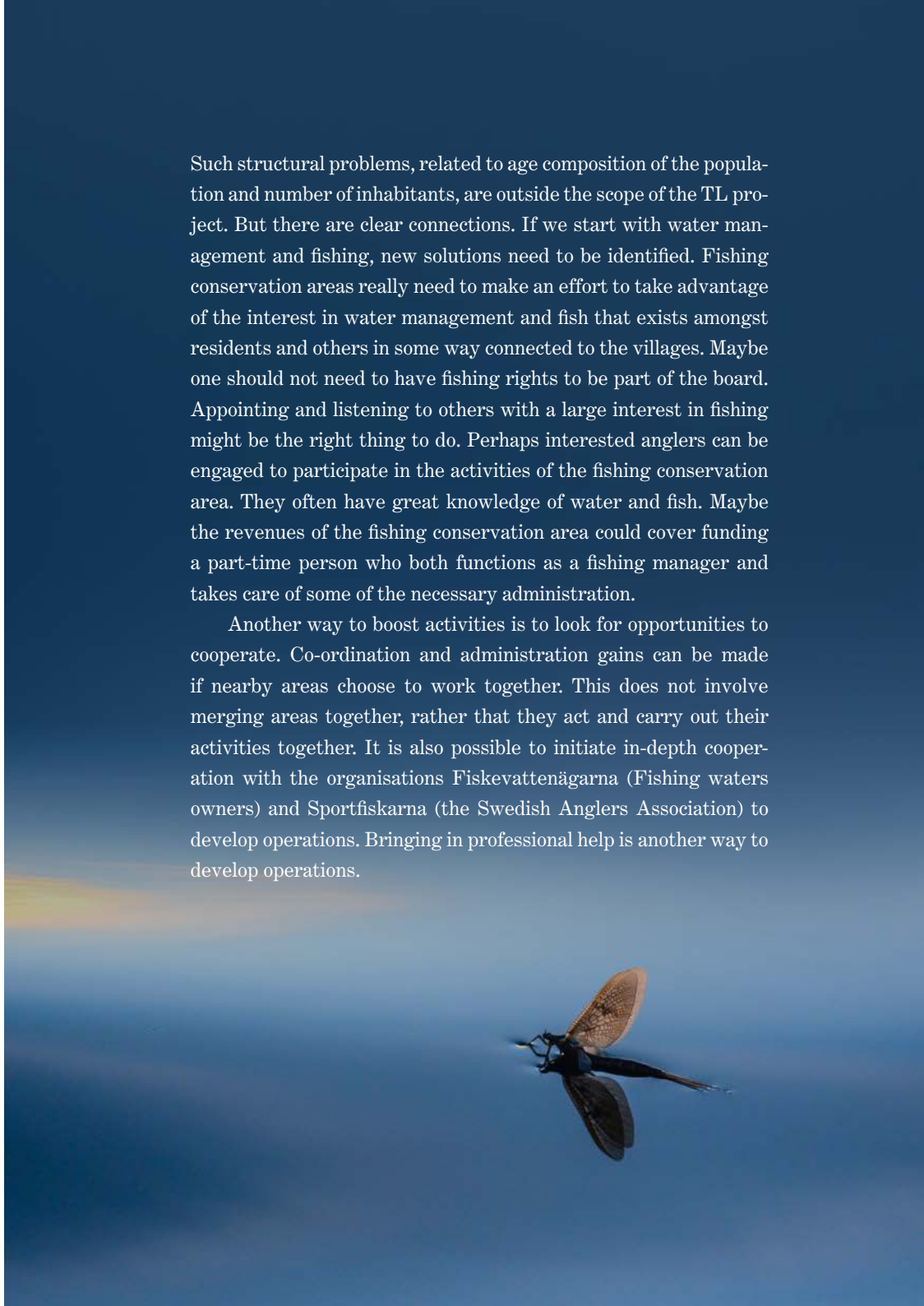
## Changing countryside

Recent decades have seen large changes in rural demography, employment, services and so on. The population is decreasing and structural changes in society are obvious in different ways. The villages around Näckten, Locknesjön and Revsundssjön lakes are not the most seriously affected ones, but neither have they escaped. From the perspective of the lakes, this can be seen for example in the difficulties in rejuvenating and maintaining the operations of the local fishing conservation areas. The need for voluntary efforts in the countryside is often significant, where sports clubs, village committees, hunting teams and others also need to operate. In the end, a lot of responsibility often lands on the shoulders of a few people, which worsens the chances of making change happen or even just maintaining activities. These problems are not unique to this area, but the responsibility for and care of collective resources often requires some form of sacrifice.



Such structural problems, related to age composition of the population and number of inhabitants, are outside the scope of the TL project. But there are clear connections. If we start with water management and fishing, new solutions need to be identified. Fishing conservation areas really need to make an effort to take advantage of the interest in water management and fish that exists amongst residents and others in some way connected to the villages. Maybe one should not need to have fishing rights to be part of the board. Appointing and listening to others with a large interest in fishing might be the right thing to do. Perhaps interested anglers can be engaged to participate in the activities of the fishing conservation area. They often have great knowledge of water and fish. Maybe the revenues of the fishing conservation area could cover funding a part-time person who both functions as a fishing manager and takes care of some of the necessary administration.

Another way to boost activities is to look for opportunities to cooperate. Co-ordination and administration gains can be made if nearby areas choose to work together. This does not involve merging areas together, rather that they act and carry out their activities together. It is also possible to initiate in-depth cooperation with the organisations Fiskevattenägarna (Fishing waters owners) and Sportfiskarna (the Swedish Anglers Association) to develop operations. Bringing in professional help is another way to develop operations.



In addition to satisfying specific needs in the form of providing fishing and drinking water, the lakes also have an important role to play from a broader rural growth perspective. Ever since the times of hunter-gatherers, large lakes have always attracted settlers and become important central points in the countryside. Fishing and farming have been concentrated around such lakes and their surroundings, even if this has not been as obvious in recent years. Perhaps the conditions exist to restore some of this though. The demand for attractive homes with access to water is on the rise. Perhaps the opportunity of a life in these rural areas can be raised via municipal planning and other special initiatives. There is plenty of scope for new thoughts and ideas in this respect. The future will unveil whether it will continue to be attractive to live, work and fish around Locknesjön, Näckten and Revsundsjön lakes.

## LIFE - an instrument for a better environment

This book collates the experience gained and issues raised during the Triple Lakes project, which was run by Länsstyrelsen Jämtland from 2014 to 2019. The project involved cooperation for better water in Revsundssjön, Näkten and Locknesjön lakes in northern Sweden.

Project work was funded by LIFE, the EU's funding instrument for the environment and climate action. The goals of the LIFE programme are to support the implementation, updating and development of EU policies and regulations related to the environment. Every year, the European Commission grants large sums of money to environmental improvement projects in its member states. Since the start of the project, for example, 130 Swedish projects have received funding from LIFE.

The overarching objectives of the LIFE programme are to generate a climate-resilient society that uses resources efficiently, to stop the loss of biological diversity, and to provide support for the management of Natura 2000 areas. Natura 2000 is a network of areas within the EU that have been highlighted as having a high natural value.

By specifically highlighting and protecting species and their habitats, the EU aims to impede the eradication of species that are typical to their region and their habitats. Revsundssjön, Näkten and Locknesjön lakes and their tributaries are all designated Natura 2000 areas.

TRIPLE LAKES

NATURA 2000

Havs och Vatten myndigheten

Länsstyrelsen Jämtlands län

Telefon: 010-225 30 00
jamtland@lansstyrelsen.se
www.lansstyrelsen.se/jamtland