REMIBAR

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The Impact of Migration Barrier Removal on Connectivity - Evaluation of Remibar

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Summary

The objective of the Remibar (Remediation of Migratory Barriers in Streams) project has been to remove 304 migration barriers in five project areas in as many river systems in the counties of Norrbotten and Västerbotten in northern Sweden. The five river systems are protected under the Natura 2000 Habitats Directive. In Norrbotten, the project areas were: Ängesån (part of the Kalix River system), Råneälven (most of the Råne River system), and Varjisån (part of the Pite River system). In Västerbotten, the two project areas Sävarån and Lögdeälven each encompassed one river system, i.e., the Sävar River and Lögde River systems. The Remibar project started in 2011 and was completed in 2016. It was financed by the EU Commission through the Life+ programme, which is an EU environmental fund.

The majority of the migration barriers (i.e., 293), were located in smaller rivers and creeks and consisted of culverts in road-river crossings and dams that were blocking the migration routes of fish and other aquatic organisms, while eleven consisted of road-river crossings unsafe to otters. The removal of the migration barriers is part of efforts to improve the conservation status for the following species and habitats: Fennoscandian natural rivers (3210), Watercourses of plain to montane levels with the Ranunculion fluitans and Callitricho-Batrachion vegetation (3260), freshwater pearl mussel (*Margaritifera margaritifera*) (1029) Atlantic salmon (*Salmo salar*) (1106), otter (*Lutra lutra*) (1355) and bullhead (*Cottus gobio*) (1163). The focus of this report is to assess the effect of the removal of the migration barriers on the connectivity of the five river systems. The evaluation of efforts targeting otters is presented in a separate report.

Following the removal of migration barriers consisting of culverts and dams, 49.1 km^2 of rivers, creeks and lakes that were previously inaccessible to organisms migrating from the ocean, such as Atlantic salmon and brown trout, due to the presence of migration barriers, have been reconnected with water areas downstream. The total surface area of rivers, creeks and lakes in the five river systems accessible to organisms migrating from the mouth of the river amounts to 220.7 km^2. Five migration barriers remain in three of the project areas (Råneälven, Sävarån and Lögdeälven). These migration barriers could not be removed as the land owners would not give their consent. As migration barriers were remediated upstream those five remaining migration barriers, connectivity has increased in an additional 17.6 km^2 of rivers and creeks and lakes have been, which will benefit non-migratory individuals of brown trout, as well as other organism groups.

The evaluation of the effect of migration barrier removal on the aquatic community was based on existing monitoring programs, as no funding had been approved for directed studies. One major challenge when evaluating the effect on the aquatic community was due to the fact that many migration barriers were removed late (the last ones were removed in 2016), and not enough time had passed to make it possible to detect and even less measure an impact. Data from targeted sampling using electrofishing focusing on assessing recruitment of Atlantic salmon and brown trout was available from all five river systems. Five electrofishing sites with time series long enough to make it possible to detect a trend were chosen per project area. This data provides a measure of spawning success and gives an indication of presence/absence of spawning adults. Data from fish counters in the Kalix and Pite Rivers with long time series was also available. Data from the fish counters give an indication of changes in the number of mature individuals migrating up the rivers to spawn. However, few electrofishing sites were located close enough to the remediated migration barriers to make it possible to get a measure of the impact of migration barrier removal on reproduction success of salmon and trout, as juveniles of the two species remain within a kilometer of the site where they hatched. Despite these limitations, an increase in

reproduction success of salmon and/or trout following the removal of migration barriers was observed at some sites in the Varjisån, Sävarån and Lögdeälven project areas. The impact of migration barrier removal on salmon and trout reproduction success in the Ängesån and Råneälven project areas could not be assessed as the electrofishing sites were located too far away from the remediated migration barriers. Although it is often not possible from the available data to determine whether the increased reproduction success of salmon and trout is a direct result of Remibar, it is very positive that the increased availability of reproductive areas and nursing areas is coinciding with the observed increase in reproduction success of salmon and/or trout.

Many migration barriers were removed very late and many of the expected effects have not yet occurred. As populations of Atlantic salmon, brown trout and freshwater pearl mussel are continuously being monitored by the County Administrative Boards of Norrbotten and Västerbotten, it is expected that future monitoring will reveal effects on the populations of those species that will only be possible to detect and measure once several years have passed.

The impact of migration barrier removal on the ecological status of the waterbodies in the five project areas is not yet known as the next reassessment will not be carried out until 2021. However, as the presence of migration barriers has been identified as the major reason why many waterbodies in the counties of Norrbotten and Västerbotten have been assigned an ecological status that is less than good, it is expected that many waterbodies will be reclassified as a result of the removal of migration barriers carried out as part of Remibar.

Introduction

Presentation of the project

The objective of the Remibar (Remediation of Migratory Barriers in Streams) project has been to remove migration barriers in five river systems in the counties of Norrbotten and Västerbotten in northern Sweden. These five river systems have been identified as Sites of Community Importance (SCIs) and are protected under the Natura 2000 Habitats Directive.

The majority of the migration barriers were located in smaller rivers and creeks and consisted of culverts in road-river crossings and dams that were blocking the migration routes of fish and other aquatic organisms, while a smaller number consisted of road-river crossings unsafe to otters. The remediation of the migration barriers has resulted in the re-opening of migration routes for aquatic species and increased the connectivity within the five river systems.

The removal of the migration barriers is part of efforts to improve the conservation status for the following species and habitats: Fennoscandian natural rivers (3210), Watercourses of plain to montane levels with the Ranunculion fluitans and Callitricho-Batrachion vegetation (3260), freshwater pearl mussel (*Margaritifera margaritifera*) (1029), Atlantic salmon (*Salmo salar*) (1106), otter (*Lutra lutra*) (1355) and bullhead (*Cottus gobio*) (1163).

The Remibar project started in 2011 and was completed in 2016. It was financed by the EU Commission through the Life+ programme, which is an EU environmental fund. In total, 304 migration barriers in five river systems were remediated as part of the project. The majority of those (i.e., 293) consisted of culverts in road-river crossings and dams, while eleven objects consisted of road-river crossings unsafe to otters.

The focus of this report is to assess the effect of the removal of the migration barriers on the connectivity of the five river systems. This will be done in three parts. First, the surface area of the water areas that have been reconnected and consequently are accessible to organisms migrating from areas upstream all the way down to the mouth of the river and the Baltic Sea will be presented. Second, the effect on migratory fish will be examined. Third, the effect on the improvement of the ecological status of the waterbodies will be assessed. The evaluation of efforts targeting otters is presented in a separate report.

In the Norrbotten County, three project areas in three separate river systems were included in the project (fig. 1). The project areas were: Ängesån (part of the Kalix River system), Råneälven (most of the Råne River system), and Varjisån (part of the Pite River system). In the Västerbotten County, the two project areas Sävarån and Lögdeälven each encompassed one river system, i.e., the Sävar River and Lögde River systems (fig. 1). In the drainage areas, the rivers are protected under the Habitats Directive, while some land areas are protected under the Habitats Directive and/or the Birds Directive (figures 2-6).

The importance of removing migration barriers

Benefits of increased connectivity

Ecological connectivity is a measure of how habitats and organisms are connected in time and space, and is a function of the physical characteristics of the landscape (e.g., distance between areas of suitable habitat), species behavior, and the ability of organisms to disperse to a patch or move between patches of suitable habitat. Structural connectivity can take the form of linear corridors or stepping stones between habitats (Auffret et al. 2015). Watercourses constitute ecological corridors in the landscape. They encompass the aquatic environment and the surrounding floodplain, and are used as habitat and migration corridors for fish and other aquatic organisms, insects, birds, mammals and other types of wildlife (Calles 2005). At the same time, different habitat types within a watercourse have a fragmented distribution with individual fragments acting as stepping stones in the spread of organisms. In addition to the two aspects of river dynamics that are of importance for this project, i.e., longitudinal connectivity (upstream-downstream) and lateral connectivity (the river and the surrounding floodplain), the concept ecological connectivity also encompasses vertical connectivity (the river and the groundwater) and temporal connectivity.

Many organisms need to access different types of habitats during the course of a year and/or during their life cycle, and require open migration corridors to move between those habitats. Examples are anadromous species (e.g., Atlantic salmon and ocean-dwelling brown trout, also called 'sea trout') that live most of their lives in the ocean but return to freshwater to spawn and catadromous species (e.g., European eel *Anguilla anguilla*) that reproduce in the ocean and live the rest of their lives in fresh or brackish water. Organisms also need to be able to access patches of similar habitat in order to recolonize them following local extinction. In the remainder of this report,' salmon' refers to Atlantic salmon, while 'trout' refers to brown trout.

Salmon generally spawn in the main stem of the river where the current is strong, while trout generally spawn in smaller rivers and creeks. Trout is able to spawn in very shallow water, while salmon is not. There is a big overlap between the two species regarding the habitat types they occur in and where they spawn, with the exception of water with very strong current (salmon only) and where it is very shallow (trout only). In habitats where the two species overlap, salmon is the stronger competitor for spawning grounds. As a result, as the salmon population growing and a higher number of individuals is migrating higher up in the river system to reach spawning grounds, salmon take over spawning grounds occupied by trout. The trout is forced to leave and must seek new spawning grounds higher up in the river system and in smaller tributaries and creeks. In the project areas, the spawning grounds higher up in the river system and in many of these smaller rivers and creeks were inaccessible due to the presence of migration barriers.

Ecological connectivity is important on different geographical scales. The maximum distance between patches of essential habitat varies among species and throughout the life cycle of a species. While adult salmon and sea trout migrate 100s of kilometers from the ocean upstream a river to reach reproductive areas located high up in the river systems, salmon fry generally disperse less than 400 m downstream after hatching to nursery areas (Webb et al. 2001) while trout fry generally disperse less than 200 m downstream to nursery areas (Andersson 2016). While some juveniles migrate further, the distance does not exceed 1 km (Webb et al. 2001). However, non-migratory individuals of trout do not migrate to the ocean after spawning but stay near the area where they hatched, and often end up competing with their own young for resources. Bullhead (*Cottus gobio*), a benthic fish living in fresh or brackish water and prefers stony substrate, also has different habitat requirements for feeding and reproduction. While the juveniles of aquatic invertebrates with terrestrial adult life stages (e.g., mayflies, dragon flies, and caddisflies) stay within a small area in a river or creek or drift downstream, the adults migrate upstream along a creek or river over longer distances.

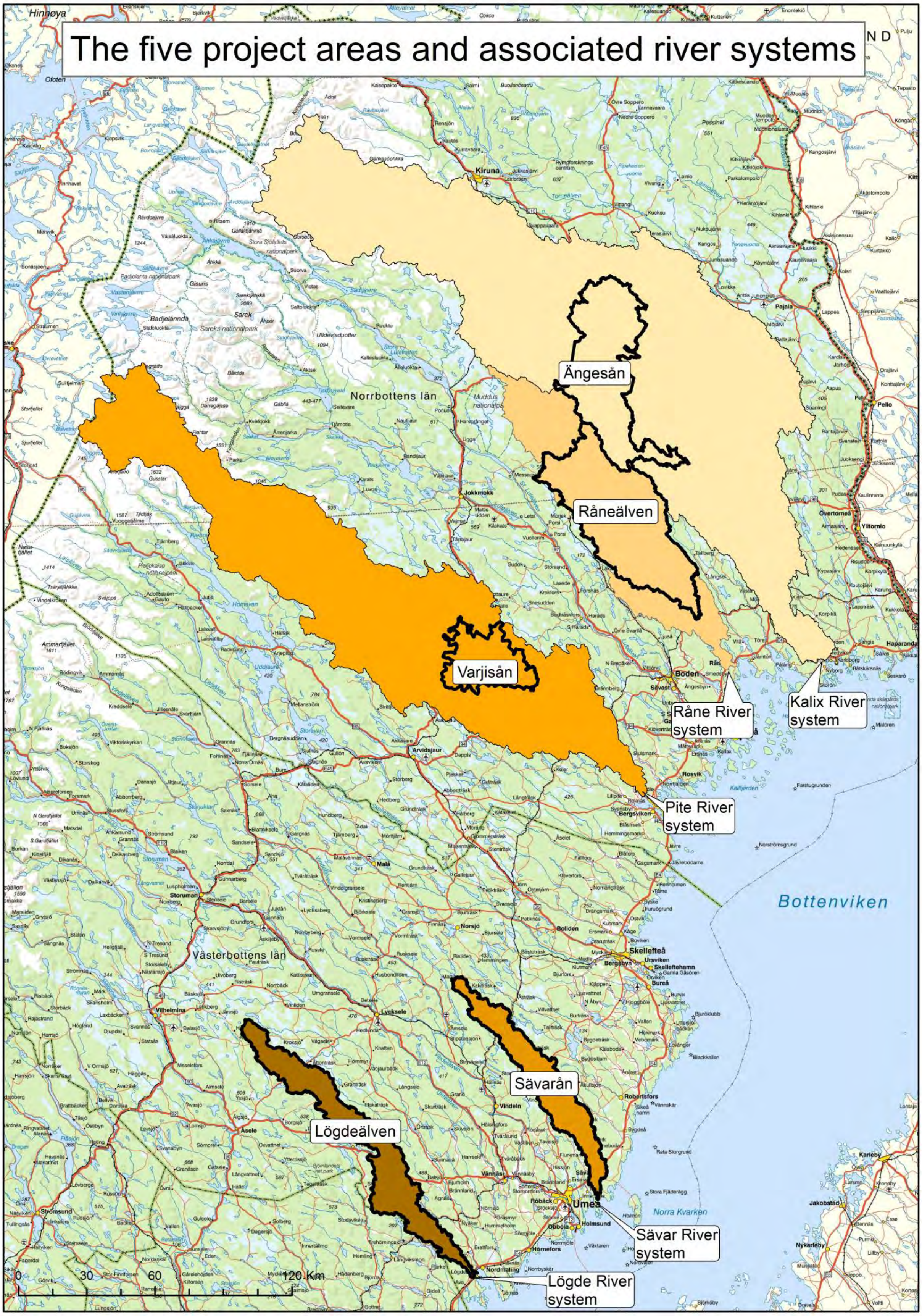

Figure 1. The project areas and associated river systems in the counties of Norrbotten (Ängesån, Råneälven and Varjisån) and Västerbotten (Sävarån and Lögdeälven).

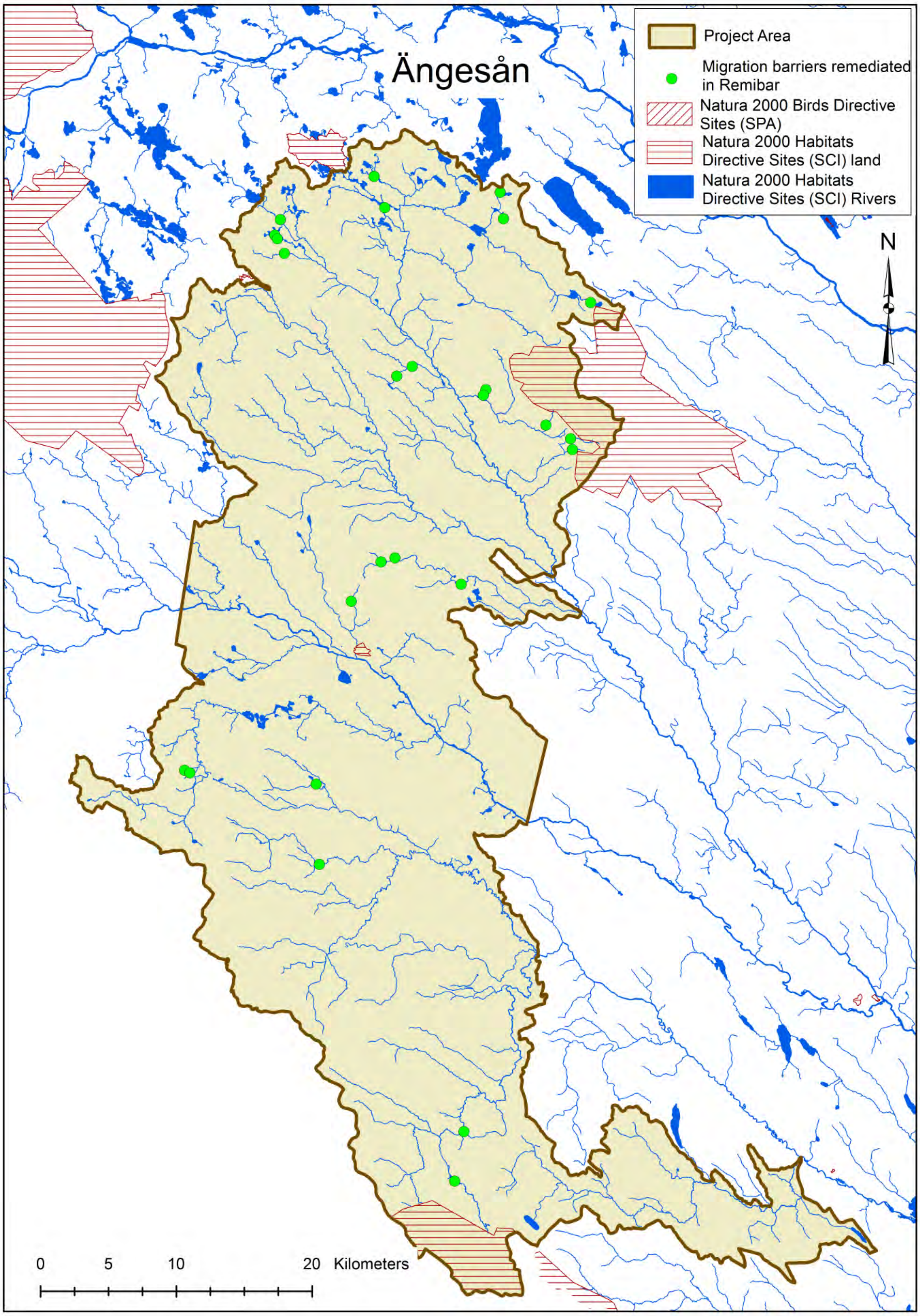

Figure 2. Sites in the Ängesån project area protected by the Natura2000 Habitats Directive and the Natura2000 Bird Directive.

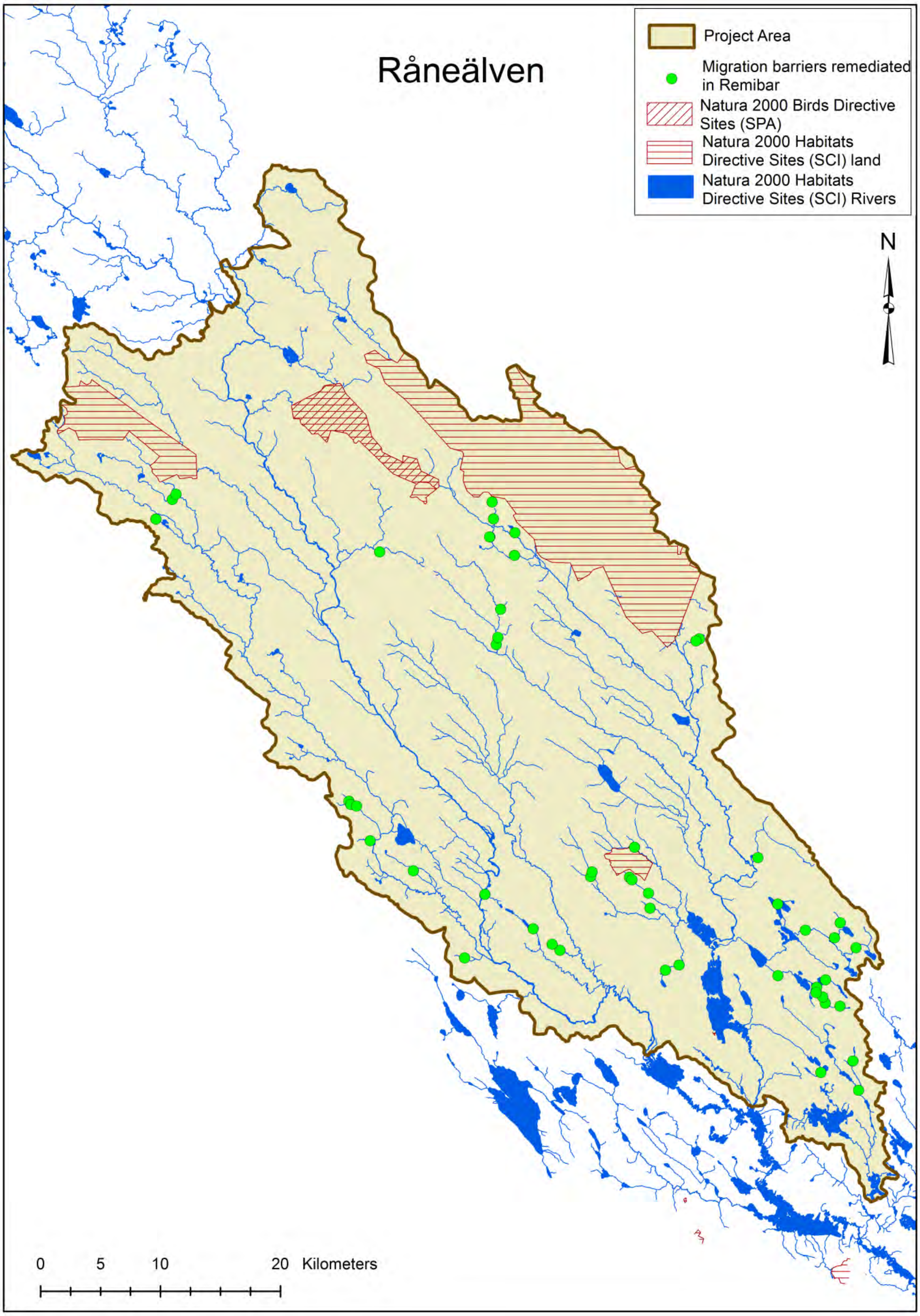

Figure 3. Sites in the Råneälven project area protected by the Natura2000 Habitats Directive and the Natura2000 Bird Directive.

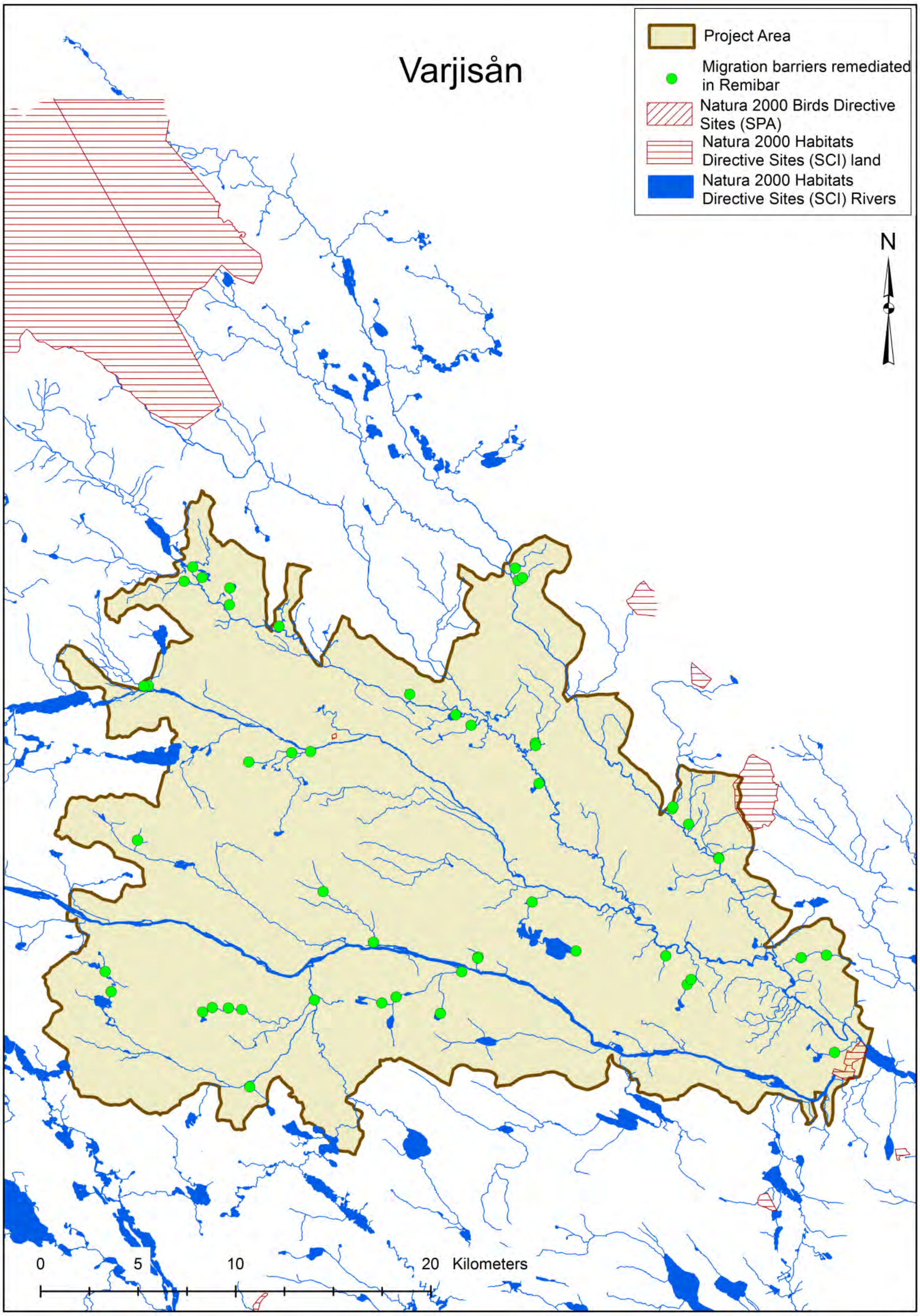

Figure 4. Sites in the Varjisån project area protected by the Natura2000 Habitats Directive and the Natura2000 Bird Directive.

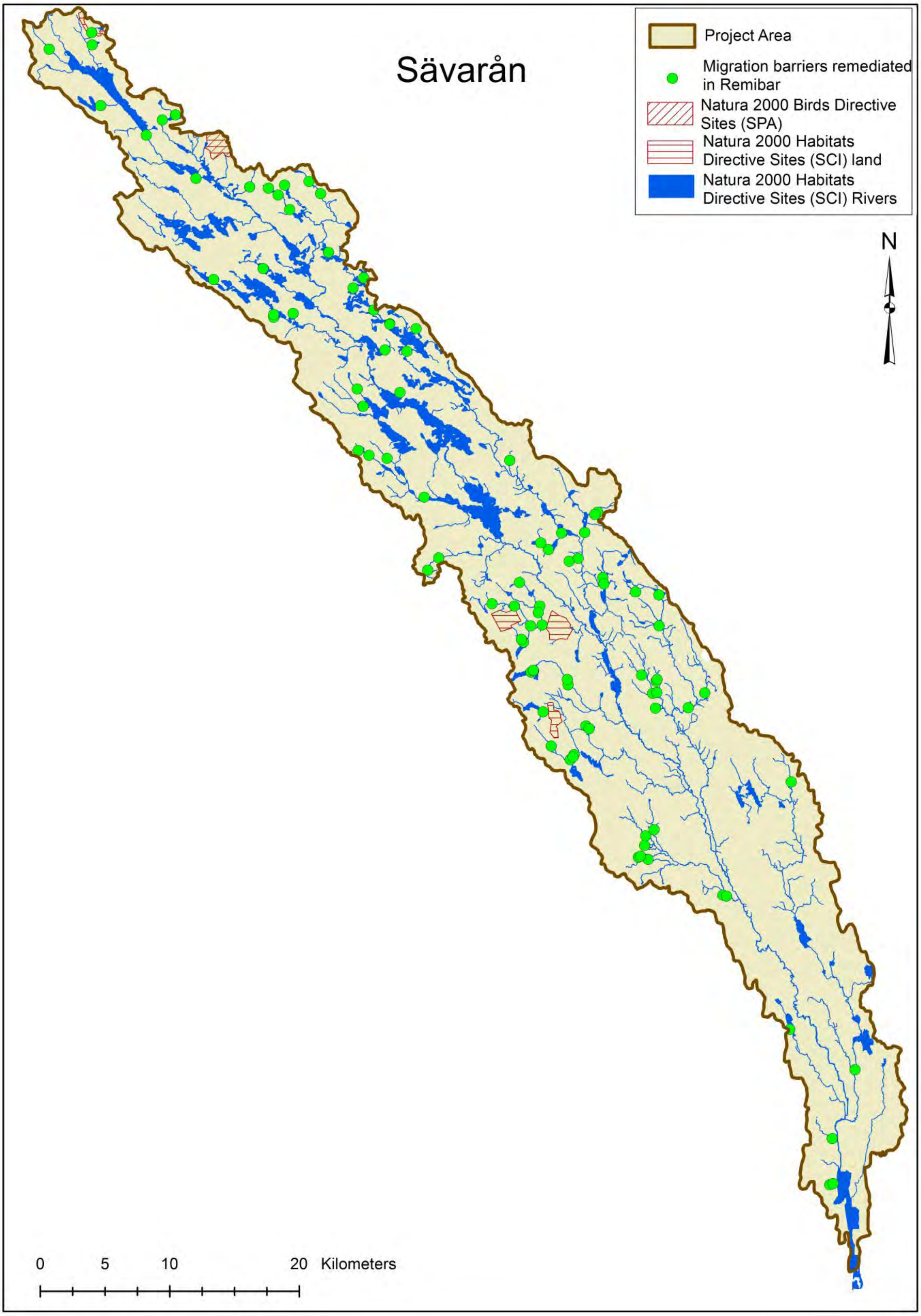

Figure 5. Sites in the Sävarån project area protected by the Natura2000 Habitats Directive and the Natura2000 Bird Directive.

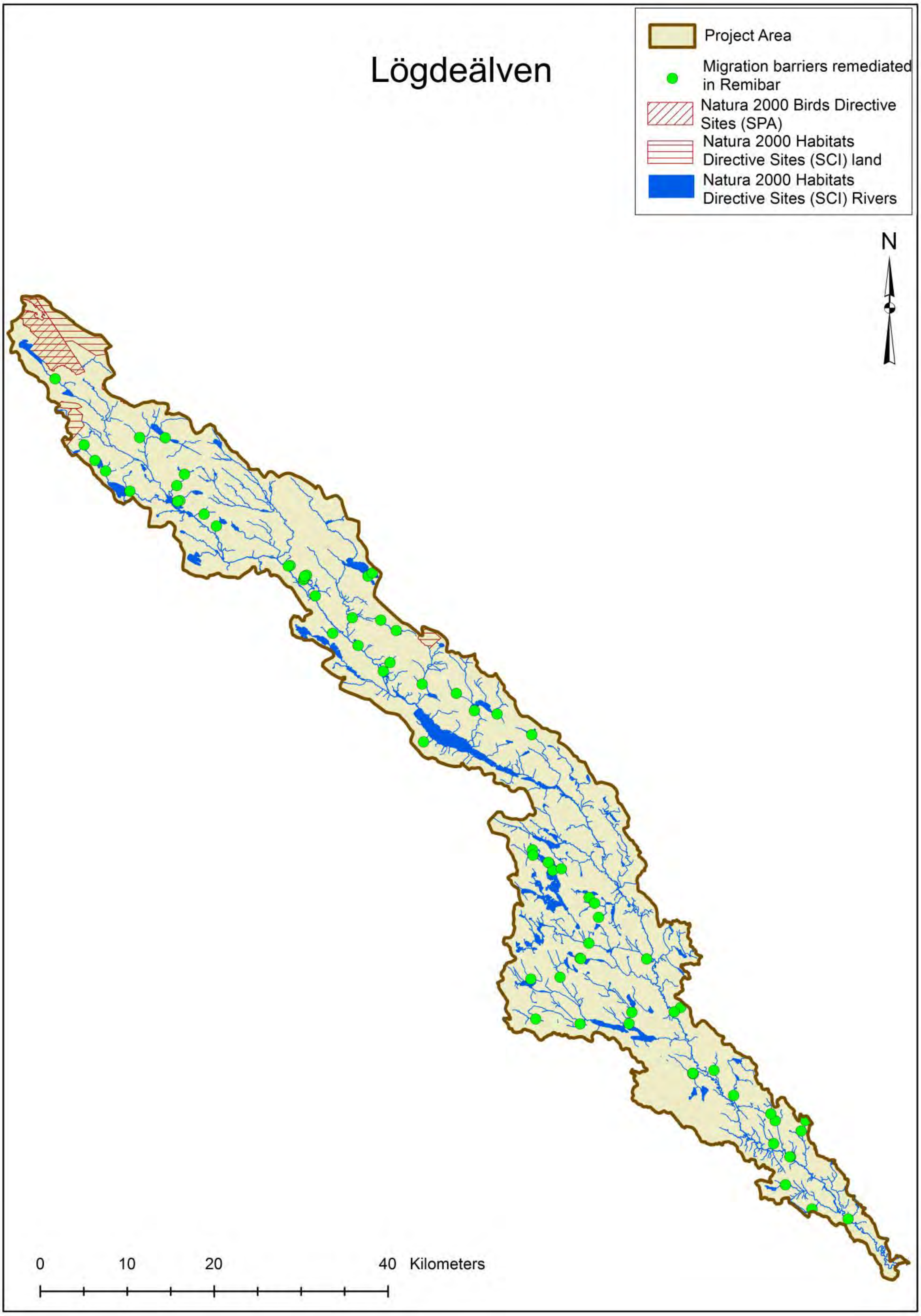

Figure 6. Sites in the Lögdeälven project area protected by the Natura2000 Habitats Directive and the Natura2000 Bird Directive.

While freshwater mussels do not migrate, but are buried in the substrate and can move short distances using their foot, they depend on different species of fish for their survival of their larvae, the so called glochidia. Many species of freshwater mussels are host-specific. Larvae of the freshwater pearl mussel depend on young trout and salmon that are less than one year old (i.e, 0+) for their survival. The freshwater pearl mussel releases its larvae in the late summer when the young trout and salmon are approximately 6 cm long and live as parasites on their gills for almost a year before they leave their host and bury in the substrate. The glochidia measure 0.5 mm when they leave the host and thereafter stay buried in the substrate for 4-5 years until they measure approximately 5 cm. Hence, freshwater pearl mussel populations depend on the successful reproduction of salmon and trout in order to survive. However, salmon and trout probably do not contribute to the spread of freshwater pearl mussels to areas outside of the nursing area of the trout and salmon juveniles. While bullhead is the host of the larvae of the thick shelled river mussel (*Unio crassus*) during the first month of its life cycle, the range of the thick shelled river mussel does not include northern Sweden.

Following the construction of dams, roads and other migration barriers, these ecological corridors have become fragmented and less connected, with negative effects on biodiversity. However, what constitutes a migration barrier varies among species. While large individuals of salmon and trout are strong swimmers and are able to swim past barriers higher than 1 m and swim against strong currents, even small vertical barriers can block migration for smaller individuals, such as young salmon and trout, and smaller adults of non-migratory trout. For the bullhead, which is a weak swimmer, a vertical barrier 20 cm high will block migration. Even partial migration barriers can be a problem for adult fish during the spawning migration. A series of partial migration barriers may delay the arrival of adult fish to the spawning areas so that they arrive too late to take part in the spawning activities.

As a result of the increasing isolation of populations and communities, many species are unable to complete their life cycle and/or recolonize areas where they have gone locally extinct. This has had negative effects on the long-term viability of the populations of many species, including Atlantic salmon, the freshwater pearl mussel, and bullhead, which are protected under the EU Habitats Directive. Atlantic salmon and sea-trout have been cut-off from their reproductive areas in the main stem and tributaries of their native rivers, while non-migratory brown trout and bullhead have been unable to move between areas within the river systems. As the migration routes for trout and salmon to their spawning areas have been cut-off, the distribution of the freshwater pearl mussel has decreased, with many populations declining or going extinct due to a lack of recruitment. Of the remaining populations of freshwater pearl mussels, only 1/3 is regenerating.

Low connectivity also affects the genetic integrity of a population. In isolated populations, even though they can complete their life-cycle, genetic diversity decreases over time and the populations become more sensitive to environmental fluctuations. In brown trout, the tendency to migrate back to the ocean varies among populations and is fluctuating depending on external factors (e.g., access to resources), and populations of non-migratory trout are not as genetically isolated as once thought. In a population of non-migratory trout, genetic diversity is lost when individuals leave the population by migrating downstream past a migration barrier that blocks upstream migration.

Migration barriers can also have a negative impact on the migration of invertebrates. For insects that are aquatic as juveniles and terrestrial flying insects as adults (e.g., dragonflies, mayflies, and damselflies), connectivity plays an important role in the recolonization of areas upstream. For adults who follow a creek or river during their migration upstream, a road-river crossing may block further migration. This has been observed in several families of mayflies (Ephemeroptera).

When arriving at the road-river crossing, the adult leaves the water surface and begin following the road. The negative impact is higher when the distance between the surface of the water and the ceiling of the culvert is too low. If the adult insect manages to cross the road, it might not find the water surface upstream the migration barrier if the view is blocked by vegetation (Lingdell and Engblom 2009).

For invertebrates where the life cycle is completely aquatic, culverts and dams constitute barriers that prevent the re-colonization of areas upstream following an environmental disturbance (e.g., an event with acid runoff) that has eliminated the population locally as the benthic fauna abandons the area by drifting downstream. This has been observed in amphipods that are an important food source for birds and fish. Hence, following an event with acid runoff the area upstream a migration barrier may result in the permanent loss of species in the area upstream the migration barrier (Lingdell and Engblom 2009).

Ecological connectivity also affects the functioning of the ecosystem and the food web through the flux of nutrients. The upstream migration of salmon results in an upstream movement of nutrients, as some salmon die after spawning (Moore 2007). Freshwater pearl mussels serve as food for other animals. The mussels also channel nutrients from the water column to the benthic zone through their filtering activities. Furthermore, salmon, trout and freshwater pearl mussels redistribute matter and nutrients through their spawning activities and burrowing behaviour.

Increasing ecological connectivity by removing dams and culverts also contributes to making rivers return to a more natural state, as it allows for natural fluctuations in water levels, a return to a more natural dynamic between erosion and sedimentation, and may increase the connectivity between the watercourse and the floodplain.

While some of the effects of barrier removal are relatively easy to observe and measure, others are more difficult to detect. Some effects appear within a year, while others cannot be recorded until many years later. In the county of Västerbotten, adult salmon and trout have been observed spawning in newly accessible spawning grounds within a year (Kjell Nilsson[1], *unpublished data*). Spawning activity was documented by observing spawning adults and monitoring gravel beds for shallow 'nests' where the female has laid her eggs. However, the impact of spawning on recruitment of salmon and trout populations will not be apparent until one generation later (approximately 5-7 years), when the offspring return to their native stream to spawn. Trout and salmon generally leave the nursing area after 3-4 years, spend 2-3 years in the ocean and return to the river to spawn after 5-7 years. However, some individuals leave the nursing area after 1-2 years and spend only one year in the ocean before returning to their native river to spawn. The recovery of freshwater pearl mussel populations is dependent upon the distribution and successful reproduction of its host, the brown trout. An impact on the freshwater pearl populations following the successful reproduction of brown trout will not be possible to detect until 6-7 years after a spawning event, when the young mussels can more easily be monitored as they leave their invisible existence buried in the sediment and start living at the surface.

Influence of other remediation efforts and policies

The aquatic habitat in the project areas has been highly fragmented due to the construction of roads and dams. Along the stretch of a watercourse, a road river crossing occurs on average every two kilometers. Of these, every third road-river crossing constitutes a migration barrier for aquatic organisms. Furthermore, reconstructions of rivers starting in the 1800s to facilitate timber floating resulted in rapids being channelized, stream beds being made more homogenous,

[1] Fiskmiljö i Nilivaara, Gällivare

and bifurcations and confluences being blocked, also contributed to the degradation or loss of habitat for stream dwelling organisms.

Beginning in the 1990s, several projects in the Norrbotten and Västerbotten counties have been carried out to improve the health of the aquatic ecosystem and the availability of habitat. These include the restoration of rivers from the impact of timber floating, restoration of feeding grounds, nursery areas and spawning areas for salmon and trout, and liming to counteract acidification (the latter only in the county of Västerbotten). The Swedish Transport Administration (STA) and its predecessor the Swedish National Road Administration have been remediating inaccurately constructed culverts for many years. This work has been carried out within the scope of the STA's ordinary activities and is routine when carrying out maintenance work (i.e., repairing and replacing culverts and other structures in road-river crossings). The forestry companies are also making improvements to road-river crossings when carrying out maintenance work (e.g., repairing culverts). In addition, the CABs in Norrbotten and Västerbotten have continuously been working on removing migration barriers throughout their respective counties, within the scope of other projects. The work done by the CABs, the STA, and other agencies is following the guidelines and policies stated in national and international agreements, e.g., the Swedish Environmental Objectives and the Water Framework Directive.

Overfishing has resulted in the decline of most of the fish stocks that migrate up the rivers to spawn. Management decisions affecting both the commercial and recreational fishery on Atlantic salmon and sea trout have contributed to the increase in abundance of those two species and as a result the number of individuals that migrate up the rivers to spawn.

While the removal of migration barriers in the five project areas has increased the connectivity within the river systems, the impact of other habitat restoration projects and policies are tightly linked with and influence the outcome of the remediation efforts carried out as part of Remibar. As the outcome of the habitat restoration efforts within each river system and the management of the fisheries are interlinked, the outcome of Remibar must be assessed and evaluated in the context of these projects and management decisions. In this report, other factors of importance will be referred to and discussed when relevant.

In the following chapters the outcome of the Remibar project will be described and evaluated. This will be done by first showing which sections of the watercourses in each project area that have been made accessible to migrating aquatic organisms following the removal of migration barriers, and the total surface area. Secondly, the impact of the increased connectivity on the fish community will be presented. Third, we will discuss the impact of the removal of the migration barriers on the improvement of the ecological status of the waterbodies.

I. Surface area of water areas that have been connected

A total of 304 migration barriers have been remediated in the five project areas. Of these, 293 migration barriers (also referred to as "objects") consisted of culverts in road-river crossings and dams that were affecting the connectivity of the aquatic environment, while eleven objects consisted of road-river crossings unsafe to otters (table 1). The latter did not affect the connectivity of the aquatic environment.

The original application included 291 objects that were culverts and dams and 13 road-river crossings unsafe to otter. Throughout the course of the project, 25 culverts and dams that were included in the original application were replaced by other objects for various reasons. Two road-river crossings unsafe to otters were removed from the project. Instead, two culverts were added to the project, resulting in a total of 293 remediated objects and eleven remediated road-river crossings unsafe to otters. The two road-river crossings unsafe to otters that were removed from the project will be remediated in other projects.

It is worth mentioning that there are remaining migration barriers in the project areas, as removing every single barrier was beyond the scope of this project. Rather, objects were prioritized and ranked based on the expected outcome of their removal. The factors taken into consideration were: the length and area of the water area upstream the barrier made accessible to migrating organisms and the biological value of this area (e.g., the occurrence of potential spawning grounds). Hence, if a barrier would open up only a very short stretch of a watercourse, or the area upstream the barrier consisted of a creek that is dry part of the year, removal of that barrier was not prioritized.

The removal of a dam or a culvert is dependent upon the consent of the landowner, which was not always possible to get. For this reason, some migration barriers that were identified as important to remove were not included in Remibar. On five occasions, these migration barriers were located downstream migration barriers that have been remediated. These five remaining barriers will be discussed in this report and their location will be indicated on the maps of the respective project area. The migration barriers in question were: one dam in the Råneälven project area, objects 256 and 257 (both dams and included in the original application) and one culvert in the Sävarån project area, and one dam in the Lögdeälven project area. The CABs of Norrbotten and Västerbotten will continue the dialogue with these land owners.

Table 1. The number of remediated migration barriers (objects) affecting the connectivity of the aquatic environment and road-river crossings unsafe to otters in each project area.

Project area	County	Remediated objects		
		affecting the aquatic environ-ment	affecting otters	Total per project area
Ängesån	Norrbotten	26	4	30
Råneälven	Norrbotten	50	3	53
Varjisån	Norrbotten	50	0	50
Sävarån	Västerbotten	96	1	97
Lögdeälven	Västerbotten	71	3	74
Total		*293*	*11*	*304*

Methods

The water areas (incl. rivers, creeks and lakes) that were accessible *prior to* Remibar and the water areas that had been made accessible *following the remediation* of migration barriers were identified using ArcMap. Data sheets with best available data were used to calculate the surface area of the water area in the respective project areas. To produce maps illustrating the connectivity in the river systems, data sheets were used where lakes, rivers and creeks were presented as lines. The calculations of area were made using maps presenting lakes, rivers, and creeks as polygons However, in the data set many of the smaller creeks are not included, and the surface area of the water area is therefore underestimated due to a lack of detail. This underestimate applies to the estimates of the water area accessible prior to Remibar, as well as the estimates of the water areas made accessible as a result of Remibar.

Results

The removal of the 293 migration barriers has resulted in an additional 49 km^2 of water area in the five project areas being accessible to aquatic organisms. These water areas are accessible for organisms migrating from the Baltic Sea. Lakes make up most of this added surface area, as the rivers and creeks where the migration barriers have been removed are generally very narrow (often less than 2 m wide). Hence, water areas with a total surface area of 221 km^2 are now accessible to migrating organisms in the five project areas (the sum of water areas accessible prior to Remibar and areas made accessible after the remediation of migration barriers, see table 2). In addition, the connectivity has been enhanced in an additional 18 km^2 in the Råneälven, Sävarån and Lögdeälven project areas. These 18 km^2 are located upstream four remaining migration barriers. Remediation of these four remaining migration barriers was not possible as the landowners would not give their consent. Yet, a large number of migration barriers have been remediated upstream these four remaining migration barriers, which has increased the quality and amount of habitat available for upstream populations of non-migratory trout. In total, the total surface of the water areas where connectivity has increased amounts to 67 km^2.

Table 2. Surface area of the water areas accessible prior to Remibar and the water areas made accessible as a result of remediation efforts.

Project area		Area (km²)
Ängesån	Accessible prior to Remibar	16.8
	Made accessible in Remibar	*3.6*
	Total accessible after Remibar	*20.3*
Råneälven	Accessible prior to Remibar	43.2
	Made accessible in Remibar, not incl. area upstream barrier	2.6
	Total accessible after Remibar	*45.8*
	Upstream migration barrier	6.4
	Total remediated in Remibar	*8.9*
Varjisån	Accessible prior to Remibar	14.0
	Made accessible in Remibar	*4.5*
	Total accessible after Remibar	*18.6*
Sävarån	Accessible prior to Remibar	48.1
	Made accessible in Remibar, not incl. areas upstream barriers	15.7
	Total accessible after Remibar	*63.8*
	Upstream migration barrier	0.04
	Upstream Remibar object 256	10.7
	Total remediated in Remibar	*26.4*
Lögdeälven	Accessible prior to Remibar	49.5
	Made accessible in Remibar, not incl. area upstream barrier	22.7
	Total accessible after Remibar	*72.2*
	Upstream migration barrier	0.6
	Total remediated in Remibar	*23.3*
Total accessible prior to Remibar		***171.6***
Total made accessible in Remibar, not including areas upstream remaining migration barriers*		***49.1***
Total accessible after Remibar**		***220.7***
Total area upstream remaining migration barriers		***17.6***
Total remediated in Remibar, including areas upstream remaining migration barriers		***66.7***

* Denotes the water area that has been made accessible to migrating organisms and is connected to the Baltic Sea.

** Denotes the total water area accessible to migrating organisms following remediation efforts and includes area accessble prior to Remibar and area that have been made accessible in Remibar.

Ängesån

In the Ängesån project area, an additional 3.6 km² of rivers, creeks and lakes are now accessible following the removal of 26 migration barriers affecting the aquatic environment (fig. 7). After the completion of Remibar, the total surface area of the water areas accessible to migrating organisms amounts to 20.3 km².

Råneälven

In the Råneälven project area, an additional 2.6 km² of rivers, creeks and lakes are now accessible following the removal of 38 migration barriers (fig.8). After the completion of Remibar, the total surface area of the water areas accessible to migrating organisms amounts to 45.8 km².

One dam in the project area was not remediated as part of Remibar, as indicated in fig. 8. The dam was not included in Remibar as the landowners would not give their consent as the dam is of cultural significance. Removing the dam was therefore not possible at this time. The County Administrative Board of Norrbotten has applied for funding to alter parts of the dam that would enable migration of aquatic organisms past the dam but leave the rest of the structure intact. However, 12 barriers upstream the dam were remediated. The surface area of the water area upstream the dam is 6.4 km^2.

In total, connectivity has increased 8.9 km^2 of rivers, creeks and lakes following the removal of the 50 migration barriers. Of this total, 71.4 % of the surface area is located upstream a migration barrier.

Varjisån

In the Varjisån project area, an additional 4.5 km^2 of rivers, creeks and lakes are now accessible following the removal of 50 migration barriers affecting the aquatic environment (fig. 9). After the completion of Remibar, the surface area of the water areas accessible to migrating organisms amounts to 18.6 km^2.

Sävarån

In the Sävarån project area, an additional 15.7 km^2 of rivers, creeks and lakes are now accessible following the removal of 84 migration barriers affecting the aquatic environment (fig. 10). After the completion of Remibar, the surface area of the water areas accessible to migrating organisms amounts to 63.8 km^2.

Objects 256 and 257 that were included in the original application were not remediated as the landowners would not give their consent, as indicated in fig. 10. In addition, one culvert was not remediated as the landowners would not give their consent. This culvert, which was not included in Remibar, is also indicated in fig. 10.

A total of 10 migration barriers were removed upstream object 256. The surface area of the water area upstream object 256 is 10.7 km^2. Two barriers upstream the culvert were remediated as part of Remibar as it might be possible to remediate this culvert in the future. The surface area of the water area upstream the culvert was 0.04 km^2.

In total, connectivity has increased in 26.4 km^2 of rivers, creeks and lakes following the removal of 96 migration barriers. Of this total, 40.5 % of the surface is located upstream a migration barrier.

Lögdeälven

In the Lögdeälven project area, an additional 22.7 km^2 of rivers, creeks and lakes are now accessible following the removal of 70 migration barriers affecting the aquatic environment (fig. 11). After the completion of Remibar, the surface area of the water areas accessible to migrating organisms amounts to 72.2 km^2.

One dam and an old sawmill located approx. 100 m further downstream in the Lögdeälven project area were not removed due to their cultural significance. The area where the sawmill is located might have constituted a migration barrier prior to when humans began using this area. However, historical records showing what the site looked like in those days are lacking. There are no plans to build a fishway that would allow fish to migrate past this barrier. One barrier upstream this migration barrier was remediated as part of Remibar. The area of the water area upstream the migration barrier is 0.6 km^2.

In total, connectivity has increased in 23.3 km^2 of rivers, creeks and lakes following the removal of 71 migration barriers. Of this total, 2.4 % of the surface area are located upstream a migration barrier.

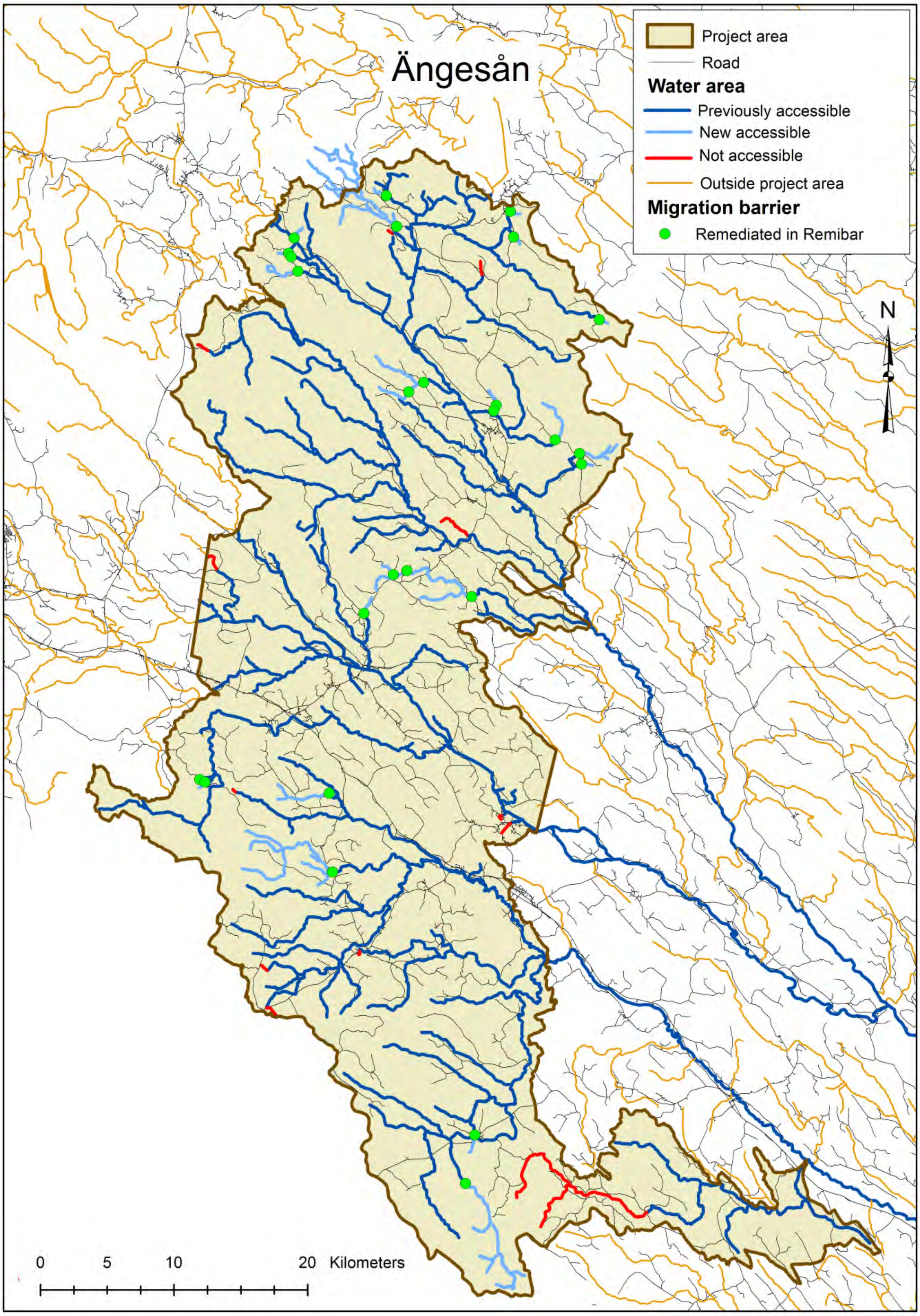

Figure 7. Water areas made accessible following the removal of migration barriers in the Ängesån project area (light blue). Lakes, rivers and creeks are represented as lines. The brown lines designate watercourses in the Kalix River drainage basin outside of the project area.

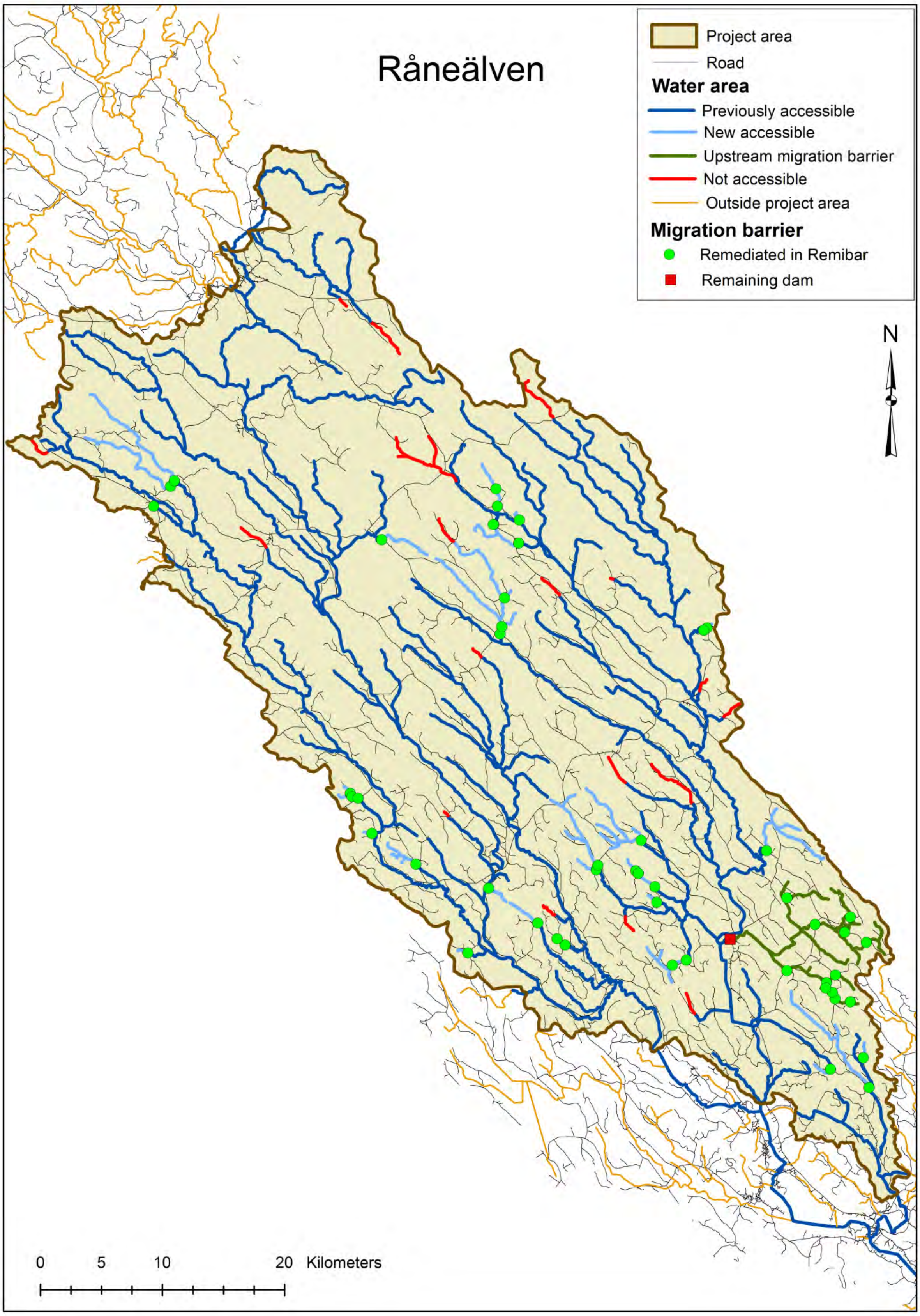

Figure 8. Water areas made accessible following the removal of migration barriers in the Råneälven project area (light blue). Lakes, rivers and creeks are represented as lines. The brown lines designate watercourses in the Råne River drainage basin outside of the project area.

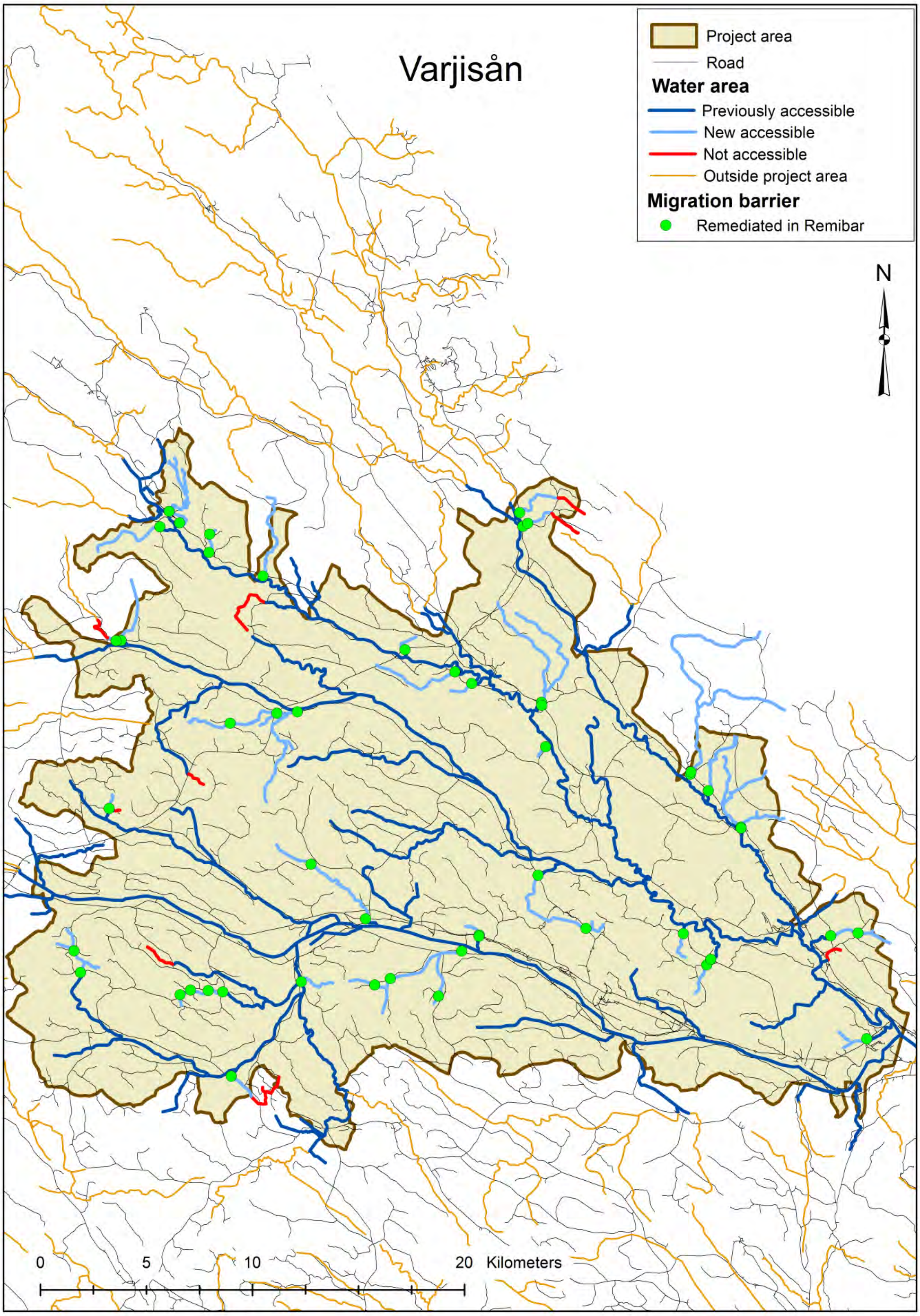

Figure 9. Water areas made accessible following the removal of migration barriers in the Varjisån project area (light blue). Lakes, rivers and creeks are represented as lines. The brown lines designate watercourses in the Pite River drainage basin outside of the project area.

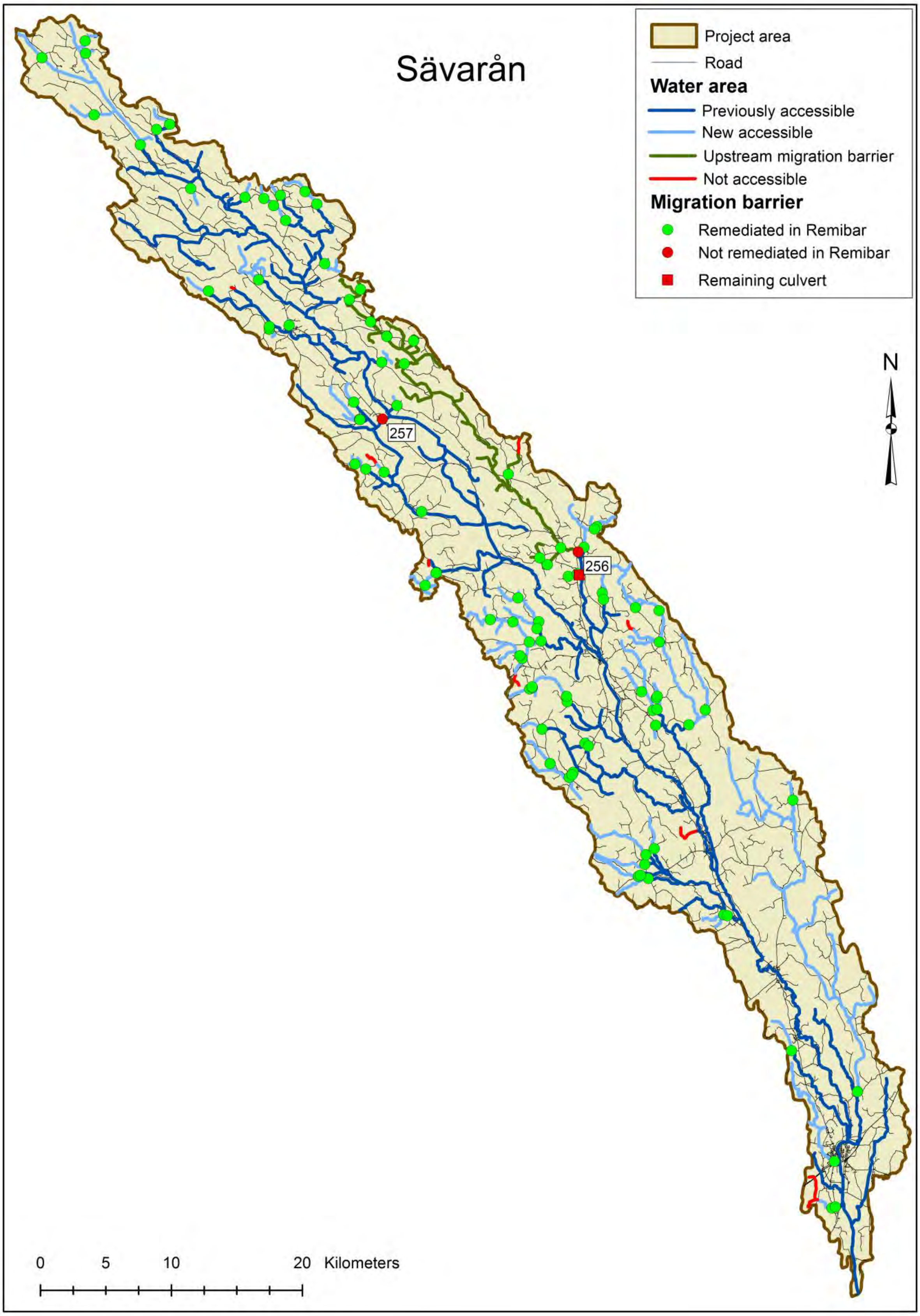

Figure 10. Water areas made accessible following the removal of migration barriers in the Sävarån project area (light blue). Lakes, rivers and creeks are represented as lines.

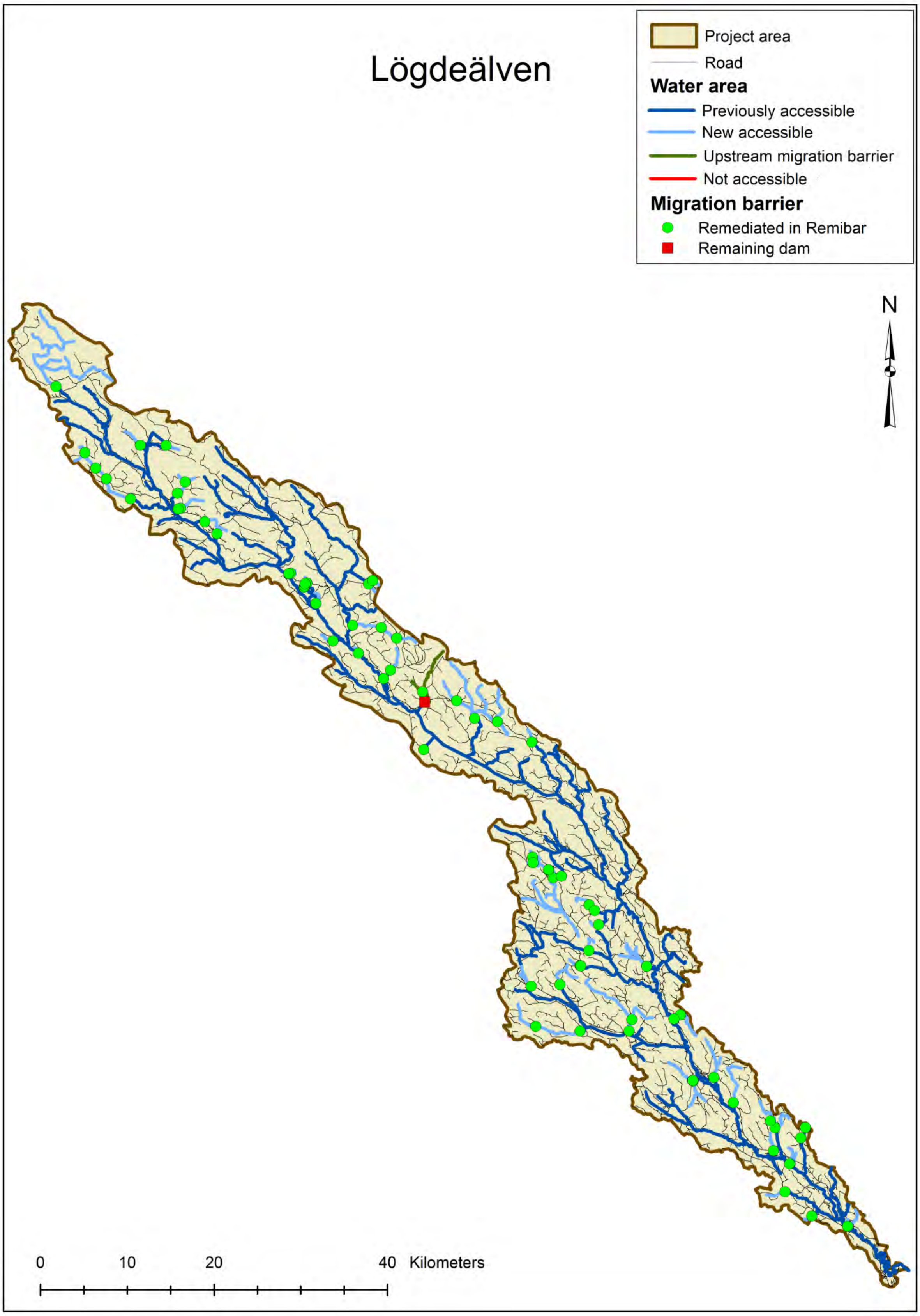

Figure 11. Water areas made accessible following the removal of migration barriers in the Lögdeälven project area (light blue). Lakes, rivers and creeks are represented as lines.

II. Effects of the increased connectivity on the fish community

Context: Other restoration projects and changes in management

In the five project areas, a range of initiatives implemented prior to the onset or Remibar have resulted in an improvement of the living conditions for stream dwelling organisms. These include the restoration of rivers from the impact of timber floating, the restoration of spawning sites for salmon and trout, and the remediation of migration barriers (dams, culverts). In the county of Västerbotten, many rivers and creeks have been treated with lime to counteract acidification. Reductions in fishing pressure in the Baltic Sea have contributed to the recovery of the stocks of salmon and sea trout and consequently an increase in the number of individuals migrating up the rivers to spawn. Changes in fish abundance, population structure and migration behavior can therefore not be attributed to Remibar alone, but Remibar must be evaluated in the context of these other projects and management decisions.

The management of the commercial fishery in the Baltic Sea will be summarized below as it affects all five project areas. Habitat restoration efforts limited to a single project area or river system will be presented in the introduction of that particular project area.

Management of Atlantic salmon and brown trout stocks in the Baltic Sea

In recent years, the commercial and recreational fisheries on salmon and sea trout in the Baltic Sea have been strongly regulated in an effort to help the stocks recover. This has contributed to an increase in the number of individuals of the two species migrating up the rivers to spawn. Below is a summary of some of the efforts to reduce the fishing pressure on the two species.

The Swedish offshore fishery on salmon has been prohibited since 2013. The commercial coastal fishery on salmon has been regulated with quotas since 2012. These quotas have since then been gradually reduced (ICES 2016). The recreational coastal fishery on salmon is not regulated with quotas.

The coastal fishery in an area near the mouth of a river is often subject to regulations specific to the area regarding time of the year fishing is prohibited and the type of gear that can be used, in efforts to limit the fishing pressure on local strains during their migration toward the spawning areas. In some areas fishing is prohibited year-round (or, no licenses are issued for fishing in these areas).

In an effort to further reduce fishing pressure on salmon at the mouth of the river, the Baltic Salmon Fund (Stiftelsen för Östersjölaxen) has been leasing fishing rights (part of the coastal fishery) in the mouth of a number of Swedish salmon rivers. The fishing rights are leased for one or several years at a time. The temporary lease of fishing rights to the Baltic Salmon Fund is based on voluntary decisions by the holders of the fishing rights. In Norrbotten County, the Baltic Salmon Fund is leasing fishing rights in the three rivers included in Remibar: the Kalix, Råne and Pite Rivers. For the two rivers in Västerbotten (i.e., the Sävar and Lögde Rivers), the Baltic Salmon Fund is not leasing fishing rights. However, there is no directed fishery on salmon in the

Sävar River. In the Lögde River, most of the fishery on salmon occurs in areas other than the mouth of the river.

Sea trout is targeted primarily by the recreational fishery, and there are no quotas for the commercial fishery. In the ocean, sea trout occurs near the coast. Of the regulations targeting the trout fishery, the "3-meter-rule", which entered into force in 2006, is among the most important regulations to protect the species in ICES sub-area 31 (i.e., the Gulf of Bothnia). Fishing with nets in waters with a depth <3 meters is prohibited during late spring/early summer and late fall/early winter, as sea trout occurs in coastal waters shallower than 3 m during these times of the year.

Methods

The assessment of the effect of increased connectivity on fish abundance at different sites in the project areas was done using data from existing monitoring programs of stream dwelling fish. As the monitoring carried out within these programs is a directed sampling focusing primarily on assessing the reproduction success of salmon and trout by measuring the abundance of juveniles, the results do not accurately reflect the abundance of other species of fish and do not include information on the abundance of adult salmon and trout. Consequently, no data is available to assess the impact of Remibar on fish species other than salmon or trout or on other organism groups such as aquatic invertebrates. Furthermore, no studies focusing on directly assessing the effect of migration barrier removal on migratory behavior (e.g., by tracking the movements of individuals) and species abundance have been carried out. Therefore, only data on salmon and trout abundance will be presented in this report.

Data was downloaded from the national Electrofishing Registry (Elfiskeregistret). The electrofishing method captures only young fish, i.e., 0-4 years old, and occasionally small adult trout. The objective of the electrofishing method is to measure reproductive success from previous years. The data used in this report has been collected in July and August. Juveniles are reported as 0+, while the other age classes are reported as a group (>0+). These 0+ hatched during the spring the same year and are the offspring of adults that spawned during the fall the previous year. This method does not record the abundance of adults at a given site and the number of adults migrating up the river to spawn. Information on the number of adults is recorded by fish counters located in the main stem of the river.

For each project area, five electrofishing sites where the fish community has been assessed yearly from 2007 or earlier to 2016 were selected (table 3). Data from 2016 was available from all sites except for two sites in the Lögdeälven project area. If less than five sites with data sets that met the requirements were available within the project area, sites outside of the project area boundaries were also included. When possible, locations were chosen near remediated migration barriers. It is worth mentioning that the number of electrofishing sites with long time series is higher for the two project areas in the county of Västerbotten, due to the extensive monitoring carried out within this county to measure the impact of liming to counteract acidification. Therefore, a high number of electrofishing sites were located in the vicinity of the remediated migration barriers in the two project areas in Västerbotten (i.e, Sävarån and Lögdeälven). In the two northernmost project areas in Norrbotten (i.e., Ängesån and Råneälven) few electrofishing sites with long enough time series were located near the remediated migration barriers. When available, data from fish and smolt counters was used as indicators of fluctuations in the number of adult salmon and trout migrating up the rivers and smolt migrating down the rivers. However, data from fish counters with long time series was available for only two project areas.

Table 3. Electrofishing sites in the five project areas.

Project area	Electrofishing site	SWEREF99TM_N	SWEREF99TM_E
Ängesån	Sistkostforsen	7402832	830750
	Lappforsen	7409016	827220
	Kurkkiokoski	7437271	806146
	Markittabron	7463375	782699
	Niilivaarabron	7467926	785169
Råneälven	Gärdan	7358133	794190
	Storåholm	7362782	784831
	Långforsen	7366433	784234
	Båthusforsen	7370354	785079
	Muorka	7390891	771079
Varjisån	Storforsen	7314241	747160
	Åkerselsforsen	7314167	737472
	Skräckselet	7321636	733627
	Ljusselforsen hö ned	7321975	705566
	Junkaberget	7330119	720739
Sävarån	Sävar	7098993	773054
	Skogsstugan	7121985	756814
	Bjurforsen	7130785	760802
	Långmyrkälen	7132518	751581
	Ikkorängesknösen	7137083	748874
Lögdeälven	Hyngelsböle	7058861	714768
	Borstmyrberget	7068731	708544
	Stormyrberget	7069644	705683
	Stora Röjdtjärnen	7089279	680939
	Ovan Långviskasjön	7102160	679676

Results

Ängesån

Site description and previous restoration projects

The Ängesån project area is located in the Kalix River system and covers the upper reaches of the Änges River and its tributaries the Lina River and the Tvärån/Skrövån River (fig. 12). The upper reaches of the Tvärån/Skrövån River is composed of two areas: the upper reaches of the Skrövån River and the Kattån River. The Lina River and the Tvärån/Skrövån River join the Ängesån River 40 km and 88 km south of the project area, respectively.

Within the project area, many efforts have been made to restore the rivers from the impact of timber floating and to recreate reproductive areas. The uppermost reaches of the Ängesån River have been restored from the impact of timber floating. This includes most of the Vettasjoki River (restoration work started in the mid-1990s and ended in 2009) and the tributary the Hartijoki River (restored in the early 1990s). Reproductive areas were also recreated in these areas. The lower parts of the Valtiojoki were restored in 2001-2009 and reproductive areas were also recreated. In the mid-2010s, reproductive areas were restored in the lower reaches of the Mailiojoki. In the mid-2010s, the uppermost reaches of the Lina River (Kutsasjoki) was restored from the impact of timber floating and reproductive areas were restored. Arrojoki, a tributary to the Skrövån River was restored from the impact of timber floating in the late 1990s-early 2000s.

The 26 migration barriers included in Remibar were remediated in 2014 (17 barriers) and 2015 (9 barriers).

Today, the Ängesån project area harbours non-migrating populations of trout and provides reproductive areas for salmon and trout. There are freshwater pearl mussel populations in the area.

Other areas in the Kalix River system, i.e., parts of the Lina and the Vassara Rivers, will be restored from the impact of timber floating as part of the project ReBorN, financed by the EU Commission through the Life+ programme. The restoration efforts will begin in 2016.

Available fish population data

There are no long time series with measurements of the number of trout and salmon migrating up the Ängesån River. In the Ängesån and Linaälven Rivers, fish counters were installed in 2015. However, there is a fish counter in the Kalix River in Jockfall, 100 km north of the mouth of the Kalix River. It was installed in 1980 and is located 40 km upstream from where the Ängesån River joins the Kalix River. While the number of migrating salmon in Jockfall does not tell us the number of individuals migrating up the Ängesån River, they do give an indication of the change in the number of salmon that migrate up the Kalix river system. The data from the fish counter in Jockfall is presented below.

Of the five electrofishing sites included in this assessment, two electrofishing sites (Niilivaarabron and Markittabron) are located within the project area. Of these two, only one (Niilivaarabron) is located downstream a large number of remediated objects. There are no objects upstream the Markittabron site. The other three electrofishing sites are located further downstream in the Ängesån River.

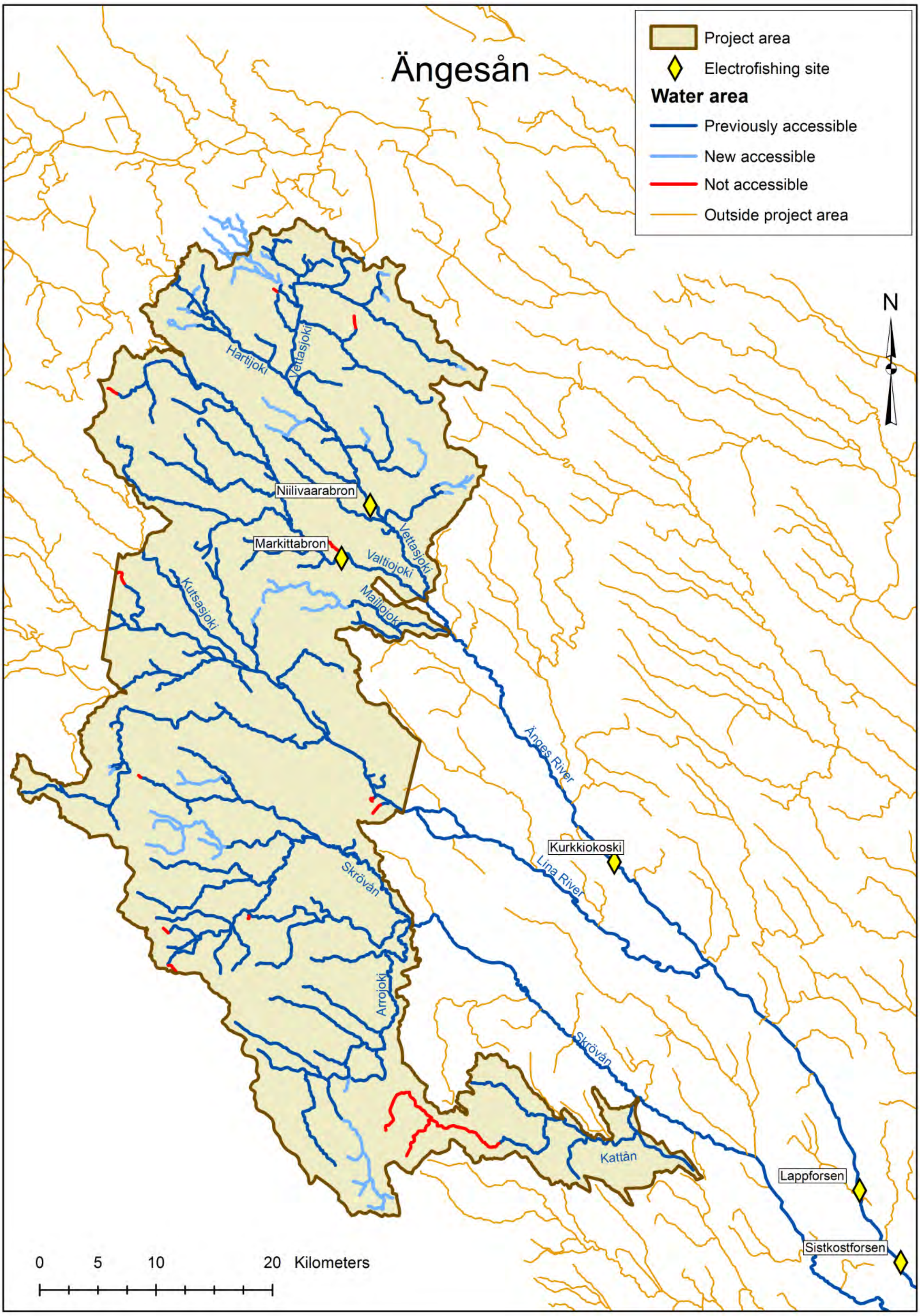

Figure 12. Electrofishing sites in or near the Ängesån project area. For clarity, the main channels of the major tributaries to the Ängesån River are indicated in blue although they are outside the project area.

Results and discussion

The number of adult salmon migrating up the Kalix River past Jockfall has increased dramatically since the early 1990s and peaked in 2013 (fig. 13).

In the Ängesån project area, migration barriers were remediated in 2014 and 2015. The available data shows that at all the five electrofishing sites, the abundance of juvenile salmon has been increasing since the mid-1990s, which reflects the general increase in migrating adults observed in Jockfall (fig. 14). There is no trend for trout at any of the sites.

At Niilivaarabron (fig 14 a and b), salmon 0+ have been recorded most years since 2002. The successful reproduction is a result of the efforts to restore habitat that started in the mid-1990s and ended in 2009. The site is located downstream 14 remediated migration barriers located in tributaries, which were remediated in 2014 and 2015. While the removal of the migration barriers have made it possible for adults to reach spawning areas in the tributaries, Niilivaarabron is located too far away from these tributaries to detect an effect on reproduction success, as juveniles generally migrate less than 400 m from the spawning area to the nursing area (Andersson 2016, Webb et al. 2001). At Markittabron (fig 14 c and d), no migration barriers had been remediated upstream. However, efforts to restore habitat carried out within other projects ended in 2009, and 0+ have been recorded at the site since 2012. This increase in the production of 0+ coincides with the increase in migrating mature individuals recorded in Jockfall. At the three sites the furthest downstream (Kurkkiokoski, Lappforsen and Sistkostforsen, fig 14 e-j), there has been an increase in the abundance of salmon juveniles since the early 2000s. Thus, the pattern of juvenile abundance seen at the five sites reflects the general pattern of an increase in the number of mature individuals migrating up the river to spawn. The pattern seen at Niilivaarabron and Markittabron are a result of previous restoration efforts. It has not been possible to detect an effect of the remediation efforts as part of Remibar on reproduction success of salmon and trout at these sites, which is due to the fact that they are located too far away from the remediated migration barriers and the spawning areas upstream. In addition, not enough time has passed for the populations of salmon and brown trout to respond to the availability of new spawning habitat.

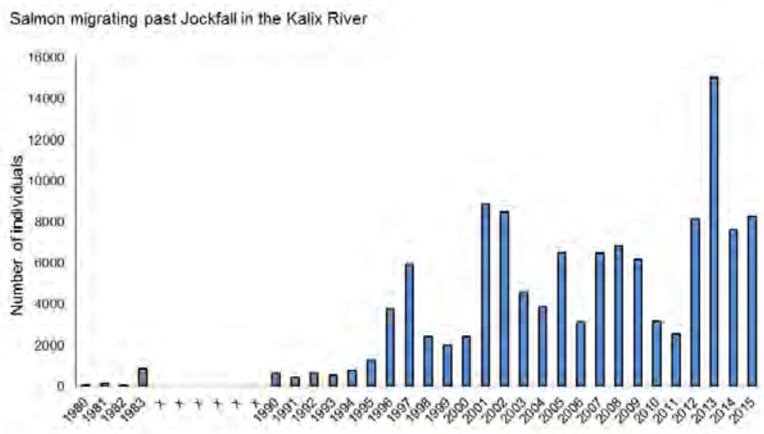

Figure 13. Numbers of wild salmon migrating past Jockfall in the Kalix River. ‘x’ denote years when no data was collected.

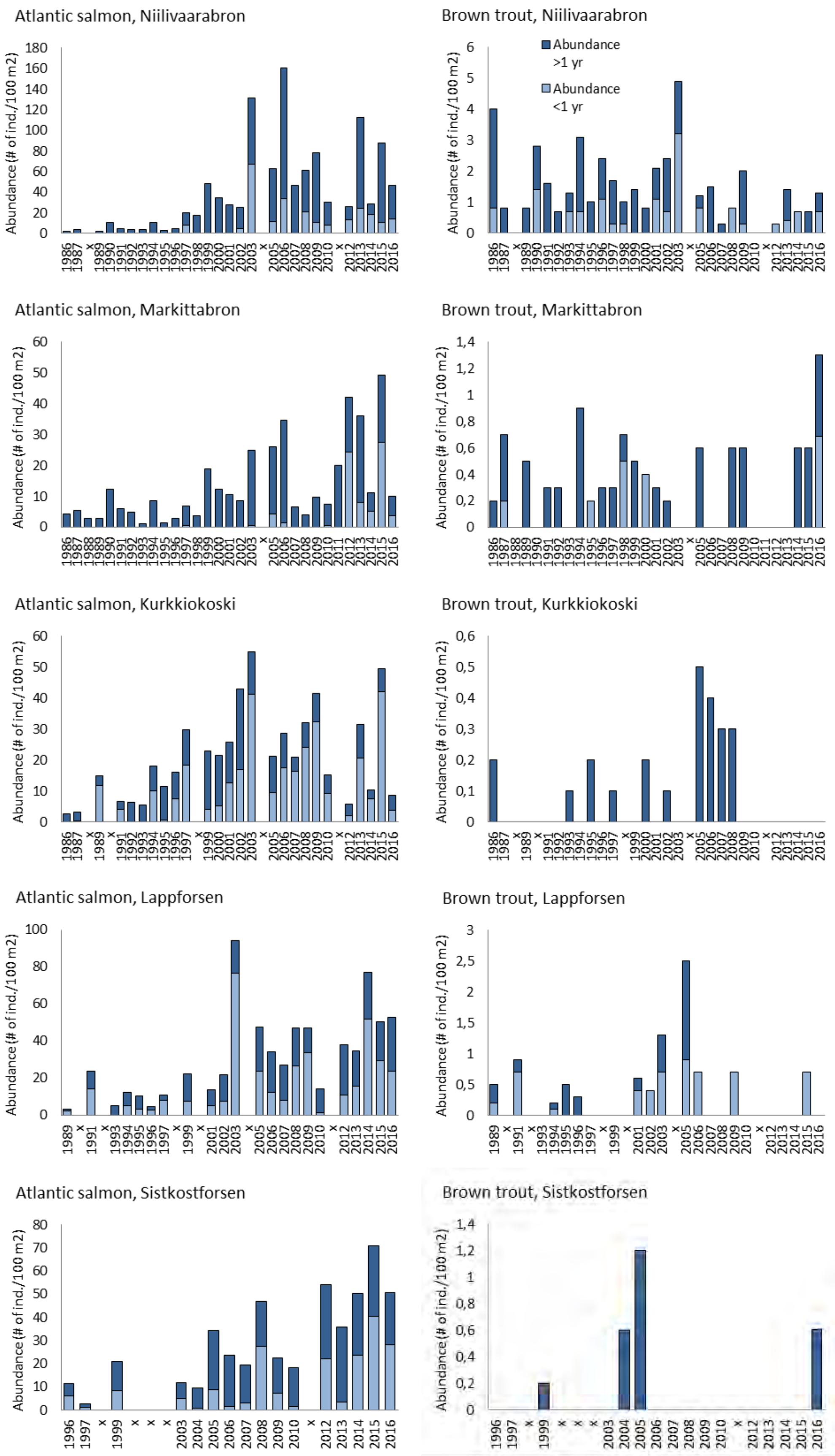

Figure 14 a-j. The abundance of Atlantic salmon and brown trout recorded by electrofishing in or downstream the Ängesån project area. 'x' denote years when no data was collected.

Råneälven

Site description and previous restoration projects

The Råneälven project area comprises the middle section of the Råne River drainage basin (fig. 15). Like many rivers in the area, the river was modified to facilitate timber floating. Compared to the Ängesån project area, the watercourses in this area have been more affected by the effects of large scale forestry including drainage of forested areas. The drainage of forested areas, together with the unregulated coastal fishery (primarily recreational fishery) on trout starting in the late 1940s, was among the main drivers in the decline of the population of migratory trout. The decline of migratory trout started in the 1950s, and in the 1960s migratory trout was gone from the Råne River. In the early 1990s, the fishing pressure from recreational fishery alone (not including the commercial fishery) near the mouth of the Råneälven River (within a distance of 2 km) was estimated to 30 000 nights of fishing/year, and the catch was estimated to 2 tons of trout/year, which corresponds to approximately 2000 individuals. Non-migratory trout occurred in restricted areas (Ingemar Perä[2], personal communication).

In 1995-2001, large stretches of rivers in the Råneälven project area were restored from the impact of timber floating. This included the tributary Rutnajoki, parts of the main stem of the Råne River, the lower reaches of the Sol River, much of the Livas River, Norr-Lillån and Sör-Lillån. Approximately 30 reproductive areas were also restored. Monitoring of salmon, trout and grayling at the sites that had been restored from the impact of timber floating was carried out during the fall of 2016. The results revealed that reproduction was low at all sites. This may be caused by the high turbidity and high rate of sedimentation, and high abundances of algae (Nilsson 2016).

The majority of the 50 migration barriers were remediated in 2013, when 33 were completed. The remaining were completed in 2012 (9), 2014 (3), and 2015 (5).

Today, the Råneälven project area harbours non-migrating populations of trout and provides reproductive areas for salmon and trout. There are freshwater pearl mussel populations in the area.

Areas in the Råne River system will be restored from the impact of timber floating as part of the project ReBorN, financed by the EU Commission through the Life+ programme. The restoration efforts will begin in 2018.

Available fish population data

There are no long time series with measurements of the number of trout and salmon that migrate up the Råne River. A fish counter is installed in Gunnarsbyn, on the Råne River. It was installed in 2014 and is located 40 km north of the mouth of the river, 3 km south of the project area. There is no other fish counter in the area with more historic data.

Electrofishing sites in the Råneälven project area that have been monitored over an extended period of time are located primarily in the main stem of the Råne River (fig. 15). Of the five electrofishing sites included in the report, only two sites (Långforsen and Storåholm) are located in the vicinity of tributaries where migration barriers have been remediated. Båthusforsen is located further upstream. The site Muorka is located high up in the project area, downstream one object. The site Gärdan is located the furthest downstream.

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[2] Vatten och Fiskeenheten, The County Administrative Board of Norrbotten

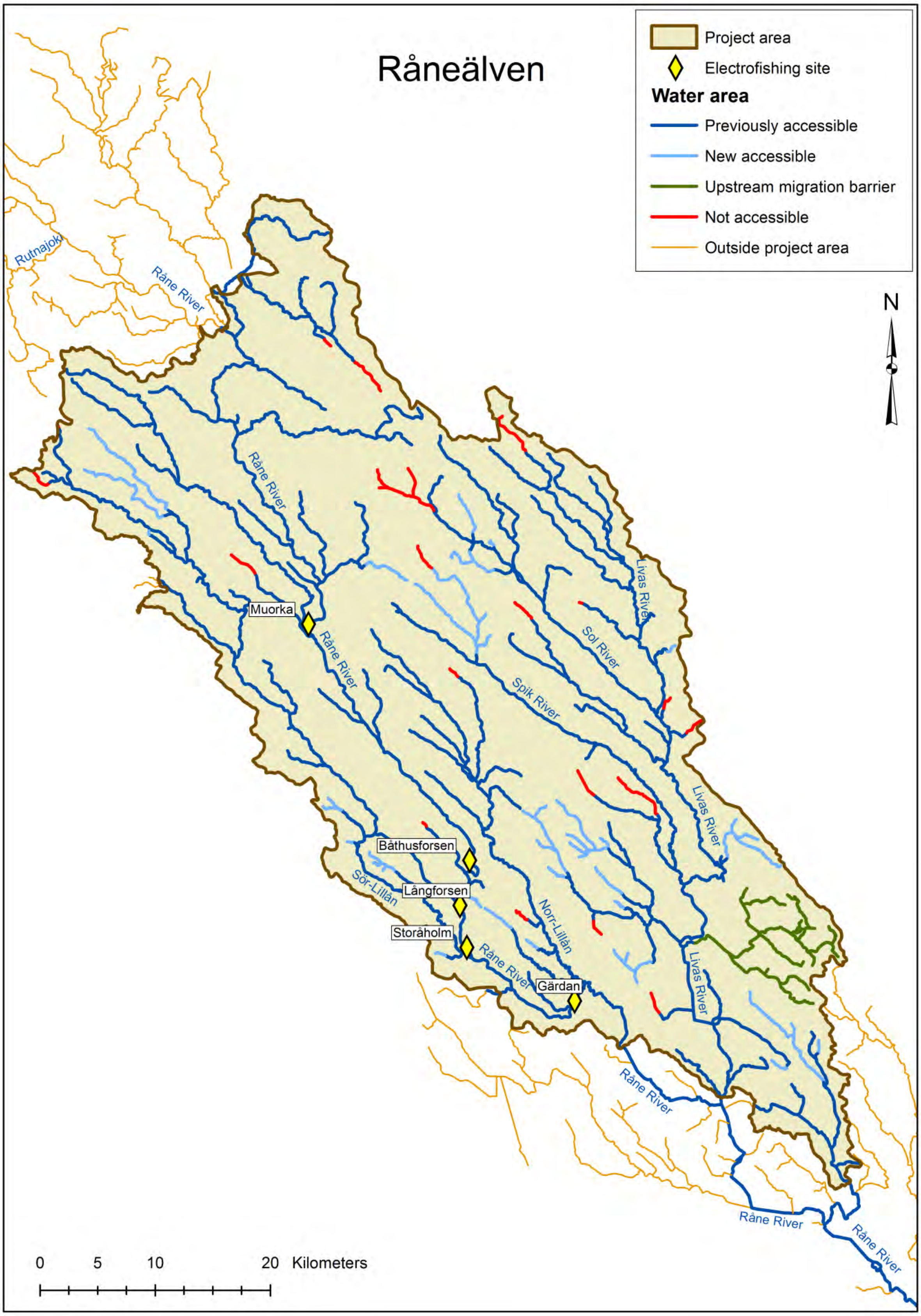

Figure 15. Electrofishing sites in the Råneälven project area. For clarity, the main channel of the Råne River is indicated in blue although it is located outside the project area.

Results and discussion

There has been a general increase in the abundance of salmon juveniles since the late 1990s at all electrofishing sites with the exception of the site Gärdan, located the furthest downstream (fig. 16f). Trout juveniles have been recorded sporadically only at one site (Långforsen, fig. 16d). At the other four sites, trout juveniles have not been recorded the past years. At Muorka, trout juveniles have not been recorded since the late 1990s, and at Båthusforsen the last record is from 1993. At Storåholm, trout juveniles have not been recorded since 2006, and at Gärdan trout juveniles have not been recorded since 1996.

At Muorka and Båthusforsen, the two sites the furthest north, salmon 0+ have been recorded in higher numbers since 2013 (11 a and b). At Långforsen, salmon 0+ have been occurring since 2012 with a peak in 2014 (fig. 16c). At Storåholm increasing numbers of 0+ have been recorded since the late 1990s (fig. 16e). This might be a result of the general increase in the number of mature individuals migrating up the river, as seen in other river systems. At the Gärdan site, few juvenile salmon have been recorded and there is no apparent trend (fig. 16f).

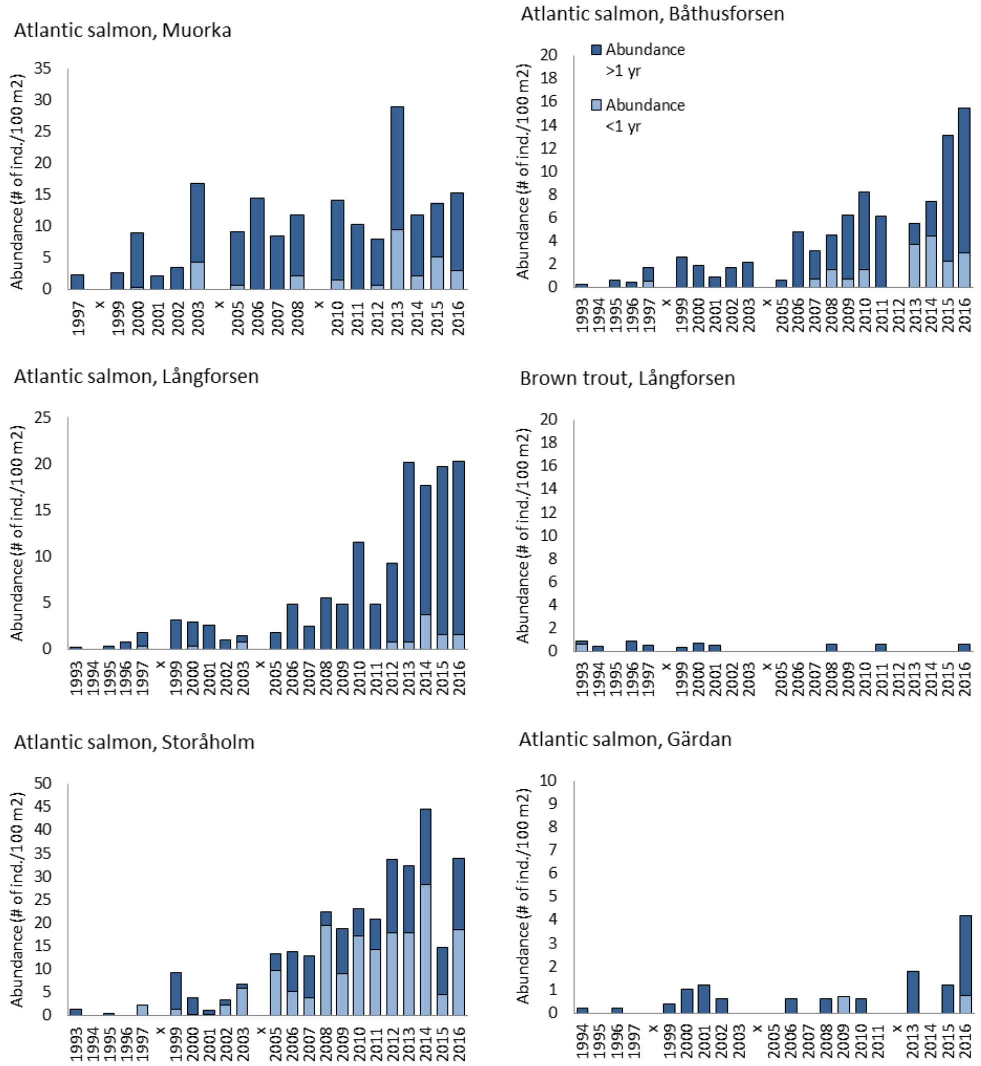

Figure 16 a-f. The abundance of Atlantic salmon and brown trout recorded by electrofishing in the Råneälven project area. 'x' denote years when no data was collected.

From the available data, it is not possible to discern an effect of Remibar on the reproductive success of salmon and trout. The major reasons is a lack of monitoring sites with long enough data series located close enough to the remediated sites.

Varjisån

Site description and previous restoration projects

The Varjisån project area is located in the Pite River system and covers approximately 45 km of the main stem of the Pite River, 45 km of the tributary the Varjisån River, as well as their tributaries (fig. 17). The Storforsen Rapids on the Pite River, right next to the site where the two rivers merge, is a natural migration barrier that prevents upstream migration of anadromous brown trout and Atlantic salmon. Hence, the trout that occurs upstream the rapids is non-migratory trout. During a 10-year period (1999 – 2009), large sections (230 km) of the Pite River and its tributaries were restored from the effects of timber floating as part of the project "Environmental restoration project Vindel- and Piteälven". Restoration efforts consisted of removing structures aimed at facilitating timber floating and recreating natural habitat, including spawning areas. Within the Varjisån project area, restoration efforts in the main channel of the Pite River were completed in 2006, while they were completed in 2002 in the Varjis River. From 2006 to 2010, spawning areas were restored in two tributaries to the Varjisån River, the Sikån River and the Vitbäcken Creek. The migration barriers remediated in Remibar were located in smaller tributaries.

The majority of the 50 migration barriers were remediated in 2012 (31 barriers). The remaining were remediated in 2013 (5 barriers), 2014 (4 barriers) and 2015 (10 barriers).

The project area harbours non-migrating populations of trout and provides reproductive areas for salmon and trout. However, as Storforsen prevents the upstream migration of sea trout and salmon, the trout recorded upstream Storforsen is from populations of non-migratory trout. There are freshwater pearl mussel populations in the area.

Parts of the Pite River system, outside the project area, will be restored from the impact of timber floating as part of the project ReBorN, financed by the EU Commission through the Life+ programme. The restoration efforts will begin in 2017.

Available fish population data

The Sikfors hydroelectric power plant is located on the Pite River, 60 km downstream the Varjisån project area. In Sikfors, a fish counter is installed in the fish ladder that directs fish past the hydroelectric power plant. Another fish ladder is installed in Fällfors, 23 km downstream the project area where it directs fish past a partial migration barrier. Only 25 % of the fish that reach the Sikfors hydroelectric power station manage to migrate past the barrier (Stefan Stridsman[3], *unpublished data*). Of the fish that migrate past Sikfors, approx. 50 % pass the fish ladder in Fällfors (Jan Isaksson[4], *unpublished data*), while an unknown proportion migrate past the Fällfors rapids on their own. The remainder migrates up tributaries between Sikfors and Fällfors or gets harvested.

The electrofishing site Storforsen is located downstream the Storforsen rapid (fig. 17). Two electrofishing sites are located in the Pite River upstream Storforsen (Åkerselsforsen and Ljusselforsen hö ned). Åkerselsforsen is located in a section of the river that was restored from the impact of timber floating, while the Ljusselforsen is located in a section of the river that has not been restored from the impact of timber floating. The last two sites (Skräckselet and Junkaberget) are located in the Varjisån River, in areas that have been restored from the impact of timber floating.

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[3] County Administrative Board of Norrbotten
[4] Pite Älv Ekonomisk Förening

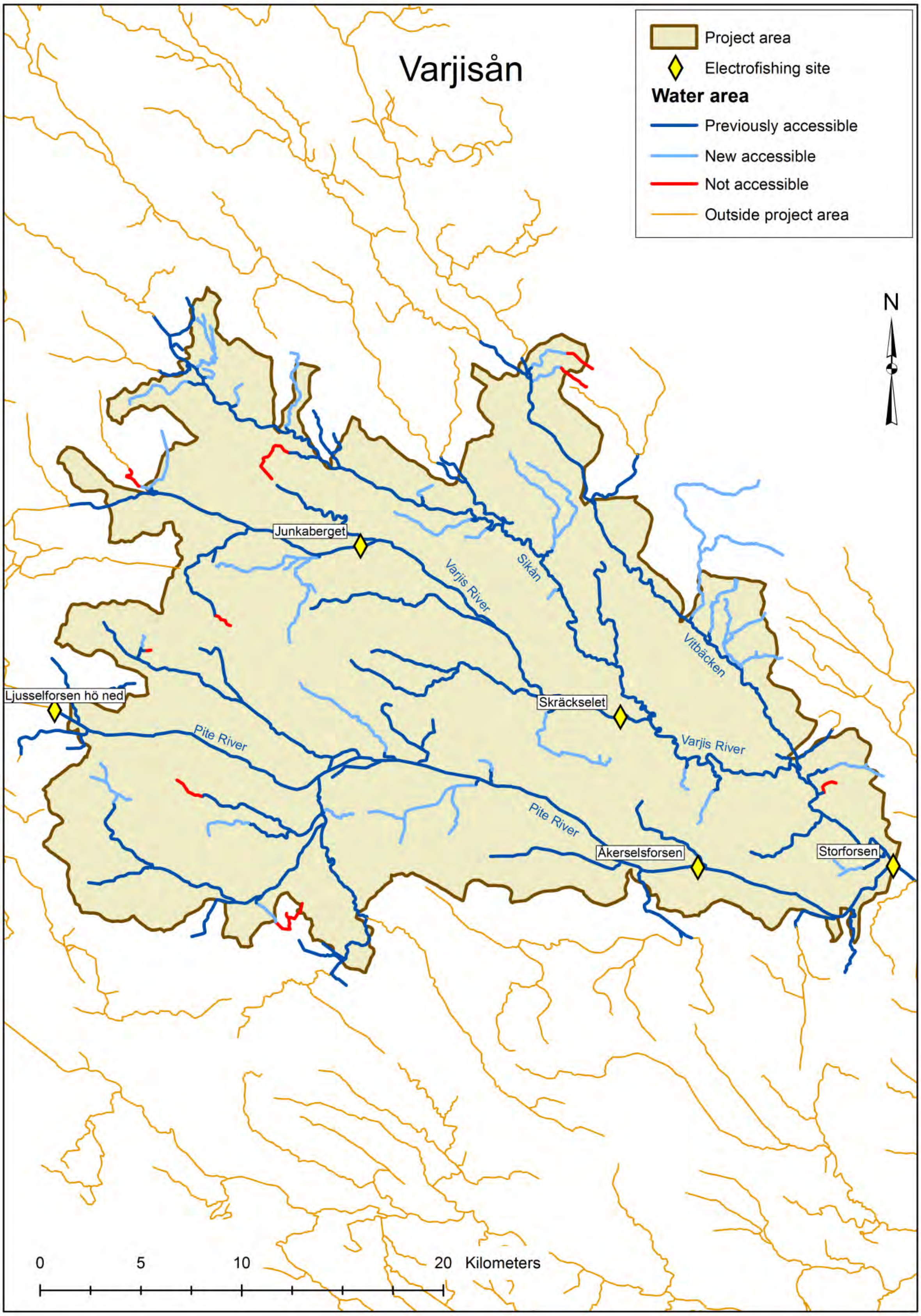


Figure 17. Electrofishing sites in or near the Varjisån project area.

Results and discussion

Data from the fish counter at the Sikfors hydroelectric power station shows that the number of trout migrating through the fishway has been increasing 15-fold from 2000 to 2015 (fig. 18). The number of salmon migrating through the fishway was approximately 2.5 times higher in 2015 compared to 2000, although salmon has experienced larger fluctuations in numbers than trout. In 2012, there was a sharp increase in the numbers of salmon and trout migrating up the Pite River. The numbers have remained high since.

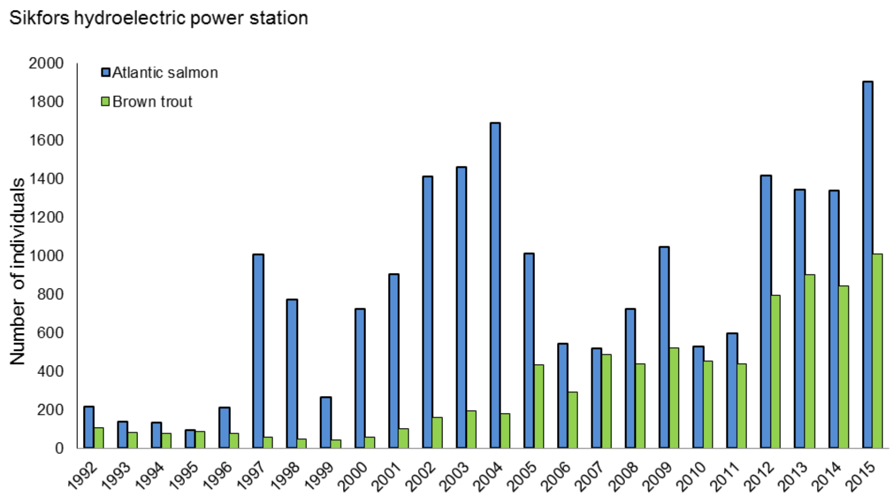


Figure 18. Number of individuals migrating past the hydroelectric power station at Sikfors.

In the area upstream Storforsen, most of the migration barriers were removed in 2012, while the restoration of the Pite River main channel (as part of the "Environmental restoration project Vindel- and Piteälven") was completed in 2006 or earlier. At the electrofishing site downstream Storforsen, there is no apparent trend, neither for salmon nor for trout (fig. 19 a and b). However, at Åkerselsforsen, the site upstream Storforsen, the abundance of trout 0+ has been high since 2013 (fig. 19 c). At Åkerselsforsen, 16 migration barriers upstream have been remediated. At Ljusselsforsen, the number of trout juveniles increased in 2012 (fig. 19 d). No salmon has been recorded at the two sites upstream Storforsen. As the Storforsen Rapids prevent upstream migration of salmon and sea trout, the increase in trout juvenile abundance is a result of an increased reproduction of non-migratory populations of trout. However, it is unlikely that the increase is a direct effect of the removal of migration barriers in Remibar, as the two electrofishing sites are located several kilometers away from the remediated migration barriers. However, it is very positive that the increased availability of reproductive areas and nursing areas upstream Storforsen is coinciding with an increased abundance of trout in the area.

The restoration of the Varjisån River (as part of the "Environmental restoration project Vindel- and Piteälven") was completed in 2002 and the migration barriers were remediated in 2012. At Skräckselet, the downstream site in Varjisån, which is located downstream a tributary where the 2 migration barriers were removed in 2012, there were infrequent records of juvenile salmon prior to 2012. Since 2012, juvenile salmon has been recorded every year (fig. 19e). The occurrence of 0+ in 2014-2016 at Skräckselet indicates that spawning has occurred from 2013 and onwards. Juvenile trout has been recorded the past 4 years (2013-2016), whereas juveniles were recorded only occasionally previous years (fig. 19f). However, no trout 0+ have been recorded at this site. At Junkaberget, the upstream site in Varjisån which is located downstream a tributary where 2 migration barriers were removed in 2012 and one in 2014, juvenile salmon, including a large proportion of 0+, have been recorded the past 4 years (2013-2016) with a peak in 2016 (fig. 19g).

This indicates that salmon is now migrating higher up in the system and is also reproducing at this site. Juvenile trout (including 0+) have been recorded at Junkaberget every year since 2002 (when monitoring began), but abundance has been high since at least 2013. This increase could be attributed to an increase in reproduction success of non-migratory trout, or be a result of increased migration and reproduction of sea trout (fig. 19h). However, while it is not possible to determine whether the increase in reproduction success of salmon and trout in the Varjisån River is a direct result of Remibar, it is very positive that the increased availability of reproductive areas and nursing areas is coinciding with an increase in the number of individuals migrating up the river to spawn and spawning success. Thus, the removal of migration barriers in the Varjisån River may have contributed to an increase in the reproduction success of both salmon and trout.

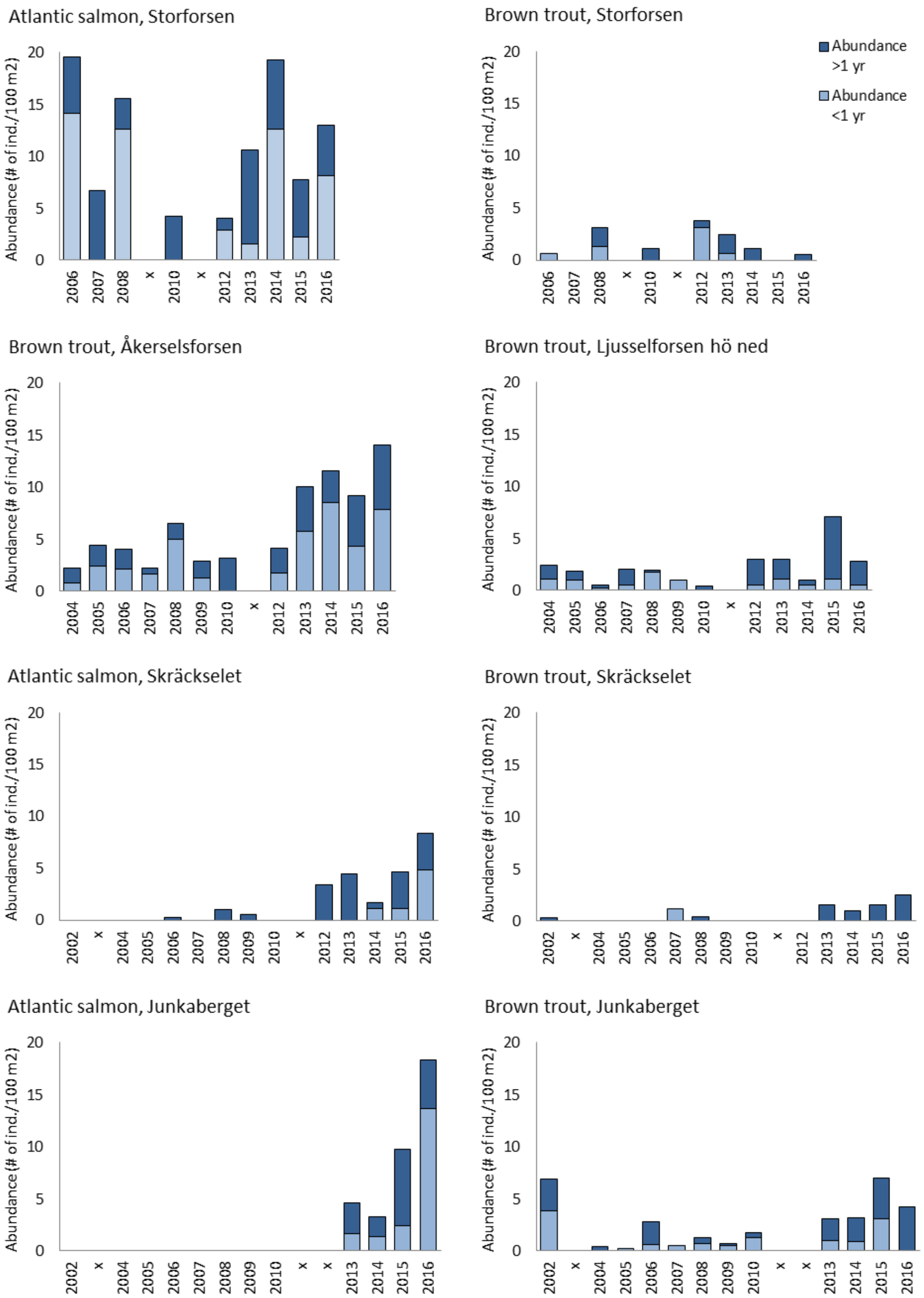


Figure 19 a-h. The abundance of Atlantic salmon and brown trout recorded by electrofishing at five sites in or near the Varjisån project area. 'x' denote years when no data was collected.

Sävarån

Site description and previous restoration projects

The Sävarån project area encompasses the entire Sävar River basin (fig. 20). Most of the Sävar River (the main stem of the river and tributaries) basin has been treated with lime since the 1990 to increase pH and counteract the effects of acid rain. Especially the lower parts of the drainage basin (an area stretching from the mouth of the Sävar River and 20 km north), and an area on the eastern side of the main channel approximately 30 km north of the mouth of the river are heavily affected by acid rain, which has had major negative consequences for aquatic organisms. Nine areas distributed along the lower 2/3 of the drainage basin and one site further north are currently being treated with lime.

Since the 1990s, many migration barriers have been remediated. There is one dam in the main channel of the Sävar River but a fish pass allows fish to swim past it. The dam is located 10 km upstream the mouth of the river, near the town Sävar.

In 2011-2013, in a project led by the County Administrative Board in Västerbotten, 6 km of rapids were restored from the impact of timber floating. This included 5 km of the main stem of the Sävar River and 1 km of its tributary the Gravån River. The work continued in the project "Living salmon rivers" (Levande laxälvar) which started in 2014 and will end in 2017. At the end of 2016, an additional 10 km of the main stem of the Sävar River had been restored, together with an additional 8.5 km in three tributaries. The 15 km of rapids in the main channel of the river that have been restored are located along a 60-km section north of the town of Sävar in the southern part of the Sävar River. This has resulted in 3 ha of land being reclaimed by the river due to the widening of the rapids.

In the Sävarån project area, 96 migration barriers in tributaries were remediated as part of Remibar during the period 2012-2016. Twenty-seven migration barriers were remediated in 2012, 19 in 2013, 25 in 2014, 17 in 2015 and 8 in 2016.

The Sävar River system harbours non-migrating populations of brown trout and provides reproductive areas for sea trout and Atlantic salmon. The populations of Atlantic salmon and sea trout are recovering and migrate up the river to spawn. The freshwater pearl mussel is established in the lower reaches of the river. The noble crayfish was extirpated from the river basin due to acid rain, but has been reintroduced.

In 2014, juvenile salmon was recorded 60 km north of the mouth of the Sävar River. This was the first time juvenile salmon was recorded that high up in the river system since monitoring by electrofishing began, which indicates that salmon is reproducing higher up in the river system than before.

Available fish population data

No fish counter counting adult fish is installed in the river. Between the years 2005 and 2013, a smolt counter was installed in the Sävar River, downstream the mouth of the Pålböleån River (i.e, 13 km from the ocean). As the smolt counter was not in place after 2013, it cannot be used to evaluate the effect of Remibar.

Electrofishing is carried out at numerous sites within the drainage basin. The objective of most of the electrofishing is to monitor the effect of liming to counteract the effect of acidification and to monitor the impact on the populations of salmon and trout. The electrofishing site Sävar is located in the main channel of the Sävar River near the mouth of the river. The other four electrofishing sites included in this assessment (Ikkorängesknösen, Lånmyrkärlen, Bjurforsen and Skogsstugan) are located in tributaries near sites where migration barriers have been remediated as part of Remibar. The migration barriers near the four electrofishing sites in the tributaries were removed in 2012-2014 (Ikkorängesknösen), 2014 (Långmyrkärlen and Skogsstugan) and 2015 (Bjurforsen), respectively.

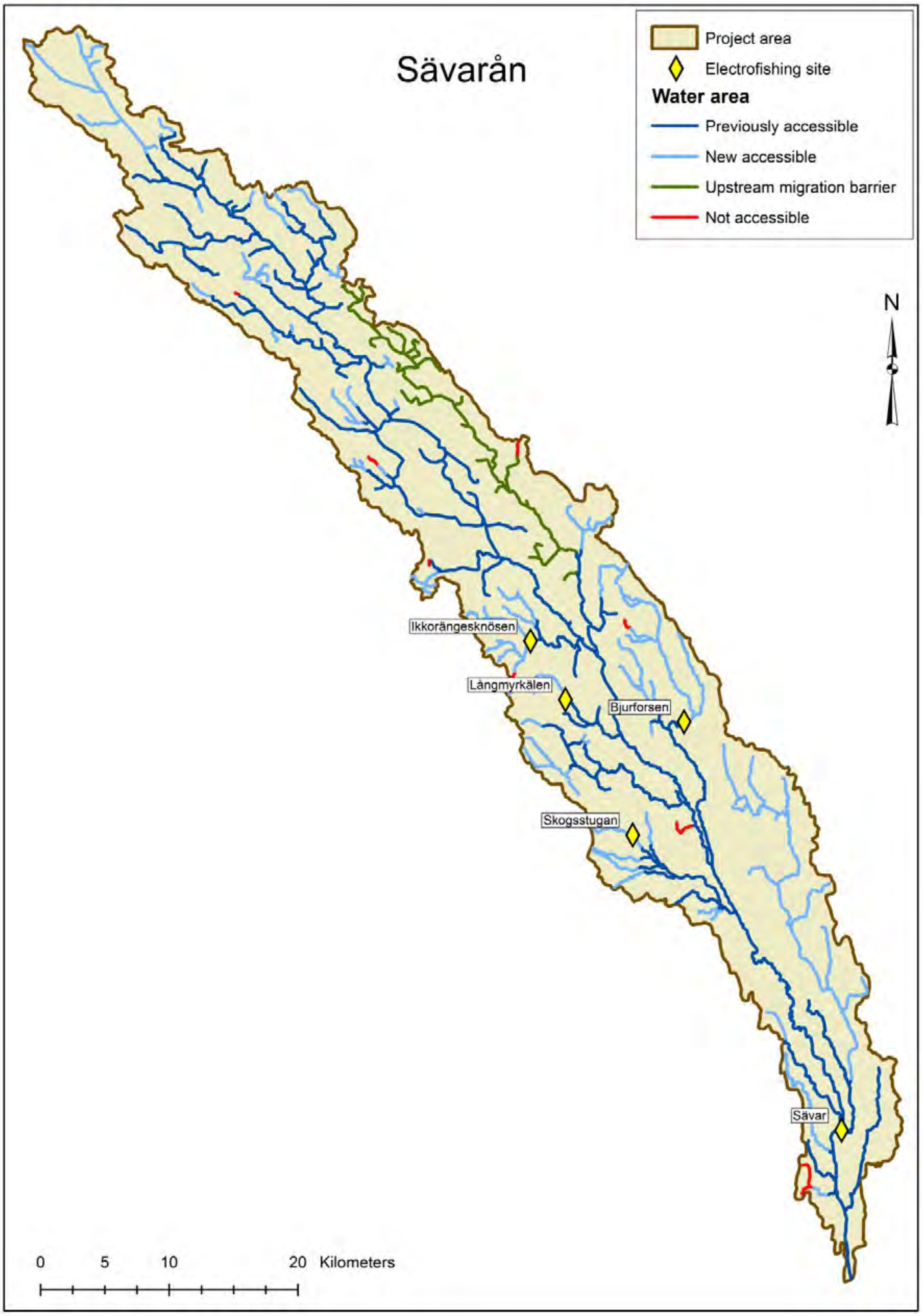


Figure 20. Electrofishing sites in the Sävarån project area.

Results and discussion

Juvenile trout was recorded at all five electrofishing sites, while juvenile salmon was recorded only at Sävar in the main stem of the river (fig. 21e). Data from Sävar shows that salmon juveniles have been recorded at the site since 2006 and that the number has been increasing since. According to assessments by the County Board of Västerbotten, the overall abundance of salmon and trout juveniles in the Sävar River basin has been increasing since the 1990s, with a strong increase since 2012. The sites in the tributaries (Ikkorängesknösen, Långmyrkärlen, Bjurforsen and Skogsstugan) harbour non-migratory populations of trout, and are also reproductive areas for sea trout. The sites in the tributaries are also potential reproduction areas for salmon.

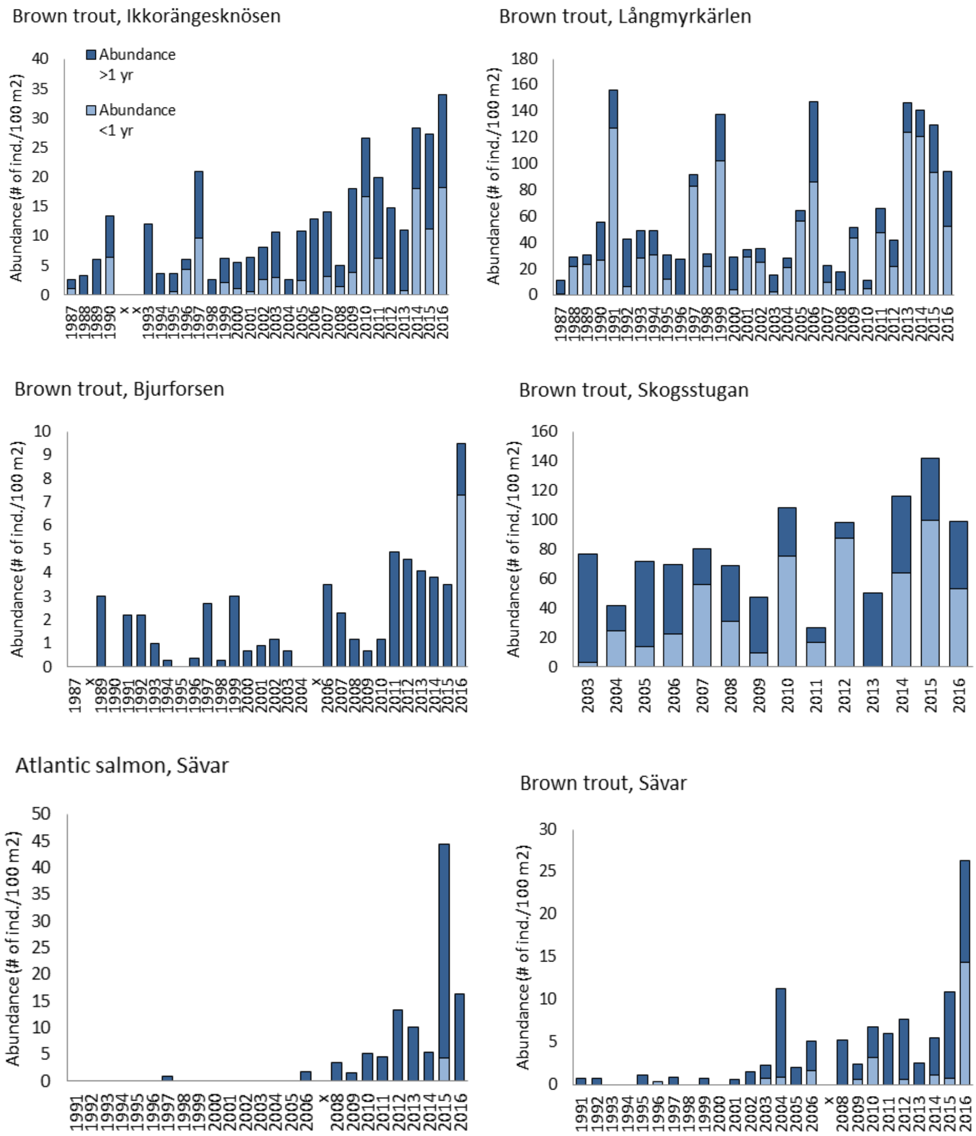


Figure 21 a-f. The abundance of Atlantic salmon and brown trout recorded by electrofishing at five sites in the Sävarån project area. 'x' denote years when no data was collected.

At Ikkorängesknösen (fig. 21a), the abundance of trout 0+ has been high the past 3 years (2014-2016). Five migration barriers were removed upstream the site in 2012-2014. No clear trend is seen at the Långmyrkärlen site (fig. 21b), where 4 migration barriers were removed in 2014. At Långmyrkärlen the abundance of 0+ trout has been high since 2013, prior to the removal of the migration barriers. At the Bjurforsen site (21c), where no 0+ trout been detected in 30 years, 0+ were recorded for the first time in 2016, one year after the removal of the 5 migration barriers upstream. The successful reproduction at Bjurforsen might be a result of the remediation of migration barriers as part of Remibar as more spawning and nursing areas are accessible in the area. At the Skogsstugan site, where one migration barrier downstream was removed in 2014, no trend is apparent, although the number of 0+ trout is high (fig. 21d). Thus, the removal of migration barriers as part of Remibar could have contributed to the positive trend in 0+ recorded at two sites, i.e., Ikkorängesknösen and Bjurforsen.

Lögdeälven

Site description and previous restoration projects

The Lögdeälven project area encompasses the entire Lögde River basin (fig. 22). Since the mid-1980s, parts of the Lögde River drainage basin have been treated with lime to increase the pH and counteract the effects of acid rain. Fifteen areas distributed along the lower 2/3 of the drainage basin are currently being treated with lime.

The river has not been exploited to produce hydroelectric power. However, there were other types of migration barriers in the drainage area, many of which were remediated in the 1990s.

The objective of the project "Levande laxälvar" is to restore sections of the main stem of the Lögde River and important tributaries from the effect of timber floating. Restoration efforts in the Lögde River started in 2015 and will end in 2020. In 2015, 795 m of rapids were restored upstream the Långviskaforsen rapid, 90 km from the mouth of the Lögde River. The restoration resulted in 0.8 ha of land being reclaimed by the river through the widening of the rapids and re-opening of areas that had formerly been closed off from the main channel.

In the Lögdeälven project area, 71 migration barriers were remediated as part of Remibar during the period 2013-2016. Twenty migration barriers were remediated in 2013, 16 in 2014, 30 in 2015, and 5 in 2016.

The Lögde River system harbours non-migrating populations of trout and provides reproductive areas for sea trout and salmon. Reproduction of sea trout and salmon occurs in the lower reaches of the river and its tributaries. Populations of freshwater pearl mussel occur in the main stem of the river as well as in some of the tributaries.

Areas in the Lögde River system will be restored from the impact of timber floating as part of the project ReBorN, financed by the EU Commission through the Life+ programme. The restoration efforts will begin in 2016.

Available fish population data

A fish counter is installed in Fällfors (45 km upstream the mouth of the Lögde River), but reliable data is available only since 2012. A smolt counter was installed in the lower Lögde River in 2015 and 2016. Data from neither of the counters can used to evaluate Remibar as the time series are too short. Overall, there has been an increase in the abundance of salmon as well as the number of sites where they occur in the area since the 1990s. Electrofishing is carried out at numerous sites within the drainage basin. Most of these have the objective to monitor the effect of liming to counteract the effect of acidification and/or to monitor the populations of salmon and trout. The electrofishing site Hyngelsböle is located in the main channel of the Lögde River near the mouth of the river. The other four electrofishing sites (Borstmyrberget, Stormyrberget, Stora Röjdtjärnen and Ovan Långviskasjön) are located in tributaries near sites where migration barriers have been remediated as part of Remibar. The migration barriers near the four electrofishing sites in the tributaries were removed in 2014 (Stora Röjdtjärnen), 2015 (Borstmyrberget and Stormyrberget) and 2014-2016 (Ovan Långviskasjön), respectively.

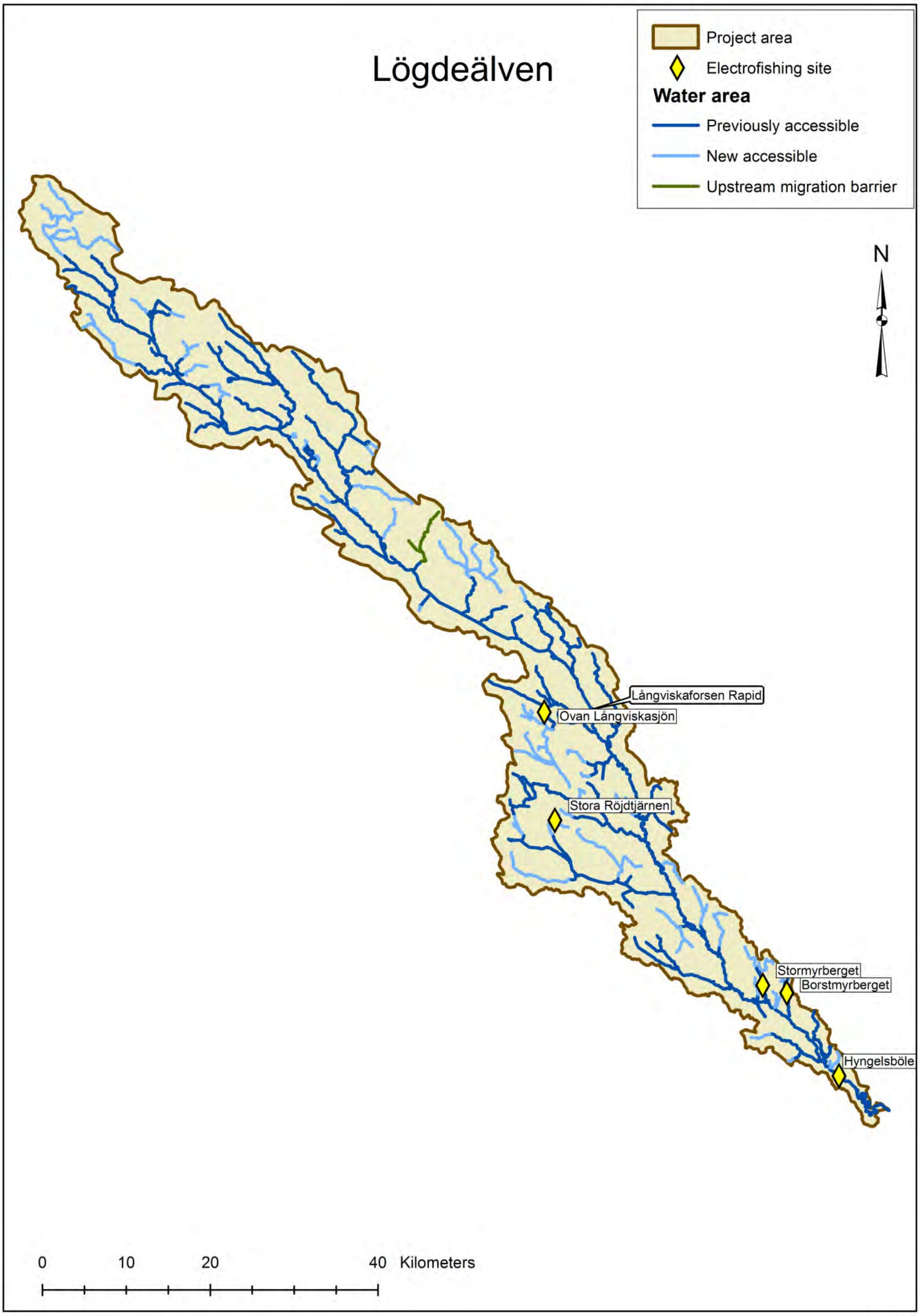
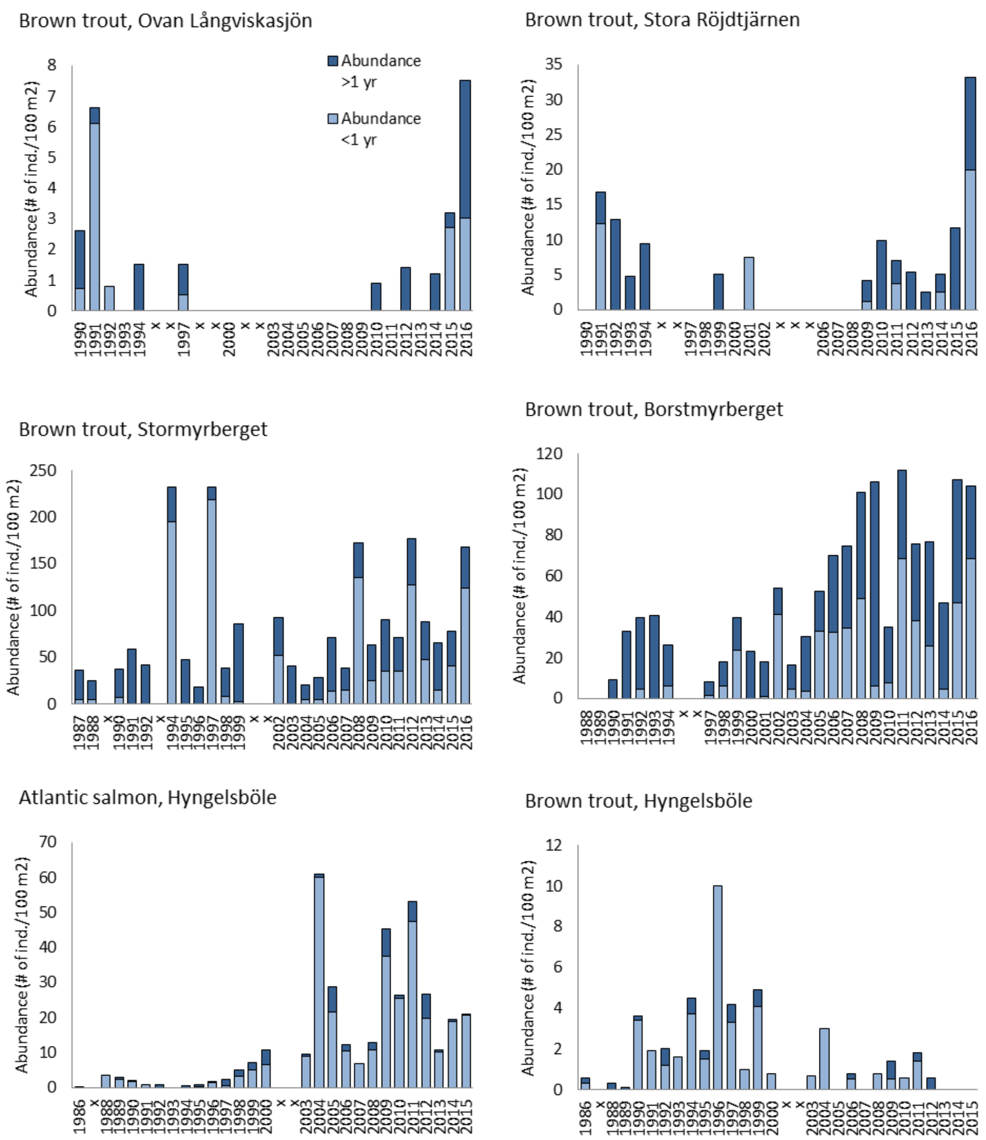


Figure 22. Electrofishing sites in the Lögdeälven project area.

Results and discussion

Trout juveniles were recorded at all five sites. Salmon juveniles were recorded only at Hyngelsböle, the site near the mouth of the Lögde River (fig. 23e). Data from Hyngelsböle shows that the abundance of salmon 0+ has been high since the early 2000s. The abundance of juvenile trout at Hyngelsböle has been low since the late 1990s.



Figur 23 a-f. The abundance of Atlantic salmon and brown trout recorded by electrofishing at five sites in the Lögdeälven project area. 'x' denote years when no data was collected.

The four sites in the tributaries (Ovan Långviskasjön, Stora Röjdtjärnen, Stormyrberget, and Borstmyrberget) generally harbour non-migratory populations of trout, and are also reproductive areas for sea trout and potentially for salmon. At Ovan Långviskasjön (fig. 23a), trout has returned to this site to spawn after a long absence. As the 6 migration barriers upstream were removed in 2014-2016, with the migration barrier the furthest downstream removed in 2016, the increased abundance of trout at this site can probably not be attributed to Remibar but has other causes, e.g., increased migration of sea trout. The abundance of trout 0+ at Stora Röjdtjärnen increased in 2016, following the removal of a migration barrier downstream in 2014. At Stormyrberget and Borstmyrberget (fig. 23 c-d), the two migration barriers upstream each site were remediated in 2015. However, there was no clear influence on the abundance of 0+, although it was high at both sites. Thus, while the remediation of migration barriers might have had a positive impact on the reproduction success of trout at all four sites in the tributaries, the link between the increase in abundance and removal of the migration barrier is apparent only at Stora Röjdtjärnen.

III. Improvement of ecological status

The Water Framework Directive states that all waterbodies must have good ecological and good chemical status. A range of assessment criteria are used when assessing the status of a waterbody. The system is complicated due to the extent of the variability and the large number of parameters that must be taken into consideration when doing an assessment. The waterbody is assigned a status that ranges from good to bad. There are five levels: high, good, moderate, bad and poor. If the status is lower than good, an action plan must be put in place.

In a waterbody where there is a migration barrier, the ecological status can never be good or high. By removing the barriers, the ecological status can be improved. However, the removal of migration barriers does not automatically lead to an improvement of the ecological status as the status is determined by a range of other factors. Other factors that determine the ecological status are, e.g., land use, eutrophication, the presence of ditches, and historic modifications of the waterbody to facilitate timber floating. In some cases, the ecological status of a waterbody does not improve following the removal of migration barriers unless these other factors are also addressed. However, in the northernmost counties the modification of rivers and creeks to facilitate timber floating and the presence of migration barriers (primarily culverts and dams) have been identified as the leading causes behind low ecological status, while eutrophication and acidification are of less concern.

No evaluation has yet been carried out to assess whether the removal of migration barriers has led to improvements in the ecological status of the waterbodies in the five project areas, as the next reassessment will not be carried out until 2021. However, as the presence of migration barriers has been identified as the major reason why many waterbodies are assigned a status that is less than good, it is expected that many waterbodies will be reclassified as a result of the removal of migration barriers carried out as part of Remibar.

The work with remediating migration barriers will continue within the scope of other projects and is part of the ordinary activities of the STA.

Discussion

The remediation of migration barriers as part of Remibar has resulted in water areas, i.e., sections of rivers and creeks, with a total surface area of 49 km^2 being reconnected to the Baltic Sea and available to migrating organisms (table 2). In three of the project areas, four migration barriers remain downstream water areas where a large number of migration barriers have been remediated. The total surface area of these water areas that have not been reconnected to the Baltic Sea is 18 km^2 (table 2).

Remibar has contributed to that five Natura 2000-areas and the habitats Fennoscandian natural rivers and Watercourses of plain to montane levels with the Ranunculion fluitans and Callitricho-Batrachion vegetation have achieved a favourable conservation status according to the Habitats Directive. Remibar has also contributed to improvements in the conservation status for the Natura 2000-species freshwater pearl mussel, Atlantic salmon, otter and bullhead.

In accordance with the Grant Agreement, no follow-up has been done in the field with the specific objective to measure the effects of the removal of the migration barriers on species abundance, behaviour, habitat use, and range. For this assessment and evaluation, only electrofishing data from existing monitoring programs focusing on measuring the recruitment of salmon and trout and data from fish counters in the main stem of the Kalix River (for the Ängesån project area) and the Pite River (for the Varjisån project area) was available.

This electrofishing data provides a measure of the reproductive success from previous years as it gives an indication of the abundance of individuals in the age span 0-4 years. The juveniles aged 0+hatched during the spring the same year and are the offspring of adults that spawned during the fall the previous year. Therefore, following the removal of a migration barrier, the effect on spawning success measured as the production of juveniles can be measured no earlier than one year later. The migration barriers were removed during the years 2012-2016. For the migration barriers removed late, the populations of salmon and trout have not yet had time to respond.

One major problem with using data collected in the national monitoring program was the electrofishing sites were often not located close enough to the remediated migration barriers to detect an effect, as juvenile salmon and trout remain within a few 100 meters of the reproductive sites where they hatched. While some juveniles migrate further, the distance does not exceed 1 km (Webb et al. 2001). As a result, the effect of the removal of the migration barriers on reproductive success could often not be properly assessed due to a lack of data.

Despite these limitations, the removal of migration barriers was followed by an increase in reproduction success (measured as the abundance of 0+ salmon and/or trout) at a number of electrofishing sites located near the migration barriers in the Varjisån project area, the Sävarån project area, and the Lögdeälven project area. In the Varjisån project area, this pattern was recorded at two sites in the Varjis River, Skräckselet and Junkaberget. In the Sävarån project area, this pattern was observed at two sites, Ikkorängesknösen and Bjurforsen. In the Lögdeälven project area, this pattern was observed at only one site, Stora Röjdtjärnen. It was not possible to detect an effect of Remibar in the Ängesån project area and the Råneälven project area as the electrofishing sites were located too far away from the remediated migration barriers. Although it is often not possible from the available data to determine whether the increased reproduction success of salmon and trout is a direct result of Remibar, it is very positive that the increased availability of reproductive areas and nursing areas is coinciding with the observed increase in reproduction success of salmon and/or trout.

Much of the impact the removal of these migration barriers will have on the aquatic community will not be possible to detect and measure until after a certain time lag, which can be several years. While it is possible to quickly assess whether salmon and trout are using newly accessible spawning grounds located upstream a former migration barrier, and thereafter measure reproduction success by recording the abundance of 0+, the impact on salmon and trout recruitment will not be apparent until the next generation returns to the stream to spawn (approximately 5-7 years later). As the electrofishing sites located in the vicinity of some of the areas where migration barriers were removed are included in the ordinary environmental monitoring carried out by the CABs, it would be possible to evaluate the reproduction success of salmon and trout at those sites in the future.

However, for salmon and trout to colonize new areas upstream, rather than spawn in the area where they were born, the abundance of spawning individuals and the competition for space must be high enough to force some individuals to continue their migration upstream. It is also worth noting that as salmon is a stronger competitor than brown trout in the competition for spawning areas in the main stem of the river. Hence, high abundances of salmon will force trout to migrate up into the smaller tributaries to spawn. It is therefore important to allow the populations of both salmon and trout downstream newly accessible spawning areas to reach high densities to allow this process to happen. This can be done by reducing fishing pressure or stopping fishing altogether for at least one generation. Collaboration with fisheries management is therefore essential for the success of restoration projects. However, in many areas competition for spawning areas is already very high, and in these areas spawning adults are more likely to migrate to the new reproduction sites upstream right away, as observed in Åkerselsforsen, Skräckselet, and Junkaberget in the Varjisån project area, in Ikkorängsknösen and Bjurforsen site in the Sävarån Project area, and Stora Rödtjärnen in the Lögdeälven project area.

When evaluating the impact of the removal of migration barriers on reproduction success of salmon and trout, it is important to remember that for successful reproduction to occur at a given site two criteria must be met: First, adults must be able to reach the site and/or occur in high enough densities. Second, spawning grounds of good quality must be available at the site. Consequently, if adults are able to migrate to a site that lacks spawning grounds, reproduction will not occur. If there are spawning grounds at a site, but adults either cannot access them due to the presence of migration barriers, arrive too late due to the presence of a series of partial migration barriers, or have not yet colonized the area (or no not occur in high enough densities), reproduction will not occur. Consequently, if reproduction is occurring at a site where none occurred previously, or if reproduction success has increased , this could be a result of several factors: a) spawning grounds have been recreated or improved, b) mature adults are able to reach the area from which they were previously excluded, c) the abundance of adults at the site has increased as partial migration barriers have been removed, d) only non-migratory trout was previously occurring at a site that has been colonized by sea trout and salmon e) there were no migration barriers but as the salmon and trout populations have grown a higher number of individuals is migrating up the river to spawn and consequently colonizing new areas. As a result, when evaluating the effect the removal of a migration barrier on salmon and trout reproduction success, it is often difficult to determine the factors that have played a role. Regarding trout, it is often difficult to determine the exact origin of the mature adults that are spawning in the area (unless studies using telemetry were to be carried out). For salmon it is easier, as all individuals spawning in an area have migrated from the ocean.

The impact of Remibar on the recruitment success of freshwater pearl mussel populations will not be possible to measure until 6-7 years after their host species have been able to successfully spawn, at the earliest, when juvenile mussels begin living at the surface of the substrate and measure approximately 5 cm. While salmon and trout have been observed using newly accessible spawning grounds within a year, this will only occur if there are mature individuals in the area. However, as many populations of freshwater pearl mussels are continuously being monitored as it is part of the ordinary environmental monitoring carried out by the CABs, it would be possible to evaluate the more long-term impact on the mussel populations (on abundance and population structure). However, in 2017, juvenile salmon and trout at a number of sites will be examined for the presence of mussel larvae on their gills as part of the project ReBorN LIFE.

Bullhead is very common in Swedish rivers and creeks and occurs throughout the country. As the species is very common, the species is not the focus for targeted monitoring and hence no population assessments are carried out. However, as the species is very sensitive to migration barriers and cannot swim past barriers higher than 20 m, the improvements of the conditions for migration carried out as part of Remibar have also improved the conditions for the bullhead.

In order to properly assess the impact of the removal of migration barriers, studies with this particular focus should have been carried out. Funding for such studies was applied for but not granted. However, the STA still intends to carry out such a study once funding becomes available. One option is to install an electronic fish counter at the site where the migration barrier used to be together with a video camera. The fish counter is able to assess the direction the fish is swimming and its silhouette. Together with the image from the video camera, it is possible to determine the species and whether the fish is swimming upstream or downstream. An assessment of the presence and migration behavior of fish upstream and downstream the migration barrier prior to the removal of the barrier is not essential. However, for partial barriers that allow downstream, but not upstream, migration it could be useful to assess the extent to which individuals were lost from populations upstream the barrier. A similar study will be carried out by the CAB of Norrbotten during the summer of 2017. While the objective of this study is to measure the extent to which different species of fish are migrating upstream and downstream creeks that flow into the Baltic Sea, the method is the same.

The presence of eDNA can be used to assess the presence of a species in the area upstream the site where the migration barrier used to be, but does not indicate the number of individuals. This method requires sampling to be carried before and after the removal of the migration barrier.

Two other options that are labour intensive are: Tagging individuals with PIT-tags and tracking their movements in order to assess the extent to which they have extended their range and do swim past the area where the barrier used to be. This method requires a large number of fish to be tagged. In a study currently being carried out by the CAB of Norrbotten, telemetry is being used to assess the movement pattern of whitefish in the lower reaches of the Alter River (near the mouth of the river). The objective of the study is to assess whether the whitefish will migrate upstream past a site where there used to be a dam. The other option is to conduct surveys of the areas upstream and downstream the migration barrier prior to and following the removal of the barrier. In this method, a large number of sites in a large area would need to be surveyed in order to get results.

While the existing data did not make it possible to accurately assess the impact of the removal of the migration barriers on the fish community due to a lack of data, positive effects of migration barrier removal has been recorded from three of the project areas. In those areas, the removal of migration barriers were in concert with previous initiatives that have been carried out in the five project areas and have contributed to improving the aquatic habitat. Data from all five river systems indicated that increasing numbers of salmon and trout are migrating higher up in the river systems, which is the result of successful management of the fishery in the Baltic Sea and in the areas near the mouth of the river, which has allowed the populations to increase in numbers and resulted in a higher number of individuals migrating up the rivers to spawn. The results from future monitoring of salmon and trout reproductive success and of the population structure of freshwater pearl mussels will provide more information of the long-term impact of the removal of the migration barriers. In those cases where a water body was given the status (according to the Water Framework Directive) less than good due to the presence of migration barriers, the status has improved to good or high. As the status is determined by a range of other factors, the removal of migration barriers has not resulted in an improvement in status for some waterbodies. However, the water bodies are one step closer to having a good or high ecological status.

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