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NATURAL RESOURCES INSTITUTE FINLAND

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Summary

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Several river restorations were conducted in FRESHABIT LIFE- EU project during 2016–2021. These included a single catchment-scale restoration in Naamijoki, a tributary of Tornionjoki located in South-Western Lapland. Multiple on-site stream restorations with the aim of enhancing the natural reproduction of brown trout (*Salmo trutta*) and land locked salmon *(Salmo salar*) were conducted on four rivers: Ostrobothnian *Isojoki* and *Karvianjoki*, *Ala-Koitajoki* in North Carelia and *Karjaanjoki* in Southern Finland. Information about the restoration measures and results of monitoring electrofishing surveys were collected. These were then analysed together with open water quality and weather or river discharge data to assess the effects of the restorations to the target populations.

Results showed that in Isojoki restorations together with migration barrier removal had increased the YOY brown trout (young of the year) production on several sites. However, the effect was not seen in older trout densities. For catchment scale restoration in Naamijoki, using water- and sediment retention increasing protective structures, no effect on trout densities was observed during the relatively short monitoring period. In Ala-Koitajoki the results of a treatment-control design with water moss (*Fontinentalis* sp.) suggested that there might be benefits in water moss transplantations for YOY salmon survival. However, this could not be verified statistically. In Karjaanjoki increasing trends could be seen in YOY densities after restorations, but the lack of adequate monitoring before the restorations hindered conclusions. In Karvianjoki YOY densities showed some decrease after restorations while densities of older trout increased. This could be a result of increased area of deeper pools and hiding places which have altered the sites better suitable for older trout and decreased the catchability of YOY trout.

This study underlined the importance of adequate monitoring planning, with long enough before- and after-restoration electrofishing survey periods. Especially in small streams, where hydrological conditions cause strong variation in the species densities a long time series is needed in order to detect possible trends. Monitoring age-class-specific habitat chances and catchability is also a good practice as restorations may impact different age-classes in dissimilar manner. The example of Isojoki shows that strong beneficial effects can, however, be detected even during shorter monitoring periods.

Keywords: Restoration, Trout, Salmon, FRESHABIT, biodiversity

Contents

1. Introduction

Hydrological alteration through hydropower building, dredging and water level regulation have led to dramatic losses in Finnish migratory fish populations. Today more than 90% of endemic salmon (*Salmo salar*) populations have been lost leaving only four river systems with their natural populations remaining. Population decline is evident also in brown trout (*Salmo trutta*) populations and today there are less than 20 rivers with their natural populations intact. Other migratory fish species such as migratory whitefish form (*Coregonus lavaretus*) and the katadromic European eel (*Angulla anguilla*) are critically endangered. Many other freshwater fish species migrate inside river systems and move between these and the brackish waters of the Baltic Sea. The effects of migratory barriers and the general degradation of riverine fish habitats are not well known for many of these species.

Habitat restoration has become a widely spread tool for rehabilitating endangered river fish populations. In the face of rapid decline in fish biodiversity and increasing need for conservation measures it provides a valuable method for supporting the natural reproduction of target species. The spawning habitat restoration of salmon and trout has been applied for the last decades in Finnish rivers with varying success. The main aim has been to restore spawning and nursery habitats that have been altered by dredging and affected by land-use related hydrological and water quality changes. On-site methods used usually include the addition of gravel, boulders and wood material that provide spawning substrate for adults and hiding places for juveniles. These additions themselves can provide more natural hydraulic conditions but additional structures, such as weirs can be built on site to create deeper pools and protect spawning sites from sand and sediment accumulation. Catchment-scale methods aim to alter the hydrological conditions and improve water quality through building of wetlands, weirs and other protective structures that improve water and sediment retention from the runoff waters. Several studies have proved on-site methods to be an effective tool in increasing the density of juvenile fish on sites, while there are others that show no observable results (Marttila 2019). A large problem with restoration studies have been the lack of consistent and long-lasting monitoring before and after the restorations that hinder the possibilities of adequate analysis.

During 2017–2021 several restoration projects were planned and implemented in EU LIFE-project “FRESHABIT” by several local operatives. Restorations were applied in six Finnish rivers spanning the geographical region from the Arctic Circle to the Gulf of Finland and from the Western coast to the Eastern border of Finland. *Naamijoki*, located in Southern Lapland flows into the large border river Tornionjoki that still hosts endemic salmon and trout populations. River *Koitajoki* runs from Russia to Eastern Finland and drains into the 4th largest Finnish lake, Pielinen, where a land-locked salmon population has been re-introduced. River *Isojoki*, located in the Western coast has an abundant trout population with individuals migrating into the Bothnian Sea. River *Karvianjoki* is located near Isojoki and has naturally reproducing trout populations. River *Karjaanjoki* is a historical salmon river in the south coast of Finland, where restorations have been plenty and re-opening of the migration routes through building of fishways is in process.

Restoration projects included before- and after monitoring of biological variables together with technical monitoring of the restoration structures. In this report we present the results of fisheries monitoring in six different Finnish rivers where restorations took place. Together with open water quality, river discharge and weather data we assess the impacts of these restorations to the local brown trout and land-locked salmon populations.

2. Methods

2.1. Research area

2.1.1. Naamijoki

Naamijoki, a tributary to river Tornionjoki, has been a very significant brown trout river but its habitats have since degraded as a result of channelization for the needs of timber transportation (Figure 1).

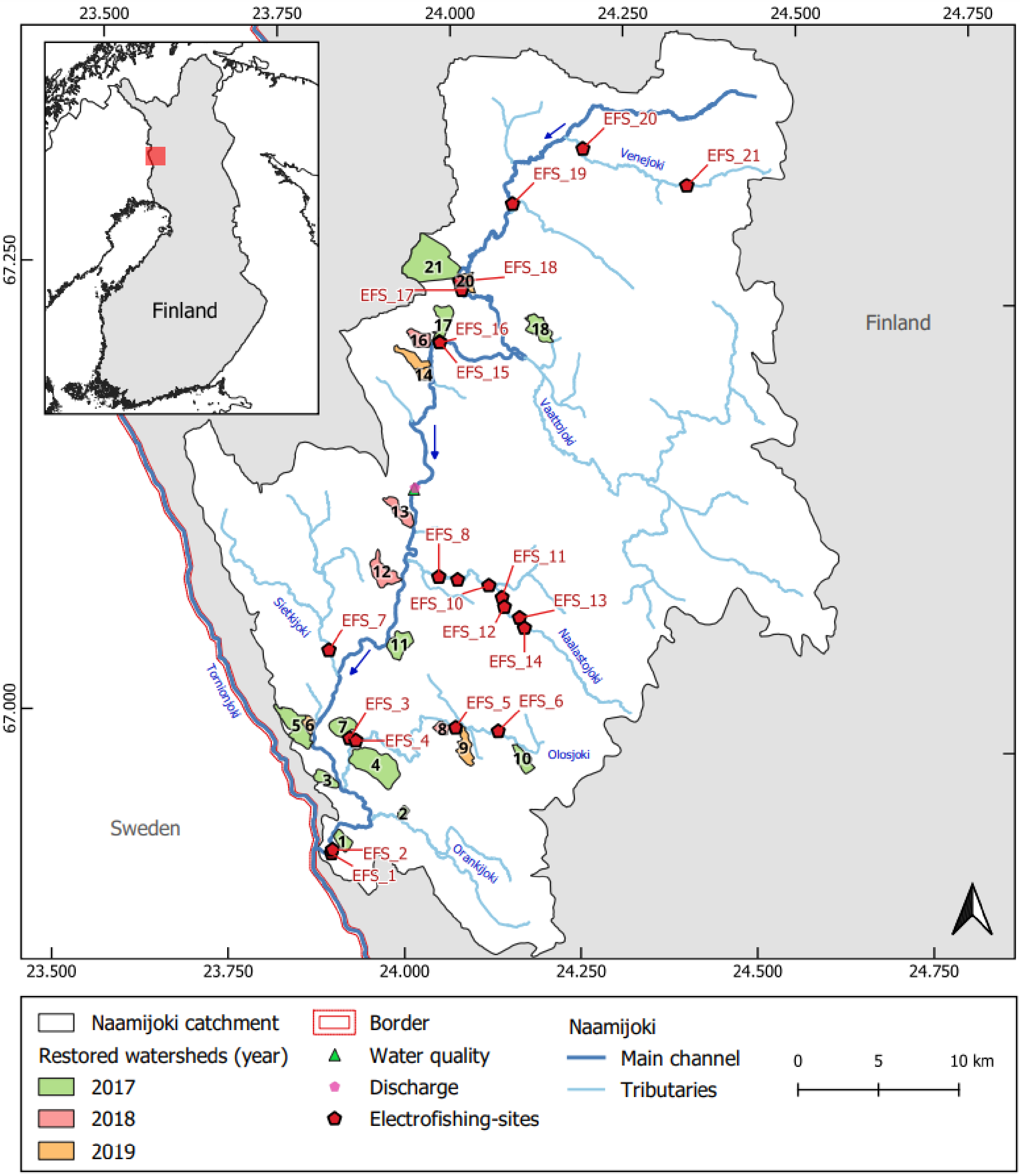


Figure 1. Study area of Naamijoki. Blue arrows indicate the flow direction. Contains open data from SYKE (2022) and MML (2022).

The catchment area has also been heavily drained to facilitate forest growth. This has resulted into sedimentation of the river: large amounts of sand and finer sediments have accumulated from erosion-sensitive soils. The latter problem is also facilitated by naturally occurring large floods in the springtime that transport even more soils into the river. There are no hydropower stations in Naamijoki, but several other structures, bridges, drums and bridge-drums act as total or partial migration barriers that obstruct the movement of fish to some of the small streams on the upper reaches of the river.

Several catchment-scale-restorations were implemented in Naamijoki by the Finnish Forest Centre and Metsähallitus ("Finnish Forest Administration") in FRESHABIT- and KEMERA-projects during 2017–2021 (Table 1). Total of 173 water-protective structures, such as sedimentation basins, submerged weirs and wetlands were built in 26 sites to protect the river against sediment load resulting from gully-erosion. The structures affect a total of 3450 ha watershed-area, where sediment loading is now mitigated. Technical monitoring in 2021 showed that all the structures were working as intended.

Table 1. Restored areas in the Naamijoki catchment.

Site	Project	Year	Area (ha)	Tributary
1. Naamivaara	FRESHABIT	2017	91	Main
2. Orankisilta	FRESHABIT	2017	34	Orankijoki
3. Mykkäkangas	FRESHABIT	2017	97	Main
4. Tuohivuoma	FRESHABIT	2017	455	Olosjoki
5. Karhakkamaa	KEMERA	2017	276	Main
6. Kaakkurisuvanto	KEMERA	2019	54	Main
7. Pitkäkoski	FRESHABIT	2017	155	Olosjoki
8. Kuusisaajo	FRESHABIT	2018	54	Olosjoki
9. Alainenniitty	KEMERA	2019	140	Olosjoki
10. Harjunniitty	FRESHABIT	2017	110	Olosjoki
11. Jässänvuoma	FRESHABIT	2017	175	Main
12. Äijävaaranoja	FRESHABIT	2018	196	Main
13. Mukkakoski	FRESHABIT	2018	131	Main
14. Koivurovanjänkkä	FRESHABIT	2019	58	Main
15. Mettokoski	FRESHABIT	2019	120	Main
16. Koivurova	FRESHABIT	2018	116	Main
17. Ollimaanräme	KEMERA	2017	166	Main
18. Kallinjänkkä	KEMERA	2017	173	Naalastojoki
19. Ojitusaluuen allas	FRESHABIT	2019	23	Main
20. Laajala	FRESHABIT	2019	49	Main
21. Karhuoja	FRESHABIT	2017(2018)	679	Main

Fish densities across Naamijoki and its sub-basins were monitored by electrofishing on several sites (Figure 1 & Table 2). Most sites were electrofished in 2017 and again in 2021 by LUKE (Natural Resources Institute of Finland), with the exception of four sites, that were only fished once. Electrofishing was conducted according to Olin et al. (2014). Individual data from to the national electrofishing-registry was used for this study. Electrofishing was conducted on sites with unobstructed migration routes.

Table 2. Registry names and codes given to the electrofishing sites for this report.

Registry Name	ID		Registry Name	ID
*Naamijoki ala**	EFS-1		Naalastontievat ylempi	EFS-12
Naamijoki Suukoski	EFS-2		Tievanääntammi alempi	EFS-13
Pitkäkoski alempi	EFS-3		Tievanpääntammi ylempi	EFS-14
Pitkäkoski ylempi	EFS-4		*Vaattojoki 30**	EFS-15
Olosjoki, Tieva	EFS-5		*Vaattojoki 30B**	EFS-16
Olosjoki Peurakoski	EFS-6		*Venejoki 28**	EFS-17
Sietkijoki	EFS-7		Naamijoki 5. ylin	EFS-18
Kossutammi	EFS-8		Naamijoki 2. ylin	EFS-19
Naalastojoki Pitkäkoski	EFS-9		Kelhujoki 3. ylin	EFS-20
Tervahaudantieva	EFS-10		Kelhujoki ylin	EFS-21
Naalastontievat alempi	EFS-11			

* EFS-1 was electrofished only in 2017 and EFS-15–17 only in 2021.

2.1.2. Ala-Koitajoki

Ala-Koitajoki is the lowest section of larger Koitajoki river that begins on the Russian side of the Finland-Russia border and drains into lake Pielinen in Finland (Figure 2). Ala-Koitajoki consisting of approximately 24 km long river section that ends as the river reaches Pielinen. The river has historically been an important spawning site for the land locked salmon populations in Pielinen, but there has been no natural reproduction for more than 60 years. As most of the flow is directed south to series of impoundments leading into Pamilonkoski hydropower station, there is little suitable habitat for salmon and trout reproduction. Even before the flow alteration the rivers salmon habitats had been largely degraded due to dredging for timber transportation. The population has been maintained by hatchery reserves and regular hatchery releases. The natural mean flow of the river before damming was approximately 70 m^3/s. Today the hydropower company is required to run 6 m^3/s from April to September and $4m^3/s$ from February to May. This has also resulted in a more lotic river habitat with excess predatory fish such as pike (*Esox lucius*) and pikeperch (*Sander lucioperca*) that increase the natural mortality of juvenile salmonids in the river.

An extensive project with aims to assess the possibilities and efficient methods of returning the natural reproduction of land locked salmon into Ala-Koitajoki was executed during 2014–2019 (Piironen 2020). This included large-scale habitat restorations, trapping and transporting spawner females from other reaches to the spawning sites, rearing eggs milked from trapped females and stocking the hatched fry. Results showed that the natural reproduction of salmon can be successful in Ala-Koitajoki but the smolt production remained low. This is most likely due to high natural mortality due to increased predator densities.

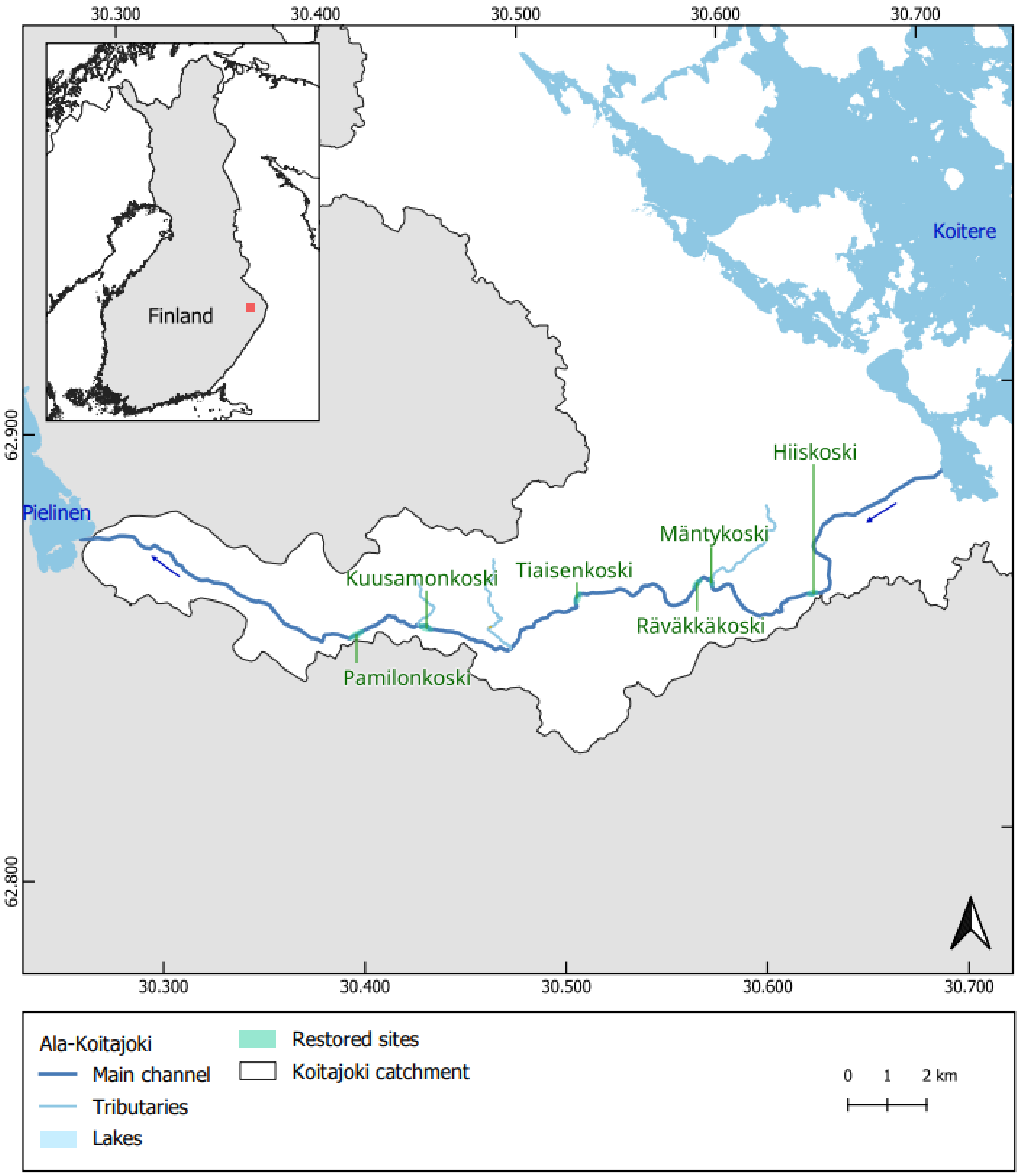


Figure 2. Ala-Koitajoki study area. Blue arrows indicate the water flow direction. Contains open data from SYKE (2022) and MML (2022).

FRESHABIT funded subproject consisting of water-moss (*Fontinalis* sp.) transplants in four restored stream habitats was executed as a part of the larger salmon restoration project (Table 3). Water-moss covered rocks and logs were introduced into the restored sites to enhance the quality of the habitat. Water mosses are known to provide important hiding places for the juveniles and many insect-species that they feed on. They also help to clear the water of suspended matter and this way help keeping the spawning substrates clear of sediments (Koljonen et al. 2012).

The water-moss growths were collected from nearby sites by hand and planted into the restored habitats in depths less than 1 m during 2016–2018 (TOIMI 2017, Siekkinen 2018). In

Kuusamonkoski, where an experimental stream with two channels was opened in 2015 water moss transplants were planted on the other channel, with the other one left as an untreated control. Electrofishing monitoring was conducted by LUKE following the Olin et al. (2014) guidelines. Implantations were repeated in 5 sites in 2021 but their effects are not evaluated in this report.

Table 3. Details of water moss-implantations in Ala-Koitajoki. N. of implants means either small boulders or logs.

Site	Year	N.of implants	Restored area (m^2)
Hiiskoski	2018 / 2021	460 / 50	1200 / 550
Mäntykoski	2018 / 2021	450 / 130	1400 / 2500
Tiaisenkoski	2018	510	500
Kuusamonkoski	2017 / 2021	400 / 150	1400 / 1500
Pamilonkoski	2021	100	850
Räväkkäkoski	2021	294	2500

2.1.3. Isojoki

River Isojoki, also known as Lapväärtinjoki, is a 75 km long river located in the Ostrobothnian coast (Figure 3). Isojoki still hosts an endemic trout population with both sea-migrating and local ecotypes. The river also has greyling (*Thymallys thymallys*) and other more common freshwater species, such as perch (*Perca fluviatilis*), pike and bream (*Abramis brama*). The watersheds catchment-area is only approximately 1100 km^2 with a lake-percentage of only 0,2 %, most of the water inflow coming from ground-water sources. Isojoki has no significant eutrophication problem but the river receives some humic substances and occasional acidity spikes during springtime from its lower catchment. The main channel and it's tributary Heikkilänjoki are part of Natura 2000 network.

Today there are a total of 9 dams in Isojoki, acting as either total or partial migration barriers. The lowermost dams, Sangrindfors and Peruskoski, had fish passages built in 2014. This opened a migration route 45 km upstream to Villamo dam. During 2016–2020 various restorations of dredged spawning habitats were preformed and in 2017 the Villamo dam removed. Restorations and dam removal were performed by local operatives overseen by Center of the Economic Development, Transport and Environment of South Ostrobothnia ("EPO-ELY"). All restorations were done mainly using excavator, except for Lohiluoma area where shovel and spade were used as well.

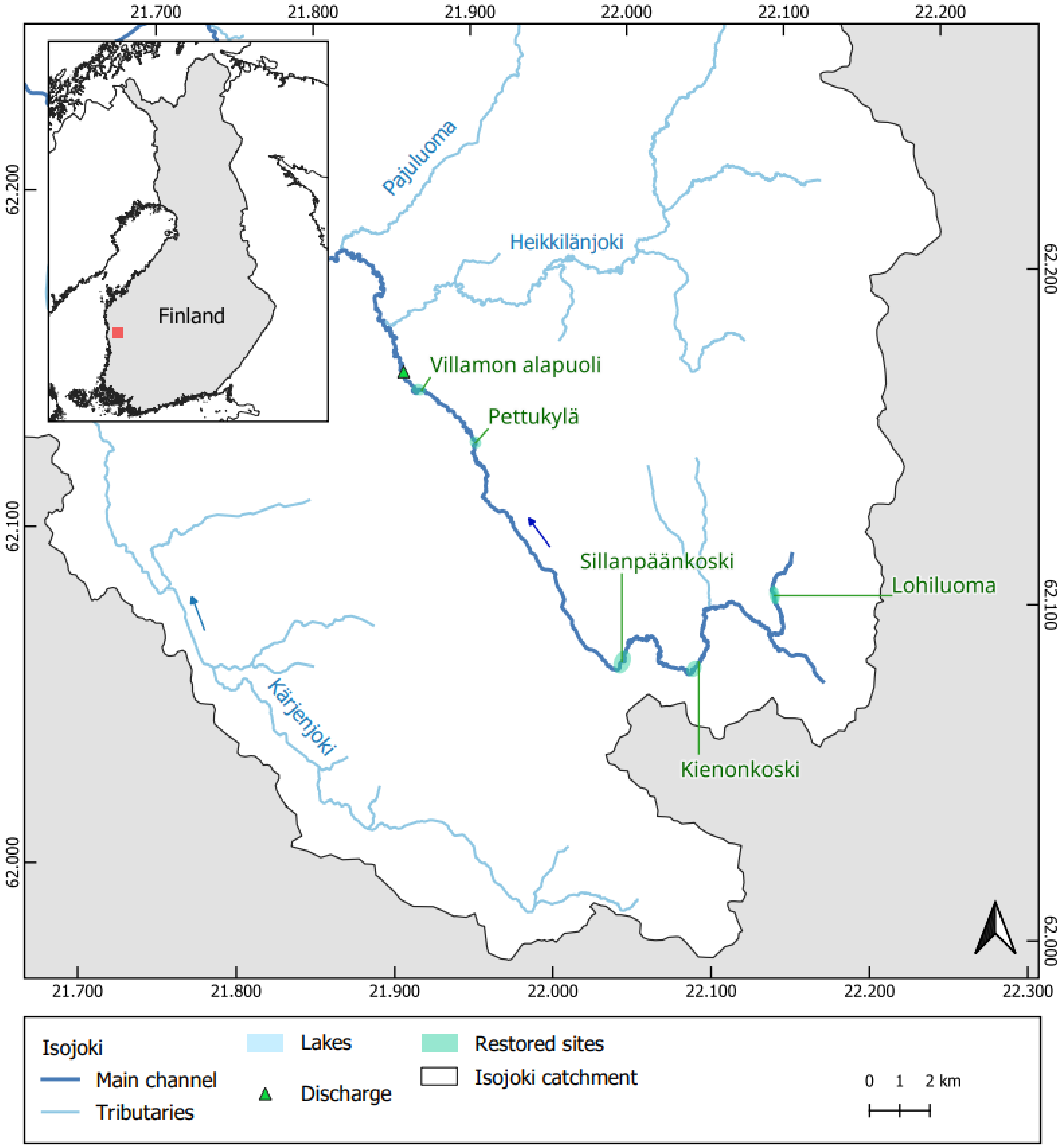


Figure 3. Study area of Isojoki. Blue arrows indicate water flow direction. Contains open data from SYKE (2022) and MML (2022).

Table 4. Restoration details of each site in river Isojoki including the area restored, volume of added stone, woody material and gravel per hectare and the number of added spawning beds.

Site name	Year	Area restored (m^2)	Stone material (m^3/ha)	Wood material (m^3/ha)	Gravel (m^3/ha)	Spawning beds (n)
Villamon alapuoli	2018	4500	80	100	40	24
Pettukylä	2018	900	105	100	80	6
Sillanpäänkoski	2018	2100	90	100	80	12
Kienokoski	2019	4500	150	20	75	24
Lohiluoma*	2016	3000	150	100		

*Restoration in Lohiluoma started in 2016 and continued until the end of 2021. Exact details about the restoration were not available at the time of the writing of this report.

Responses of trout population to the restoration measures were monitored by electrofishing on the restored sites. These were conducted by EPO-ELY, a consult (Terrapolar Oy) and LUKE.

2.1.4. Karvianjoki

Karvianjoki is a 110 km long river located in the Northern Satakunta region (Figure 4). The river separates into three different channels; Merikarvianjoki, Pohjajoki and Eteläjoki before it drains into Bothnian Sea, expressing complex hydrology. The drainage system has gone through extensive man-made modifications such as draining lakes for agricultural land, dredging and channelizing the river for log driving as well as damming for flood protection. The drainage system is subject to nutrient and solid matter loading from forestry and agriculture in addition to other stressors. The ecological status of several parts of the river system is classified as poor or bad. Some higher status sections remain, and the river still hosts local trout populations.

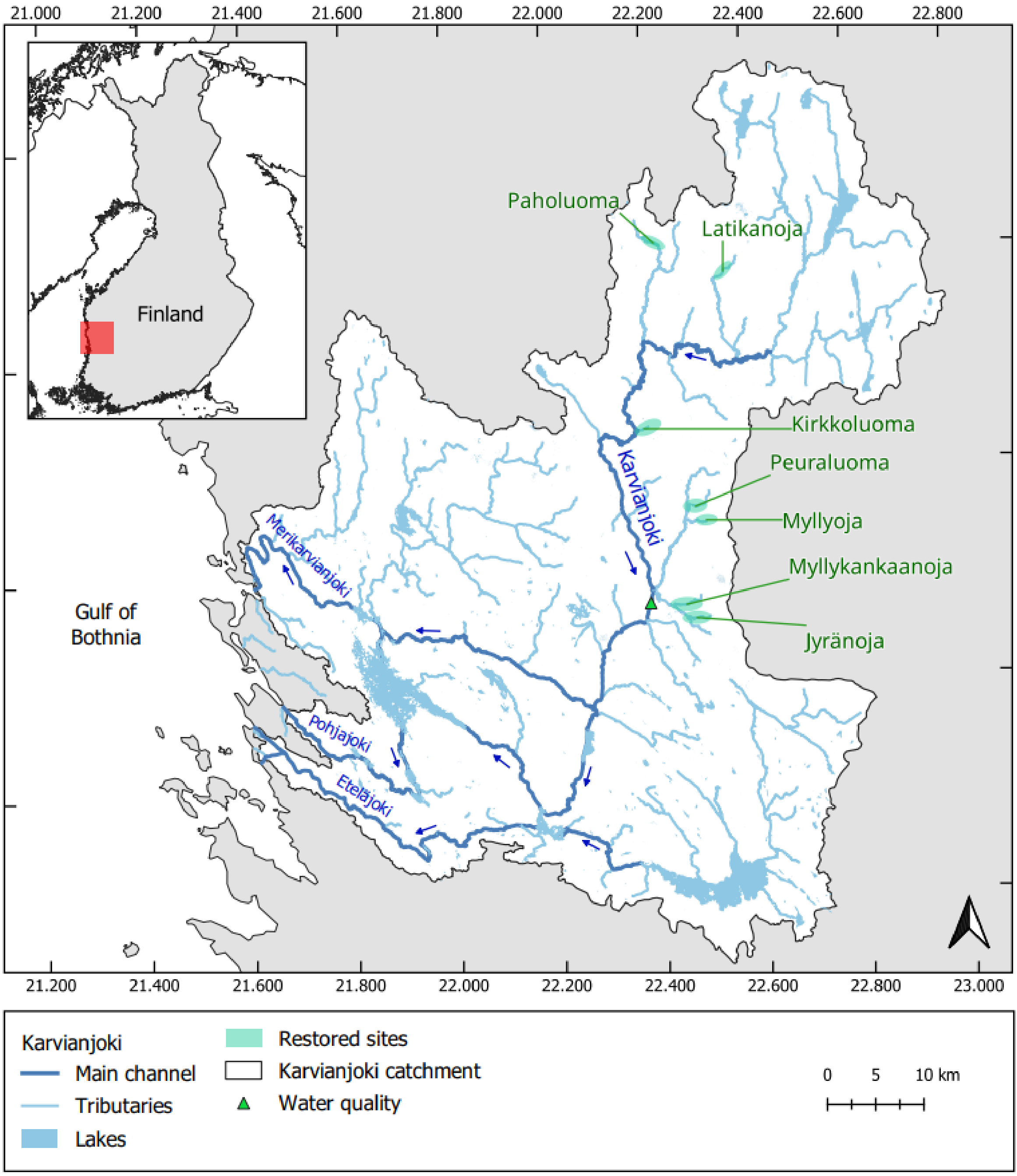


Figure 4. Karvianjoki catchment. Blue arrows indicate river flow direction. Contains open data from SYKE (2022) and MML (2022).

During 2016–2021 several spawning sites in the upper reaches of Karvianjoki were restored as a part of the FRESHABIT-project by a consult (Terrapolar Oy). Restorations included building wooden stream reflectors, as well as addition of boulders, gravel beds and additional wood materials. The restorations were conducted during wintertime for logistic reasons. All restorations utilized both machine-powered (excavator) work together with work by hand using shovel and spade. Electrofishing surveys were conducted yearly between 2016–2021 by Terrapolar Oy.

Table 5. Details of the restored sites in river Karvianjoki.

Site name	Year	Area restored (m^2)	Stone material (m^3/ha)	Wood material (m^3/ha)	Gravel (m^3/ha)	Spawning beds (n)
Jyränoja	2016	2500		58	80	12
Kirkkoluoma (lower part)	2017	1500		100	93	10
Kirkkoluoma (lower part)	2018	1500	100			
Kirkkoluoma (upper part)	2018	3000		50		
Kirkkoluoma (upper part)	2019	2600	115		100	16
Latikanoja	2016	1500		73		
Latikanoja	2017	3000	66	50		18
Latikanoja	2018	1500	133			8
Myllykankaanoja	2019	3600			72	20
Myllyoja	2016	1000		100		
Myllyoja	2017	1000	150			
Peuraluoma	2016	1312,5		83,80952		
Peuraluoma	2017	1312,5	190			
Paholuoma*	2020	3500		100	-	1

*Restorations in Paholuoma were started in 2019 and finished in the end of 2020.

2.1.5. Karjaanjoki

Karjaanjoki watershed, located in Southern Finland drains into Gulf of Finland as river Mustionjoki (Figure 5). The river has been heavily altered and contains multiple hydropower stations. The ecological status in many parts of the rivers has been classified only as moderate, but in the upper tributaries there are still some sections with a good ecological status. Despite the water quality problems and hydrological alteration, the river still holds high nature values as it hosts critically endangered species such as brown trout and freshwater pearl mussel (Margarita margaritifera). Historically the river had a salmon population as well, but the original population has been lost due to hydropower development.

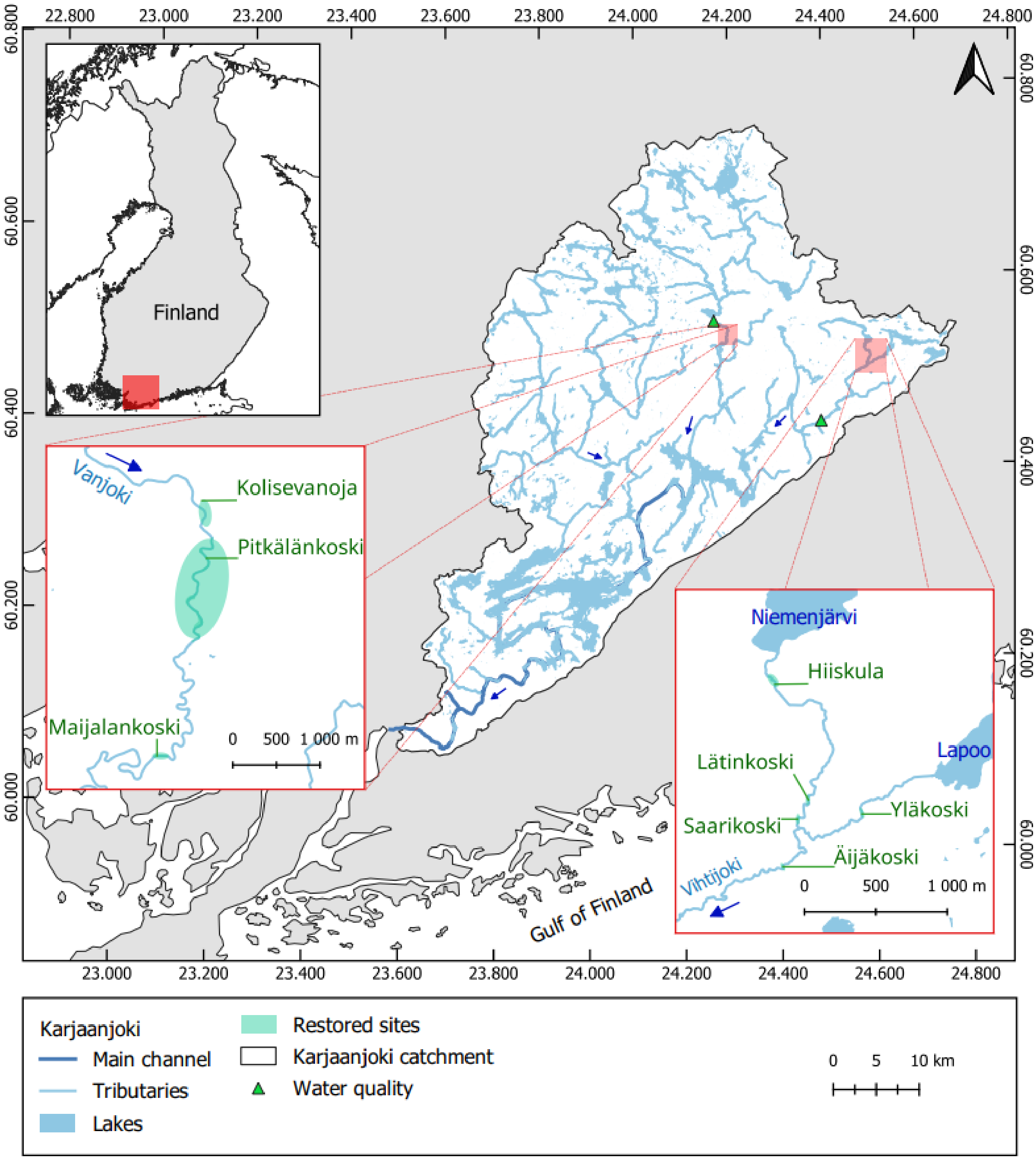


Figure 5. Study area of Karjaanjoki. Blue arrows indicate river flow direction. Contains open data from SYKE (2022) and MML (2022).

There have been multiple restoration projects during the last 20 years in Karjaanjoki watershed with brown trout and freshwater pearl mussel as target species. FRESHABIT- funded restorations were conducted during 2017–2021 by LUVY (Länsi-Uudenmaan Vesiensuojeluyhdistys) (Table 6). These included both hand-made and excavator restorations with boulder addition and gravel bed building. Woody material gathered from the banks was also added in small quantities. Restorations were conducted during summer, so that the sites were usable by spawners during the same years spawning season. Electrofishing surveys were conducted by LUVY on the restored sites.

Table 6. Details of restored sites in Karjaanjoki watershed.

Site name	Year	Method	Area restored (m^2)	Stone material (m^3/ha)	Wood material (m^3/ha)	Gravel (m^3/ha)	Spawning beds (n)
Pitkälänkoski, upper part	2017	By hand	7000	71	0	71	31
Pitkälänkoski, lower part	2020	Excavator	6120	114	>0	150	35
Yläkoski	2017	Excavator	646		>0	1161	6
Hiiskula	2017	Excavator	1348	89	0	586	12
Lätinkoski	2017	Excavator	1048		>0	305	7
Saarikoski	2017	Excavator	871		>0	1033	–
Maijalankoski	2019	Excavator	5720	656	0	575	50
Äijäkoski	2018-2020	Mixed	1320	275	0	412	15

2.2. Data and analysis

Electrofishing survey data of trout densities was collected from National Electrofishing Registry, except for Ala-Koitajoki where the data was collected from project reports. In the cases of Naamijoki and Karvianjoki, where no age-grouping had been done in the field, individual measurement data was used. Individual trout length-measurements were used to divide the fish into two separate age-cohorts of YOY-trout (0+) and older fish (>0+). This was done in R-software (R Core Team 2021) using the "Mclust"-packages (Scrucca et al. 2016) clustering algorithm and by verifying the results by visual inspection of the length histogram. Catchability of 0,4 was used for YOY-trout and 0,6 for older fish to calculate the densities at each site. From Isojoki and Karjaanjoki the densities calculated by the database were used. The densities before and after the restorations were then compared to assess the impacts of the restorations. In Kuusamonkoski of Ala-Koitajoki the differences in densities between the water-moss-transplanted channel and the control channel were tested using Welch Two-Sample t-test.

Water quality data, including water temperature, dissolved oxygen concentration, suspended solids concentration, turbidity, watercolor, Secchi depth, pH and conductivity were collected from SYKE (Finnish Environmental Institute) database Hertta (Table 7). River discharge data from Isojoki and Naamijoki was also collected from the same database. For Karvianjoki and Karjaanjoki precipitation and snow depth data was collected instead as there were no representative continuous discharge monitoring points for them. Air temperature and precipitation data was collected from FMI (Finnish Meteorological Institute) observation download service (Table 8). Water quality, air temperature and discharge/precipitation data were used for inference about the environmental conditions possibly affecting the electrofishing survey results.

Table 7. Monitoring points from Hertta-database used for discharge and water quality data.

River	Registry name	ID	LAT	LON	type
Isojoki	Perus Q	3700300	62,238	21,582	Discharge
Naamijoki	Naamijoki	6701300	67,134	23,982	Discharge
Naamijoki	Naamijoki 302	38688	67,134	23,980	Water quality
Isojoki	Isojoen Lohi Halkola	59765	62,155	21,875	Water quality
Karvianjoki	Karvianjo Hirvikankaanku	9764	61,838	22,311	Water quality
Karjaanjoki	Vanjoki 25,0	1292	60,535	24,200	Water quality

Table 8. FMI weather stations used for air temperature (T), precipitation (P) and snow depth (SND).

River	Station name	ID	LAT	LON	type
Naamijoki	Pello Kirkonkylä	101914	66,77	23,96	T
Isojoki	Karvianjoki Alkkila	101272	62,18	22,8	T
Karvianjoki	Kankaanpää Niinisalo lentokenttä	101291	61,84	22,46	T, P, SND
Karjaanjoki	Vihti Hiiskula	101135	60,52	24,52	P, SND
Karjaanjoki	Vihti Maastoja	100976	60,42	22,4	T

3. Results

3.1. Naamijoki

Highest densities of YOY brown trout (0+) were observed in 2017 in the tributary Naalastojoki (EFS 10–14) (Figure 6). One site (EFS-5) in tributary Olosjoki also had high YOY densities in 2017. Densities of older trout were much lower than YOY densities on each site where YOY were present. Older trout were also caught in two sites of tributary Kelhujoki and in two sites in Naalastojoki where no YOY trout were present. No brown trout were caught in the main channel sites on either of the electrofishing survey years.

In 2021 the YOY densities had decreased on each study site compared to 2017 (Figure 6). There were two sites, one in Kelhujoki tributary and one in Naalastojoki where YOY were absent in 2017 but now appeared in small densities. There was an average increase in the densities of older trout when all sites were considered, in 8 sites the densities had increased and in 2 decreased. Increases in densities were much higher than the decreases.

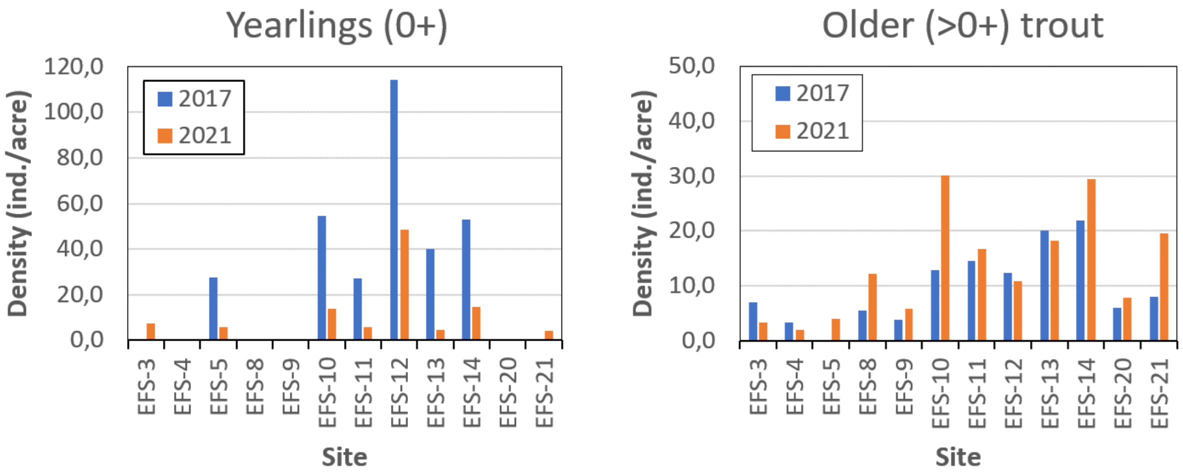


Figure 6. Densities of brown trout in Naamijoki electrofishing sites in 2017 and 2021. Missing bars indicate that no brown trout were observed. Main channel sites are omitted from the figure as they had no brown trout observations in the monitored years.

Other fish species caught on sites were alpine bullhead (*Cottus poecilopus*), European bullhead (*Cottus cobio*), greyling, roach (*Rutilus rutilus*), common minnow (*Phoxinus phoxinus*), common bleak (*Alburnus alburnus*), ide (*Leuciscus idus*), pike, Eurasian perch (*Perca fluviatilis*) and burbot (*Lota lota*). The total densities of all fish species, including brown trout were generally lower in 2021 than in 2017 and no significant changes in species number or composition were observable (Figure 7).

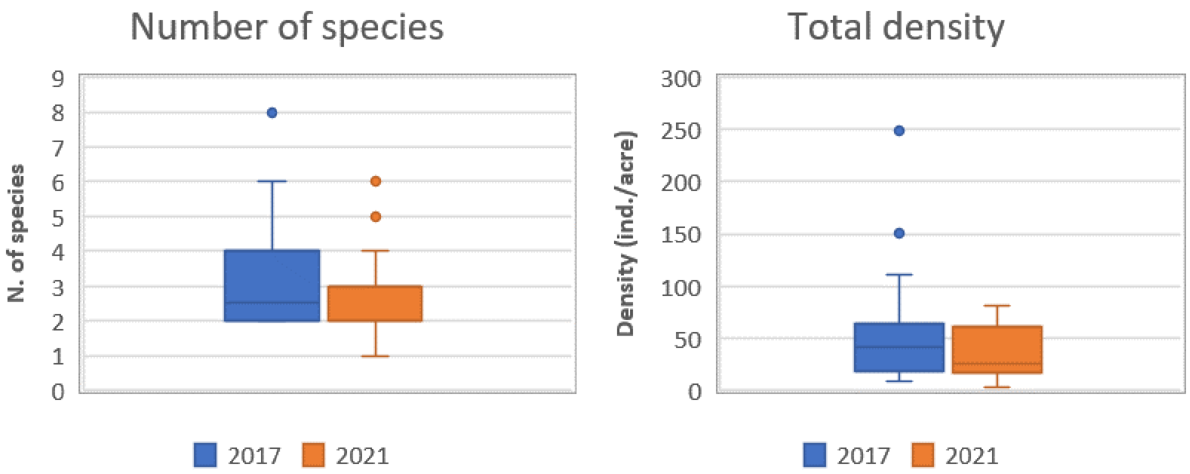


Figure 7. Distribution of species number and total density of all species in 2017 and 2021.

Weather conditions differed between the periods 2016–2017 and 2020–2021. In fall of 2016 the rainy season came much earlier than in 2020 which can be seen from the discharge data (Figure 8). The early spring of 2021 was much colder than in 2017 and the discharge rates remained higher during the whole winter season. In 2021 electrofishing was conducted in more challenging high-water conditions, when in in year 2017 conditions were more optimal for the survey. Water quality measurements showed no significant changes in water quality during 2016–2021, although some decrease in the level suspended solids and water turbidity could be seen from spring of 2020 to summer of 2021 (Figure 9). During the same time period the dissolved oxygen did not seem to reach the maximum levels around 25mg/l as in previous years.

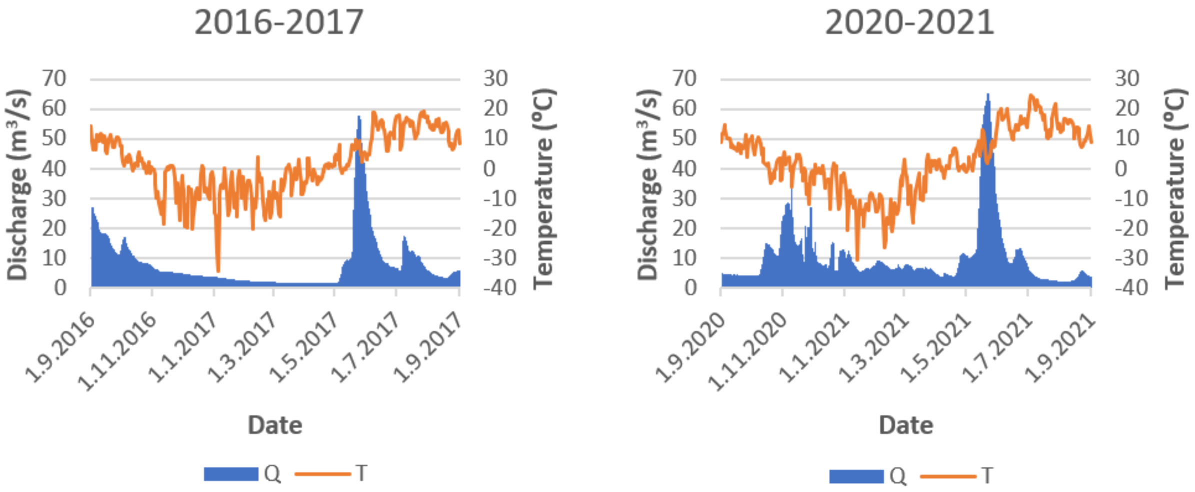


Figure 8. Temperature and discharge data from Naamijoki.

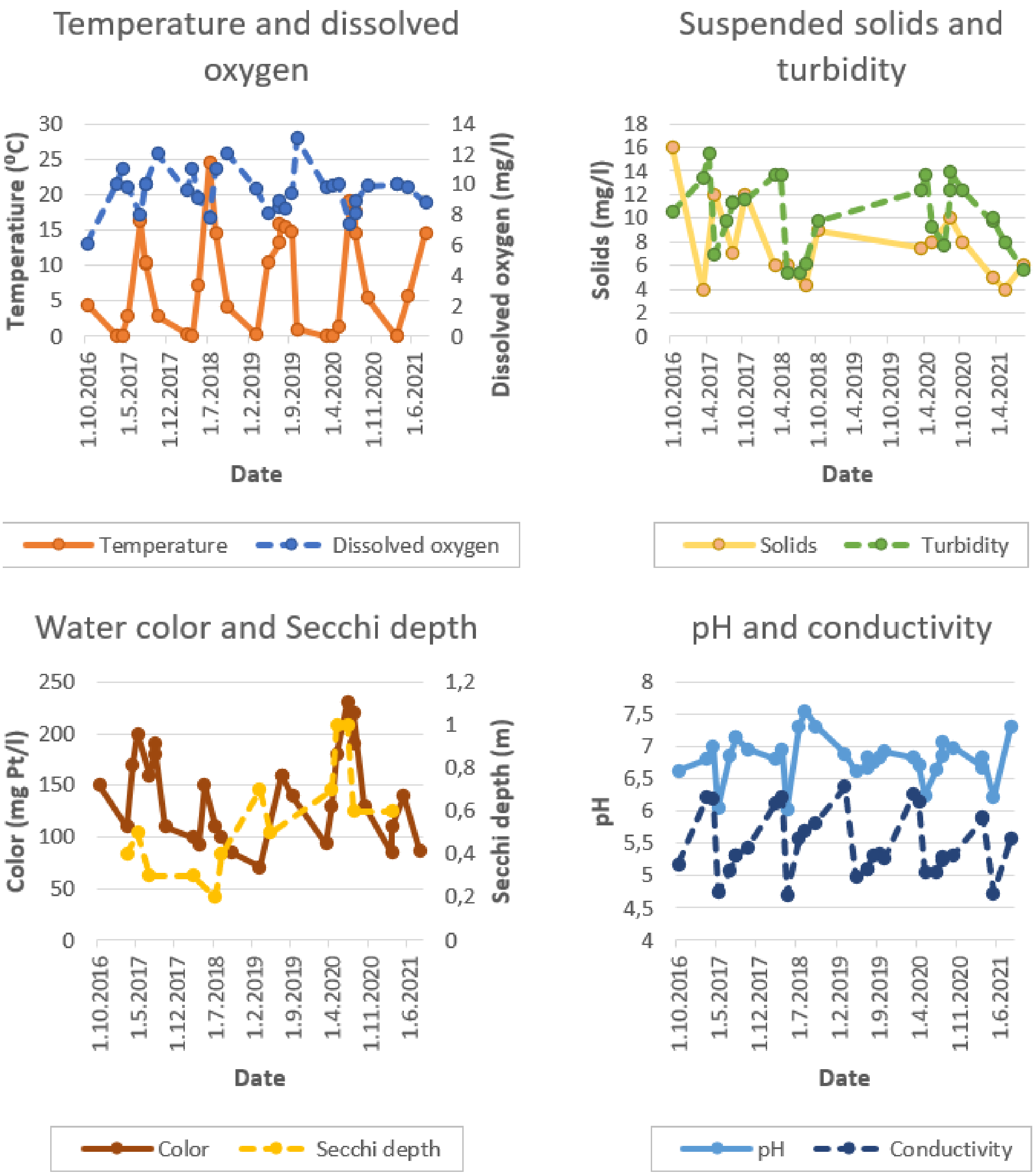


Figure 9. Water quality results from Naamijoki.

There were only 3 sites (EFS 3–5) in which were downstream from restored watershed areas and where trout was observed. These could therefore be considered affected sites where additional sediment load would be diminished. In each of these the yearling densities decreased. Older brown trout densities increased in two other sites but decreased slightly in EFS-5. This means that there were no observable positive effects on brown trout densities and as we only had two monitoring years, one pre- and one post-restorations it is almost impossible to make assumptions about the effectiveness of the restorations for brown trout. In addition, these restorations only decrease the load coming from the drainage area. They would therefore require actual on-site habitat restorations or a sufficiently long monitoring period to yield observable effects. Changes in brown trout densities can most probably be attributed largely to differences in weather conditions between the monitoring years. Challenging electrofishing conditions in 2017 may have affected the density estimates as no age-class-specific catchability estimates were calculated.

3.2. Ala-Koitajoki

During 2015–2019 densities of brown trout in all sites remained low (Table 9). Hiiskoski was the only site where brown trout were caught on multiple years. On other sites trout were only observed once during the survey period. In 2019 there were no brown trout caught on any of the sites. Salmon yearling densities averaged the highest in 2017 and in 2018 (Table 10). Older salmon were observed in highest average density in 2018 although 2016 held the highest densities for Hiiskoski, Mäntykoski and Tiaisenkoski.

Table 9. Densities (individuals/acre) of YOY brown trout (0+) and older (>0+) individuals at the sites during the monitoring period.

	2015		2016		2017		2018		2019	
Site	0+	>0+	0+	>0+	0+	>0+	0+	>0+	0+	>0+
Hiiskoski	-	-	18,30	0,40	13,68	0	0,42	2,08	0	0
Kuusamonkoski (w.m. transplant)	-	-	-	-	0	0	0	0	0	0
Kuusamonkoski (control)	-	-	-	-	0	0	0	0	0	0
Mäntykoski	0	0	0	0	0	0,60	0	0	0	0
Tiaisenkoski	-	-	0	0	0	0	0,58	0	-	-

Table 10. Densities (individuals/acre) of YOY salmon (0+) and older (>0+) individuals at the sites during the monitoring period.

	2015		2016		2017		2018		2019	
Site	0+	>0+	0+	>0+	0+	>0+	0+	>0+	0+	>0+
Hiiskoski	-	-	0,80	1,70	4,21	0	0,83	1,67	0	0
Kuusamonkoski (w.m.)	-	-	-	-	68,10	0	28,32	23,01	3,50	1,80
Kuusamonkoski (control)	-	-	-	-	48,60	0	11,27	21,13	3,50	4,90
Mäntykoski	221	0	34,70	18,00	69,50	0,60	28,74	10,78	5,80	1,00
Tiaisenkoski	-	-	4,10	4,70	14,62	1,17	1,75	3,51	-	-

Changes in salmon densities were strongly correlated with the stocking volumes of yearlings in the sites (PCC >0,85) (Figure 10). In addition to yearling stocking some spawner relocations to the sites were made during the survey period. This further confuses the results and render them unfit for restoration efficiency evaluation. The survey sites were probably not optimal reproduction habitats for brown trout which usually utilizes smaller streams and creeks for spawning. The post-restoration monitoring period was also left short, ranging from one to two years. In Tiaisenkoski there were no surveys conducted after the restoration. Water mosses may take years to spread and cover significant areas of the implanted sites. Therefore, we would not expect to see results in such a short post-restoration monitoring period (Muotka & Laasonen 2002). Separating out the effects of the water moss implantations is also challenging as many other restoration measures were conducted shortly before and following the implantations.

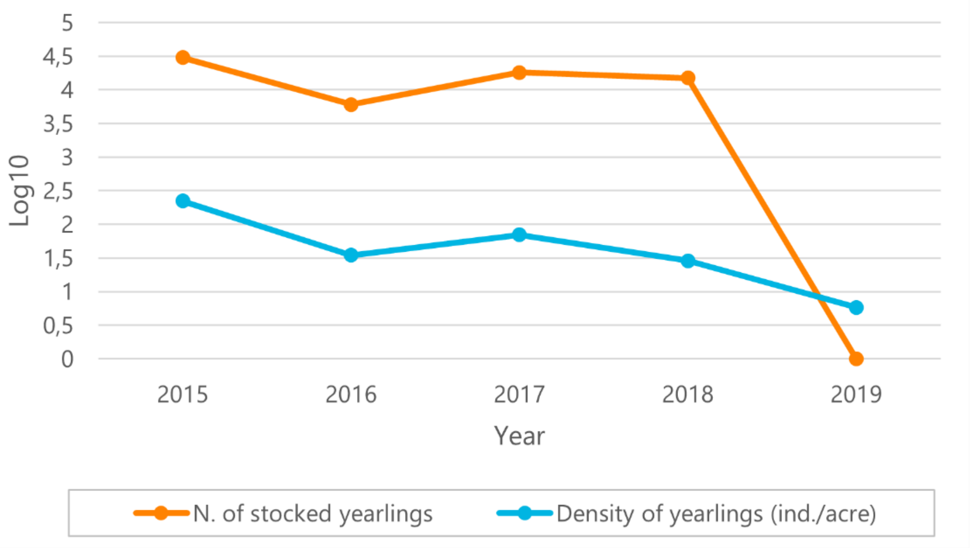


Figure 10. Number of stocked salmon-YOY and densities of YOY from electrofishing surveys both transformed to log10-scale.

In Kuusamonkoski two experimental streams were opened in 2017 and 5000 salmon larvae were stocked into both in 2017 and 2018. The one with water moss transplants seemed to have a better survival rate (Table 9). The densities remained higher than in the control channel, although in 2019 the density of older salmon was a little higher in the control stream. There were no statistically significant differences between the treatments in the densities of YOY (t = 0.51988, df = 3.6842, p-value = 0.6328) or older salmon (t = -0.040999, df = 3.9166, p-value = 0.9693). The results still hint that there could be some survival benefits in water moss transplantations but validating this would require a longer monitoring period as well.

3.3. Isojoki

Brown trout YOY densities showed a general increase post-restoration in the sites Kienokoski, Sillanpäänkoski and Villamo (Figure 11). In Lohiluoma a clear restoration year or period could not be set as the restoration process continued through the whole monitoring period until 2021. Still, even at Lohiluoma a clear increasing trend in the YOY densities can be seen in, despite the high inter-annual variation. Clearest increase can be seen in the mean densities of YOY-trout of Kienokoski where they nearly tripled during 2019-2021. Densities of older (>0+) trout seemed to remain the same or even decrease by a small amount, as was the case in Villamo (Figure 12).

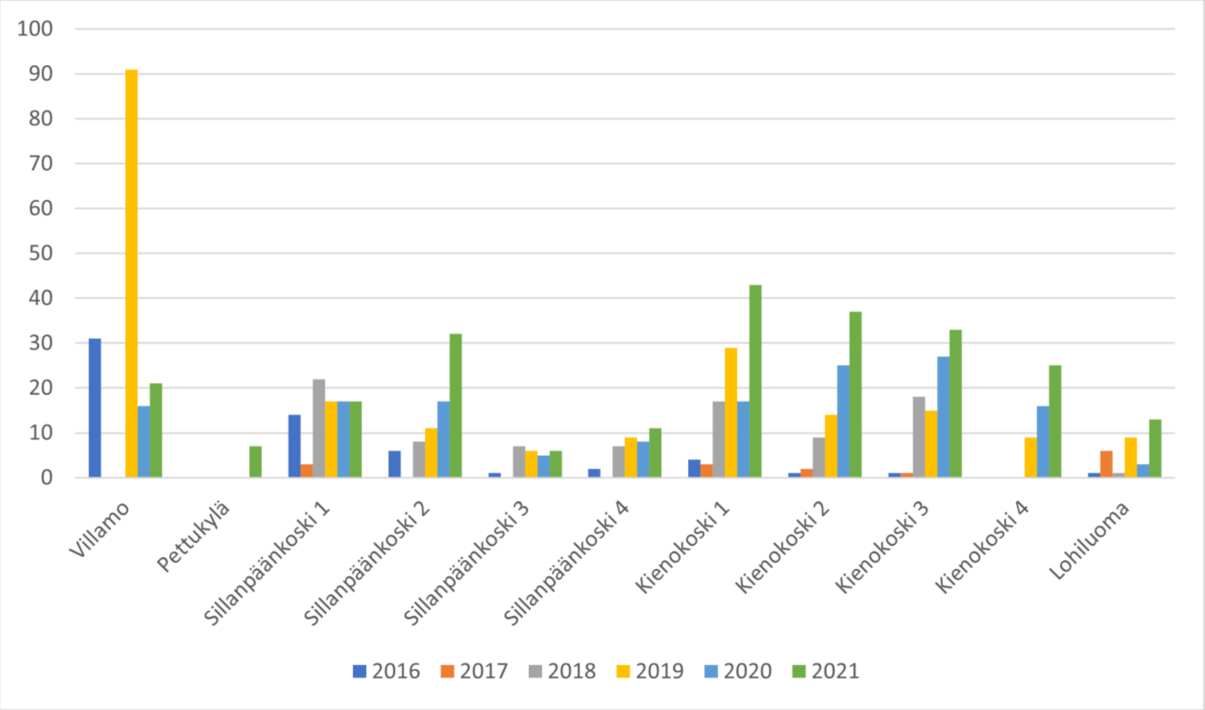


Figure 11. Brown trout YOY densities during 2016-2021 in the monitored sites of Isojoki. Pettukylä was electro-fished for the first time in 2021. Kienokoski 4 was fished from 2019 to 2021. Villamo was not fished in 2017 and 2018.

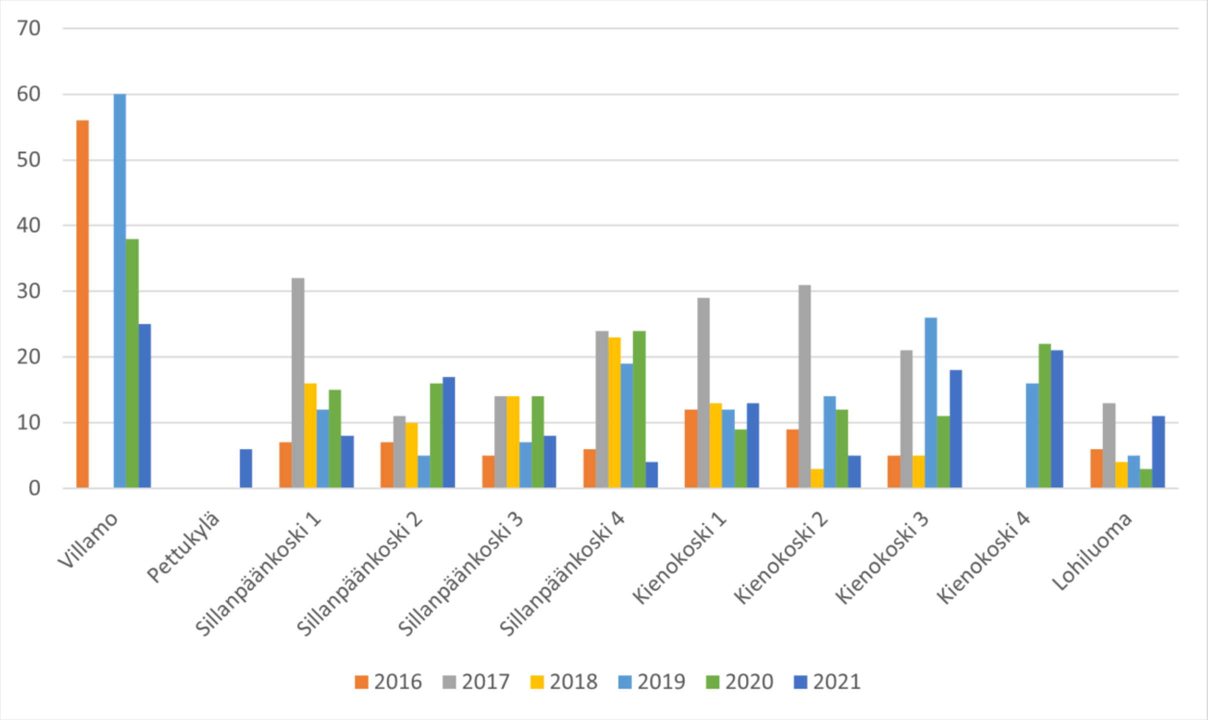


Figure 12. Older brown trout (>0+) densities during 2016–2021 in the monitored sites of Isojoki. Pettukylä was electro-fished for the first time in 2021. Kienokoski 4 was fished from 2019 to 2021. Villamo was not fished in 2017 and 2018.

Other caught species were grayling, alpine bullhead, stone loach (*Barbatula barbatula*), ruffe (*Gymnocephalus cernua*) and burbot. In 2019 lamprey ammocoetes (Lampetra fluviatilis /

planeri) were observed in Sillanpäänkoski and Kienokoski. In 2020 adult brook lamprey (L. planeri) were observed Sillanpäänkoski and Villamo and in 2021 in Kienokoski. Lamprey species were not observed in any sites during the pre-restoration period (2016–2018). There were no evident changes in species number or total fish density distributions of the sites post-restoration (Figure 13).

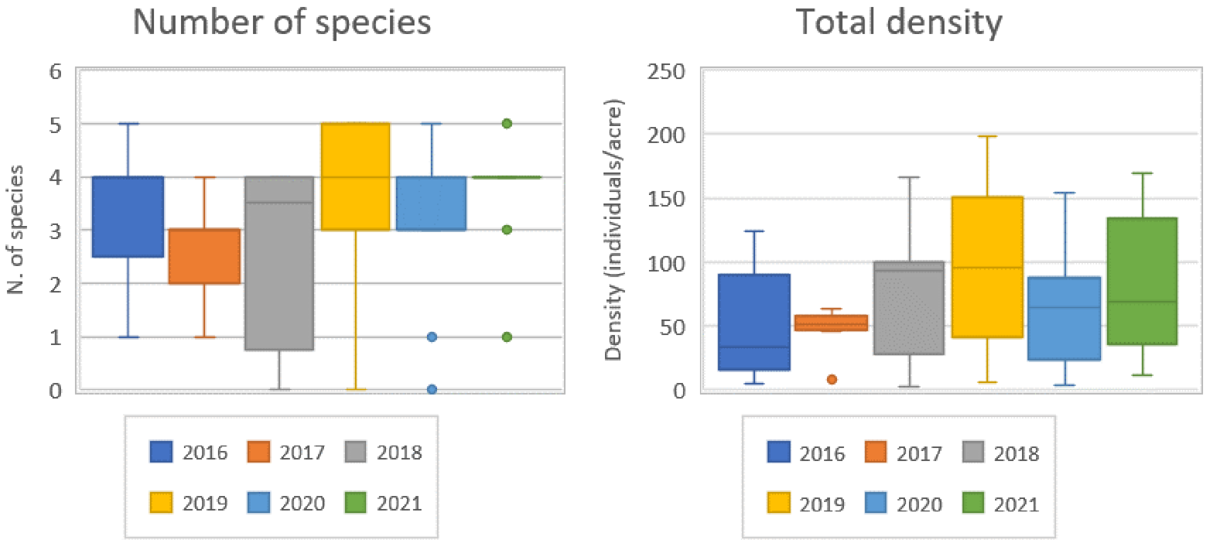


Figure 13. Distribution of species number and total density of all species in 2017 and 2021 in Isojoki.

River discharge rates seemed to increase during 2019–2021 compared to 2015–2018 (Figure 14). Winter 2019–2020 was relatively warm compared to the early spring of 2021 when temperatures remained generally below 0 degrees. Summer of 2021 had exceptionally long high-temperature periods, which lowered the discharge rates to minimal levels. There were no observable changes in water quality during the pre- and post-restoration monitoring period (Figure 15). Slight increase in the concentration of suspended solids and water turbidity could be seen in the fall of 2018. This was probably related to the restorations undertook in Villamo and other sites upstream. The effect was most probably temporary, although there is only one sampling of suspended solids in 2020 to verify this.

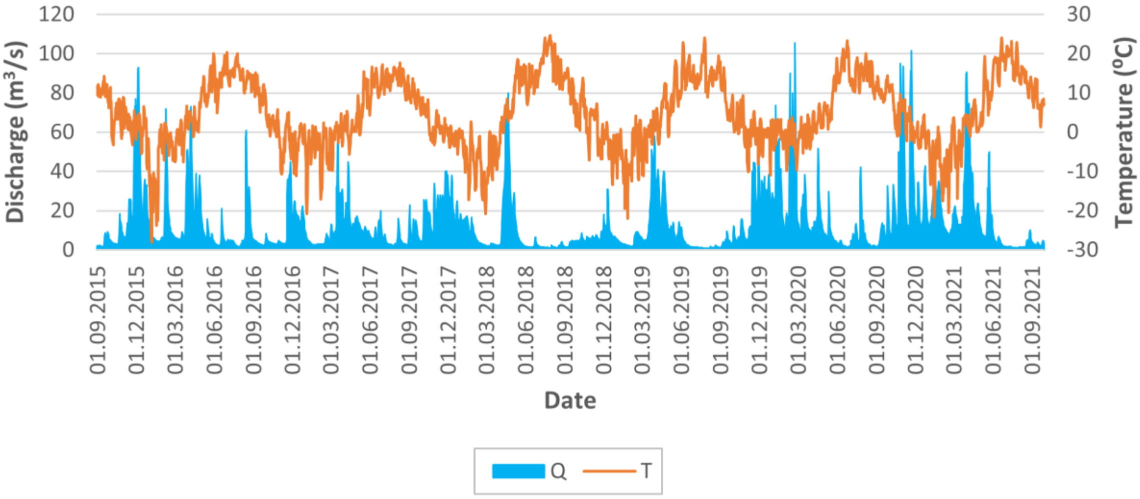


Figure 14. Air temperature and river discharge in Isojoki.

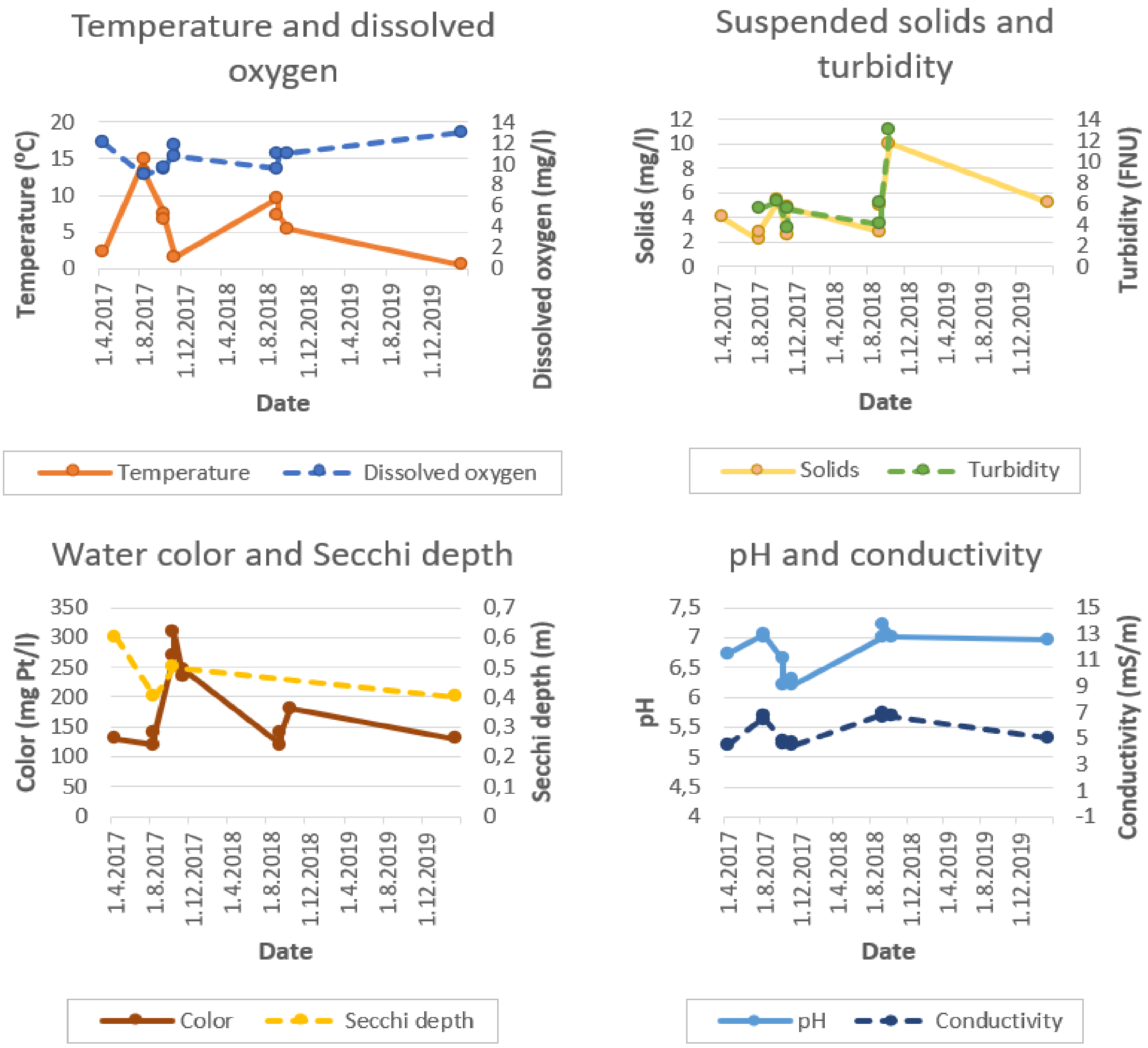


Figure 15. Water quality results for Isojoki.

The results suggest that the restorations had a positive effect on the spawning success of brown trout. Clear increases in YOY-trout densities post-restoration show that the habitats functioned well and provided good spawning, incubation and first summer habitats for the YOY-trout. However, it is not straightforward to attribute these increases entirely on the restorations as they coincided with the removal of the Villamo dam in 2017. Villamo dam acted as a migration barrier. Telemetry study conducted in 2019 and 2020 showed that only a few sea-migrating trouts ascended Villamo (Panu Orell, personal communication 24.2.2022). Somewhat contrary to this monitoring using VAKI Riverwatchers showed that at least 93 trouts ascended Villamo in 2019 (Viertokangas 2021). This leads us to attribute the increase of YOY densities into the increased quality of the spawning habitats together with the migration barrier removal effects. In contrast the results of the older brown trout densities suggest the suitable habitat for older trout has not increased as much or the survival of yearlings is somehow density dependent. The fact that older trout can utilize more broad range of habitats and spread out in search for better habitat can also affect the results. Weather conditions seem not to provide clear patterns explaining the changes in either age-classes as the yearly variation was in conditions was high. The exceptionally high flow rates from fall 2015 to the fall of 2016 might have provided adverse conditions for spawning as well as egg and larvae development. This can be one explanatory factor for the low yearling densities in 2016 and 2017.

3.4. Karvianjoki

Densities of both YOY brown trout and older fish exhibited high inter-annual variation (Figure 16). Mean YOY densities showed some after restorations. This was most evident in Latikanoja, Myllyoja and Peuraluoma. Densities of older trout (>0+) had, on the contrary, increased. Exception to this was Latikanoja, where densities dropped during 2019–2021. Very few other species were observed occasionally on the sites. These included pike, stone loach, burbot and brook lamprey.

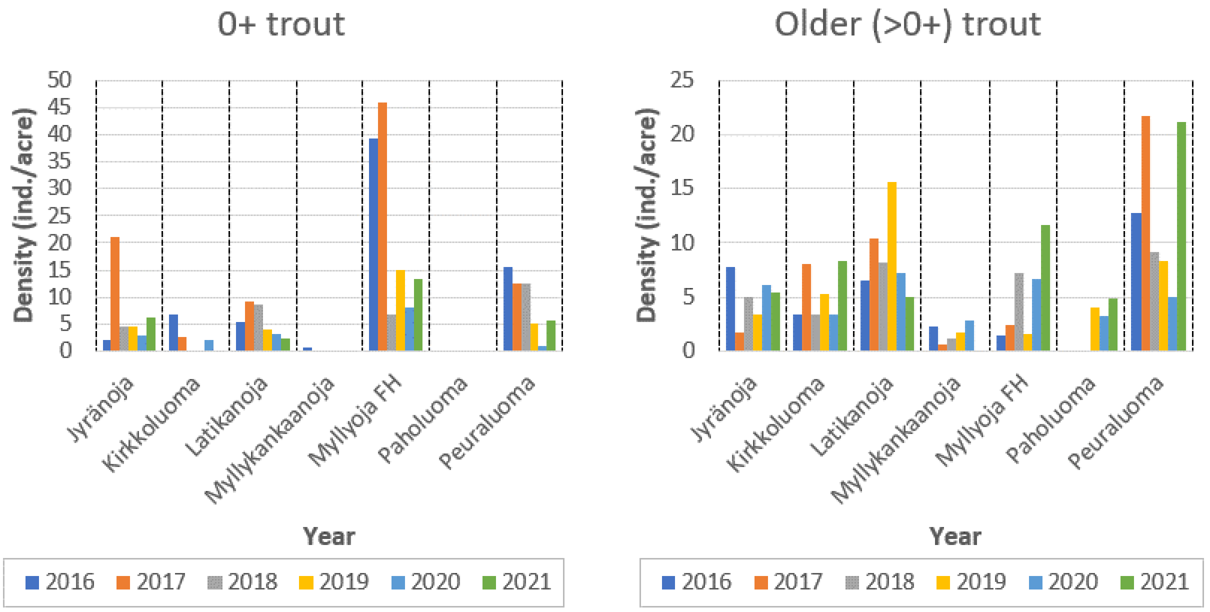


Figure 16. Densities of brown trout in the Karvianjoki monitoring sites during 2016-2021.

The weather conditions during the monitoring period had a high inter-annual variability (Figure 17). Exceptionally low precipitation through fall 2016 to spring 2017 and the very warm winter of 2019–2020 are one of the examples of the varying conditions which have surely affected the habitat conditions such as water level, flow, temperature and ice cover.

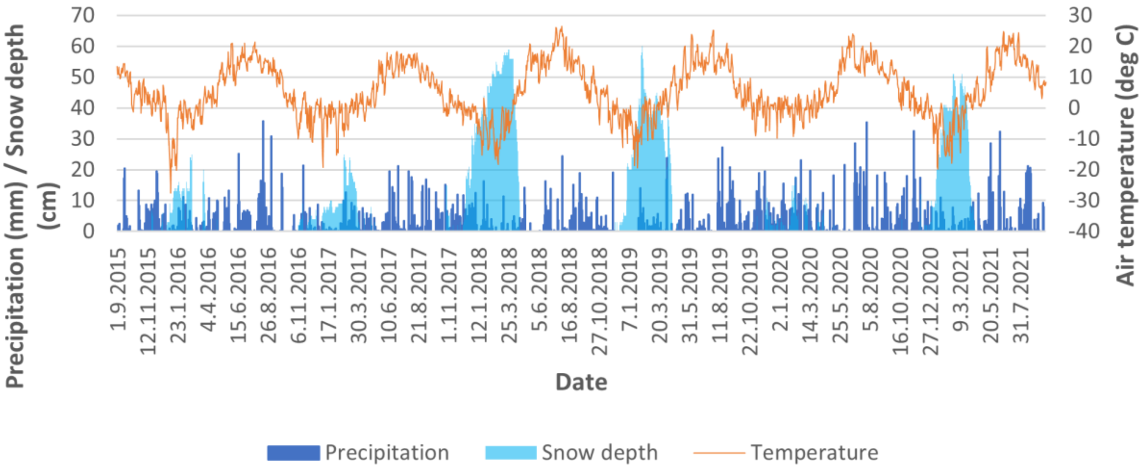


Figure 17. Precipitation, snow depth and precipitation in Karjaanjoki.

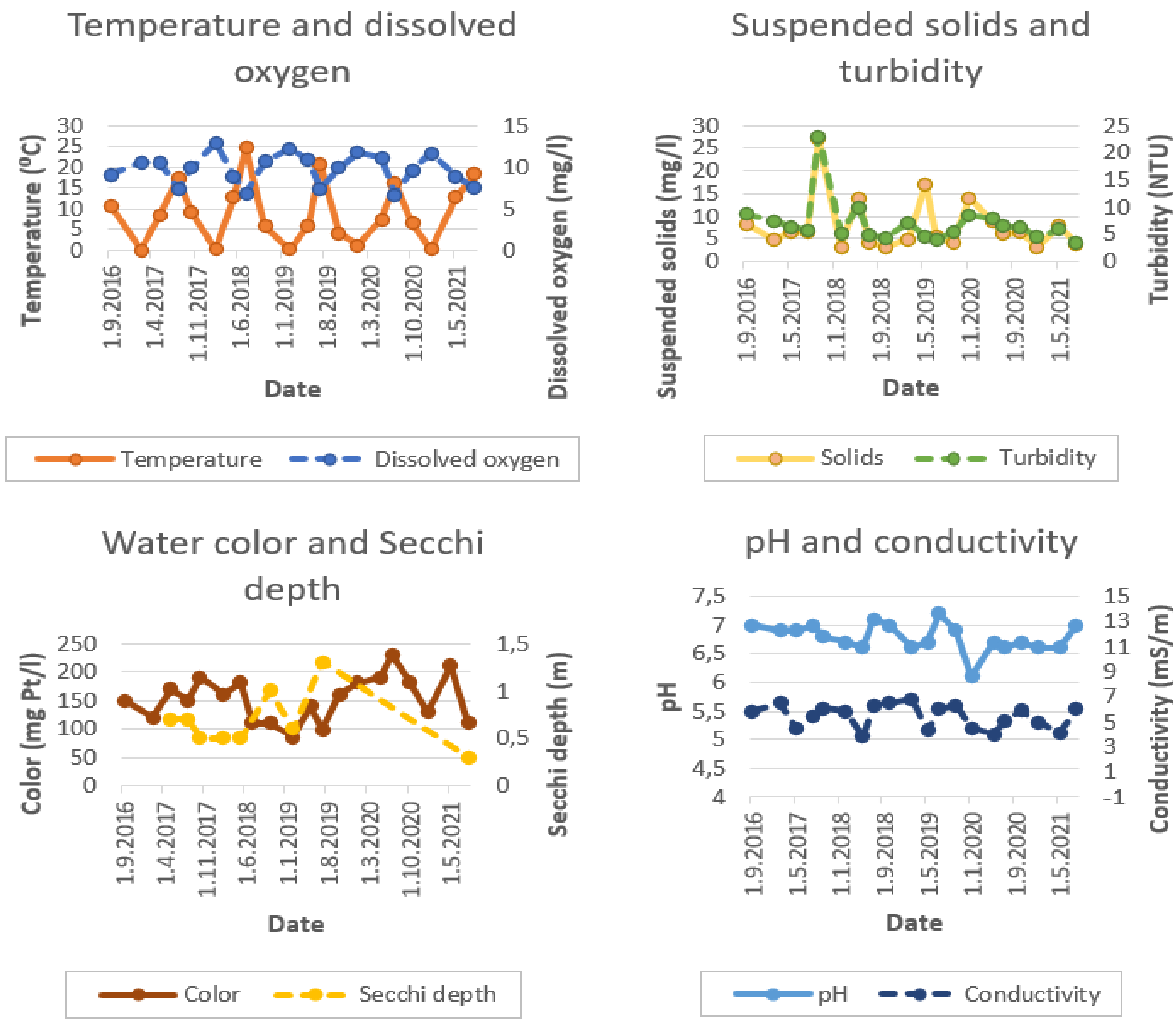


Figure 18. Water quality results for Karvianjoki.

The results suggest that the restorations have altered some of the sites into a more suitable habitat for older trout. This could be a result of the added wooden stream reflectors and woody material that has increased the amount of deeper pools. Increase of habitat complexity as a result of the restorations can also have decreased the catchability of YOY trout, as pointed out by the consult conducting the electrofishing surveys. The small creeks and streams surveyed are also strongly affected by high yearly variation in hydrological conditions steered by temperature and precipitation in general. Including this variation in the analysis of temporal trends in brown trout populations would require a very long monitoring period. In addition, as restoration efforts spanned multiple years in many of the sites the exact breakpoint for pre- and post-restoration monitoring period is difficult to set for comparisons.

3.5. Karjaanjoki

Brown trout YOY densities had an increasing trend in Äijäkoski during the post-restoration period, but there was no pre-restoration monitoring to compare to (Table 11). In Hiiskula the YOY densities were still much lower post-restoration than in the only pre-restoration monitoring year 2017. In Pitkälänkoski there was a noticeable mean increase in the YOY densities post-restorations, but no increasing trend was evident. Densities of older (>0+) trout in Hiiskula seemed to have a slight, increasing trend during 2018–2021, despite being much lower than before the restorations (Table 12). Only one pre-restoration datapoint (2017) was available to compare against. In Saarikoski there was a large increase in the YOY density between 2020 and 2021, following a decrease between 2019 and 2020. Only one year of pre-restoration monitoring had been conducted to compare against.

Table 11. Yearling (>0+) brown trout densities at the Karjaanjoki monitoring sites in 2010–2021. The restoration time is indicated by the dashed line, after which the results are considered a part of post-restoration monitoring. Note that in 2018 there were no electrofishing-surveys conducted.

Site	2010	2013	2016	2017	2019	2020	2021
Hiiskula				37,2	20	1,03	7,2
Lätinkoski					10,1	0	
Saarikoski				0	11,8	5,35	22,6
Yläkoski				2,14	2,91	0	2,5
Äijäkoski					16,7	23,2	34,3
Maijalankoski	0	0	0		3	0	0
Pitkälänkoski	0	0	2,43		4,66	7,99	1,89
Pitkälänkoski 2						3.05	

Table 12. Older (>0+) brown trout densities at the Karjaanjoki monitoring sites in 2010–2021. The restoration time is indicated by the dashed line after which the results are considered a part of the post-restoration monitoring. Note that in 2018 there were no electrofishing-surveys conducted.

Site	2010	2013	2016	2017	2019	2020	2021
Hiiskula				29,4	3,22	4,17	5,12
Lätinkoski					0,71	9,26	
Saarikoski				4,2	2,05	4,63	0,85
Yläkoski				0,43	0,65	3,89	0,56
Äijäkoski					0	11,4	1,9
Maijalankoski	0	0	0		0,67	0	0,18
Pitkälänkoski	4,77	0,93	1,08		0,78	3,98	1,26
Pitkälänkoski 2						10,8	

Winters were generally mild. In the winter of 2019–2020 there was basically no snow cover formed as the temperature remained close to 0 degrees °C the whole winter. There was an exceptionally dry period from the fall of 2016 to spring of 2017, followed by a colder winter (Figure 19). From 2016–2021 weather conditions showed high inter-annual variation (Figure 20 and 21). For some reason there was a sudden rise in suspended solids and turbidity in spring 2017 in Vanjoki and then again in Vihtijoki during the late fall (Figures 20 and 21). This might be related to the exceptional weather conditions or the restoration work done on multiple sites. The rise was temporary and there were no other notable chances in water quality during the monitoring period.

Lack of adequate pre- and post-restoration monitoring makes it difficult to assess the effectiveness of the restorations for brown trout reproduction. The increasing trend in Äijäkoski YOY-trout densities, although evaluated only on three sample, seems clear but it cannot be determined when this trend has started and is it related to the restoration process. Exceptional weather conditions in 2016–2017 and during the monitoring period in general add their own uncertainties into making conclusions.

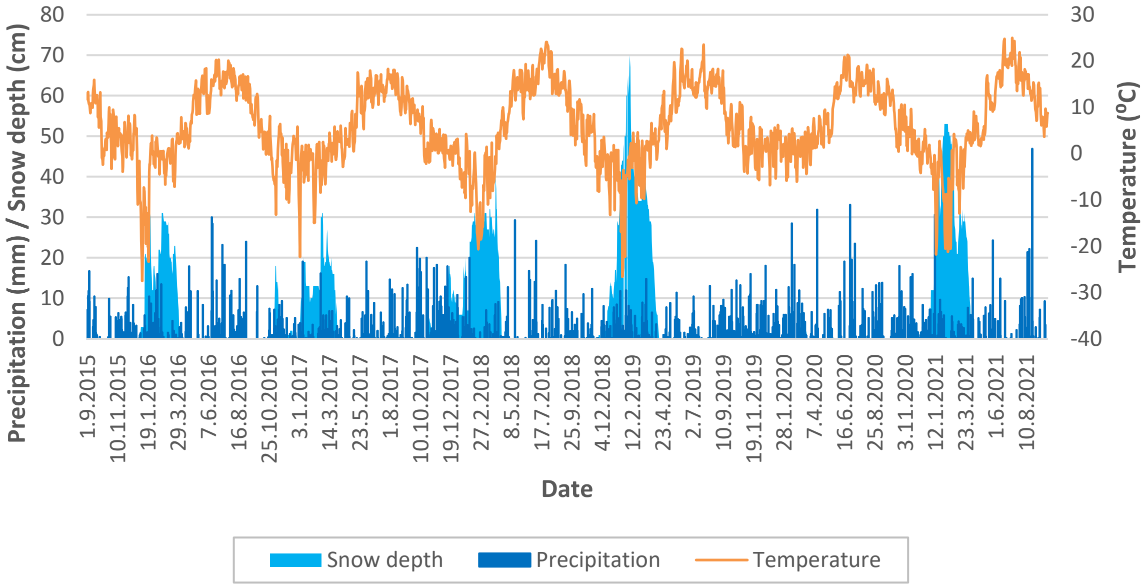
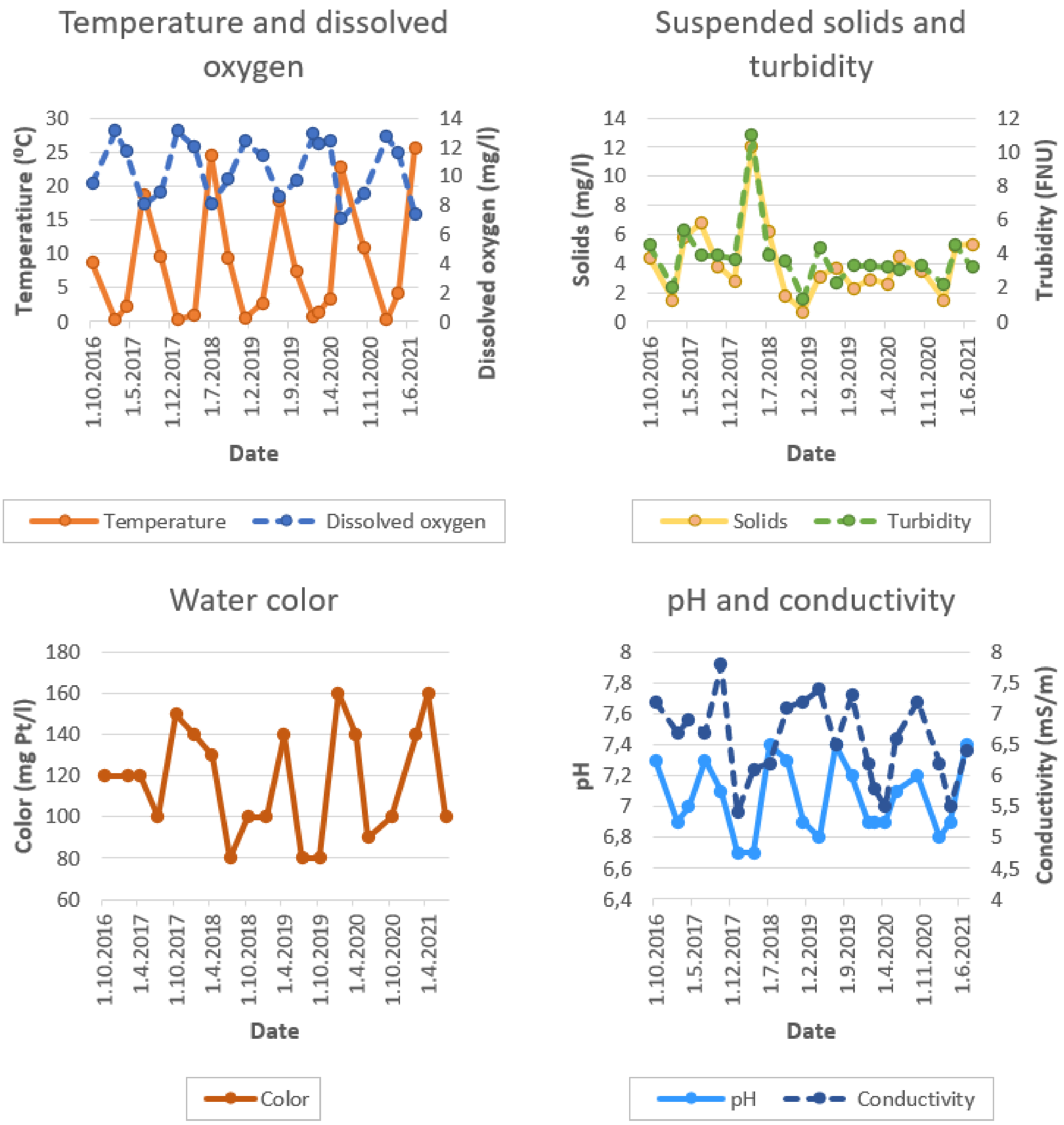


Figure 19. Precipitation, snow depth and precipitation in Karjaanjoki.


Temperature and dissolved oxygen

Suspended solids and turbidity

Water color

pH and conductivity

Figure 20. Water quality results for Vanjoki.

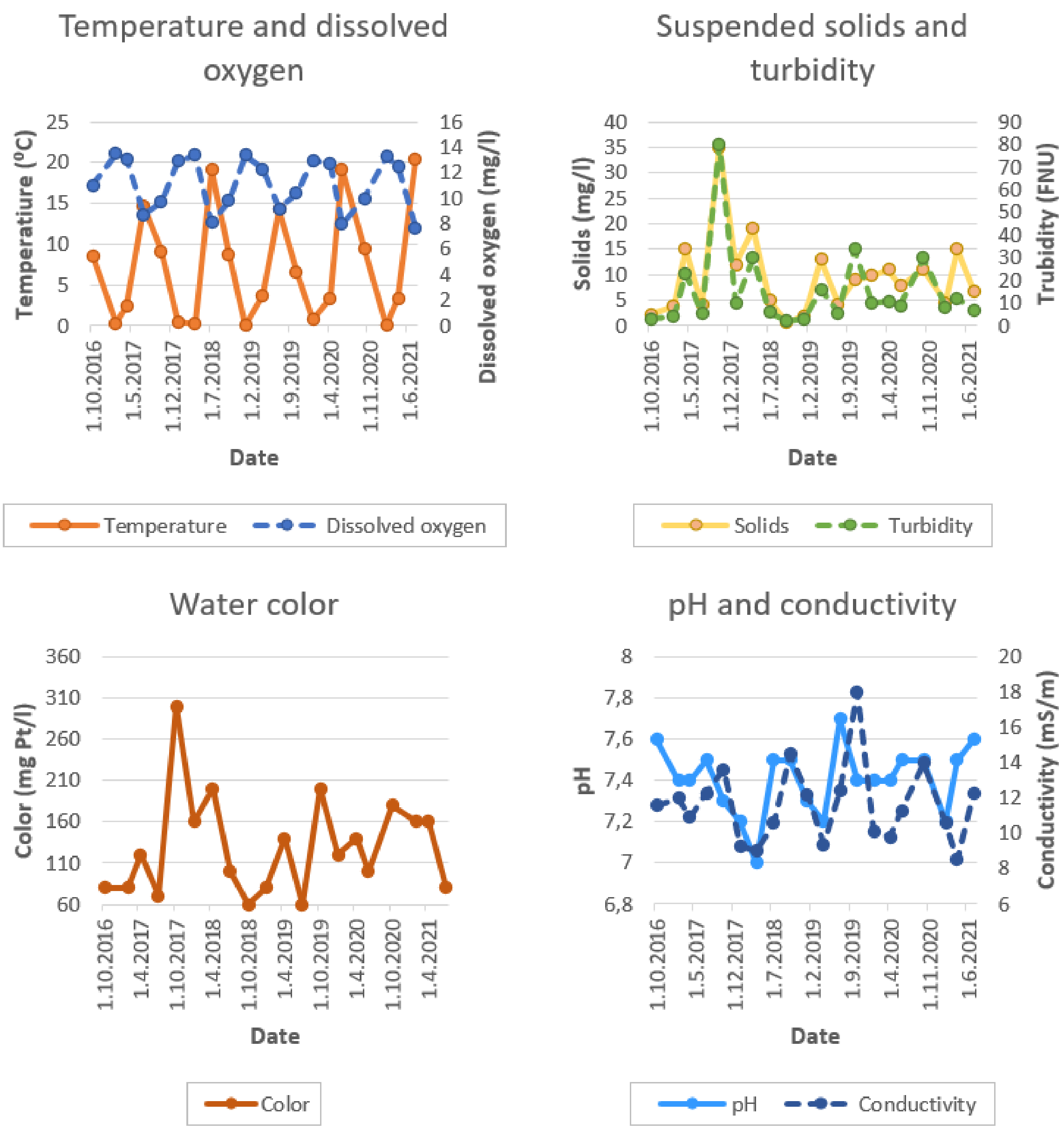


Figure 21. Water quality results for Vihtijoki.

4. Conclusions

Restorations can provide an effective method of salmon and trout reproduction improvement in degraded areas. The most effective set-ups for restoration impact monitoring include pre- and post monitoring (before-after) or pre- and post-monitoring with unimpacted control area (before-after-control-impact) (Christie et al. 2019). Restoration should be designed so that they always include the monitoring of the results to evaluate their effectiveness.

Clear positive impacts can be seen at least when spawning and nursery habitat restorations are combined together with migration barrier removals. This was the case in Isojoki where YOY-trout densities showed clear increases after Villamo dam removal and extensive restoration efforts on several sites. It is still clear though, that more focus should be put into good planning and adequate resourcing of the monitoring in order to verify the effiency of restorations. Previous studies show that in some cases electrofishing surveys need to be conducted for at least 5, or even 10 years before a clear trend can be distinquished from other sources of variation, such as weather conditions and natural population dynamics (Louhi 2016).

Water moss (*Fontinalis* sp.) transplantations and their benefits for brown trout and salmon reproduction still require further research, although previous studies have shown aquatic mosses to be key features for ecosystem restoration in streams (Muotka & Laasonen 2002). The experimental control-treatment design in Kuusamonkoski hinted that salmon larvar and fry survival in habitat where water moss has been introduced can be higher than in a habitat with no water moss growth. Better survival of juveniles could not, however, be statistically proven in our study. Further studies utilizing the before-after-control-impact-design would be a key factor in determining the effectiviness of water moss transplantations as means of restoration. In determining the monitoring period the time needed for transplants to spread needs be to taken into account. Monitoring the area covered by water-moss in conjunction with the electrofishing surveys would also be a good practice.

Restorations using different methods can affect the target populations unexpectedly. In Karvianjoki it is likely that the restoration, using weirs and stream deflecting structures have led to an increase of habitats that favor older trout over the YOY (Young Of the Year) trout. In restorations, it is necessary to understand how the actual changes in habitat characteristics affect the different age-/size-classes. This information is also needed during the planning phase to focus the restoration measures to fit the requirements of the targeted age-classes. Increased habitat complexity in the streams might alter the catchability of the juveniles. It is therefore important to distinquish the age-classes during the surveys to allow separate cathability estimates. This allows taking into account the changes in catchability that might alter the density estimates differently for each class.

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