Master's thesis

Success of stream channel restoration in the Iijoki catchment area

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KOCIS EEVI MARIA: Uomakunnostusten onnistuminen Iijoen valuma-alueen puroissa

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Työn ohjaajat: FT Heikki Hämäläinen, Prof. Jouni Taskinen, Pirkko-Liisa Luhta

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TIIVISTELMÄ

Purot ovat tärkeitä luonnon monimuotoisuudelle. Ihmisten aiheuttamat häiriöt, kuten purojen patoaminen ja valuma-alueen ojittaminen uhkaavat puroja ja niiden eliöstöä. Huoli pienvesien kunnosta yhdessä vesipuitedirektiivin tuoman lakivelvoitteen kanssa on lisännyt purojen kunnostusta ympäri Eurooppaa. Tämän pro-gradu työn tavoitteena oli arvioida Iijoen valuma-alueella toteutettujen purokunnostustoimenpiteiden onnistumista ja käytetyn inventointimenetelmän soveltuvuutta. Tutkimusasetelma sisälsi kunnostettuja, ei-kunnostettuja ja luonnontilaisia puroja, jokaista 5 toistoa. Työhön valitut purot oli kunnostettu samanlaisilla menetelmillä ja pääasiallinen toimenpide oli puun lisääminen uomaan. Muita toimenpiteitä olivat metsäojien tukkiminen, vanhojen uomien aukaisu ja kivien palauttaminen takaisin purouomaan. Purot oli inventoitu ennen kunnostusta ja tässä työssä vuonna 2017 tehty uudelleeninventointi tapahtui 7–14 vuotta kunnostustoimenpiteiden jälkeen, käyttäen yhdenmukaista menetelmää. Työn hypoteesit olivat, että kunnostus on i) lisännyt puun määrää puroissa, ii) kohentanut purojen luonnontilaisuutta, iii) vähentänyt hiekan määrää, iv) lisännyt syvänteiden määrää, sekä v) lisännyt purojen mutkittelevuutta. Lisäksi odotuksena oli kalojen kutupaikkojen ja purouoman leveysvaihtelun lisääntyminen. Tulokset viittasivat siihen, että kunnostustoimet olivat lisänneet puun määrää kunnostetuissa puroissa. Lisäksi syvänteiden ja puron leveysvaihtelun määrä kasvoi kunnostetuissa puroissa ja väheni ei-kunnostetuissa, mutta erot muutoksissa eivät olleet tilastollisesti merkitseviä. Näiden tulosten perusteella kunnostustoimia voidaan kuitenkin pitää ainakin osittain onnistuneina. Muissa tutkituissa muuttujissa havaittuja muutoksia ei voi lukea kunnostustoimenpiteiden ansioksi, koska samankaltaisia muutoksia havaittiin myös ei-kunnostetuissa ja/tai luonnontilaisissa puroissa. Esimerkiksi puron luonnontilaisuusasteessa havaittiin nousu sekä kunnostetuissa että kunnostamattomissa puroissa, mikä viittaa siihen, että myös kunnostamattomat purot voivat osittain toipua ihmisten aiheuttamista häiriöistä ajan myötä. Käytetty inventointimenetelmä osoittautui soveliaaksi purokunnostusten seurantaan. Tämä tutkimus tuki kunnostusten seurannan tärkeyttä ja antaa pohjaa tulevaisuuden kunnostusprojekteille.

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ABSTRACT

Streams are important for biodiversity. Human disturbances such as damming and ditching of the catchment areas, are threatening the streams and their biota. The concern about the state of small waters together with the legislation of Water Framework Directive has initiated major restoration efforts all over Europe. The aim of this Master thesis was to evaluate the success of restoration measures conducted in streams of the Iijoki drainage area and asses the suitability of the inventory method used. The study design included restored, unrestored and natural streams, each in 5 replicates. The chosen streams were restored with similar measures and the principal restoration measure was adding wood into the stream channel. Other restoration measures were blocking the forestry ditches, reopening old channels and placing stones back to the streams. The streams were inventoried once before and again in 2017, 7–14 years after the restoration measures, by using a consistent method. The hypotheses of this thesis were that restoration had i) increased the amount of wood in the stream channels ii) enhanced the level of naturalness of the streams iii) decreased the percentage cover of sand as a bottom substrate iv) created more pools within the channel and v) increased the meandering of the channel. In addition, creation of spawning areas for the fish and increase in the channel width variation were expected. The results suggested that restoration had increased the amount of wood. In addition, the amount of pools and channel width variation increased in the restored streams and decreased in the unrestored streams, but the differences in changes were not statistically significant. Based on these results, the restoration measures were at least partially successful. Changes in the other examined variables cannot be attributed to the restoration measures as equivalent changes were observed also in the reference streams. For example, the increase in the level of naturalness both in restored and unrestored streams indicates that also the unrestored streams can partially recover over time. The inventory method proved to be a suitable tool in monitoring the effects of restoration. This study supported the importance of monitoring of restorations and created foundations for future restoration projects.

Contents

1. INTRODUCTION

Due to human induced changes in the environment, global biodiversity is changing at a fast rate. The scenarios for the year 2100 suggest that the biodiversity in freshwater ecosystems will decline much faster than even the most affected terrestrial ecosystems. Moreover, the biodiversity in rivers and streams is much more sensitive than other freshwater ecosystems because streams response highly to runoff (Sala et al. 2000). Streams have a significant role in the nature's water management and biodiversity. The characteristics of streams have created premises for the development of unique organisms and vegetation. Several plants, birds, fish and insects depend on small waters for their survival. In Finland it has been estimated that approximately 6 % of the endangered species are inhabitants of small waters (Hämäläinen 2015). These endangered and rare species include for example several spring and stream mosses, freshwater pearl mussel and trout. Streams also form ecological networks which have an important role as breeding sites, spreading and passageways of several plant and animal species. In addition to these ecological values streams have social and economic value through the ecosystem services they provide. Streams retain nutrients, control floods and improve the water quality as well as increase the value and coziness of residential areas (Hämäläinen 2015).

The number of natural/pristine small waters such as streams, brooks and ponds has been decreasing due to pressure in land use, forestry, land drainage, log floating and peat extraction. Outside of nature protection areas, very few pristine small waters can be found (Räike 1994). Human disturbance to the streams decreases the streams' habitat diversity. Channelization is generally one of the main reason for habitat degradation and the consequences on stream habitats are often severe, causing loss in structural complexity and simplifying the flow patterns (Allan & Flecker 1993). Ditching increases stream gradients when meanders are removed, and channel is being shortened. The stream bottoms are usually dredged which creates uniform and unstable substrate without any pools or riffles. Ditching and dredging are usually done as an attempt to increase the drainage efficiency but often result in damaging the buffering capacity of the stream which then increases the severity of flooding and draught in the area (Gorman & Karr 1978).

Concern about the state of existing small waters has initiated major restoration efforts and billions of dollars are being spent on stream restoration in the USA alone (Palmer et al. 2003) and it has led to several inventory projects, of which the first ones were conducted in Finland already in 1960s. In Finland the so far most comprehensive research about the state of small waters was implemented by regional water and environmental centers during the years 1989 to 1994. This inventory was targeted to ponds and small lakes (less than 100 hectares) streams, springs, flads and salt marshes and it shows that already more than 20 years ago only a fraction of small waters remained undisturbed (Räike 1994). The consequence of the past and present degradation of the stream ecosystems in Europe is that the majority of the streams fail to reach the "good ecological status" as defined and obligated to be achieved by the legislative Water Framework Directive (European Commission 2008). Therefore, there is an urgent need to implement effective restoration projects to enhance the ecological status of water bodies in Europe (Pedersen et al.2014). The aim of stream restoration measures often is to rehabilitate degraded streams as close to their pre-disturbance state as possible. The restoration process typically includes adding stones and other obstructions that had been removed from the streams and constructing enhancement structures such as boulder dams and deflectors in an attempt to enhance the channel diversity (Yrjänä 1998).

Adding large woody debris (wood) to the streams is one of the most popular techniques to improve the riverine habitat, especially for fish (Roni & Beechie 2013). The physical responses of streams to wood adding are increased pools, enhanced habitat complexity and other improvements of aquatic habitat, which are known to be important for fish. The ideal amount of wood placement should be linked to the historical or natural wood loading, accumulation, location and function of that stream reach of interest (Roni et al. 2015). Once the wood is in the stream it affects a great deal of stream functions including formation of pools (Beechie & Sibley 1997), sediment storage, creation of alluvial reaches (Montgomery et al. 1996) and increased retention of organic material and nutrients (Flores et al. 2011). Wood can also decrease the grain size of the stream bed material and therefore alter the available spawning areas by controlling the substrate size (Buffington & Montgomery 1999).

In the spring of 1997 the ELY Centre of North Ostrobothnia and Metsähallitus founded a team whose purpose was to plan restoration measures to save valuable streams in Koillismaa area and enhance the condition of already deteriorated streams. The evaluation of the streams had to be done systematically, in a reasonable timescale and the method should be suitable also for broader use. An inventory method was established in which the basic variables were determined, the degree of naturalness of the streams and the factors affecting the naturalness were evaluated. In addition, restoration proposals were formed. By using this method 257 brooks were inventoried during the years 1998−2003 (Hyvönen et al. 2005). The restored streams chosen for this study have been restored during the years 2003 to 2010. Restoration measures included adding wooden structures to the stream channels, blocking forestry ditches, re-opening old stream channels and adding stones to the streams.

The aim of this study was to evaluate channel restoration success of chosen forest streams in the Iijoki catchment area. BACI design (before, after, control, impact) was used to investigate if the ecological characteristics of the streams changed because of the restoration actions. This was done by using a consistent habitat inventory method and one aim of this study was also to evaluate the suitability of this method. Various aspects of the streams were examined, such as morphological features, the quality of the stream bottom, occurrence of aquatic vegetation and the amount of human disturbance. The research hypotheses were as follows: 1) the amount of wood in the streams and 2) level of naturalness of the stream increase, 3) proportion of sand as bottom substrate decreases, 4) amount of pools and 5) level of meandering increase, and 6) number of trout spawning places as well as 7) channel width variation increase as the result of stream restoration.

2. BACKGROUND

2.1. Definition and aim of restoration

Stream restoration includes any action which is aimed at improving the health of a stream system. (Speed et al. 2016). Stream restoration can involve both active and passive restoration measures (Roni & Beechie 2013). Active restoration includes direct interventions to alter the stream system for example by planting riparian vegetation, modifying the stream channel or reintroducing native species. Passive restoration mainly involves changing how the human systems such as people, government, business and societies work and focus on reducing their impact on the stream ecosystems. These measures can include education, restrictions on certain harmful behaviour or providing economic incentives to support nature protection (Speed et al. 2016).

The aim of stream restoration is to bring the river closer to its natural state which existed before any harmful human activities came along. Some of the human made alterations can be reversed (for example straightened channels) but others might be irreversible (for example changes in the valley slope due to mining). If irreversible change has occurred, the recovery of the stream to its pre-historical nature is impossible (Kauffman et al. 1997, Brown 2002). Stream restoration can also be defined as assisting the improved ecological, hydrologic and geomorphic processes in impaired river system and replacing some of the lost or damaged elements of the natural system (Covich et al. 2004).

2.2. Standards for a successful restoration project

According to Palmer et al. (2005) ecologically successful restoration includes a dynamic guiding image of hydrology, geomorphology, physical habitat, biology and the probability of the fact that these system variables are not static. Guiding image should consider how much local restoration can then contribute to the restoration in the watershed-level. Restoration should improve the ecosystems (for example improve water quality, increase the ecosystem functions and/or return natural flow regime) and increase their resilience towards future disturbances. Pre- and post-monitoring of the restoration project should show that the impacts of restoration activities did not cause irreversible damage to the ecosystem. In addition, ecological assessment of the project has to be completed. This assessment includes setting clear project goals with evidence that the post-restoration data were collected from the variables of interest and that the results were analyzed and distributed to all interested parties. Most effective river restoration success considers ecological success, stakeholder success which reflects to human satisfaction with the restoration (for example aesthetics, economic benefits and recreation) and learning success which will benefit future restoration action (for example management experience and improvement in the methods) (Palmer et al. 2005) (Figure 1).

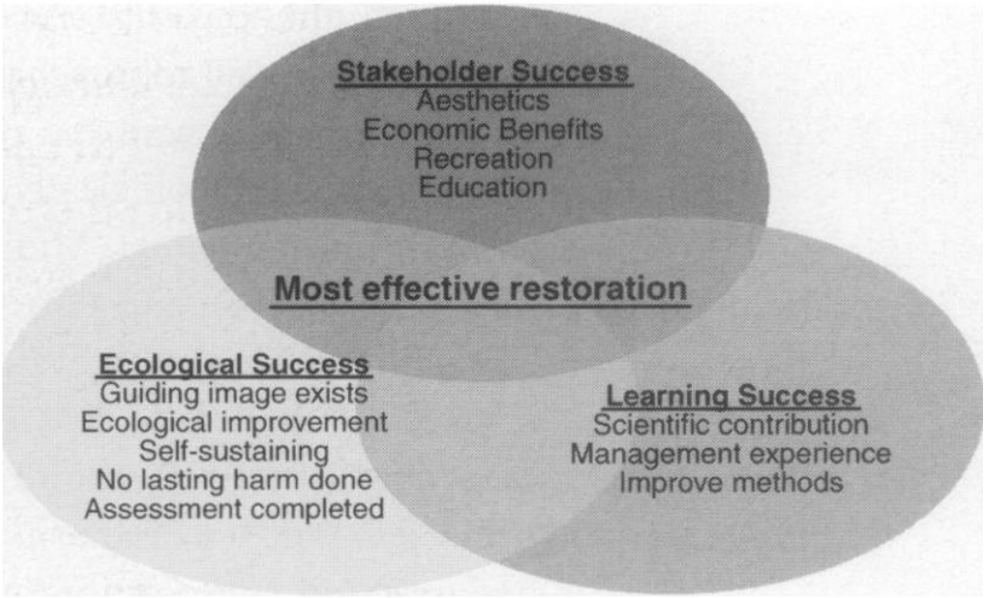

Figure 1. Three primary restoration success aspects that create the most effective restoration (Palmer et al. 2005).

2.3. Importance of monitoring and follow-up studies

To determine the success of a restoration project, monitoring needs to be an inherent part of the project right from the start. Regardless of the type of the restoration there are several steps that should be followed to design a successful monitoring program (Figure 2). These steps include clearly establishing the project objectives, selecting the monitoring design, choosing the parameters which are being monitored, determining spatial and temporal replication, selecting a proper sampling scheme and finally implementing the monitoring program. Once the monitoring has been implemented the results also have to be communicated (Roni et al. 2005).

Ideally project monitoring should be conducted before and after the project execution for both the affected reach (where restoration measures have been/will be carried out) and a control reach (where no restoration have been/will be carried out and which will not be affected by the restoration work). Before After Control Impact (BACI) design is a generally used analytical framework in order to determine the size and direction of any disturbance occurring against a natural variation monitored at control sites. Control or reference sites help to estimate community stability while the impact site data allow us to assess community impact and resilience (Russel et al. 2015).

Given the ongoing debate about the effectiveness of different restoration techniques (Bernhardt et al. 2007, Naiman et al. 2012) monitoring can offer valuable information on what approaches have and have not been successful and why. With clear project objectives (that can be measured), careful data collection and analyzing, researchers can collectively increase the knowledge base of restoration which can then help to identify what restoration techniques are most successful for different river types (Hammond et al. 2011). Monitoring data are collected in a hope that they can indicate when in a restored ecosystem a considerable change has happened which exceeds the expected changes in normal circumstances (Russel et al. 2015). Proper project monitoring helps to demonstrate to government and project funders how, when and where restoration can benefit the environmental as well as economic objectives. At its best, monitoring will strengthen the foundations for future restoration projects (Speed et al. 2016). However, all too often project monitoring is not seen as a top priority due to financial constraints and lack of guidance in appropriate monitoring levels and methods. As a result, river restoration monitoring is rarely accurate enough to measure the success or failure of the project (Hammond et al. 2011).

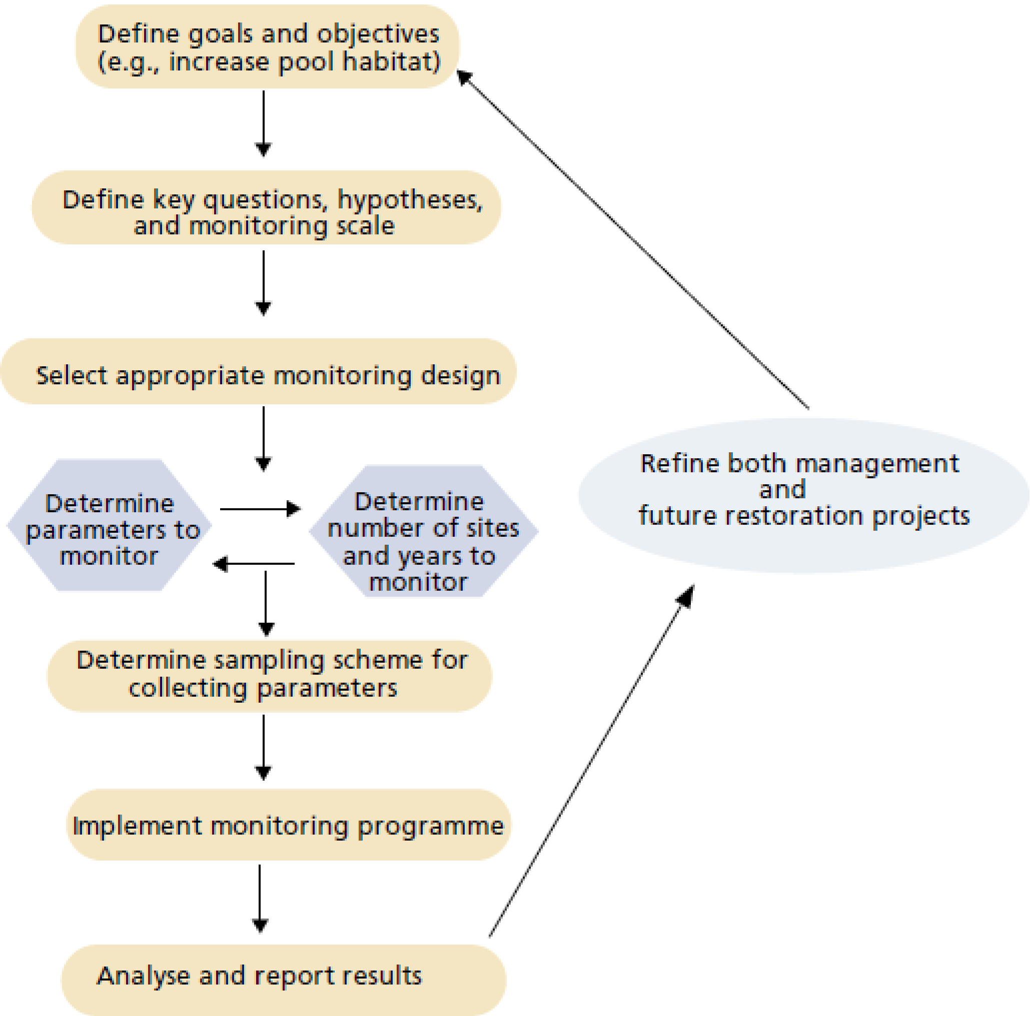

Figure 2. Key steps in developing a comprehensive monitoring program for restoration measures (Roni et al. 2005).

3. MATERIAL AND METHODS

3.1. Study streams

All of the streams chosen for this research are situated in the Iijoki drainage area which has total area of 14 1919 km^2 (Hyvönen et al. 2005), and they are situated in the Pudasjärvi and Taivalkoski municipalities (Figure 3).

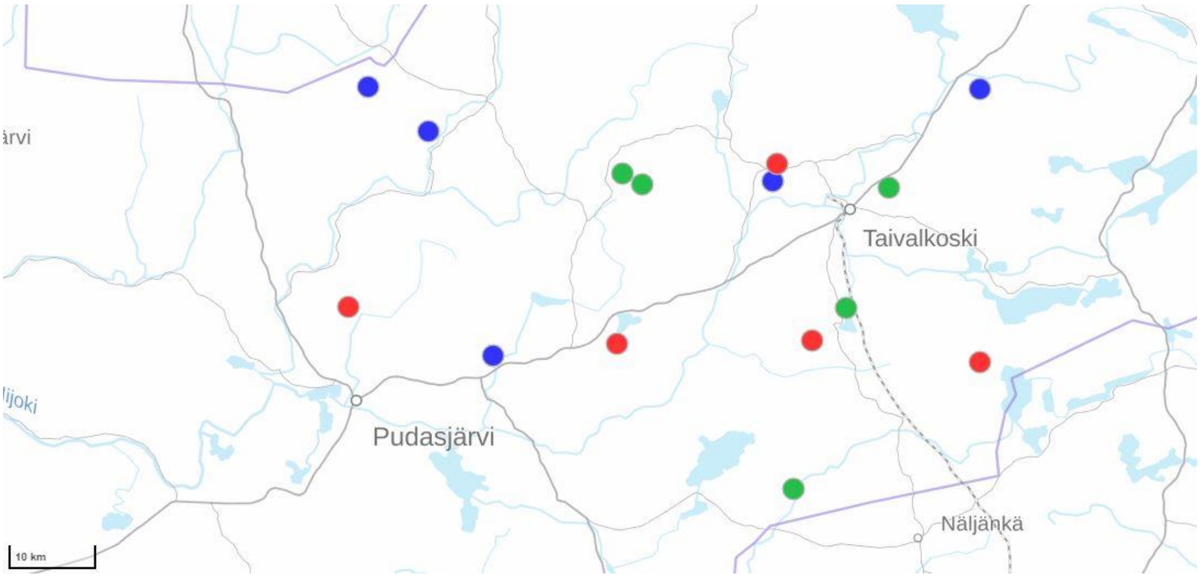

Figure 3. Location of the study streams. Natural (n = 5), restored (n = 5) and unrestored streams (n = 5) are indicated by green, red and blue symbols, respectively.

The chosen five restored streams were inventoried once before the restoration measures during the years 1999 to 2010. The restoration measures were completed during the years 2003 to 2010 and the after-restoration inventory was done in the present work in 2017, leaving approximately 7 to 14 years recovery time for the streams. This was one of the criteria in selecting the suitable streams, because to successfully compare them, they had to be restored during the same period. The five unrestored reference streams were inventoried in 2008–2011 and the five natural reference streams in 2001–2003 (Table 1).

Table 1. The restored (R), unrestored (U) and natural (N) study streams, their before-restoration inventory years and restoration years, with details of restoration effort.

Stream	Stream category	Inventory year	Restoration year	The length of the stream (m)	The length of restored sections (m)
Kanervaoja	R	2000	2003	3450	701
Hoikanoja	R	2001	2007/2008	2940	3118
Keskijärvenoja	R	2009	2010	3460	1370
Ohtalammenoja	R	2010	2010	1075	722
Laukkupuro	R	1999	2007	700	260*
Syrjäpuro	U	2008		2188	
Hillinoja	U	2009		2875	
Kirsiojan Vilmihaara	U	2009		1210	
Välioja (Rojola)	U	2011		3130	
Kostonlamminoja	U	2010		2780	
Portinoja	N	2003		2440	
Romeoja	N	2003		2309	
Lauttapuro	N	2003		2969	
Koronoja	N	2002		2410	
Ahvenoja	N	2001		2720	

* On top of this some catchment area restoration in the headwaters

The restored streams chosen for this thesis were Kanervaoja, Hoikanoja, Keskijärvenoja, Ohtalammenoja and Laukkupuro (Table 2) and they were chosen by Pirkko-Liisa Luhta, my supervisor from Metsähallitus.

Table 2. Characteristics of the restored streams.

Stream	Coordinates	Main flow type	Main forest type	Main growth type
Kanervaoja	3529116-7254290	slow flow (72.5%)	spruce (59.5%)	swamp (52.2%)
Hoikanoja	3571171-7257458	slow flow (72%)	mixed (47.1%)	swamp (61.6%)
Keskijärvenoja	3500493-7263850	slow flow (75.6%)	spruce (47.7%)	coniferous swamp (68.2%)
Ohtalammenoja	3548843-7280208	slow flow (52%)	spruce (51%)	fresh pine forest (79%)
Laukkupuro	3551015-7259700	slow flow (50%)	mixed (62.2%)	meadow (44%)

The unrestored reference streams were Syrjäpuro, Hillinoja, Kirsiojan Vilmihaara, Välioja (Rojola) and Kostonlamminoja (Table 3) and they were chosen from a group of streams, which had clear or urgent demand for restoration. Chosen streams are all also less than 3km long due to limited inventory time. With these basic criteria, the streams were narrowed down to those mentioned.

Table 3. Characteristics of the unrestored streams.

Stream	Coordinates	Main flow type	Main forest type	Main growth type
Syrjäpuro	3570872-7284176	slow flow (47%)	deciduous (47.9%)	meadow (36.1%)
Hillinoja	3508581-7282987	slow flow (90.2%)	mixed (58.9%)	fresh pine forest (45.3%)
Kirsiojan Vilmihaara	3500109-7287604	stagnant (55.4%)	spruce (82.6%)	coniferous swamp (94.9%)
Välioja (Rojola)	3516656-7258284	slow flow (65.5%)	deciduous (35.5%)	swamp (64%)
Kostonlamminoja	3548158-7278938	slow flow (45.6%)	deciduous (46.5%)	fresh pine forest (66.6%)

Natural (or as natural as possible) reference streams are Portinoja, Romeoja, Lauttapuro, Koronoja and Ahvenoja (Table 4). These streams were chosen from the publication of Hyvönen et al. (2005) listing the stream inventories completed in the years 1998 to 2003. The natural streams were first divided in groups based on their location and then further selected by their length (less than 3km) and by the amount of natural sections of the stream (more the better). After these pre-selection measures, the streams were drawn randomly.

Table 4. Characteristics of the natural streams.

Stream	Coordinates	Main flow type	Main forest type	Main growth type
Portinoja	3533943-7277730	slow flow (44.1%)	spruce (36%)	fresh pine forest (49.8%)
Romeoja	3530082-7279220	slow flow (38.4%)	spruce (51.9%)	swamp (52.4%)
Lauttapuro	3557295-7263713	slow flow (40.8%)	mixed (28.5%)	swamp (38.9%)
Koronoja	3564134-7277320	slow flow (76.1%)	deciduous (51.2%)	fresh pine forest (36.5%)
Ahvenoja	3551011-7241289	stagnant (89.7%)	spruce (46.5%)	swamp (66.6%)

3.2. Restoration measures conducted

All the five restored streams had similar restoration measures conducted. The main restoration material used was wood. Wood was added simply by placing some large woody debris to the stream or by building different woody structures such as underminer structures and flow deflectors. The most important targets of the restoration measures were to enhance the flooding mechanisms and with these mechanisms to get the excess sand flooding out of the stream channels and to create a more diverse bottom substrate. The overall aim of wood adding was to create pools and fish habitats and increase the channel bed material diversity by decreasing the dominance of finer material, such as sand, and increasing the cover of coarser substrates such as gravel or boulders. In addition, re-opening the old (still visible in the field) stream channels were used as a restoration measure to slow down the flow and increase the length of the stream. By increasing the meandering more diverse channel was hoped to be achieved. In more than half of the restored streams the method of blocking the forestry drainage ditches were used in order to prevent sediment loading to the channel.

Most of the restoration measures were done by hand with a group of people but in Hoikanoja, Ohtalammenoja and Laukkupuro sand pockets, surface drainage areas and blocking of forestry drainage ditches were done by a small excavator. The wood used for building the underminers and wooden flow deflectors was collected on site. Spawning grounds were established or restored in two of the streams and stones were used as flow deflectors and to create shelter for the fish. In addition, stones that clearly had been removed from the channel were returned to the channel from the banks.

3.3. Inventory method

Inventory of the selected 15 streams was conducted in July 2017. Before the fieldwork, my workpartner and I received one-day training, where the method was explained to us and tested in practice in the field. However, my work partner was already familiar with the method from his previous inventory work with Metsähallitus. During our inventory days, we walked the streams through, starting from the place where the stream falls to a lake or a river and finishing to its origins. We managed to go through one stream per day and usually the inventory distance was approximately 2–3 km. In our team of two, one person was measuring the basic variables of the stream, for instance width and depth while walking and the other person was writing down the observed variables and the roles were frequently changed. Both of us were observing the desired variables while walking and every time the stream section changed, we stopped to record the observations.

The inventory was done by using the method created by Metsähallitus, in which several factors of the streams were examined (Table 5). The basic principle of this inventory method was to divide the stream channel in sections with uniform basic features and the observed variables were recorded separately of these sections. Sections were determined according to flow type, the riparian forest type or channel bottom substrate or vegetation. Depending on the stream, the number of stream sections varied between 2 and 15. Across all the stream sections, averages were counted for each variable which were then used in further analyses. As far as it was possible, the field workers were unaware of the nature of the stream, whether it was restored, reference or natural stream.

Table 5. Examined variables in the stream inventory, units of their measurement and description of the measurement/classification.

Variable	Unit of measure	Description
Length, width, average depth, deepest point)	m	Length was measured from the map after returning from the field. Width was assessed in the field. Average depth and the deepest point was measured with a measuring stick.
Quality of flow • rapid • strong flow • slow flow • stagnant	0-100%	Percentage of each stream section.
Quality of the bottom substrate • 1st dominant • 2nd dominant • biggest (in size)	Wentworth scale	Mud, clay (< 0.5mm), sand (0,5-2mm), fine gravel (2-8mm), gravel (8-16mm), small stones (16-32mm), stones (32-64mm), big stones (64-128mm), small boulders (128-25mm), boulders (256-512mm), big boulders (512-1024mm) and rock (>1024mm).
Channel bottom vegetation type	1/ 2/ 3	1= grass 2= moss 3= other
Channel bottom vegetation cover	scale 0-5	0= no vegetation 1= less than tenth 2= approx. one third 3= approx. half 4= approx. two thirds 5= nearly full/full of vegetation
Percentage of moss/other vegetation	0-100%	Percentage of moss and other vegetation from the whole vegetation of the stream section.
Shading of the riparian zone	scale 0-5	0= riparian zone without any shading provided by trees/vegetation/banks 1= less than tenth 2= approx. one third 3= approx. half 4= approx. two thirds 5= nearly full/full shading of the channel bottom
Riparian zone forest type • pine • spruce • deciduous • mixed • brushwood	0-100%	Percentage of each stream section.
Riparian zone growth type • swamp • meadow • fresh pine forest • grove • coniferous swamp	0-100%	Percentage of each stream section.
Level of naturalness	scale 0-5	0= low protection value, cannot be restored to a better state without highly intense restoration measures, “dredged stream“ 1= low protection value, cannot be restored to a better state without intense restoration measures, “forest ditch“ 2= state highly weakened, stream can be restored to a category 3-4 with fairly intense restoration measures, “gutter“ 3= state weakened, can be restored to a category 4-5 with various restoration measures 4= state slightly weakened, can be restored to category 5 with light restoration measures or by letting the stream recover over time 5= fully natural, no human induced changes
Spawning places/pools/shelter	scale 0-5	0=missing 1= perceivable 2= scarce 3= moderate 4= considerably 5= abundant

Table 5. continues.

Variable	Unit of measure	Description
Potential for electric fishing	yes/no	X= yes, empty= no
Level of meandering	scale 0-5	0= no meandering 1= perceivable meandering 2=scarce meandering 3= moderate meandering 4= considerable meandering 5= highly meandering
Level of channel width variation	scale 0-5	0= no variation 1= perceivable variation 2=scarce variation 3= moderate variation 4= considerable variation 5= high variation
Amount of wood in the channel > 5cm	scale 0-5	0= no wood 1= less than tenth 2= approx. one third 3= approx. half 4= approx. two thirds 5= nearly full/full of wood
Factors influencing the level of naturalness and magnitude of the effects	scale 0-5	0= no effect 1= barely noticeable effect 2= weak effect 3= clear effect, 4= strong effect, 5= complete change. Factors such as forest ditching, logging, ploughing/harrowing of the logging area, channel dredging, mud, sand, water quality (possible algae, turbidity), sliming and eutrophication influencing the level of naturalness.
Restoration suggestions	scale 0-5	0= no effect 1= barely noticeable effect 2= weak effect 3= clear effect, 4= strong effect, 5= complete change Restoration suggestions such as adding stones, removing suspended solids such as sand and mud, creating spawning places, removing migration barriers, adding stone and wood deflectors, blocking forestry ditches, planting trees on the riparian zone and their estimated effect.
Spotted fish species	yes/no	X= yes, empty= no If possible, identification of the species.

3.4. Chosen variables

The examined variables in this thesis were the amount of wood in the channels, coarser bottom material (the more, the less sand), meandering and width variations of the stream channels, the level of naturalness of the stream sections, the amount of pools in the channel and the number of spawning places for fish. Therefore, these variables were measured for every stream and stream section.

3.5. Data analysis

Numerical data analyses were conducted by IBM®SPSS® statistics software (version 24.0). One-way ANOVA with a Fisher's Least Significant Difference (LSD) post hoc test was used to detect differences among the stream groups. This test was first conducted for all the chosen variables, before restoration to evaluate if the unnatural streams differed from the natural streams. Then, to evaluate if the restoration measures had any effect on the target variables, the change (after minus before) was calculated for each variable and stream and then compared across stream groups. In addition, the Tests of Between- Subject Effects were carried out to all dependent variables and effects were tested among the groups in order to get the estimate of the effect size (Partial Eta Squared, n_p^2).

4. RESULTS

4.1. Amount of wood in the streams

Before the restoration measures, natural streams had the highest amount-of-wood score (mean score 1.6, Figure 4), whereas the restored group had the lowest wood score (1.1) and the unrestored group in between (1.38). However, the amount of wood within studied stream sections was not significantly different among the stream groups ($F = 0.642$, $p = 0.543$, $n_p^2 = 0.097$).

After the restoration, the amount of wood had increased in the restored streams (mean difference of 0.54 to the before restoration score) almost to the same level as in the natural streams (Figure 4). In contrast, the amount of wood decreased in unrestored streams (mean difference −0.32) and grew only slightly in natural streams (+0.08). However, the change in the amount of wood was not significantly ($F = 2.101$, $p = 0.165$, $n_p^2 = 0.259$) different among the stream groups, even though the difference between restored and unrestored streams was quite close ($p = 0.063$) to being statistically significant.

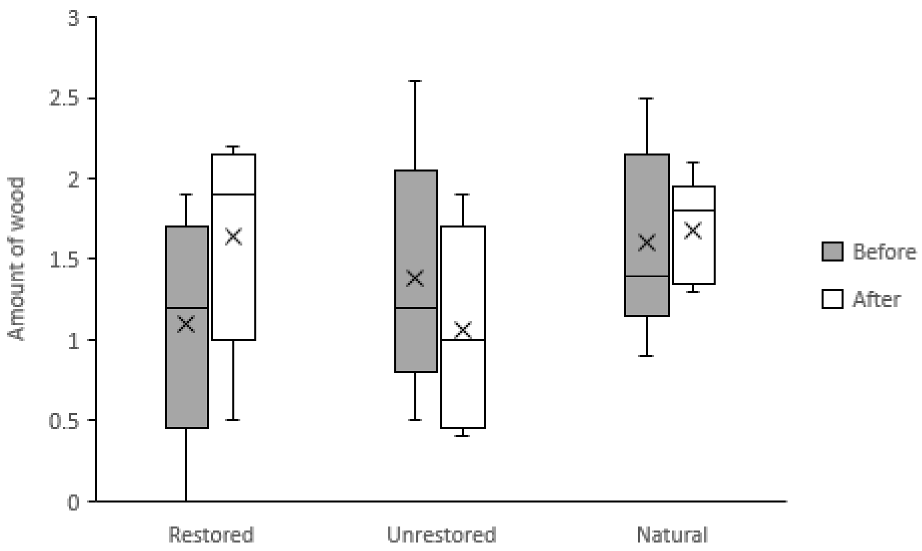

Figure 4**.** The mean score (x) and median (horizontal line), of the amount of wood among the three stream groups before and after restoration, with interquartile range (box) and standard deviation (whiskers). The classification used for the amount of wood was as 0 = no wood 1 = less than tenth 2 = approx.one third 3 = approx.half 4 = approx.two thirds 5 = nearly full/full of wood.

4.2. Level of naturalness

The level of naturalness within the stream sections before any restoration measures were conducted was significantly different ($F = 15.128$, $p = 0.001$, $n_p^2 = 0.716$) among the stream groups (Figure 5). The natural streams had much higher score of naturalness in their stream sections (mean 4.22) than the restored (2.64, $p < 0.001$) and the unrestored ones (2.8, $p = 0.001$). There was no statistically significant difference between the restored and unrestored streams ($p = 0.622$).

After the restoration the level of naturalness had increased in all of the stream groups, but the degree of change differed among the stream groups ($F = 6.595$, $p = 0.012$, $n_p^2 = 0.524$). The increase was similar ($p = 0.656$) in the restored streams (mean difference +1.24) and in the unrestored streams (+1.12) and greater in both ($p = 0.006$ and $p = 0.014$, respectively) than in the natural streams (+0.36).

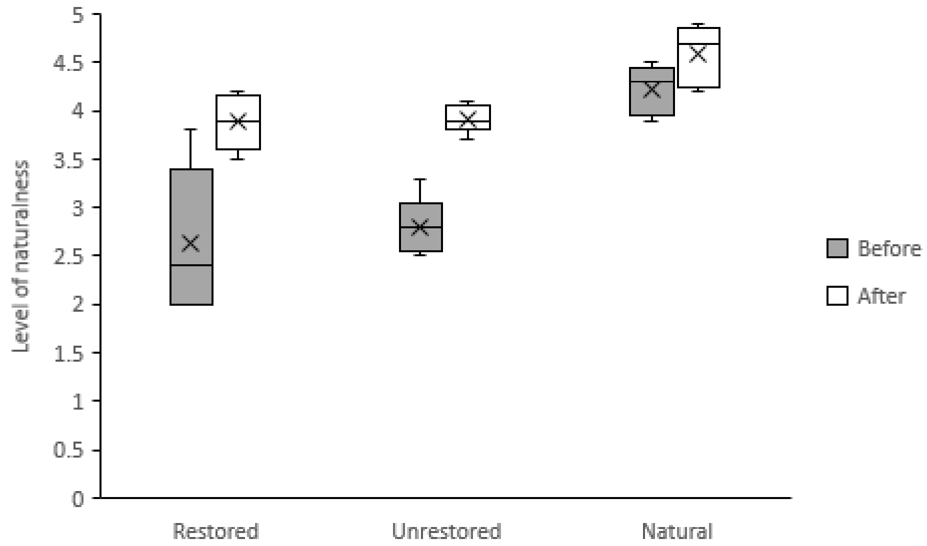

Figure 5. The mean score (x) and median (horizontal line), of the level of naturalness among the three stream groups before and after restoration, with interquartile range (box) and standard deviation (whiskers). The classification used for the level of naturalness was as 0 = low protection value, “dredged stream” 1 = low protection value, “forest ditch” 2 = state highly weakened, “gutter” 3 = state weakened 4 = state slightly weakened 5 = fully natural, no human induced changes.

4.3. The percentage of sand as a primary bottom substrate

Before any restoration activities were conducted, there was a statistically significant difference ($F = 5.100$, $p = 0.025$, $n_p^2 = 0.459$) in the percentage of sand as a primary bottom substrate among the stream groups (Figure 6). The natural streams had much lower (mean 12%) percentage of sand in their stream sections than the restored (60.4 %, $p = 0.011$) and the unrestored streams (51.8%, $p = 0.03$).

After the restoration the percentage of sand in the restored streams (mean difference -19 %) and in unrestored streams (−18 %) decreased almost the same amount and increased in the natural streams (+16.8 %). The difference in change among the stream groups was statistically significant ($F = 4.206$, $p = 0.041$, $n_p^2 = 0.412$). The restored ($p = 0.026$) and the unrestored ($p = 0.029$) streams differed from natural ones. There was no statistically significant difference between the restored and unrestored streams ($p = 0.944$).

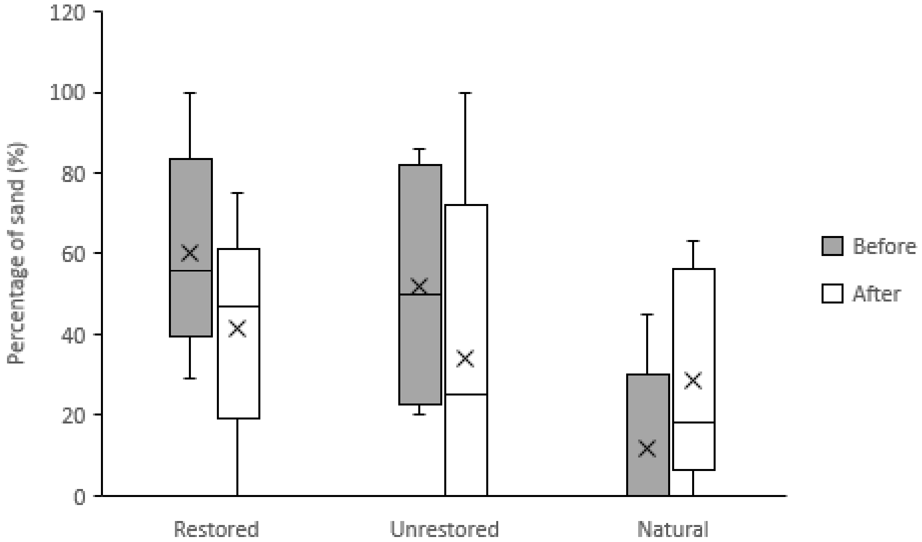

Figure 6. The mean score (x) and median (horizontal line), of the percentage of sand as a primary bottom substrate among the three stream groups before and after restoration, with interquartile range (box) and standard deviation (whiskers). The classification used for the percentage of sand was from 0-100%, percentage of each stream section.

4.4. Amount of pools

Before the restoration, the restored streams had less pools in their stream sections (mean 1.4) than the unrestored streams (1.88), whereas the natural streams had the lowest amount of pools (1.28). However, the difference in the amount of pools among the stream groups (Figure 7) was not statistically significant ($F = 0.662$, $p = 0.534$, $n_p^2 = 0.099$).

After the restoration measures the amount of pools in the restored streams increased slightly (mean difference +0.38), decreased in unrestored (−0.32) and increased in the natural streams (+0.36). However, the change in the amount of pools was not significantly different among the stream groups ($F = 1.256$, $p = 0.320$, $n_p^2 = 0.173$).

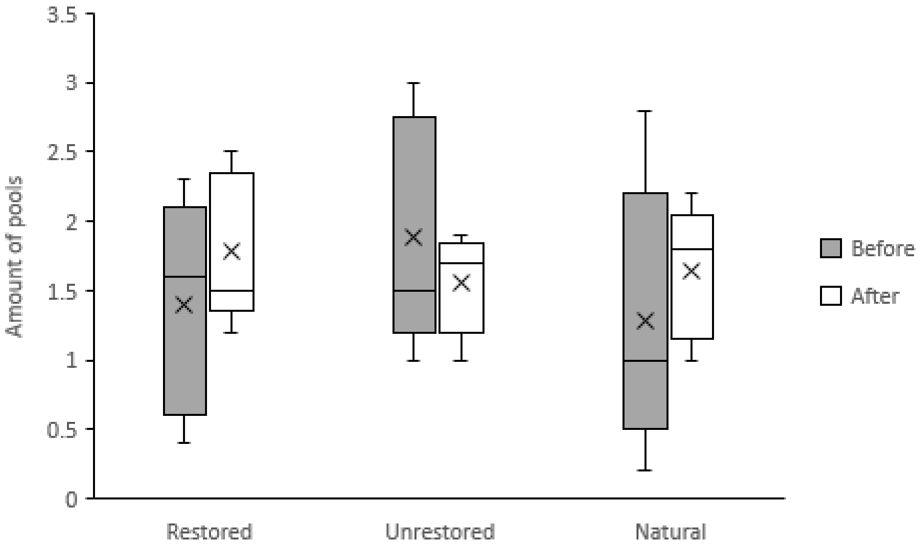

Figure 7. The mean score (x) and median (horizontal line), of the amount of pools among the three stream groups before and after restoration, with interquartile range (box) and standard deviation (whiskers). The classification used for amount of pools was as 0 =missing 1 = perceivable 2 = scarce 3 = moderate 4 = considerably 5 = abundant.

4.5. Level of meandering

Before the restoration, the level of meandering increased from the restored streams (mean score 2.04), and unrestored streams (2.32) to the natural streams (2.58) (Figure 8). However, there was no statistically significant difference among the stream groups ($F = 1.581$, $p = 0.246$, $n_p^2 = 0.209$).

After the restoration measures, the level of meandering increased from the before-restoration situation in the restored streams (mean difference + 0.32) and in the unrestored streams (+ 0.18). In the natural streams the level of meandering decreased slightly (−0.12). However, the change in the level of meandering among the groups was not quite significantly different ($F = 0.515$, $p = 0.610$, $n_p^2 = 0.079$).

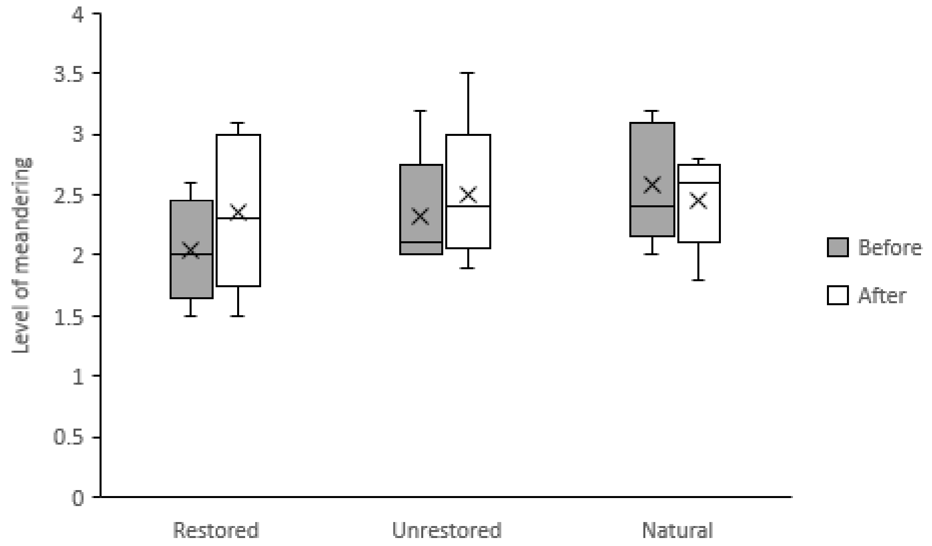

Figure 8. The mean score (x) and median (horizontal line), of the level of meandering among the three stream groups before and after restoration, with interquartile range (box) and standard deviation (whiskers). The classification used for the level of meandering was as 0 = no meandering 1 = perceivable meandering 2 =scarce meandering 3 = moderate meandering 4 = considerable meandering 5 = highly meandering.

4.6. Number of spawning places of fish

Before the restoration the restored streams had the highest number of spawning places (mean 0.88), the unrestored streams situated in the middle (0.74) and the natural streams had the least of spawning places (0.62), but there was no significant difference ($F = 0.256$, $p = 0.778$, $n_p^2 = 0.041$) among the stream groups (Figure 9).

After the restoration, the estimated number of spawning places in the restored streams increased slightly (mean difference +0.06), decreased in the unrestored streams (−0.08) and increased in the natural streams (+0.06). Nevertheless, the change in the number of spawning places did not differ among the stream groups ($F = 0.149$, $p = 0.863$, $n_p^2 = 0.024$).

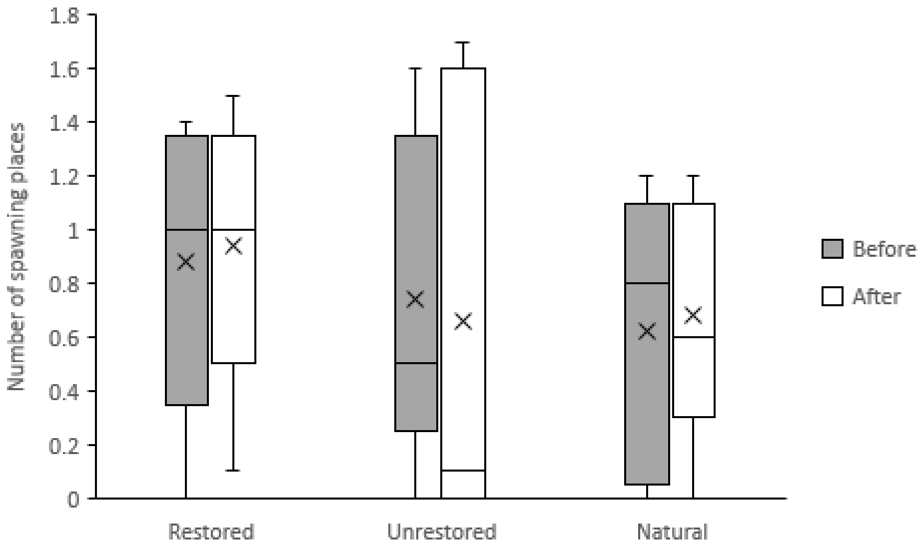

Figure 9. The mean score (x) and median (horizontal line), of the number of spawning places among the three stream groups before and after restoration, with interquartile range (box) and standard deviation (whiskers). The classification used for the number of spawning places was as 0 =missing 1 = perceivable 2 = scarce 3 = moderate 4 = considerably 5 = abundant.

4.7. Channel width variation

Before the restoration measures, the restored streams had least width variation (mean 1.88), unrestored streams situated in the middle (2.08) and the natural streams had the highest level of width variation (2.44). However, the difference in the channel width variation among the stream groups (Figure 10) was not statistically significant ($F = 1.798$, $p = 0.208$, $n_p^2 = 0.231$).

After the restoration measures, the channel width variation increased in the restored streams (mean difference +0.3) and decreased in both unrestored (−0.18) and in natural streams (−0.3). However, there were no statistically significant differences in change among the stream groups ($F = 1.597$, $p = 0.243$, $n_p^2 = 0.210$).

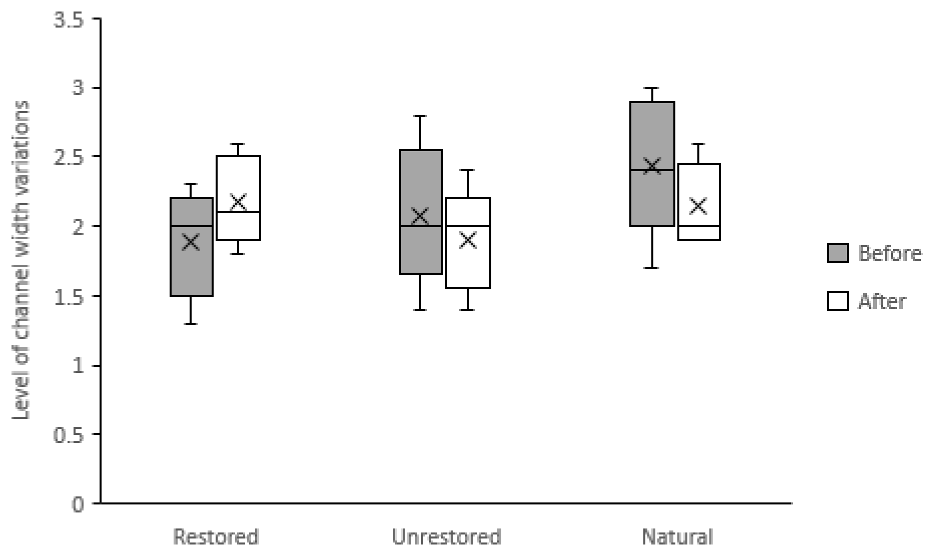

Figure 10. The mean score (x) and median (horizontal line), of the level of channel width variation among the three stream groups before and after restoration, with interquartile range (box) and standard deviation (whiskers). The classification used for the level of channel width variation was as 0 = no variation 1 = perceivable variation 2 =scarce variation 3 = moderate variation 4 = considerable variation 5 = high variation.

5. DISCUSSION

5.1. Effects of restoration

The results of this study indicated that the amount of wood in the restored streams had increased after the restoration measures. Restoration brought the restored streams to the same level with the natural streams. This is clearly explained by the fact that most of the used restoration measures were adding of woody debris to the stream and constructing deflectors and log jams. In addition, the "after" inventory was executed in a way that human made wooden structures were considered natural to the stream. Amount of wood decreased in the unrestored reference streams and increased slightly in the natural streams. The unrestored streams were selected from a group of streams which were on the same level as the restored streams before restoration, having therefore an urgent need for restoration. Probably, the condition of these streams, when it comes to wood in the stream channel, has continued to deteriorate, whereas natural streams have got more wood input from the stream banks, probably in the form of fallen trees.

The level of naturalness increased in the restored streams. Restoration brought the restored streams closer to the natural streams, however they did not quite reach to the same level. Interestingly, the level of naturalness increased both in the unrestored and natural streams as well. This can be explained with the fact that no further man-made alterations have been made to the streams since the last inventory and the streams have been able to recover. Natural streams had improved their status slightly or alternatively the slight change in the naturalness can be due to differences in the individual opinions of the people doing the inventory. The pre-restoration state of these the restored and unrestored streams were relatively poor and these results show that the streams can recover and develop towards a more natural state on their own if the human disturbances on the catchment area are reduced or stopped completely. However, it is still unknown how extended period of time is required before a new, ideally more natural status (when compared to pre-restoration conditions) of the stream is attained (Januschke et al. 2014). The observed rise in the level of naturalness in the restored streams cannot be declared as a positive outcome of the restoration measures, as an equivalent change was observed in unrestored streams.

Sedimentation is a natural fluvial process within the streams. However, it can turn into a stressor on periphyton production (Izagirre et al. 2009), leaf decomposition (Sponseller & Benfield 2001) and on benthic macroinvertebrates (Jones et al. 2012) when exceeding a particular level. Blogging of forestry drainage ditches, building of log weirs and flow deflectors were done to reduce the amount of deposited sediments in the channels. The percentage of sand as a primary bottom substrate in both restored and unrestored streams decreased during the period between the before and after inventories. Restored streams got closer to the natural streams in their amount of sand, however this was mostly explained with the increase of sand in the natural streams. Without the increase of sand in the natural streams the restored streams would have had even bigger difference. These results support the results by Niemelä (2016) from the Iijoki catchment area. She examined 9 streams and compared them with 11 reference and 12 sedimentation affected streams. Restored streams were restored during 2004–2010 and according to her results the amount of sand decreased in the streams. However, there was a great variation in the success of sand removal in the restored streams. This can be explained according to Niemelä (2016) by the fact that in some of the streams catchment scale restoration was also conducted, which then improved the situation in those streams. In Hoikanoja and Laukkupuro catchment scale restoration were added on top of other measures while the other streams had only stream channel restoration conducted. However, based on the slightly different restoration measures no clear difference in the decrease of sand can be observed in the stream individual level. There was a decrease in the amount of sand also in the unrestored streams. Natural streams, however, had an increase in the percentage of sand in the stream channels. Unrestored and restored streams might have benefitted from the recovery time and from the fact that no timber logging has been conducted in the recent years. The increase in the amount of sand in the natural streams can be due to channel bank erosion or some disturbance in the catchment area. Some of the natural streams were flowing in a terrain where sand was the dominant soil type which can partly explain the increase. In addition, the hydrological conditions during the different years might have been affecting the erosion rates and floods, therefore increasing the amount of sand. When examining the direction of the change in the percentage of sand among the stream groups, it cannot be declared that restoration measures are the only reason for the decrease in the amount of sand in the restored streams.

The amount of pools in the restored streams increased slightly, however the change, when compared to reference stream groups, was not statistically significant. Restored streams exceeded natural streams in the amount of pools, however there was a higher amount of pools already before restoration measures, which indicates that when it comes to pools, there was no urgent need for restoration. Comparable results came from a study conducted by Muotka & Syrjänen (2007) where they examined the effect of restoration in three forest streams in Central Finland. The streams were surveyed before and 2 years after restoration and only in one of the streams the amount of pools had increased slightly. Studies conducted on the stream channel physical response to placed wood have showed that wood leads to increases in the amount of pools. However, the magnitude of the response varies from one study to another, which makes it extremely difficult to assess how much wood is needed to evoke a change in physical habitat conditions. The magnitude of change appears to be greatly linked to the size, type and amount of placed wood and geomorphic settings (for example sediment supply, hydrology, and channel slope) (Roni et al.2014). However, another study conducted by Zika & Peter (2002) reported restoration success in a Swiss stream. They placed whole trees in a 2km reach of channelized stream and discovered that the mean water velocities, volume and number of pools increased after the placement of large woody debris in comparison to the control sections. The number of pools in the wood sections was remarkably higher in the study area (9.1 pools/100m) than in the control sections (5.5 pools/100m). In addition, volume of the pools was greater in the wood sections (total volume of 17m^3) than in the control sections (2.2 m^3). These results show that wood structures are a key factor in regulating pool formation and characteristics. Change in the amount of pools in the unrestored streams showed a decreasing trend. For example, the lack of woody debris could explain the decrease in the formation of pools. In the natural streams amount of pools increased, which might reflect the increase in the amount of wood. Based on the results, it is possible that the restoration measures have been successful in creating more pools in the restored streams.

Level of meandering showed slight increase in the restored and unrestored streams. In the natural streams meandering decreased. Restored streams got a bit closer to the natural streams. However, since the change was relatively small in all the stream groups, it is hard to conclude whether the adding of wooden structures have caused the increase in meandering or is the change due to different opinions while conducting the inventory. The results also question the need for restoration when it comes to enhancing meandering. The effectiveness of restoring meandering can be measured for example by an increase in the total stream length. Iversen et al. (1993) reported stream length increases ranging from 17% to more than 60% for five stream restoration projects in Danish streams. When looking at the directions of the meandering changes among the stream groups, it is not clear that the conducted restoration measures were behind the increase in meandering.

The success in creating spawning places for fish varied among the different stream groups. Restored streams had the highest number of spawning places within the channels before any restoration measures and the amount grew slightly after restoration. Spawning places in the unrestored streams had decreased when compared to the earlier inventory. In the natural streams number of spawning places had increased slightly. However, the change among the stream groups was not statistically significantly different. Creation of spawning places is dependent on various aspects of the channel, for example on the type of bottom substrate, water depth and flow speed (Eloranta 2010). If one of these aspects is compromised, ideal spawning places might not be formed. In the natural streams the conditions for pool formation seemed to be sufficient. The purpose of placing log structures (such as deflectors, logs and weirs) in to the channel is to form pools, create cover and spawning area for fish and trap gravel (Roni 2005). Previous studies show that placement of instream structures appears to be successful in increasing fish abundance, but the gained results are highly variable on the used structure type, fish species and the life stage of the fish (Roni et al. 2005). Studies conducted by Hunt (1988) and Avery (1996) showed that by installing deflector structures and increasing bank cover local abundance of brown trout increased by 25% or more. In addition, the size and biomass of trout increased. Saunders and Smith (1962) found increased abundance of brook trout 1 year after weir, deflector and cover structure placement in a stream on Prince Edward Island, Canada. However, no increase in fish growth was observed. When looking at the directions of the changes between the stream groups, it cannot be declared that restoration measures were behind the observed increase in the number of spawning places in the restored streams. The increase was so slight that it can be due to differences in inventory styles.

The channel width variation showed a slight increase in the restored streams and brought them at the same level with the natural streams. This may be explained with the fine material such as sand entering the stream from the catchment areas, added wood, stream bank erosion and from natural fluvial processes. Impacts of restoration on the physical habitat of streams have been studied previously in the Iijoki drainage area and in a study conducted by Yrjänä (2003) where a 22–53% increase in one of the dredged river channel width had been reported. After the construction of large boulder dams and other in-stream structures such as cobble ridges and deflectors the channel width approached the streams' original width. The cross section of the studied stream channel changed from U- or V-type to a wider and more diverse shape. The channel width decreased in the unrestored and natural stream groups over time. The differences between before and after situations are not extensive so it is hard to draw conclusions. In the case of natural streams, the channels might have straightened due to the hydrological changes which have resulted in increase in the amount of sand and in the unrestored streams the lack of wood and stones can keep straightening the channel. Alternatively, the observed changes are only differences in the inventory person's opinions. When looking at the directions of the changes among the stream groups it can be declared with caution that the restoration measures have been successful in enhancing channel width variations.

Limitation of this study was that only 5 restored streams were examined due to restricted resources. Catchment scale characteristics between the different stream individuals can also affect the results gained from this study and by including more streams to the future studies more comprehensive results from the effects of restoration can be expected. Because of the small amount of examined streams, only general conclusions can be made.

Amount of wood, naturalness, amount of sand and the channel width developed in the desired direction in the all the restored stream individuals. Two restored stream individuals out of five (Keskijärvenoja and Ohtalammenoja) did not have an increase in the amount of pools. One restored stream out of five (Ohtalammenoja) did not have an observed increase in the level of meandering. One restored stream out of five (Hoikanoja) had a slight decrease in the number of spawning places and in one other restored stream the number of spawning places stayed the same (Laukkupuro). Approximately one third of the streams sections had been restored and since some of the streams were situated on a privately-owned land, restoring more sections would have not been possible. The conducted restoration measures varied somewhat among the stream individuals and for example different amount of wood were used, which might explain some of the failures. To get more detailed information of the possible reasons behind the failure of these stream individuals in reaching the restoration targets another field inventory could be conducted and the practises used in the successful stream individuals could be replicated to the other streams.

5.2. Durability and the future use of the wood

The amount of wood in the restored streams after 7–14 years stayed reasonably high and the improvement compared to the before restoration state of the streams was positive. However, the stability and structural success of the wooden structures had failed in few streams. This was mainly the case when the water flow had been guided to the old natural channel and the man-made channel had been blocked with a dam. These dams were leaking, and the water was still flowing to the current channel. This can be the result of failure while constructing the dams or exceptionally strong floods in the area which then damaged the dams. One study reporting the structural success (stability) rates of wooden structures in a meadow stream in California stated that 24% of the instream structures were still in place and functioning after 18years (Ehlers 1956). However, the structural success rates were remarkably better in a long-term study reported by Thompson (2002) who stated that 48% of the instream structures were still functioning after 50 years in the Blackledge and Salmon rivers in Connecticut. Highest failure rates have been reported in the streams with high sediment loads and unstable channels (Frissell & Nawa 1992). The size (length, diameter), type (natural, fixed or mobile) and amount of placed wood affects the magnitude of the physical response of the stream. In addition, the stability and longevity of the wood and the geomorphic settings (for example channel slope, sediment supply and hydrology) influence the response. How much and what is the correct size of the placed wood is still unclear and there are several studies conducted with variable amounts and types of wood (Brooks 2006, Nagayama & Nakamura 2010). However, it is inevitable that the wooden structures will "fail" or start to decay at some point and then it is important to remember that in a degraded stream any wood in the stream is good wood from an ecological perspective (Brooks 2006). Wood is a natural part of the stream channels in most of the streams and although wood placement might meet the short-term restoration objectives of the restoration projects it does not enhance the process that naturally delivers wood to the stream channels. Long term and self-sustaining levels of natural wood in streams require combining wood placement with riparian zone restoration to support the natural sources of woody debris (Beechie et al. 2010, Roni et al. 2015). In the future, more wood could be used as a restoration material and planting of trees to the formerly cleared riparian zones could in the long run enhance the stream ecosystems.

5.3. Evaluation of the small stream inventory method

The inventory method created by Metsähallitus seems to give relevant information about the changes in the stream channel. It is a suitable method for monitoring the streams after restoration. The method is fairly easy to use and easy to teach to people engaged in restoration projects. With the method comes an inventory manual which works as a reminder and helps with the interpretation of the observed variables in the field.

Few minor limitations of the inventory method could be detected. Same person should be doing the inventory at the same time, “before” and/or “after”, in all the stream groups so that possible differences in opinions will be systematic. Only then comparisons between the groups and conclusions of the restoration effects can be made. In addition, the persons doing the inventory have to be somewhat consistent in their evaluations and have a suitable background for this kind of work.

More detailed answers of the restoration success could be attained if each stream would be compared with otherwise similar design but with stream section by section and when developing the method even further, more objective measurements would be in order. Instead of calculating the averages for each stream section, a weighted average according to the stream section’s length could be used. By doing the calculations this way, the problems created by different amounts of stream sections and possibly slightly different inventory distances could be avoided. In addition, by knowing the exact locations of each stream sections while conducting the after inventory, photographs of the change could be compared even on site and the changes in the channel form could be more easily detected. There can be a slight danger when not comparing the changes section by section that some of the changes might be left unnoticed. The scale of the desired level of monitoring details can vary among restoration projects and in some cases more overall picture of the restoration effects is sufficient enough.

Including reference streams to a study which aims to evaluate the success of restoration measures is highly important. Reference streams bring out the changes caused by restoration measures and eliminate the background effects which could cause changes in the streams.

6. CONCLUSIONS

Humans and human actions have a significant role in protection of the valuable stream ecosystems in Koillismaa area. The future of these streams is highly dependent of the future land use decisions, protection willingness, adequate funding and allocated resources. The aim of this study was to provide material to support the future restoration decisions and to investigate if by restoring streams positive impact can be made to the stream channel diversity.

Restoration measures conducted (blocking of forestry ditches, adding free flowing wood and wooden structures to the streams, opening old channels and adding stones back to the stream) had an impact on the streams. Restoration measures seemed to increase the amount of wood and possibly created more pools and enhanced channel width variations in the restored streams. Even during the relatively short recovery period of 7–14 years change could be seen in the stream channels and a natural recovery of the unrestored reference streams was also detected in few variables such as in the amount of meandering, percentage of sand as primary bottom substrate and in the level of naturalness.

This study highlighted the importance of long-term monitoring of restoration projects, use of reference streams and strengthened the foundations for future restoration projects. Finally, the present results indicate that the small stream inventory method that have been applied to hundreds of streams in the River Iijoki area seems to be a suitable tool in detecting the changes in the streams after restoration. This inventory method could be used in the future monitoring as well and it can be possibly even further developed when comparing the calculations gained from the stream sections.

In the future restoration projects, using wood as a restoration material is highly justified and even more wood could be used alongside with riparian zone tree planting and catchment area restoration.

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