Aspects of erosion of restored trout spawning beds in two streams in Northern Sweden

Erosion av restaurerade lekbottnar för öring i två bäckar i norra Sverige

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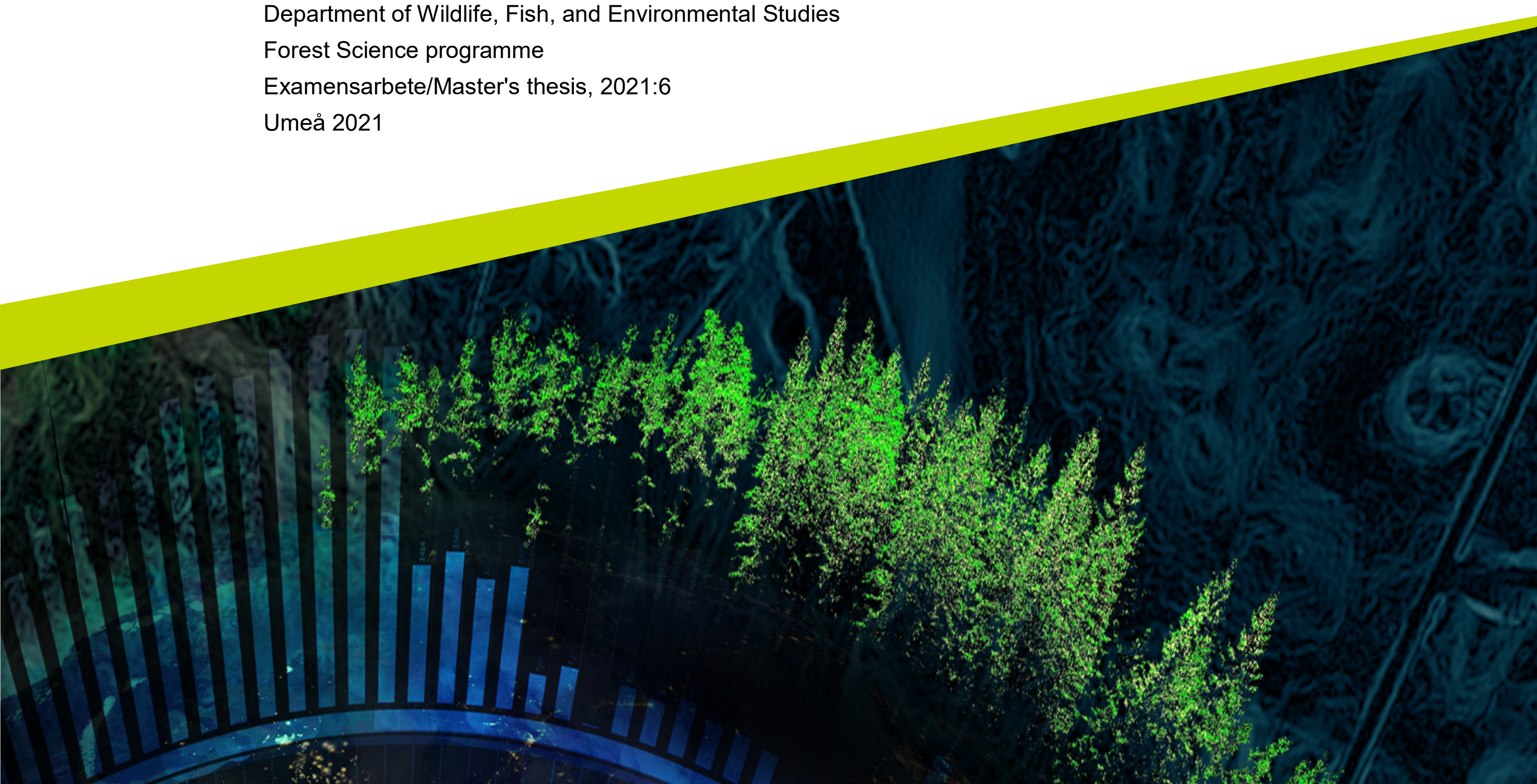
Master’s thesis • 30 credits
Swedish University of Agricultural Sciences, SLU
Department of Wildlife, Fish, and Environmental Studies
Forest Science programme
Examensarbete/Master's thesis, 2021:6
Umeå 2021



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Credits:	30 credits
Level:	Second cycle, A2E
Course title:	Master’s thesis in Forest Science, A2E - Wildlife, Fish, and Environmental Studies
Course code:	EX0969
Programme/education:	Forest Science programme
Course coordinating dept:	Department of Wildlife, Fish, and Environmental Studies
Place of publication:	Umeå
Year of publication:	2021
Title of series:	Examensarbete/Master's thesis
Part number:	2021:6

Keywords: in-stream restoration, reproductive habitat, Salmonids, passive integrated transponders tags (PIT-tags)

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Abstract

Many rivers and streams in northern Sweden have been channelized due to timber floating. This has severely degraded the spawning habitats for salmon and trout, and therefore a common action when restoring channelized rivers is to establish new spawning beds by adding gravel to the streambed. However, little is known about the longevity of these spawning beds, and erosion caused by both water discharge and spawning fish may move gravel/pebbles out the spawning bed, gradually decreasing their functionality.

In this thesis, I studied erosion of eight spawning beds (approx. 5 x 2 m), constructed in two different streams, Storkvarnbäcken and Mattjokkbäcken, in northern Sweden. In total, 643 pebbles were tagged with half-duplex passive integrated transponder tags and placed on newly constructed spawning beds, which made it possible to study their movement over multiple years by scanning the spawning beds with PIT-tag reader/antennas.

The overall objectives for this study were to quantify and describe erosion process of constructed spawning beds. More specifically, I investigated the effect of streambed slope and pebble size on the distance substrate were moved by erosion processes, and on the likelihood of substrate remaining on the spawning bed. Further, I evaluated different methods used to position PIT-tagged pebbles in boreal streams (conventional GPS, High Precision GPS, and Laser distance meter), and specifically investigated precision and accuracy of commonly used GPS-systems integrated in PIT-tag reader units.

Overall, recovery of PIT-tagged pebbles by scanning spawning beds with PIT-tag antennas were high despite multiple years between the deployment of pebbles and the scanning. 85 % of pebbles were found in Storkvarnbäcken 8 years after deployment, and 60 % were found in Mattjokkbäcken 6 years after deployment. There was a big difference between the two study streams in the proportion of recovered pebbles that had remained on the spawning beds (82% remaining in Storkvarnbäcken, and 45% in Mattjokkbäcken), and the probability of pebbles being found outside the spawning bed were significantly higher in Mattjokkbäcken.

The average distance pebbles had been moved by erosion was 1m in Storkvarnbäcken, translating into 0.13 m / year, and 6.21 m in Mattjokkbäcken (1,04 m /year). However, there was a considerable variation in erosion rate over time, and in Storkvarnbäcken the average distance moved was 0.48m the first month after deployment, after which erosion-rate decreased to less than 0.08/year, suggesting that average annual erosion rates should be used carefully.

There was a positive relationship between the slope of the spawning bed and the distance pebbles were moved by erosion, and pebbles located on spawning beds with a steeper slope had moved longer distances on average. Within the range of 0-3% slope, average distance increased from <1 m to >7m.

Erosion caused small pebbles (45-55mm) to move a significantly longer distance than medium sized pebbles (65-75mm), however no difference in distance moved could be found between small and large size (85-95 mm) pebbles.

In average, GPS integrated in PIT-tag reader units had very poor accuracy compare to high-precision GPS (Mean Absolute Error (MAE) 4.7m), and to laser-distance meter (MAE 2.5m). Also, the precision of pebble distances calculated using integrated GPS were low, (±2.87m for mean distances in Storkvarnbäcken, ±1.34m for Mattjokk). The MAE for the high precision GPS was somewhat higher than when using the laser, which indicates that the high precision GPS is closer to the true value.

Results are discussed based on the many interacting factors underlying erosion rates and spawning bed longevity, and the way the results could be used as guidelines for construction of trout spawning beds.

Keywords: in-stream restoration, reproductive habitat, Salmonids, passive integrated transponders tags (PIT-tags)

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1. Introduction

Today restoration is receiving increasing attention, both the Convention on Biological Diversity and the United Nations have proclaimed 2021-2030 as the decay of restoration (United Nations u; Convention on Biological Diversity 2018). The European Commission has also stated restoration of ecosystems as one of their main element in their strategy for 2030 (European Commission u). Restoration actions in aquatic systems are being undertaken due to the degradation caused by various human activities (Council et al. 1992). However, within the discipline of river restoration the literature is sparce (Buijse et al. 2002) and most of the studies have been conducted over a short period of time (Roni et al. 2008; Morandi et al. 2014). When looking at the biotic response and the physical changes of a river post restoration, long time studies are needed (Kondolf & Micheli 1995; Nilsson et al. 2015). Kondolf and Micheli (1995) recommend that the monitoring of effects post restoration should be conducted for a period of at least 10 years since it takes time for the channel to adjust to the geomorphological adjustments followed by in stream restoration and floods that may modify the channel.

The river restoration activities are often focusing on re-establishing the reconnection of floodplains or to create a more variable habitat by adding instream structures like boulders or logs (Roni et al. 2008). These river restoration activities can sometimes have extensive costs. Between the years 2003-2006, 55 million Swedish crowns were registered to river restoration annually, however the county administrative board estimate that the actual cost was approximately 100 million (Riksantikvarieämbetet et al. 2007). Most river restoration projects have the main focus to improve the situation for the fishery resource (Roni et al. 2008). One fishery resource that is commonly targeted by river restoration is the Salmonids (Merz et al. 2004; Palm et al. 2007, 2010). One of the Salmonids found in Sweden is the Brown trout (*Salmon trutta*). The trout is spawning in the autumn and the spawning usually takes place close to where it was once hatched, a behaviour called homing (Fiskeriverket 2001). After some digging the female trout select a suitable spot for the spawning (Jones & Ball 1954; Fleming 1996) where the eggs will be buried at a dept proportional to the length of the female (Fiskeriverket 2001). The eggs will be hatched in the spring the following year (Fiskeriverket 2001).

The trout and other Salmonids has declined and in some areas been exterminated over vast parts of their native range (Parrish et al. 1998). The decline of salmonids is often driven by anthropogenic actions (Waples & Hendry 2008). One such anthropogenic action is the historical usage of the rivers for timber floating, which have altered the physical attributes of the rivers (Östlund & Zackrisson 1997; Törnlund & Östlund 2006; Nilsson 2007).

1.1. Timber floating

The rivers in the north of Sweden have played an essential role for the large-scale exploitation of the forest taking place during the industrialisation of the country since there was no proper industrial transport infrastructure existing (Törnlund & Östlund 2006). By the end of 1930's, 18 million cubic meter of timber were floated annually and the floating network covered 30,000 km, consisting of 14,350 km main float ways (rivers) and 18,570 km of minor float ways (streams and creeks) (Törnlund 2002; Nilsson 2007). The rivers and streams used for floating have been channelized for making the floating easier and some common actions have been building of dams and clearing the rivers and streams from boulders and rocks to avoid logjams (Östlund & Zackrisson 1997; Törnlund & Östlund 2006; Nilsson 2007). However, these boulders and rocks have several functions in the water. First they provide habitat for juvenile and adult salmonids (Palm et al. 2007), secondly the boulders and rocks reduce the water velocity that in turn lower the sediment transport (Nilsson 2007). The removal of boulders and rocks have therefore resulted in loss of fine sediment and gravel due to the increasing water velocities which have led to spawning beds being flushed away (Nilsson 2007).

1.2. River restoration

Due to the limited sediment recruitment in the northern parts of Sweden (Rosenfeld et al. 2011; Nilsson et al. 2015) and the fact that the availability of spawning beds seems to be a limiting factor for the salmonids (Palm et al. 2007; Hauer et al. 2020), a common action of river restoration is to establish new spawning beds. Research looking at the biological function of restored spawning beds has shown positive impact on the fry, adult or spawning activity (Merz et al. 2004; Rubin et al. 2004; Palm et al. 2007). However, there are few studies looking at the longevity of spawning beds. Previous research have shown that high-water velocities during flooding and spawning activities cause bedload transport (Gottesfeld et al. 2004; Hassan et al. 2008). During the redd excavation the morphology of stream beds are modified and the bead load transport is increased by direct sediment movement (Gottesfeld et al. 2008; Hassan et al. 2008). Since the river restoration projects often have a limited budget the projects need to be prioritized. When making these priorities and for reaching a successful restoration project it would be useful to know if there are certain factors affecting the rate of transport for the gravel making a stream less suitable for establishing new spawning beds or not (Tritthart et al. 2019). Two factors of interest are the slope of the spawning beds and the size of the gravel. A greater slope could increase the concentration of oxygen in the spawning bed, which is important for the egg survival (Fiskeriverket 2001), but potentially the erosion of the spawning beds will increase and thus reduce the longevity of the spawning beds. The size of the gravel preferred by the female trout for spawning seem to be ranging between 20-70mm (Näslund 1992 see Fiskeriverket 2001), it would thus be of interest to see if there is a difference in the erosion depending on the size of the pebbles. Tracing the gravel is a way to obtain information about rate of transport and thus also the stability of the beds (Tritthart et al. 2019).

1.3. Evaluation of method

During the last decade, the use of passive integrated transponders (PIT-tags) to analyse the erosion of gravel beds has increased (Houbrechts et al. 2015). By using PIT-tags the pebbles can be localised by their unique identification number without any need to disturb the bed since the gravel doesn't need to be handled for identification (Houbrechts et al. 2015). For localisation of the PIT-tags an antenna is used, as the electronic field from the antenna activates the microchip in the PIT-tags (Houbrechts et al. 2012). For positioning the pebbles, GPS (Staehly et al.; Arnaud et al. 2017) and laser (Tylstedt 2013; Rainato et al. 2018) have been used. However it has been shown that the accuracy and reliability for GPS receivers vary greatly (Wing et al. 2005). It would therefore be of interest to evaluate the precision and accuracy of a conventional handheld GPS for positioning the pebbles compared to using a laser or a high precision GPS.

In this study spawning beds have been established in two different study sites in the North of Sweden. Some of the pebbles have been tagged with half-duplex passive integrated transponder (PIT) tags making it possible to study the movement of the pebbles.

1.4. Objectives for the study

Since the knowledge about the longevity and erosion of restored spawning beds is sparce the objectives for this study are (1) to quantify and describe erosion process of spawning beds (2) to determine if there is a difference in the probability of pebbles leaving the spawning beds between the two streams (3) to determine if the slope of the spawning beds have influenced the distance moved (4) to determine if the size of the pebbles affect the distance moved and (5) to determine the precision of the locations given by a conventional GPS and its accuracy for localising pebbles compared to using laser or a high precision GPS.

2. Methods

2.1. Study sites

The study comprises two streams, Storkvarnbäcken and Mattjokkbäcken, located in the north of Sweden (Figure 1).

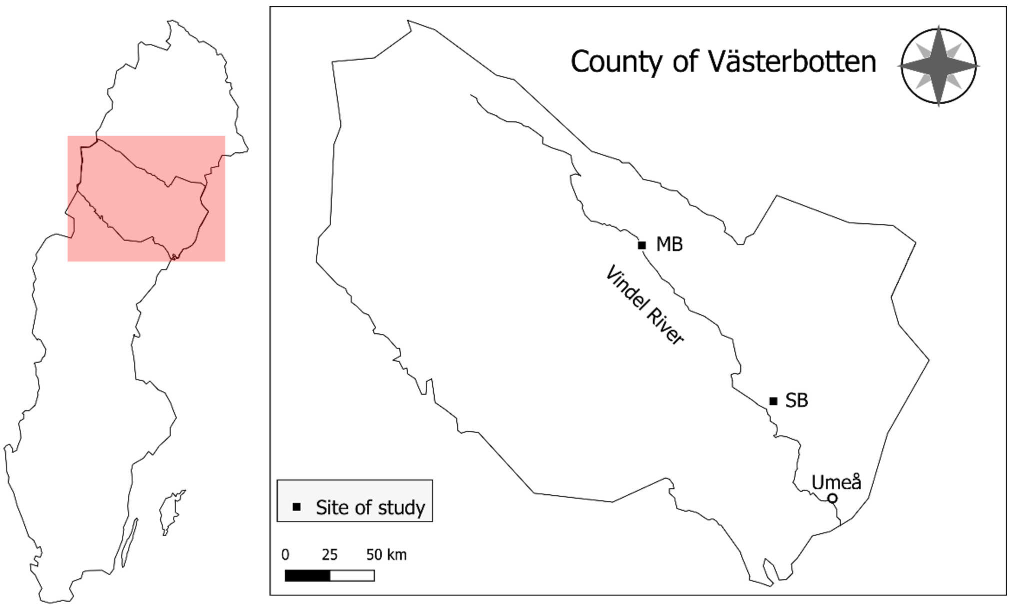

Figure 1. Location map of the two streams of study, Storkvarnbäcken (SB) and Mattjokkbäcken (MB)

The two streams are both tributaries to Vindel river. Vindel river runs from the Fennoscandia mountain range in the west towards the Baltic sea in the east (Figure 1). The length of SB is 3km and it is situated between the lake Stor-Sandsjön and Hjuksån Mattjokkbäcken has the length of 4km and is situated between the lake Kvarnträsket and Vindel river. SB is located at the altitude of 220-255m and Mattjokkbäcken on an altitude of 260-331m. At the spawning beds, the channel of

SB has a slope ranging between 0.04-0.6 % and 1.9-2.2 % for Mattjokkbäcken. The discharge of both streams follows a simple nival regime whit a peak of discharge during April to May. Over the three decades, 1981-2010, SB had an annual average water discharge of 0,60m^3/s, typically ranging from 0.26m^3/s to 1.44m^3/s; Mattjokkbäcken had an annual average water discharge of 1.71m^3/s, typically ranging from 0.38m^3/s to 8.99m^3/s (SMHI & Havs och Vatten myndigheten u)

During the period 2011 to 2018, electrofishing has been conducted at five occasions in SB (Sveriges lantbruksuniversitet 2020). The total average density of individuals was 100,4 per 100m^2, out of which 81,4 individuals were yearlings and 19 were older. Resident fish found during electrofishing in SB include Brown trout, Common bleak (*Alburnus alburnus*) European bullhead (*Cottus gobio*), grayling (*Thymallus thymallus*), Lamprey (*Petromyzontidae*), northern pike (*Esox lucius*). Since 2010, yearly electrofishing has been conducted in Mattjokkbäcken, the total average density of individuals was 396.7 per 100m^2, out of which 156.4 were yearlings and 240.3 were older (Sveriges lantbruksuniversitet 2020). Resident fish found during the electrofishing in Mattjokkbäcken include Brown trout, burbot (*Lota lota*), European perch (*Perca fluviatilis*), grayling and salmon (*Salmon salar*).

The sea trout arrive at the time of spawning that occurs during the last weeks of September and the first weeks of October (Lundqvist & Östgren 2015). The trout spawning in Storkvarnbäcken is resident or adfluvial were as the trout spawning in Mattjokkbäcken is resident or sea trout.

2.2. Construction of spawning beds

The spawning beds were constructed by placing boulders in a horseshoe like formation in which gravel were dispersed (Tylstedt 2013). The idea of the boulders is that they will prevent the gravel from leaving the bed and increase the current velocity and thus also the oxygen supply. The oxygen supply is important for the development of eggs and larvae of trout (Gottesfeld et al. 2004).

For the selected pebbles a grinder was used to make a slot where 4×23mm half-duplex passive integrated transponder (PIT) tags where fixated using epoxy glue. The tagged pebbles were painted white for making visual detection under water easier. The tagged pebbles were given a soft push into the gravel bed to reduce the risk of the PIT-tag marked pebbles being more prone to move than the non-tagged pebbles (Tylstedt 2013).

The five spawning beds in SB were constructed during the summer and fall of 2011 (Tylstedt 2013). Gravel in the size of 1-5cm in diameter were dispersed within the horseshoe like formation covering an area of approximately 2×5m. The pebbles with a diameter ±5mm of the median diameter was selected and tagged with PIT-tags. Late in September 2012, the 373 pebbles tagged with PIT-tags were deployed over the spawning beds in a grid with spacing of 0.3m between each pebble in a cross section and 0.6m between cross sections (Figure 2 (d)). It was noted on which transect each pebble was deployed. Reinforcing bars were placed at the end of each spawning bed to create a perpendicular reference line (Figure 2 (d)) (Tylstedt 2013). In Mattjokkbäcken three spawning beds were constructed and a total of 270 pebbles tagged with PIT-tags was distributed over the three beds (Palm *et al.* u). Pebbles of three different diameter classes, 50, 70 and 90mm ±5 mm, were used. In December 2014, 90 PIT-tagged pebbles were placed (30 pebbles of each diameter class) in three transects located 0, 1 and 2m from the end of each spawning bed (Figure 2 (e)) (Palm *et al.* u). It was noted on which transect each pebble were deployed. Due to high water velocities no reinforcing bars were used to mark the reference line in Mattjokkbäcken.

Figure 2. (a) Photograph of Mattjokkbäcken looking downstream from spawning bed 2.2. (b) Photograph from Storkvarnbäcken looking upstream spawning bed 1.4. (c) The concrete building blocks with a wooden roof at spawning bed 1.1 in Storkvarnbäcken. (d) Illustration of the spawning beds in Mattjokkbäcken and the transect on which the pebbles were distributed and the placement of the reference point (red point).

2.3. Inventory

The first inventory of Storkvarnbäcken was conducted in October 2012, one month after deploying the tagged pebbles, when the position of each pebble in relation to the reference transect was measured (Tylstedt 2013). A stick reader (RS 320, Allflex) was used to recover the pebbles and their position was determined using a laser distance meter (LDM-100, CEM-Industry CO.) (Tylstedt 2013).

The second inventory of Storkvarnbäcken and the first inventory in Mattjokkbäcken were conducted during August to November 2020. Time since deploying the tagged pebbles and the second inventory was nine years for Storkvarnbäcken and six years for Mattjokkbäcken. During the second inventory, a BP Lite Portable Antenna combined with a HPR reader was used to search for the tagged pebbles. When reading a PIT-tag the HPR Plus will register a GPS position for the PIT-tag (Biomark u). For further precision of pebbles detected but not visually observed a stick reader (RS 320, Allflex) was circulated over the area to reduce the detection zone and thus improve the localisation accuracy. In Storkvarnbäcken a high precision GPS (Trimble Geo7X with Access, Rangefinder and a Zephyr antenna) with the maximum margin of error set to 5cm was used to position the tagged pebbles. Concrete building blocks located by spawning bed 1.1 (Figure 2 (c)) caused pore GPS-signal thus the distance to the reference line was measured by tape for 36 PIT-tags. Spawning bed 1.1 was scanned 100m downstream but due to time constrains the rest of the spawning beds were scanned 35m downstream or until reaching the next spawning bed. The spawning bed 1.2 to 1.5 were located within the distance of 100m. In Mattjokkbäcken a laser (Leica Disto X3) was used to measure the distance from the recovered pebble to a set reference point at the end of the spawning bed. When the laser point could no longer be seen the reference point was moved downstream. Since the pebbles in Mattjokkbäcken were not given a GPS position it was noted if the detected pebble was located on the spawning bed or not. At spawning bed 2.3 the reference point was placed one meter to far downstream. All registered distances on spawning bed 2.3 were adjusted for the misplaced reference point before making any analyses. The distance for pebbles found upstream the reference was reduced by a meter and one meter was added to the pebbles found downstream or at the reference line at spawning bed. All spawning beds in Mattjokkbäcken were scanned 40m downstream.

The slope of the spawning beds in Mattjokkbäcken had been measured in 2014 and the slope of the spawning beds in Storkvarnbäcken was measured in 2020 using an L400 Laser Instrument. When measuring the slope, the instrument was placed by the reference line or as close as possible to the reference line. The slope was then measured between two points, one as far upstream and one as far downstream as possible, at the shoreline on the opposite side of the stream.

2.4. Data analyses

R-studio version R-4.0.3 was used for all statistical analyses with package nlme (Pinheiro et.al. 2020), lme4 (Bates et.al. 2015), car (Fox & Weisberg 2019, multcomp (Hothorn et. al. 2008) and stats (R Core Team 2020). Further Microsoft Excel version 2010 and QGIS version 3.14 have been used to visualise the data.

In Storkvarnbäcken, the distance moved between time of deployment and the first and second inventory respectively was calculated, as well as the distance moved between the first and second inventory. In Mattjokkbäcken the distance moved between the year of deployment 2014 and the first inventory in 2020 was calculated. All distance moved that were less than 5cm was considered to not have moved and was set to 0 for both Storkvarnbäcken and Mattjokkbäcken.

2.4.1. Probability to leave the spawning bed

A Generalized Linear Mixed-Effects model with a binomial error distribution was conducted to test if there is a difference in the likelihood for the pebbles to leave the spawning beds between the two streams. The response variable was the position of the pebbles where the pebbles were given a value of 0 if still on the spawning bed and a 1 if they had left the spawning bed. The stream, Storkvarnbäcken or Mattjokkbäcken, was used as explanatory variable. Since the there are several spawning beds, eight in total, the likelihood for a pebble to leave the spawning bed is dependent on which spawning bed it is situated on, thus there is a random effect depending on the spawning beds. The p-value was given by using a statistical inference with a Chi-square test. A total of 482 pebbles were included on the analyse out of which 318 were from Storkvarnbäcken and 164 form Mattjokkbäcken.

2.4.2. Does the slope of the spawning bed influence the distance moved?

To analyse if the slope has an influence on the travel distance of the pebbles a linear regression was used. The response variable was the distance moved and in the analysis the mean for the distance moved at each spawning bed was used. Only the pebbles that had not moved or had moved downstream was included in the analyse the pebbles moved upstream was thus excluded.

2.4.3. Does the size of the pebble influence the distance moved?

In Mattjokkbäcken a linear mixed model was used to identify if there was any difference in distance moved for the three different size classes of pebbles, 50,70 and 90 mm ±5 mm. A linear mixed model was used since the model accounts for random effects. In this case there is a randomness since there are eight different spawning beds, where the pebbles movement was depending on the spawning bed they were located at. The explanatory variable was the size class of the pebble. For the analysis, the different size classes were given a non-numerical value, small (45-55 mm), medium (65-75 mm) and large (85-95 mm). In the model the response variable was the distance moved between 2014 and 2020. All distance moved was scaled based on which spawning bed they belonged to which makes it possible to determine how deviant a certain distance moved is compared to the others. To determine what size classes significantly differed from each other a Tukey HSD post-hoc test was used. A total of 105 pebbles were included in the analyse. Three of the 105 pebbles had not moved, two medium and one large. Out of the 105 pebbles included in the analyse the number of pebbles for the different size classes were 37 small, 34 medium and 34 large.

2.4.4. Evaluation of conventional GPS

During the inventory 2020 a BP Lite Portable Antenna was used for detecting tagged pebbled in both Storkvarnbäcken and Mattjokkbäcken. When the HPR reader connected to the BP Lite Portable Antenna reads a PIT-tag a GPS position is registered. If set to "continuously" the same PIT-tag will be read several times. One PIT-tag can thus have several GPS positions. To determine the precision of the HPR reader the distance to the reference were calculated for all registered positions. The variance and standard deviation of the distance to the reference was calculated for PIT-tags read more than once. For the accuracy, the first registered GPS position for each PIT-tag were used to calculate the distance to the set reference. This distance is referred to as the estimated distance. The estimated distance was then compared to the distance given by the laser in Mattjokkbäcken and the GPS in Storkvarnbäcken. Only PIT-tags registered by both methods (HPR reader and high precision GPS/laser) were used when calculating the accuracy. For quantifying the accuracy of the estimated values, several measures can be used. In this study mean absolute error was used to remove the any potential problems from outliers in the data.

In Storkvarnbäcken 38 pebbles were registered by the HPR reader but not by the high precision GPS. 36 out of the 38 pebbles not registered by the high precision GPS were measured with tape. Further there were 12 pebbles not registered by the

HPR reader but registered by the high precision GPS. These 12 pebbles were compared to the list of pebbles deployed in 2012 to confirm that their ID matched and thus not a result of manually entering the ID incorrectly to the high precision GPS. In Mattjokkbäcken 10 pebbles were registered by the HPR but not by the laser and two pebbles were registered by the laser but not the HPR reader. For the analyse of mean absolute error only pebbles registered by both methods, the HPR reader and the high precision GPS/laser, were included. Thus, the comparison of the HPR reader and high precision GPS is based on 272 pebbles and the comparison of the HPR reader and laser includes 162 pebbles.

3. Results

3.1. Description of the erosion process and the probability to leave the spawning bed

The rate if recovery of the tagged pebbles was high in both streams. In Storkvarnbäcken the rate of recovery was 89% for the first inventory conducted 2012 and 85% for the second inventory 2020. The rate of recovery was 60% in Mattjokkbäcken.

Out of the deployed pebbles the percentage of pebbles still at the spawning beds in 2020 was 70% ±3.59 (mean ± SE) in Storkvarnbäcken and 27% ±8.4 Mattjokkbäcken (Figure 3). Out of the recovered pebbles, 82% was still on the spawning bed in Storkvarnbäcken and 45% in Mattjokkbäcken. The result from the General Linear Mixed-Effect model showed that the likelihood for a pebble to leave the spawning bed statistical differ between the two streams ($X_{1,482}$=16.408, p<0.01).

The amount of pebbles that had left the spawning bed was 16% ±2.93 in Storkvarnbäcken and 34% ±5.6 in Mattjokkbäcken. From the first to second inventory in Storkvarnbäcken the amount of pebbles still at the spawning beds had overall decreased from 82% ±3.54 to 70% ±3.59. Since the first inventory to the second inventory the rate of recovery had increased from 84% to 87% on spawning bed 1.1 and from 91% to 94% on spawning bed 1.4.

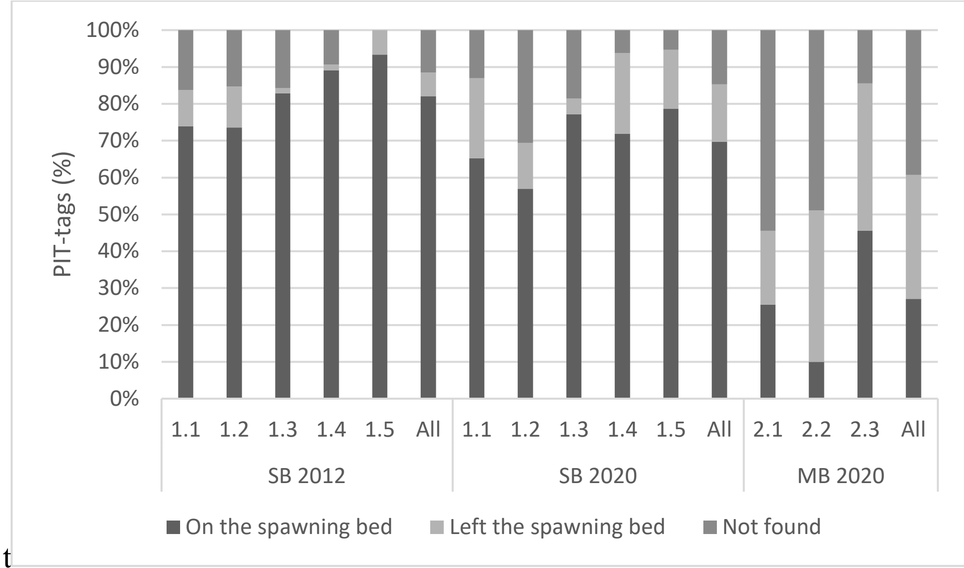

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Figure 3. Frequency of pebbles that were still on the spawning bed, had left the spawning bed or could not be recovered during the inventory 2012 and 2020 in Storkvarnbäcken (SB) and 2020 in Mattjokkbäcken (MB). The percentage is given for the separate spawning beds and for all spawning beds.

The percentage of pebbles that had moved downstream was 73% in Storkvarnbäcken and 62% in Mattjokkbäcken (Figure 4). In Storkvarnbäcken 17% of the pebbles had moved upstream and 35% in Mattjokk. Only a smaller fraction of the pebbles had not moved at all, 10% in Storkvarnbäcken and 2% in Mattjokkbäcken. The maximum distance moved upstream was similar for the two streams, 5.23m in Storkvarnbäcken and 5.05m in Mattjokkbäcken (Table 1). The percentage of pebbles which had moved >3 m upstream was 2% in Storkvarnbäcken and 4% in Mattjokkbäcken and they were allocated on spawning bed 1.2 respectively 2.3. The mean distance moved downstream was 1.12m in Storkvarnbäcken and 6.39m in Mattjokkbäcken (Table 1).

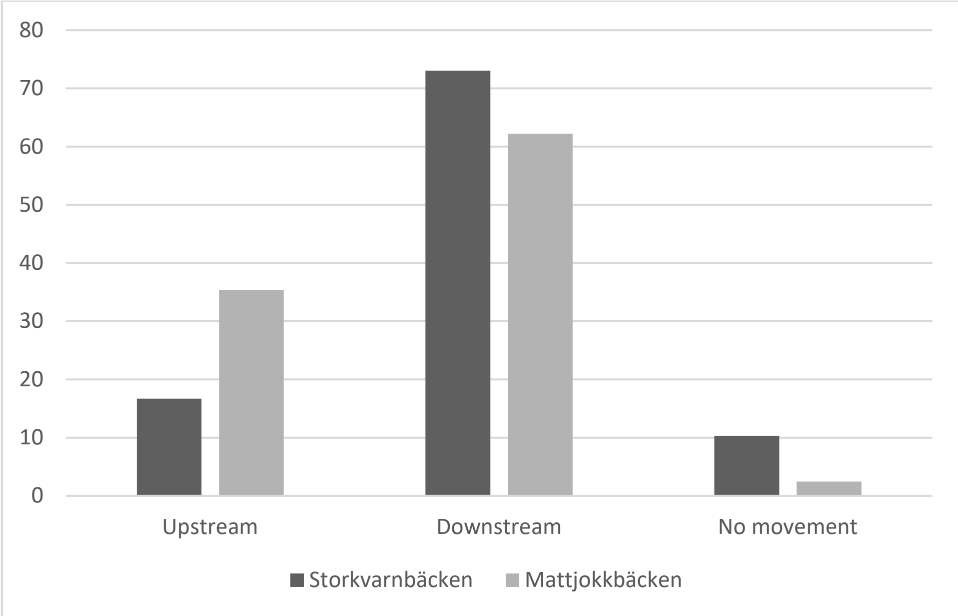

Figure 4. The percent of pebbles that have moved upstream, downstream, or not moved at all out of the recovered pebbles, since the year of deployment to the last conducted inventory in Storkvarnbäcken and Mattjokkbäcken.

Table 1. The distance pebbles moved upstream or downstream in meters for the two streams Storkvarnbäcken and Mattjokkbäcken

Stream	Direction	Min	Max	Mean
Storkvarnbäcken	Upstream	0.05	5.23	0.85
	Downstream	0.05	6.11	1.12
Mattjokkbäcken	Upstream	0.05	5.05	2.13
	Downstream	0.03	18.23	6.39

Form the year of deployment till 2020, 61 % of the pebbles in Storkvarnbäcken had moved less than 1m. In Mattjokkbäcken 6% of the pebbles had moved less than 1m since the year of deployment till 2020. Note that the pebbles that had moved upstream are not included in these estimations. The furthest distances moved from the year of deployment to 2020 was 6.1m in Storkvarnbäcken and 18.2m in Mattjokkbäcken (Figure 5).

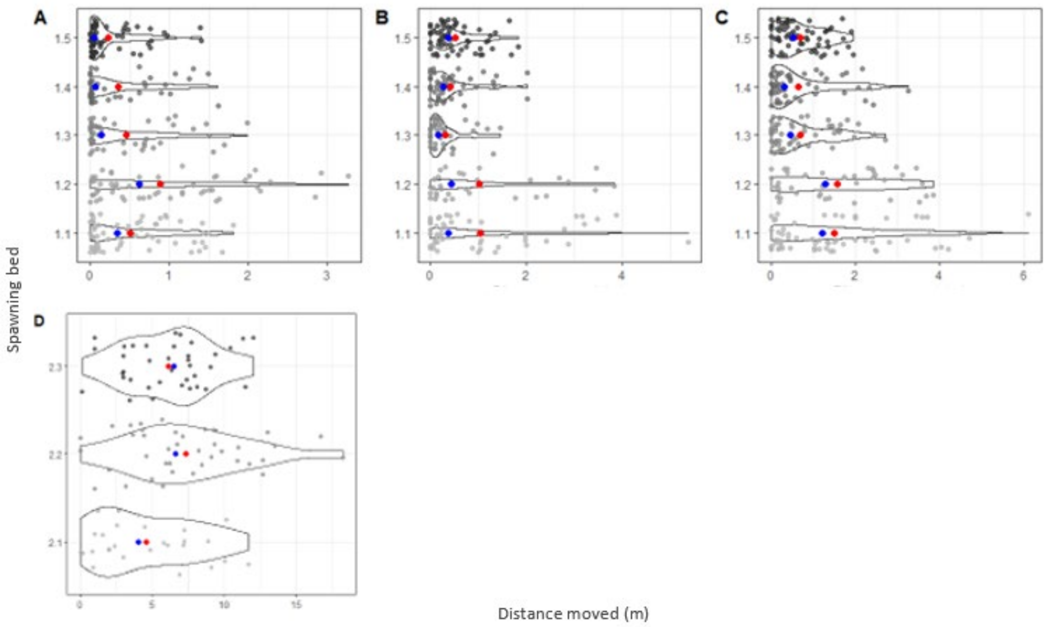

Figure 5. The distribution of the distance moved for the recovered pebbles for the different periods in Storkvarnbäcken and Mattjokkbäcken. A: Deployment to first inventory in SB, B: First inventory to second inventory in Storkvarnbäcken, C: Deployment to second inventory in Storkvarnbäcken, D: Deployment to first inventory in Mattjokkbäcken. Only the pebbles that have not moved or have moved downstream are included. The blue point is the median and the red point is the mean distance moved.

Table 2. The distance in meters that pebbles had moved during different periods for all spawning beds in Mattjokkbäcken (MB) and Storkvarnbäcken (SB). Only pebbles that had not moved or had moved downstream are included

Stream	Period	Median	Mean	Mean distance per year
SB	Sep 2012-Oct 2012	0.15	0.48	0.48
SB	Sep 2012-2020	0.55	1.00	0.13
SB	Oct 2012-2020	0.28	0.64	0.08
MB	2014-2020	6.21	6.21	1.04

From the year of deployment to 2020 the mean distance that pebbles had moved was 1m in Storkvarnbäcken and 6.21m in Mattjokkbäcken (Table 2). The annual distance moved since the year of deployment to 2020 was 0.13m in Storkvarnbäcken and 1.04m in Mattjokkbäcken. In Storkvarnbäcken the mean distance moved per year is 0.48m for the period September to October 2012 compared to 0.08m for the period October 2012 to 2020, thus most of the movement have occurred shortly after deployment.

3.2. Does the slope of the bed effect the distance pebbles moved?

There is a positive corelation between the spawning bed slope and the distance pebbles moved ($p<0.001$) (Figure 6) and the regression predictions fit the data well ($R^2=0.92$). The pebbles moved further as the slope over the spawning bed increased (SD=2.43).

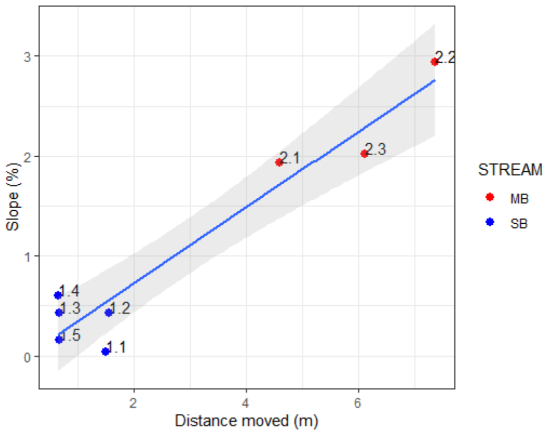

Figure 6. The mean distance moved in meters for the spawning beds at respective stream, Storkvarnbäcken (SB) and Mattjokkbäcken (MB). Only pebbles that had not moved or had moved downstream are included.

3.3. Does the size of the pebble effect the distance moved?

The large class had moved the furthest distance upstream (5.05m) followed by the medium (3.73m) and the small (3.03m) class (Table 3). The ten most extreme outliers of the distance moved upstream were ranging between 3.03 to 5.06m, out of which nine had moved between 3 to 4m. Out of the extreme outliers 60% were pebbles in the size class large, 30% in the medium class and 10% in the small class. All ten extreme outliers were located on spawning bed 2.3. The mean distance moved downstream for the different size classes was 7.37m for small, 6.08m for large and 5.58m for medium.

Table 3. Distance moved downstream and upstream for the three different size classes, small, medium, and large, from 2012–2020 in Mattjokkbäcken

Movement	Size class	Min	Max	Mean	Median
Upstream	Large	0.48	5.05	2.34	2.24
	Medium	0.05	3.74	1.94	2.07
	Small	0.66	3.03	1.91	1.81
Downstream	Large	1.00	12.99	6.08	5.77
	Medium	0.13	13.49	5.58	6.25
	Small	0.90	18.23	7.37	7.09

There is significant difference in the distance moved between the different size classes ($F_{2,103}$= 3.549002, p= 0.0342). The difference in the distance moved was between the small and medium sized pebbles (p=0.0275) (Table 4) where the small pebbles had moved longer distances (Table 3).

Table 4. The p-values given by the Tukey HSD post-hoc test for determining what size classes significantly differed in the distance pebbles moved

Size classes	p-value
Medium-Large	0.7587
Small-Large	0.1544
Small-Medium	0.0275*

The distance moved does not differ between the medium and large sized pebbles (Table 4). Out of the 30 deployed pebbles in each size class 17% of the small, 30% of the medium and 34% of the large was still on the spawning bed 2020 (Table 5).

Table 5. The percentage of deployed pebbles still on the spawning 2020 bed for the different size classes in Mattjokkbäcken

Size class	Still on the spawning beds (%)
Large	34
Medium	30
Small	17

3.4. Evaluation of conventional GPS

The precision of the HPR reader is very low since there is a great variation in the distances given by the readings of the same pebble (Figure 7 and Table 6). The variance is ranging from 0-3031 in Storkvarnbäcken and 0-23.7 in Mattjokkbäcken. For the standard deviation, the range is 0-50.1 in Storkvarnbäcken and 0-4.9 in Mattjokkbäcken. Out of the outliers identified in Storkvarnbäcken 50% are from spawning bed 1.1.

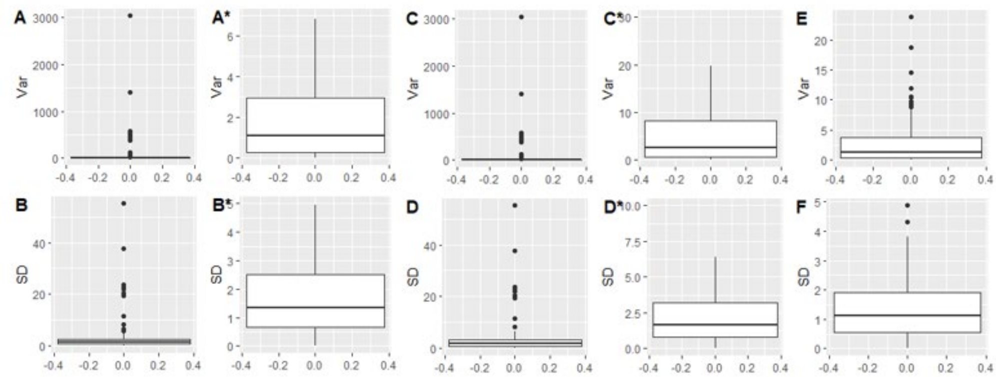

Figure 7. Variance (Var) and standard deviation (SD) for the distance to referenceline for pebbles registered more than once by the HPR. A and B are for both Storkvarnbäcken and Mattjokkbäcken, C and D are for Storkvarnbäcken and E and F are for Mattjokkbäcken. In A, B*, C*, and D* outliers are removed. Number of pebbles and readings included A and B: 405 pebbles and 3794 readings, C and D: 255 pebbles and 1663 readings, E and F: 150 pebbles and 2131 readings.*

Table 6. Variation (Var) and standard deviation (SD) of distance moved among the spawning beds at the streams combined and at the streams separated. Storkvarnbäcken (SB) and Mattjokkbäcken (MB). Only pebbles registered more than once were included in the analys

Stream		Median	Mean
SB and MB	Var	1.96	22.41
	SD	1.40	2.30
SB	Var	3.15	33.96
	SD	1.77	2.87
MB	Var	1.27	2.78
	SD	1.12	1.34

Table 7. The accuracy of the HPR is estimated with mean absolute error (MAE) by comparing how close the distance given by the HPR are to the distances given by the GPS or the laser. The distance used is the distance for the pebbles to the reference. The estimation is based on a total of 272 pebbles in Storkvarnbäcken and 162 pebbles in Mattjokkbäcken (MB). Pebbles that had moved upstream, downstream or had not moved are included

Creek	Methods	MAE	Spawning bed
SB	HPR/GPS	9.978[1]	1.1
		4.986	1.2
		3.377	1.3
		4.684	1.4
		2.340	1.5
		4.728	All
MB	HPR/Laser	3.896	2.1
		2.151	2.2
		1.902	2.3
		2.487	All

1. There were concrete building blocks on both sides of the stream with a wooden roof by the spawning bed.

The mean absolute error was ranging between 2.3-10 in Storkvarnbäcken and 1.9-3.9 in Mattjokkbäcken (Table 7). The mean absolute error for spawning bed 1.1 in Storkvarnbäcken is close to ten which is more than two times greater than for the other spawning beds. Some of the positions given by the HPR reader were far from the positions given by the high precision GPS, especially on spawning bed 1.1 (Figure 8). The five most extreme outliers having a distance to the reference line ranging between 41 to 113 m have been excluded in 1.1* Figure 8.

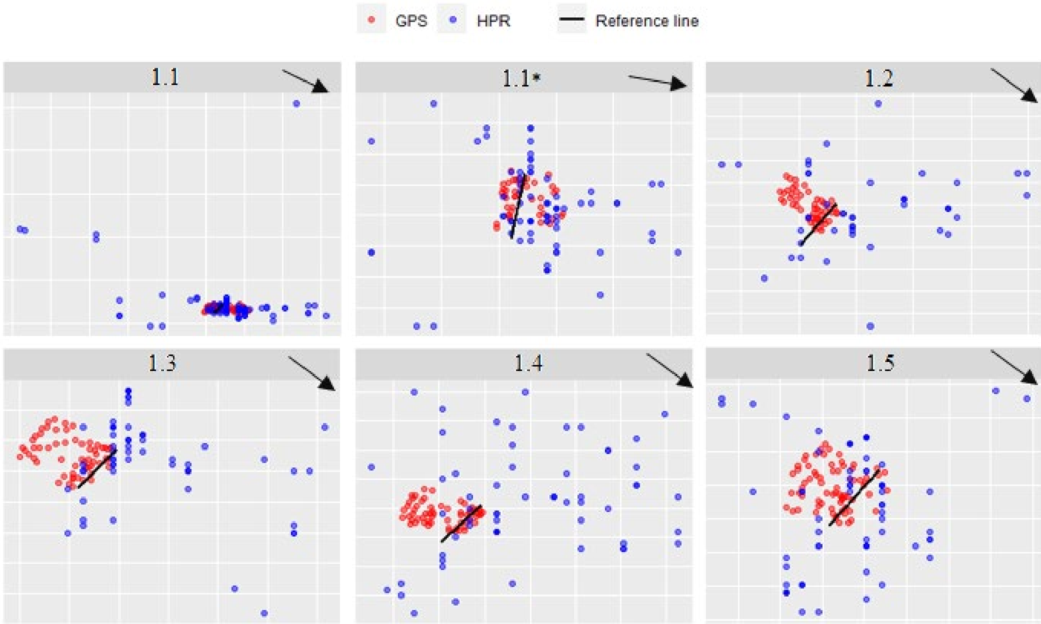

Figure 8. The position of the pebbles given by the high precision GPS in red and the HPR reader in blue for the spawning beds in Storkvarnbäcken. In 1.1 five pebbles are excluded to get a better visualisation. The arrow indicates the direction of the waterflow.*

4. Discussion

The availability of spawning beds seems to be a limiting factor for the salmonids (Palm et al. 2007; Hauer et al. 2020) thus a common action of river restoration is to establish new spawning beds by adding gravel to the stream bed. In this study different aspects of erosion of restored spawning beds have been studied by tagging some of the pebbles with PIT-tags. By tracing pebbles information about rate of transport and thus also the stability of the beds can be obtained (Tritthart et al. 2019).

4.1. The probability to leave the spawning bed and the influence of the slope

When comparing the two streams, the pebbles in Mattjokkbäcken had a significantly higher chance of leaving the spawning bed. The result from this study also indicates that there is a corelation between the slope of the spawning beds and the distance moved by the pebble, in where pebbles located on spawning beds with a steeper slope had moved longer distances on average. Both the water discharge and the slope of the spawning beds is higher in Mattjokkbäcken compared to in Storkvarnbäcken. Since the shear stress is increasing with increasing slope and discharge (Kasprak et al. 2015), the force of the water to move the pebbles could potentially be higher in Mattjokkbäcken compared to in Storkvarnbäcken. Beside the hydrology of the water there could also be other factors contributing to the difference in the distance pebbles have moved. Models have shown that the morphology of the stream has an influence on the distance moved due to pebbles being trapped behind obstacles which affect the momentum of the particle (McDowell & Hassan 2020). Another factor to take in consideration when looking at rivers in the Northern Hemisphere is the impact of ice. The freezing and breakup are the most active periods where the erosion and the sedimentation processes in rivers can be affected (Beltaos & Prowse 2009), and this could potentially differ between the two streams in my study.

Our results show a high recovery rate of pebbles, 60-89%. Some of the PIT-tags in this study were not registered by the HPR but registered by the stick reader. Previous research have shown a highly variable efficiency of PIT-tags, with a recovery rate ranging from 12 to 100% (Chapius et al. 2014; Chan et al. 2016). In previous research the recovery rate has been examined as a function of the clustering of the PIT-tags, if they are buried or not and if there is any difference in the reading distance between readings in water or in air (Chapius et al. 2014; Chapuis et al. 2015). The effect off PIT-tags being buried or in water did only have a small impact on the reading distance (Chapius et al. 2014; Chapuis et al. 2015). The clustering of the PIT-tags is however affecting the recovery rate (Chapius et al. 2014; Chapuis et al. 2015). According to Cassel et.al (2020) signal collision is occurring when multiple PIT-tags are within the search field of the antenna and therefore Chapius et al. (2014) recommend using a stick reader for localisation when PIT-tags are clustered. Clustering is thus a likely explanation to why some pebbles in this study were registered by the stick reader but not by the BP Lite Portable Antenna.

In my study a minimum distance moved of 5cm was used due to the resolution of the equipment. This minimum distance of movement is most likely to small. Houbrechts *et al.* (2015) state that the PIT-radius in which the PIT-tags can be localized is 0.5m, and thus one can consider the pebble to have moved if the distance is minimum one meter. For the pebbles not visually detected we used a stick reader to improve the localisation accuracy. The zone in which the electrical current from the antenna is sufficient for the PIT-tag to send its unique identification number is called the detection zone (Chapius et al. 2014). In field we noticed that the stick reader did have a reduced detection zone compared to the BP Lite Portable Antenna which is in line with previous research were the stick reader has been shown to have a shorter detection distance and a more distinct transmitter location (Chapius *et al.* 2014). However, the localisation accuracy for the stick reader is still not on the scale of cm. When taking the size of the spawning beds (2×5m) in consideration and the fact that most pebbles in Storkvarnbäcken have moved less than 1.5m, setting the limit for minimum distance moved to one meter will give only a rough estimation. From a restoration perspective the question of importance might rather be if the pebbles are still on the spawning bed or not rather than if the pebbles have moved 4cm or one meter since the amount of gravel still on the spawning bed is crucial for its function.

During the first inventory only the stick reader was used for detecting the pebbles were as for the second inventory both the stick reader and the BP Lite Portable Antenna were used. The shorter detection distance and the more distinct transmitter location for stick readers could be the explanation for why less pebbles were recovered on spawning bed 1.1 and 1.4 in Storkvarnbäcken during the first inventory when only the stick reader was used.

All pebbles that had moved >3 m upstream were allocated on spawning bed 1.2 in Storkvarnbäcken or 2.3 in Mattjokkbäcken. In Mattjokkbäcken there is a possibility that the adjustment of one meter for the misplaced reference point on spawning bed 2.3 was not enough. Since similar distances were also measured in Storkvarnbäcken there is potentially other explanations to why we can find pebbles that have moved long distances upstream. One possible explanation could be that when deploying the pebbles their position was not correctly noted. A further explanation could be the impact from spawning fish. During the redd excavation the salmon use its tail to flap over the bed setting the water in to motion witch is making the gravel dislodge (Gottesfeld et al. 2004). The distance clasts are moved by the fish tend to be shorter than by the floods but for a few occasions the mean distance was between 3-8m (Gottesfeld et al. 2004). However, Gottesfeld et al. (2004) does not clarify if any of the movements are upstream. The explanation to why pebbles have moved several meters upstream in my study is unclear.

In Storkvarnbäcken most of the movement seem to have occurred after the first flooding. Conducting short term studies could potentially lead to an overestimation of the erosion of the spawning beds. It has been shown that overestimations regarding the vertical mixing of particles are common when conducting services for a short period as the time it takes to reach equilibrium depends on the flood sequence of the specific stream (Haschenburger 2011). Merz et al. (2006) observed the greatest loss of material during the first surveys where up to 20% of the gravel was lost form the spawning beds the first year.

Based on our results the spawning beds in Storkvarnbäcken seem to be less prone to erode and thus their longevity is likely longer. In 2020, 82% of the recovered PIT-tags was still on the spawning bed in Storkvarnbäcken compared to 45% in Mattjokk. The lower recovery rate of the pebbles in Mattjokkbäcken need to be taken in consideration since the non-detected pebbles might be buried but still located on the spawning bed. If the pebbles are buried >20cm they might not be detected due to loss of signal (Houbrechts et al. 2012). There is thus a possibility that the erosion of the spawning beds in Mattjokk is overestimated since gravel could still be seen at the beds when conducting the inventory. However, Hauer et al. (2020) found a high variability in the erosion rate, 32-95%, and the longevity, 1-10 years, of restored spawning beds in the Aurland river, Norway. For future research I recommend that when using PIT-tags complimentary measurements as the depth and area of the spawning bed should be used to provide additional information about the erosion of the beds and thus increase the reliability of the results.

4.2. Does the size of the pebble influence the distance moved?

The result from this study showed that the size class small moved longer distances compared to the medium class. However, there was no difference in the distance moved between the small and the large class. Results from previous research are differentiating. Some results have shown that the distance moved by pebbles does corelates to their size, where finer pebbles travels further (Liébault et al. 2012; Milan 2013; Mao et al. 2020). Einstein (1937 see Church & Hassan 1992) could however not find a relationship between the distance moved and the size of the pebbles, and instead he describes the distance moved by different size classes to be random. (Hassan et al. 1991) state that the movement of the bedload is a highly complex process, depending on three main factors. The first factor is what he calls the "sedimentological characteristics of the bed" (Hassan *et al.* 1991:508) including the armouring of the bed, its texture, the packing of the gravel, and the form of the bed. The second factor is referring to the condition of the water flow including the discharge and velocity of the water. The last factor refers to the pebble moving and its features e.g., the shape of the particle such as its roundness. Further (Hassan et al. 1991) explain that these three factors are all integrated with each other hence making the movement even more complex. Hassan *et al.* (1991) mean that this is explaining why one can find a great variation in the movement even when observing the same bed under the same conditions.

When there is a heterogeneity in the substrate the movement of the substrate seems to become even more complex. The heterogeneity have been shown to affect the movement and the shear stress needed for movement of particles relatively smaller and larger than the median sized pebbles differently (Church & Hassan 1992; Tritthart et al. 2011). The movement of pebbles relatively larger than the median seem to be size dependent were as the movement for the relatively smaller pebbles seem to be more influenced by their increased chance of getting trapped rather than by their size (Church & Hassan 1992). When there is a heterogeneity in the bed material hiding effects can have an impact on the sheer stress needed for a pebble to move (Tritthart et al. 2011). The smaller pebbles can be hidden by larger pebbles and the sheer stress needed to move the small pebble will thus increase (Tritthart et al. 2011).

Since the distance pebbles move is a complex process depending on multiple factors that are integrated with each other a different approach could be more suitable from a restoration perspective. Another approach could be to look at if there is a difference in the amount of pebbles still located on the spawning beds between the different size classes.

4.3. Evaluation of conventional GPS

Both the resolution and the performance of the HPR reader is very low and therefore this method cannot be considered as suitable for conducting surveys on this scale. The mean absolute error for the high precision GPS is somewhat higher than when using the laser, and this could be an indication that the high precision GPS is closer to the truth. However one needs to take in consideration that the high precision GPS and the laser have not been used in the same streams. For a more accurate comparison of the methods both the high precision GPS and the laser should have been used in both streams but due to time limitations this was not possible.

The reason for the high mean absolute error on spawning bed 1.1 is the concrete building blocks with a wooden roof located over the spawning bed. These building blocks and planks hinder the satellite signals to reach the HPR reader and thus affecting the accuracy of the positioning (Wing et al. 2005). Not only the HPR reader was affected by this bridge also the high precision GPS was severely impacted. A total of 36 pebbles could not be positioned at all by the high precision GPS and their distance to the reference line had to be measured with a tape. The risk for pore satellite signal should therefore be taken in consideration when using a high precision GPS to position substrate in small tributaries, and complimentary equipment might be needed.

A suggestion for improving the method of using the laser and thus get a higher mean absolute error is to move along the reference line instead of aiming for a fixed point when measuring the distances. When aiming with the laser to a fixed reference point the pebbles that are close to the reference point and at the same time close to land will be given a longer distance than if they would be measured straight to reference line. One drawback with the laser is that the laser dot was getting difficult to see at longer distances and we then needed to move the reference point further downstream increasing the risk for measurement bias.

As mentioned above both the laser and high precision GPS have their advantages and disadvantages. However, when conducting measurements on this scale the laser and high precision GPS are more suitable for positioning compared to the HPR reader.

4.4. Summary

The high recovery rate of pebbles suggests that PIT-tags are very good tracers for long term monitoring of movement. Additional measurements would however be useful to gain a better understanding of the erosion of spawning beds.

A higher percentage of the recovered PIT-tags was still on the spawning bed in Storkvarnbäcken compared to in Mattjokkbäcken and the pebbles in Mattjokkbäcken had a significantly higher probability to leave the spawning beds. This indicates that there is a difference in the extent of the erosion thus also the longevity of the spawning beds between the streams. One possible explanation to the difference in erosion is that the slope of the bottoms influences the erosion of the spawning beds. Channels with a slope steeper than >1.9% seem to be less suitable for establishing spawning beds due to the increased risk of erosion. There are potentially other important factors, such as the water discharge, that can have impacted my result and this needs to be taken in consideration as when evaluating the suitability of the channel.

My results regarding the size of the pebbles influence on the distance moved was difficult to interpret. The movement of pebbles seem to be a very complex process and with multiple factors intergraded with each other. The size of the substrate could therefore be decided based on the preferred size of the fish at the site.

The resolution as well as the performance of the HPR reader is very low. The HPR reader is therefore not suitable for conducting surveys on this scale. For positioning the pebbles, I recommend using the laser or the high precision GPS.

In this study the main focus has been to look at the distance pebbles have moved. However, since the distance pebbles move is a complex process depending on multiple factors that are integrated with each other and the limitations of the antenna a different approach could be more suitable from a restoration perspective. A more suitable approach would be to look at if the pebbles are still on the spawning bed or not since the amount of gravel on the spawning bed is important for the function of the spawning bed.

Acknowledgements

I would like to thank my supervisors Gustav Hellström, Lo Persson, Daniel Palm and Lina Polvi Sjöberg for their support. Annika Holmgren, Saun Juthberg and Mikael Marberg for good company and guidance during my fieldwork. A huge thanks to Örjan Blom for repairing the field equipment. Thanks to Daniel Holmqvist for valuable information and guidance. Navinder Singh and Lukas Graf for patiently helping me with the coding. I would also like to thank the fellow students in the computer lab for your exquisite company.

References

Arnaud, F., Piegay, H., Beal, D., Collery, P., Vaudor, L. & Rollet, A.-J. (2017). Monitoring gravel augmentation in a large regulated river and implications for process-based restoration. *Earth Surface Processes and Landforms*, 42 (13), 2147–2166. https://doi.org/10.1002/esp.4161

Bates, D. Maechler, M. Bolker, B. & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 1-48. doi:10.18637/jss.v067.i01.

Beltaos, S. & Prowse, T. (2009). River-ice hydrology in a shrinking cryosphere. *Hydrological Processes*, 23 (1), 122–144. https://doi.org/10.1002/hyp.7165

Biomark (u). *HPR Plus*. *Biomark- Specialists in identification soultions*. https://www.biomark.com/hpr-plus [2020-12-07]

Buijse, A.D., Coops, H., Staras, M., Jans, L.H., Geest, G.J.V., Grift, R.E., Ibelings, B.W., Oosterberg, W. & Roozen, F.C.J.M. (2002). Restoration strategies for river floodplains along large lowland rivers in Europe. *Freshwater Biology*, 47 (4), 889–907. https://doi.org/10.1046/j.1365-2427.2002.00915.x

Cassel, M., Piegay, H., Fantino, G., Lejot, J., Bultingaire, L., Michel, K. & Perret, F. (2020). Comparison of ground-based and UAV a-UHF artificial tracer mobility monitoring methods on a braided river. *Earth Surface Processes and Landforms*, 45 (5), 1123–1140. https://doi.org/10.1002/esp.4777

Chan, N., Takeda, S., Suzuki, R. & Yamamoto, S. (2016). Assessment of biomass recovery and soil carbon storage of fallow forests after swidden cultivation in the Bago Mountains, Myanmar. *New Forests*, 47 (4), 565–585. https://doi.org/10.1007/s11056-016-9531-y

Chapius, M., Bright, C.J., Hufnagel, J. & MacVicar, B. (2014). *Detection ranges and uncertainty of passive Radio Frequency Identification (RFID) transponders for sediment tracking in gravel rivers and coastal environments*. (39 (15)). Wiley. https://onlinelibrary.wiley.com/doi/full/10.1002/esp.3620 [2020-12-08]

Chapuis, M., Dufour, S., Provansal, M., Couvert, B. & de Linares, M. (2015). Coupling channel evolution monitoring and RFID tracking in a large, wandering, gravel-bed river: Insights into sediment routing on geomorphic continuity through a riffle–pool sequence. *Geomorphology*, 231, 258–269. https://doi.org/10.1016/j.geomorph.2014.12.013

Church, M. & Hassan, M.A. (1992). Size and distance of travel of unconstrained clasts on a streambed. *Water Resources Research*, 28 (1), 299–303. https://doi.org/10.1029/91WR02523

Convention on Biological Diversity (2018). *Actions to Enhance Implementation of the Strategic Plan for Biodiversity 2011-2020*. https://www.cbd.int/sp/actions.shtml [2020-09-10]

Council, N.R., Studies, D. on E. and L., Resources, C. on G., Environment and & Policy, C. on R. of A.E.S., Technology, and Public (1992). *Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy*. National Academies Press.

European Commission (u). *EU Biodiversity Strategy for 2030*. https://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm [2020-09-10]

Fiskeriverket (2001). *Havsöringens ekologi*. (2001:10). Göteborg: Fiskeriverket.

Fleming, I.A. (1996). Reproductive strategies of Atlantic salmon: ecology and evolution. *Reviews in fish biology and fisheries*, 6 (4), 379–416. https://doi.org/10.1007/bf00164323

Fox, J. & Weisberg, S. (2019). An {R} Companion to Applied Regression, Third Edition. Thousand Oaks CA: Sage. URL: https://socialsciences.mcmaster.ca/jfox/Books/Companion/

Gottesfeld, A.S., Hassan, M.A. & Tunnicliffe, J.F. (2008). Salmon Bioturbation and Stream Process. 65, 175–193

Gottesfeld, A.S., Hassan, M.A., Tunnicliffe, J.F. & Poirier, R.W. (2004). Sediment Dispersion in Salmon Spawning Streams: The Influence of Floods and Salmon Redd Construction1. *JAWRA Journal of the American Water Resources Association*, 40 (4), 1071–1086. https://doi.org/10.1111/j.1752-1688.2004.tb01068.x

Haschenburger, J.K. (2011). Vertical mixing of gravel over a long flood series. *Earth Surface Processes and Landforms*, 36 (8), 1044–1058. https://doi.org/10.1002/esp.2130

Hassan, M.A., Church, M. & Schick, A.P. (1991). Distance of movement of coarse particles in gravel bed streams. *Water Resources Research*, 27 (4), 503–511. https://doi.org/10.1029/90WR02762

Hassan, M.A., Gottesfeld, A.S., Montgomery, D.R., Tunnicliffe, J.F., Clarke, G.K.C., Wynn, G., Jones-Cox, H., Poirier, R., MacIsaac, E., Herunter, H. & Macdonald, S.J. (2008). Salmon-driven bed load transport and bed morphology in mountain streams. *Geophysical Research Letters*, 35 (4). https://doi.org/10.1029/2007GL032997

Hauer, C., Pulg, U., Reisinger, F. & Flödl, P. (2020). Evolution of artificial spawning sites for Atlantic salmon (Salmo salar) and sea trout (Salmo trutta): field studies and numerical modelling in Aurland, Norway. *Hydrobiologia*, 847 (4), 1139–1158. https://doi.org/10.1007/s10750-019-04173-1

Hothorn, T. Bretz, F. & Westfall, P. (2008). Simultaneous Inference in General Parametric Models. Biometrical Journal 50(3), 346--363.

Houbrechts, G., Levecq, Y., Peeters, A., Hallot, E., Van Campenhout, J., Denis, A.-C. & Petit, F. (2015). Evaluation of long-term bedload virtual velocity in gravel-bed rivers (Ardenne, Belgium). *Geomorphology*, 251, 6–19. https://doi.org/10.1016/j.geomorph.2015.05.012

Houbrechts, G., Van Campenhout, J., Levecq, Y., Hallot, E., Peeters, A. & Petit, F. (2012). Comparison of methods for quantifying active layer dynamics and bedload discharge in armoured gravel-bed rivers. *Earth Surface Processes and Landforms*, 37 (14), 1501–1517. https://doi.org/10.1002/esp.3258

Jones, J.W. & Ball, J.N. (1954). The spawning behaviour of brown trout and salmon. *The British Journal of Animal Behaviour*, 2 (3), 103–114. https://doi.org/10.1016/S0950-5601(54)80046-3

Kasprak, A., Wheaton, J.M., Ashmore, P.E., Hensleigh, J.W. & Peirce, S. (2015). The relationship between particle travel distance and channel morphology: Results from physical models of braided rivers. *Journal of Geophysical Research-Earth Surface*, 120 (1), 55–74. https://doi.org/10.1002/2014JF003310

Kondolf, G.M. & Micheli, E.R. (1995). Evaluating stream restoration projects. *Environmental Management*, 19 (1), 1–15. https://doi.org/10.1007/BF02471999

Liébault, F., Bellot, H., Chapuis, M., Klotz, S. & Deschâtres, M. (2012). Bedload tracing in a high-sediment-load mountain stream. *Earth Surface Processes and Landforms*, 37 (4), 385–399. https://doi.org/10.1002/esp.2245

Lundqvist, H. & Östgren, J. (2015). *Öringracet: Radiomärkning för att följa havsöringens lekvandring i Vindelälven och Piteälven.* Umeå: Institutionen för Vattenbruk, SLU.

Mao, L., Toro, M., Carrillo, R., Brardinoni, F. & Fraccarollo, L. (2020). Controls Over Particle Motion and Resting Times of Coarse Bed Load Transport in a Glacier-Fed Mountain Stream. *Journal of Geophysical Research-Earth Surface*, 125 (4), e2019JF005253. https://doi.org/10.1029/2019JF005253

McDowell, C. & Hassan, M.A. (2020). The influence of channel morphology on bedload path lengths: Insights from a survival process model. *Earth Surface Processes and Landforms*, 45 (12), 2982–2997. https://doi.org/10.1002/esp.4946

Merz, J.E., Pasternack, G.B. & Wheaton, J.M. (2006). Sediment budget for salmonid spawning habitat rehabilitation in a regulated river. *Geomorphology*, 76 (1), 207–228. https://doi.org/10.1016/j.geomorph.2005.11.004

Merz, J.E., Setka, J.D., Pasternack, G.B. & Wheaton, J.M. (2004). Predicting benefits of spawning-habitat rehabilitation to salmonid (Oncorhynchus spp.) fry production in a regulated California river. *Canadian Journal of Fisheries and Aquatic Sciences*, 61 (8), 1433–1446. https://doi.org/10.1139/f04-077

Milan, D.J. (2013). Virtual velocity of tracers in a gravel-bed river using size-based competence duration. *Geomorphology*, 198, 107–114. https://doi.org/10.1016/j.geomorph.2013.05.018

Morandi, B., Piégay, H., Lamouroux, N. & Vaudor, L. (2014). How is success or failure in river restoration projects evaluated? Feedback from French restoration projects. *Journal of Environmental Management*, 137, 178–188. https://doi.org/10.1016/j.jenvman.2014.02.010

Nilsson, C. (2007). *Återställning av älvar som använts för flottning : en vägledning för restaurering*. (Rapport 5649). Stockholm: Swedish Environmental Protection Agency. https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A152097&dswid=-4916 [2020-09-01]

Nilsson, C., Polvi, L.E., Gardeström, J., Hasselquist, E.M., Lind, L. & Sarneel, J.M. (2015). Riparian and in-stream restoration of boreal streams and rivers: success or failure? *Ecohydrology*, 8 (5), 753–764. https://doi.org/10.1002/eco.1480

Palm, D., Brännäs, E., Lepori, F., Nilsson, K. & Stridsman, S. (2007). The influence of spawning habitat restoration on juvenile brown trout (*Salmo trutta*) density. *Canadian Journal of Fisheries and Aquatic Sciences*, 64 (3), 509–515. https://doi.org/10.1139/f07-027

Palm, D., Lepori, F. & Brännäs, E. (2010). Influence of habitat restoration on post-emergence displacement of brown trout (Salmo trutta L.): A case study in a Northern Swedish stream. *River Research and Applications*, 26 (6), 742–750. https://doi.org/10.1002/rra.1279

Parrish, D.L., Behnke, R.J., Gephard, S.R., McCormick, S.D. & Reeves, G.H. (1998). Why aren't there more Atlantic salmon (Salmo salar)? 55, 7

Pinheiro, J. Bates, D. DebRoy, S. Sarkar, D. & R Core Team. (2020). _nlme: Linear and Nonlinear Mixed Effects Models_. R package version 3.1-150, URL: https://CRAN.R-project.org/package=nlme

Rainato, R., Mao, L. & Picco, L. (2018). Near-bankfull floods in an Alpine stream: Effects on the sediment mobility and bedload magnitude. *International*

Journal of Sediment Research, 33 (1), 27–34. https://doi.org/10.1016/j.ijsrc.2017.03.006
R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/.
Riksantikvarieämbetet, Fiskeriverket & Naturvårdsverket (2007). *Nationell strategi för restaurering av skyddsvärda vattendrag: delmål 2 : levande sjöar och vattendrag.* (5746). Stockholm: Naturvårdsverket.
Roni, P., Hanson, K. & Beechie, T. (2008). Global Review of the Physical and Biological Effectiveness of Stream Habitat Rehabilitation Techniques. *North American Journal of Fisheries Management*, 28 (3), 856–890. https://doi.org/10.1577/M06-169.1
Rosenfeld, J., Hogan, D., Palm, D., Lundquist, H., Nilsson, C. & Beechie, T.J. (2011). Contrasting Landscape Influences on Sediment Supply and Stream Restoration Priorities in Northern Fennoscandia (Sweden and Finland) and Coastal British Columbia. *Environmental Management*, 47 (1), 28–39. https://doi.org/10.1007/s00267-010-9585-0
Rubin, J.-F., Glimsäter, C. & Jarvi, T. (2004). Characteristics and rehabilitation of the spawning habitats of the sea trout, Salmo trutta, in Gotland (Sweden). *Fisheries Management and Ecology*, 11 (1), 15–22. https://doi.org/10.1111/j.1365-2400.2004.00349.x
SMHI & Havs och Vatten myndigheten (u). *Modelldata per område. SMHI.* http://vattenwebb.smhi.se/modelarea/ [2020-12-30]
Staehly, S., Franca, M.J., Robinson, C.T. & Schleiss, A.J.Erosion, transport and deposition of a sediment replenishment under flood conditions. *Earth Surface Processes and Landforms*,. https://doi.org/10.1002/esp.4970
Sveriges lantbruksuniversitet (2020). *Svenskt elfiskeregister- SERS.* Institutionen för akvatiska resurser. http://www.slu.se/elfiskeregistret
Tritthart, M., Gmeiner, P., Liedermann, M. & Habersack, H. (2019). A meso-scale gravel tracer model for large gravel-bed rivers. *Journal of Applied Water Engineering and Research*, 7 (2), 89–102. https://doi.org/10.1080/23249676.2018.1449674
Tritthart, M., Schober, B. & Habersack, H. (2011). Non-uniformity and layering in sediment transport modelling 1: flume simulations. *Journal of Hydraulic Research*, 49 (3), 325–334. https://doi.org/10.1080/00221686.2011.583528
Tylstedt, V. (2013). *Predicting spawning bed erosion and longslivity: a case study in tributarities to river Vindelälven, northen Sweden*. (2013:3). Umeå: Department of Wildlife, Fish and Enviormental Studies, Swedish University of Agricultural Sciences.
Törnlund, E. (2002). "Flottningen dör aldrig" : bäckflottningens avveckling efter Ume- och Vindelälven 1945-70. http://urn.kb.se/resolve?urn=urn:nbn:se:umu:diva-10788 [2020-09-01]
Törnlund, E. & Östlund, L. (2006). Mobility without Wheels: The Economy and Ecology of Timber Floating in Sweden, 1850–1980. *The Journal of Transport History*, 27 (1), 48–70. https://doi.org/10.7227/TJTH.27.1.5
United Nations (u). *What is the Decade?* https://www.decadeonrestoration.org/what-decade [2020-09-10]
Waples, R.S. & Hendry, A.P. (2008). Special Issue: Evolutionary perspectives on salmonid conservation and management. *Evolutionary Applications*, 1 (2), 183–188. https://doi.org/10.1111/j.1752-4571.2008.00035.x
Wing, M.G., Eklund, A. & Kellogg, L.D. (2005). Consumer-Grade Global Positioning System (GPS) Accuracy and Reliability. *Journal of Forestry*, 103 (4), 169–173. https://doi.org/10.1093/jof/103.4.169
Östlund, L. & Zackrisson, O. (1997). The history and transformation of a Scandinavian boreal forest landscape since the 19th century. 27, 9

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