UMEÅ UNIVERSITET

Quantifying the physical effects of stream restoration

With unmanned aerial vehicles and geographic information systems

Annika Karlsten

Master thesis in Earth Science, 30 hp
Vt 2019

Cite as: Karlsten, A. 2019. *Quantifying the physical effects of stream restoration: With unmanned aerial vehicles and geographical information systems*. M.Sc. Thesis. Department of Ecology and Environmental Science, Umeå University, Sweden.

Supervisor: Lina Polvi Sjöberg, Umeå University

Front cover: Upper panel: Storforsen 1, channelized condition. Lower panel: Storforsen 1, restored condition.

Abstract

Stream restoration efforts often aim at restoring the physical complexity in streams, as an increased habitat heterogeneity is believed to increase biodiversity. It is important to quantify the physical complexity of streams before and after restoration, to know what actions are needed, and to monitor the results of the restoration. The use of unmanned aerial vehicles (UAVs) and geographic information systems (GIS) for data acquisition is rapidly increasing, and the use of UAVs and GIS could facilitate the monitoring process. The aim of this study was to determine how the spatial complexity in streams can be determined by using UAVs and GIS. The physical features and the spatial complexity were quantified in five reaches in the Lögde River, pre- and post-restoration, by analyzing UAV photos in a GIS program. Three of six reach descriptive metrics, and three of seven complexity metrics, were shown significantly different after restoration. To validate the GIS analyzing method, a qualitative comparison of data from the GIS analysis to field survey data was conducted. The GIS method was shown effective for distinguishing morphological features on a larger spatial scale, and to show the spatial distribution of instream features, such as wood pieces and boulders. The accuracy when digitizing the bankfull edge of the stream was low on small scales, and the method likely underestimates the number of wood pieces and boulders in the streams. Preferable camera settings and weather conditions to avoid blurry UAV photos, and thereby enhance the accuracy of the GIS analysis, are discussed.

Key words: Unmanned Aerial Vehicle; Geographic Information Systems; Stream restoration; Spatial complexity; Geomorphology; Instream wood.

Table of Contents

1 Introduction 1
1.1 Objectives 2
2 Method 3
2.1 Site descriptions 3
2.2 Complexity metrics 4
2.3 UAV data processing 5
2.4 Comparison with field survey data 7
2.5 Statistics 8
2.6 General quality comparison of the photos 8
3 Results 8
3.1 Descriptive metrics 8
3.2 Complexity metrics 9
3.3 Data comparison with field data 10
4 Discussion 13
4.1 Pre and post-restoration 13
4.1.1 Descriptive metrics 13
4.1.2 Complexity metrics 14
4.1.3 The ReBorN project goals 15
4.2 UAV and GIS data as a monitoring method 15
4.2.1 Bankfull edge 16
4.2.2 Wood 16
4.2.3 Other observations 17
4.3 Future implementation 18
4.4 Conclusion 19
Acknowledgements 20
References 21

1 Introduction

A physically complex system is believed to inhabit a high habitat richness with a correlating high biodiversity (Stanford, Lorang and Hauer 2005; Elosegi, Díez and Mutz 2009; Wyzga et al. 2012). In landscape ecology the complexity of an ecosystem is commonly described to function in three dimensions: heterogeneity, connectivity, and temporal contingencies (Cadenasso et al. 2006). The heterogeneity identifies distinct patches separated by biotic or abiotic structures or composition in the landscape, and the function, number, and configuration of the patches (Pickett and Cadenasso 1995). The connectivity between the patches describes the interaction and flux of energy, matter and organisms between patches; and the temporal contingencies describe how the patches respond to interactions and change over time (Cadenasso et al. 2006). In geomorphology a similar approach is used, as the morphology of a landscape can be quantified and described by the configuration, size classes, behavior and temporal changes of physical characteristics within the landscape (Wohl 2016). In geomorphology, the term 'complexity' is often used when describing the geomorphic heterogeneity. The characteristics and processes of landscapes can be viewed at all scales, ranging from sorting and grain size of sediments at the microhabitat scale, to sediment load and channel form at the landscape scale (Frissell et al. 1986; Elosegi, Díez and Mutz 2009; Wohl 2016). This study focuses on the spatial complexity in streams, which can be described in five dimensions: the longitudinal profile, which describes the change in elevation over distance; the cross section; the planform which is the shape of the stream channel when viewed from above; the instream wood; and the sediment distribution (Polvi, Nilsson and Hasselquist 2014).

The spatial complexity influences several processes in stream ecosystems (Cardinale et al. 2002; Frainer et al. 2016). Stream channels are always changing as the water erodes the banks and deposits the sediment elsewhere, and as large floods destroy habitats and create new ones. The size, number and positions of sand bars, islands, shallow and deep areas, wood, and temporary ponds in the stream channel is dynamic (Stanford, Lorang and Hauer 2005). The disturbances and shifting mosaic of habitats is a fundamental process of stream ecosystems and the life cycles of stream biota is closely connected to its dynamic environment (Connell 1978; Ward 1989; Poff et al. 1997; Pollock, Naiman and Hanley 1998; Ward 1998; Junk and Wantzen 2005; Stanford, Lorang and Hauer 2005). A stream with multiple channels, heterogeneous substrate, and obstacles such as logjams and beaver dams, slows down the water velocity and attenuates the downstream fluxes of nutrients, organic material, and sediments (Wallace, Webster and Meyer 1995; Gooseff, Hall and Tank 2007; Polvi and Wohl 2012). The attenuation of the water velocity affects the biogeochemical cycling and the energy input to the food web, as the contact time with microbial and invertebrate communities' increases with slower water velocities (Muotka and Laasonen 2002). Woody debris are important for riverine fish as it provides areas of slow flow where it can rest, and it serves as hiding place from both predatory fish and birds (Crook and Robertson 1999).

As described, the physical characteristics of a stream channel are important for biodiversity and the processes within the stream ecosystem. Research has focused on the spatial complexity as it is believed to correlate with biodiversity, resistance, resilience, and many processes within a stream (Wohl 2016). Changes in the physical environment may alter the function of river channels and the habitats available for organisms, thus, surveys and evaluations of the spatial heterogeneity can be used as an indicator of the streams' health (Norris and Thoms 1999). It has been recognized that streams exposed to anthropogenic alteration has a lower complexity than pristine streams (Gooseff, Hall and Tank 2007; Polvi, Nilsson and Hasselquist 2014). When restoring streams, the aim is often to increase the spatial complexity, as a higher biological diversity is believed to follow the increase in habitat heterogeneity (Nilsson et al. 2005: Lepori et al. 2005; Degerman 2008; Palmer, Menninger and Bernhart 2010; Gardeström et al. 2013). Quantifications of the spatial complexity in streams should be conducted both prior to and after restoration, as it is important to know what restoration actions to make, and to be able to evaluate the success of the restoration effort (Palmer et al. 2005; Degerman 2008).

When quantifying the spatial complexity in streams, the physical characteristics and features in the streams are generally mapped by doing field surveys. The morphological features, such as the channel edges, width and depth, sediment size, and wood is manually counted and measured within the stream (Laub et al. 2012; Gardeström et al. 2013; Polvi, Nilsson and Hasselquist 2014). There are inconveniences and safety risks involved when working in the water. Therefore, the extent of the field survey often covers only a small area of the stream and does not capture the variability in the whole system (Marcus and Fonstad 2010). Complexity metrics are used to describe the diversity of the features, the numerical range, and the arrangement of the features in space. It is generally presented as count or percent data, or fractal dimensions that relate one feature to another. Simple mathematical calculations such as the mean, range and variation are used, as well as more complicated approaches, such as clustering analysis and spatial statistics (Wohl 2016).

By using remote sensing and geographic information systems (GIS) instead of field surveys, time and labor costs can be saved when mapping the physical characteristics in streams. Georeferenced high resolution aerial photos can be used to make quick classifications of habitats, separated by e.g. vegetation cover, substrate type, water depth and velocity (Lorang et al. 2005; Marcus and Fonstad 2010; Tarolli 2014; Woodget et al. 2017). The use of remote sensing for surveying landscapes allows more rapid, quantitative, continuous, and objective data of high resolution to be gathered, compared to traditional field survey methods (Woodget et al. 2017). Traditional use of remote sensing involves satellites and aircrafts to obtain optic imagery, radar, and Light detection and ranging (LiDAR) data. Optical imagery are photos that have captured the reflected sunlight from the earth's surface, in which the different wavelength can be analyzed. LiDAR and radar uses light and radio waves to measure distances, which is used to map the topography and create 3D models (Marcus and Fonstad 2010). However, the use of aircrafts and satellites are costly, not easily tailored to map specific sites, and the scale of the data derived is often too large to capture features on an intermediate spatial scale (i.e. 10^1 - 10^3 m), that is of interest when studying and monitoring processes in stream habitats (Tamminga et al. 2015). In the last decade, the use of unmanned aerial vehicles (UAVs) for mapping stream habitats has increased tremendously. A UAV is a small aircraft operated by a pilot standing on the ground. UAVs has gone from being predominantly for military use, to being available for civilians and commercial use. The technology regarding the UAV itself, the cameras, software and image analyzes has developed rapidly and become more user friendly (Woodget et al. 2017). Now it is relatively easy and inexpensive to get imagery of study reaches, to create digital elevation models (DEMs) and orthophotos with resolutions up to 10^{-3} m (Marcus and Fonstad 2010; Ortega-Terol 2014; Tamminga et al. 2015; Woodget et al. 2017).

1.1 Objectives

Starting in mid-19th century, a majority of the streams in northern Sweden were used for timber floating (Törnlund and Östlund 2002). To facilitate the timbers ability to be transported to the sea, boulders and wood within the stream channel, in which the timber logs could be trapped, were removed and placed along the channel edge. Stone piers and wing dams were built to make the channel narrower and to raise the water level. Side channels were cut off and difficult rapids were bypassed by flumes (Törnlund and Östlund 2002; Nilsson et al. 2005; Gardeström et al. 2013). When streams are channelized this way, the channel roughness is reduced, the sinuosity of the channel decreased, and areas of slow velocity are lost (Nilsson et al. 2005). This has resulted in a habitat loss for many organisms when spawning grounds, shelter, food and nutrient resources are reduced (Gardeström et al. 2013). The timber floating ended in the 1970s (Törnlund and Östlund 2002), and actions are now taken to improve and restore the channelized streams in northern Sweden. The County Administrative Board of Västerbotten (CAB) is, together with other partners, coordinating the EU LIFE project ReBorN (Restoration of Boreal Nordic Rivers) (LIFE15 NAT/SE/000892). The main objectives of the project are to improve the streams' conservation status as defined in the EU Habitats Directive, and for the streams to achieve a good ecological status according to the EU Water Framework Directive (LIFE15 NAT/SE/000892). This will be done by restoring the stream channels to a more natural state and rebuild lost habitats for fish and other stream living organisms. The target species are the freshwater pearl mussel (*Margaritifera margaritifera*), Atlantic salmon (*Salmo salar*), and European otter (*Lutra lutra)*. Side channels will be opened up, stone walls removed, and boulders and gravel reintroduced to the stream channel. The expected effects on channel morphology specified in the ReBorN project's proposal are: an increase in rewetted area of 0.126 ha/per restored channel reach; a more heterogeneous channel geometry; and an increased hydraulic roughness (LIFE15 NAT/SE/000892).

The overall aim of this study is to determine how the spatial complexity in streams can be determined by using UAVs and GIS. Several studies have shown that restoration increases the complexity in streams (Muotka and Laasonen 2002; Lepori et al. 2005; Gardeström et al. 2013; Polvi, Nilsson and Hasselquist 2014), thus the main hypothesis in this study is that the complexity within the reaches will be higher after restoration. Monitoring is one important part of the restoration process, as an evaluation of the physical and ecological response to the restoration is necessary to enhance the effectiveness of the procedure (Palmer et al. 2005). The CAB has used UAVs to take aerial photos of reaches in the Lögde River and its tributaries, before and after restoration was done, as a part of the monitoring process of the ReBorN project. The more specific objectives of this study were: (i) to quantify the physical features and the spatial complexity in the reaches pre- and post-restoration, by analyzing the UAV photos with a simple method in a GIS program, (ii) to compare the data derived in the GIS analysis to field survey data, to validate the GIS analyzing method, and (iii) to review the UAV photo quality and its importance for the accuracy of the data acquisition in the GIS program. These objectives will serve to assist the CAB in the evaluation of the restoration efforts and the follow up of the specific goals stated in the ReBorN project.

2 Method

2.1 Site descriptions

Six reaches along the Lögde River are used in this study (Table 1, Figure 1). Five reaches (Lögdån 1, Lögdån 2, Storforsen, Gunnarsaggan and Storfall) are located along the main stem and one reach (Mjösjöån) is a tributary. The Lögde River's origin is in the boreal forest landscape of northern Sweden. The landscape is dominated by the coniferous trees Scots pine (*Pinus sylvestris*) and Norwegian spruce (*Picea abies*), and deciduous birches (*Betula pendula* and *Betula pubescens*). The stream flows towards the southeast, close to the border between the counties of Västerbotten and Västernorrland, before it enters the Baltic Sea, approximately 50 km south of the city of Umeå. The monthly average temperature in the region range from -13 to + 15 ° C, and 600 mm of precipitation falls during a year (Sveriges Meteorologiska och Hydrologiska institut [SMHI] 2019a).

Table 1. Description of the study reaches. FHC = former highest coastline. n.a. = not available.

Site	Restoration date	Reach length (m)	Elevation a.s.l. (m)	Location in relation to the FHC	Field survey
Lögdån 1	1/7 – 20/7 2018	355	459	Above	Prior to restoration
Lögdån 2	1/7 – 20/7 2018	720	419	Above	Prior to restoration
Storforsen	3/10– 20/10 2017	934	193	Close	n.a.
Gunnarsaggan	15/9 – 1/10 2017	432	191	Close	n.a.
Mjösjöån	1/7 – 30/10 2018	1315	133	Below	Prior to restoration
Storfall	10/7-20/8 2017	361	71	Below	Prior to and after restoration

The bedrock in the area consists mostly of Precambrian granites and metamorphic rocks. The sediment production is low due to the weathering resistant bedrock and low relief of the landscape. The former glaciations in the area have affected the landscape, which is undulating and covered in various forms of till (Ivarsson 2007). The former highest coastline (FHC) is a result of isostatic rebound, the rise of land after the weight of the ice sheet is removed. Above the FHC the till is undisturbed and below the FHC, the till has been sorted by the movement of water and consists of more fine deltaic sediment (Fredén 1994; Lindén et al. 2006; Ivarsson 2007). Lögdån 1 and Lögdån 2 are located above the FHC, Mjösjöån and Storfall below the FHC, and Storforsen and Gunnarsaggan are located very close to the FHC. The County Administrative Board of Västerbotten restored the reaches in 2017 and 2018 (Table 1). The reaches Lögdån 1, Lögdån 2, Storforsen, Gunnarsaggan, and Mjösjöån are used in the evaluation of the effect of restoration on complexity. Parts of the reaches Lögdån 1, Lögdån 2, and Mjösjöån, and the whole reach Storfall is used in the comparison of field survey data and data derived from using UAVs and GIS.

2.2 Complexity metrics

The complexity metrics quantified in this study were determined by a literature study and constrained to those that can be quantified by using aerial photographs. The aerial photos of the reaches contain no elevation data which makes it impossible to get any measurements of the longitudinal dimension or the cross section. Metrics were chosen that (1) can be obtained in GIS from an aerial photo without elevation data, (2) can easily be calculated in Excel, and (3) are of interest to the County Board. Six reach-scale descriptive metrics associated with channel geometry were initially quantified (Table 2). The geometric features are needed to

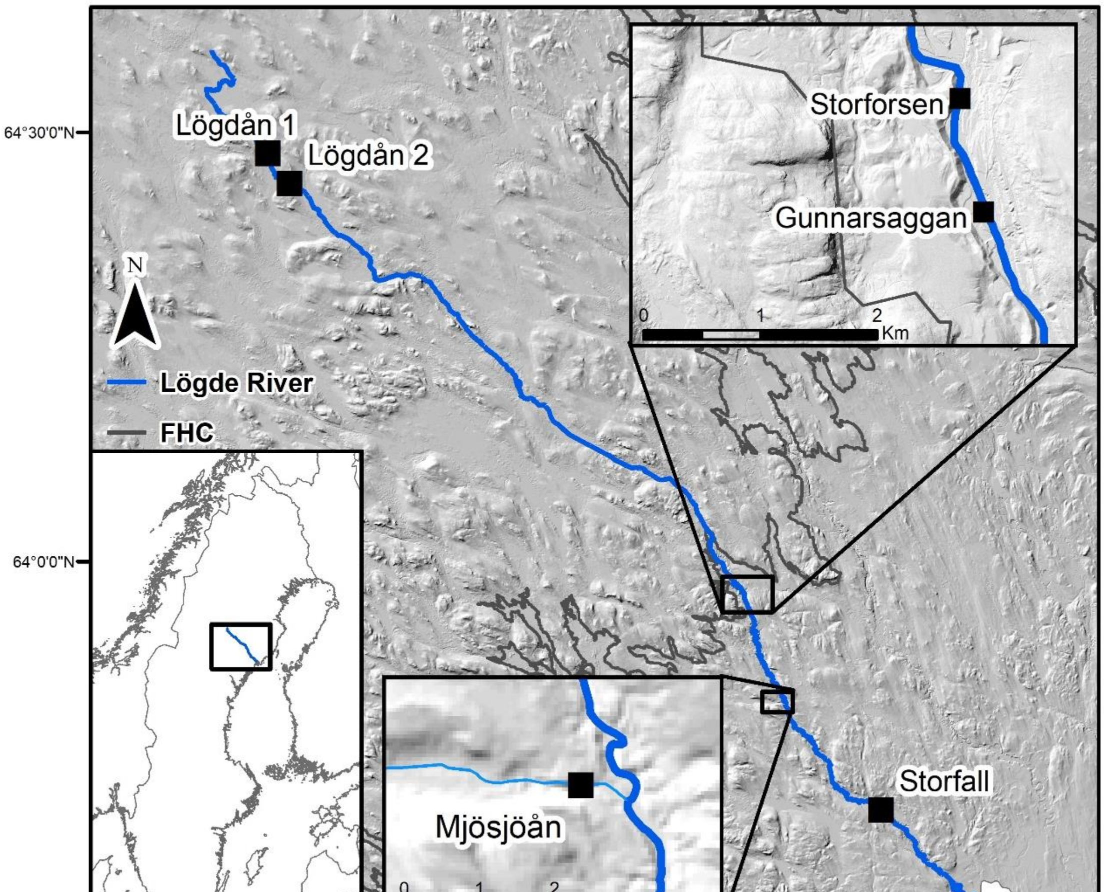

Figure 1. Location map of the study reaches. FHC = Former highest coastline (Lantmäteriet 2018; Havs- och Vattenmyndigheten 2018).

calculate the complexity metrics, and are also needed to determine if the goals of the ReBorN project is met. A total of seven complexity metrics was calculated, of which two describe instream wood, four describe the planform, and one describes the sediment spatial distribution (Table 3). The value of the complexity metric increases with increased complexity.

Table 2. The reach-scale descriptive metrics measured for each reach.

Geometric metric	Description	Features needed
Reach length	Measured as a straight line from each end of the reach. The length is measured from a point positioned midway between the bankfull edges.	Lines of the bankfull edges
Bankfull area	The area inside the highest banks on either side of the channel.	Bankfull area polygon
Wetted area	The area covered by water.	Wetted width polygon
Mean width	Mean width of the channel measured at evenly spaced transects.	Lines of the bankfull edges Evenly spaced transects along the reach
Total wood pieces	The total number of instream wood pieces (≥5 cm in mid-diameter and ≥ 1 m in length) inside bankfull area.	Lines representing the wood pieces Lines of the bankfull edges
Wood volume	The sum of the volume (length x mid-diameter) of the instream wood.	Lines representing the wood pieces with a length of (≥ 1 m) and mid-length diameter (≥ 5 cm)
Boulders	The numbers of boulders (≥ 25 cm diameter) visible above the water inside the bankfull area.	Bankfull area polygon Points representing the boulders

2.3 UAV data processing

The CAB used UAVs (Inspire 1, Mavic Pro and Phantom 4 Pro V2) to obtain imagery of the streams before and after restorations were performed. Restorations were done in 2017 and 2018 (Table 1). The flight altitude was on average 100m. The UAV photos of the reaches were imported to ESRI™ ArcMap 10.5® (ESRI 2018), henceforth referred to as GIS. The reach Storforsen was photographed three times as overlapping sections of about 350 m: Storforsen 1, Storforsen 2, and Storforsen 3. In this study these three photos were merged into one larger photo. The photo of Storfall taken prior to restoration did not cover the whole bankfull width, which means that it is not possible to digitize all necessary features of the stream. Therefore, Storfall is not used when evaluating the post- restoration change in complexity.

The features of the reaches were manually delineated as polygons, lines and points (Table 2). A line on each side of the channel was drawn to represent the bankfull edge. The placement of the line was based on visible sediments in the channel and vegetation patterns on land, where big bushes and trees marks the upper boundary for the bankfull width. In the post-restoration photos, the visible sediment that had been exposed during the restoration activity was determined to be inside the bankfull edges. In cases where vegetation covered the view of the ground, the placement of the bankfull edge was interpolated between last exposed parts of the ground. The reach length was defined as the length of a straight line drawn from each end of the reach that is visible in the photos. The line was from a point positioned midway between the bankfull edges at the top and bottom of the reach. The length of the lines of the bankfull edges and the reach length were used to calculate the bank length ratio (Bratio). The Bratio is the mean value of the right bank length ratio and the left bank length ratio, and was calculated with the formula:

$$Bratio = \frac{(L_r/L) + (L_l/L)}{2} \qquad \text{Eq. 1}$$

where:

L_r = length of the right bank
L_l = length of the left bank
L = reach length

Table 3. The complexity metrics calculated for each reach.

Geomorphic Complexity Dimension	Complexity metric	Abbr.	Description	Features needed	References
Instream wood	Wood pieces per 100 m	W_100m	The number of wood pieces per 100 m reach	Number of wood pieces Reach length	Degerman 2008
	Wood volume per hectare	W_ha	The wood volume per bankfull area (ha)	Wood volume Bankfull area	Wohl, Scott and Lininger 2018.
Planform	Bank length ratio	Bratio	Ratio of total bank length to reach length Expresses bank irregularity	Length of the bankfull edges Reach length	Polvi, Nilsson and Hasselquist 2014
	Width standard deviation	SDw	The standard deviation of the mean width of the stream	Mean width	Polvi, Nilsson and Hasselquist 2014
	Coefficient of variation of width	CVw	Standard deviation of widths scaled by the mean width Expresses the standard deviation as percentages of the mean.	Mean width Width standard deviation	Laub et al 2012
	Multithread index	MTI	The average number of channels along the reach	Evenly spaced transects along the reach Number of channels at each transect	Polvi and Wohl 2012
Sediment distribution	Boulder to bankfull distance	B_D	The mean distance from the boulders to the bankfull edge, scaled by mean width of the reach	Lines of the bankfull edges Number of boulders The distance from each boulder to the bankfull edge Mean width	This study

The channel width was measured by dividing the reaches into 20 equally sized sections. First, a line along the middle of the channel was digitized, which served as the input feature in the tool 'Generate points along lines. The tool was used to place 21 evenly spaced points along the line, to mark the placement for transects. Lines representing transects were drawn between the bankfull edges, at the shortest distance through the point at the midline. In case of transects crossing islands in the channel, the width of the island was subtracted from the length of the transect. The length of the transects was calculated in GIS and exported to Excel, where the mean width, the width standard deviation (SDw), and the coefficient of variation of width (CVw) was calculated. The same transects were used to calculate the multithread index (MTI), which is defined as the average number of channels along the reach.

Polygons were drawn to calculate the bankfull and wetted area. The bankfull area was defined as the area between the bankfull edges, and the wetted area was defined as all area covered by water in the channel. In cases where vegetation covered the view of the wetted area, the polygon was interpolated between last exposed parts of the water. All boulders visible above the water within the bankfull area were manually measured with the measuring tool in GIS. Boulders larger than 25 cm in diameter were represented by a point in a shape file. The nearest distance from each boulder to the bankfull edge was calculated using the tool 'Create near table' and exported to Excel. To get an index of how the placement of the boulders might have changed after restoration, the mean distance of the boulders to the bankfull edge, scaled by mean width of the reach (B_D), was calculated. This was done by using the formula:

$$B\_D = \frac{\bar{d}}{\bar{w}} \qquad \text{Eq. 2}$$

where:
$\bar{d}$ = mean value of the boulders distance to the bankfull edge
$\bar{w}$ = mean width of the channel

The width of the channel is included in the formula to standardize this value to changes in the width of the channel.

Each wood pieces that had any part of the piece inside the bankfull area, ≥ 1 m long, and had a mid-length diameter of ≥ 5 cm, were represented by a line in a shape file. The mid-length diameter of the wood pieces was manually measured and noted by using the measuring tool in GIS. In cases where the resolution or quality of the UAV photo made the measurement uncertain, several measurements of the width of a wood piece were taken and the average value was noted. The lengths of the wood pieces were calculated in GIS. The length and width of the wood pieces were exported to Excel where the volume and the metrics wood pieces per 100 m (W_100m) and wood volume per hectare (W_ha) was calculated.

2.4 Comparison with field survey data

Field surveys had been done prior to the restoration in smaller sections of the reaches Lögdån 1 in 2018, Lögdån 2 in 2017, and in Mjösjöån in 2017. These sections will further on be called L1_comp, L2_comp and Mjö_comp to not be confused with the whole reaches used in the post-restoration evaluation (Appendix, figure 1). The reach Storfall was field surveyed both before and after restoration was performed (Table 4). In this study only, the post-restoration field survey data of Storfall was used. The lengths of the field surveyed reaches were approximately 10 times the channel width before restoration. Field surveys were done by taking multiple points that marks the position of the bankfull edge and instream wood, with a survey-grade RTK-GPS or a total station. A total station is an optical instrument used to determine distances, angles and coordinates. Points of the bankfull edges were taken at intervals of 3 m. The bankfull edges of any islands present were also surveyed. The instream wood (with any part of the piece within the bankfull width) with a length of ≥ 1 m and mid-diameter of ≥5 cm was surveyed by taking a point at each end of the wood piece. The width of the instream wood was measured and noted during the surveying. The data points from the field surveys were imported to GIS and converted into polylines. The bankfull area, Bratio, number of wood pieces and wood volume was quantified as described in 2.2.

The reaches L1_comp, L2_comp and Mjö_comp had insufficient GPS satellite coverage and were surveyed by using a Trimble S3 total station and Trimble TSC3 data logger. These instruments create a local coordinate system, which is not referenced to a real world projected coordinate system, in which the data points from the survey are placed. To project the total station data points to a real-world coordinate system, which is needed to use them in the GIS analysis, the add-in CHaMP Transformation Tool (CTT) (Wheaton et al. 2012) was used in GIS. The CTT uses benchmark coordinates collected with a handheld GPS at the study site to position the total station data points in a real world projected coordinate system. During field surveying six to eight benchmark points were taken at each site with both the handheld GPS and the total station. The CTT visualize the total station points over a georeferenced imagery of the survey site by using the benchmark points. The use of different benchmark combinations shifts and rotate the total station data points over the imagery. Once the combination of benchmark points that gives the best projection of the total station data points over the imagery of the study site is found, the total station points can be transformed to a real world projected coordinate system (Wheaton et al. 2012).

Table 4. The sites used in the comparison of the field survey method and the UAV and GIS analysis method.

Site	Reach length (m)	Field survey date	Photography date	Reach condition
Storfall	361	25-26/6 2018	1/11 2018	Restored
L1_comp	89.76	2/7 2018	26/6 2018	Channelized
L2_comp	94.49	11/7 2017	26/6 2018	Channelized
Mjö_comp	98.66	14/7 2017	27/6 2018	Channelized

2.5 Statistics

Paired one-tailed Student's T-tests were used on the reach-scale descriptive metrics and the complexity metrics to test whether the channel morphology changed significantly after restoration. Two-tailed Student's T-test were used to test if there was a difference between field data and GIS data. All statistical tests were performed in Excel.

2.6 General quality comparison of the photos

The UAV photos were qualitatively reviewed regarding how easy it was to detect the features of interest while digitizing. General conclusions on causes of differences in photo quality were drawn based on the camera settings ISO value and shutter speed, in combination with the time of the day and time of the year the photos were taken.

Following is a simplified description of how the camera settings function. The ISO setting change the camera sensors sensibility to light. The ISO setting commonly ranges from 100 up to 800, although many cameras can allow even higher values. A high ISO value gives a high light sensibility of the sensor. During deficient light conditions the ISO value can be increased to get brighter pictures, but also more image noise, meaning the photos become grainy (McHugh 2019). The shutter speed determines how long the shutter is open and thus how much light will reach the sensor. The shutter speed is reported as fractions of a second, for example 1/100 s. A fast shutter speed gives sharp pictures, but also a low amount of light will reach the sensor and the pictures might get dark depending on the light conditions. A slow shutter speed allows more light to reach the sensor but a risk of motion blur might occurs. The photographer can use standardized exposure modes for the camera, where the photographer chose a value for one setting and the camera automatically adjust the other setting. For example, if the ISO is set to a low value in deficient light, the camera will compensate with a slower shutter speed to absorb more light. And the other way around, if the shutters speed is set very fast in deficient light, the camera will increase the ISO value (McHugh 2019).

3 Results

3.1 Descriptive metrics

The GIS analyzes showed that all descriptive metrics were different in the channelized condition and the restored condition (Appendix Table 1, Appendix Figure 1). The statistic T-test showed that the mean width ($p = 0.0465$), bankfull area ($p = 0.0317$), and the wetted area ($p = 0.0374$) significantly increased after restoration (Table 5). The total wood pieces and wood volume also increased after restoration, but it is not significant. The mean number of boulders in the restored condition decreased compared to the channelized condition. However, the sample size was only 5 reaches. When looking at the reaches individually (Table 6), the number of wood pieces increased in four out of five reaches, the wood volume in all reaches, and the number of boulders in three out of five reaches. In both the Storforsen and Gunnarsaggan reach, all the descriptive metrics increased after restoration, of which Gunnarsaggan got the largest percentage increase (Table 6).

Table 5. Mean and standard deviation (SD) for the reach-scale descriptive metrics for the channelized and restored conditions (n=5). Significant differences (α=0.05, one-sided) are highlighted with a bold font.

	Reach condition		
	Channelized	Restored	*p*-value
Mean width (m)	24.75 (14.64)	38.97 (28.31)	**0.0465**
Bankfull area (ha)	2.13 (1.67)	3.46 (2.72)	**0.0317**
Wetted area (ha)	1.46 (1.17)	2.38 (1.98)	**0.0374**
Total wood pieces	174 (151)	364 (429)	0.1412
Wood volume (m^3)	6.89 (5.23)	22.06 (25.10)	0.0844
Boulders	916 (748)	716 (681)	0.1888

The wetted area in the reaches increased with an average of 1.48 ha per restored kilometer, with the highest increase of 2.31 ha in the reach Storforsen, and the lowest increase in Mjösjöån with a rewetted area of 0.21 ha. The bankfull area increased with an average of 2.07 ha per restored km. Gunnarsaggan had the highest increase with 5.11 ha per restored kilometer and Lögdån 2 the lowest with an increase of 0.33 ha bankfull area per restored kilometer.

Table 6. The change in the reach-scale descriptive metrics for each reach. The column denoted with a '±' show the change in absolute value and the column denoted with a '%' change in percentage. Increased values are highlighted in green and decreased in blue, where a darker color means a larger difference according to the percentual change.

	Lögdån 1		Lögdån 2		Storforsen		Gunnarsaggan		Mjösjöån	
	±	%	±	%	±	%	±	%	±	%
Mean width (m)	+5.55	+39	+2.30	+16	+19.73	+48	+37.21	+ 92	+6.33	+47
Bankfull area (ha)	+0.39	+39	+0.24	+22	+2.89	+57	+2.21	+104	+0.93	+51
Wetted area (ha)	+0.33	+57	+0.35	+54	+2.16	+63	+1.50	+127	+0.27	+24
Total wood pieces	+9	+10	+64	+139	+770	+220	+216	+386	-105	-32
Wood volume (m^3)	+0.5	+15	+2.96	+244	+49.98	+349	+7.41	+131	+15.0	+153
Boulders	-1000	-65	-113	-14	+51	+12	+15	+125	+45	+2

3.2 Complexity metrics

Restoration increased the mean value of six of the seven quantified complexity metrics. There is a significant increase in the metrics B_D (p = 0.0403), Bratio (p = 0.0376), and MTI (p = 0.0201) (Table 7). The mean values of W_100m, W_ha, and SDw increased after restoration, but the change is not significant. In the reaches Storforsen and Gunnarsaggan all complexity metrics increased, and in Lögdån 2 all metrics but the MTI increased, as no additional channels were created within that reach (Table 8). Values for the complexity metrics for each reach in its channelized and restored state are shown in the Appendix, Table 2.

Table 7. Mean and standard deviation (SD) for the complexity metrics for the channelized and restored conditions (n=5). Significant differences (α=0.05, one-sided) are highlighted with a bold font.

	Reach condition		
	Channelized	Restored	*p*-value
W_100m	21.37 (12.01)	48.47 (44.07)	0.0921
W_ha	3.23 (1.53)	5.31 (3.02)	0.0650
Bratio	1.368 (0.482)	1.465 (0.434)	**0.0376**
SDw	8.40 (4.43)	13.41 (9.62)	0.1101
CVw	0.388 (0.225)	0.345 (0.075)	0.2940
MTI	1 (0)	1.219 (0.164)	**0.0201**
B_D	0.182 (0.093)	0.269 (0.028)	**0.0403**

In Mjösjöån three complexity metrics, W_100m, CVw and B_D, decreased after restoration and four metrics, W_ha, Bratio, SDw and MTI, increased. In Lögdån 1 three complexity metrics, W_100m, MTI and B_D, increased, and three metrics decreased (W_ha, SDW and CVw), whereas the change in Bratio was negligible.

Table 8. The change in the complexity metrics for each reach. The column denoted with a '±' show the change in absolute value and the column denoted with a '%' change in percentage. Increased values are highlighted in green and decreased values in blue, where a darker color means a larger difference according to the percentual change.

	Lögdån 1		Lögdån 2		Storforsen		Gunnarsaggan		Mjösjöån	
	±	%	±	%	±	%	±	%	±	%
W_100m	+2.54	+10	+8.89	+139	+82.09	+220	+49.97	+386	-7.99	-32
W_ha	-0.62	-18	+2.06	+181	+5.27	+185	+0.05	+2	+3.64	+67
Bratio	+0.005	±0	+0.021	+2	+0.114	+8	+0.231	+22	+0.114	+10
SDw	-1.78	-16	+0.90	+23	+7.37	+51	+17.65	+226	+0.89	+19
CVw	-0.308	-40	+0.016	+6	+0.006	+2	+0.135	+70	-0.065	-19
MTI	+0.095	+10	±0	±0	+0.286	+29	+0.381	+38	+.0333	+33
B_D	+0.106	+84	+0.069	+37	+0.146	+94	+0.161	+151	-0.048	-14

3.3 Data comparison with field data

There is no significant difference ($p > 0.05$) between the values for Bratio, wood volume, bankfull area, and the number of wood pieces, derived from the field survey and the GIS analyzes (Table 9). The mean values of the metrics from the field survey is slightly higher compared to the GIS analyzes, but due to the small sample size ($n=4$), the digitized data from the two methods is also visualized to enable a qualitative comparison of the results (Figure 2). The study area of reach Storfall is larger in comparison to the other reaches, which explains the higher values of total wood pieces, wood volume and bankfull area. Wood was only identified in three of the surveyed reaches. Data from the field survey shows a higher number of wood pieces in two of the reaches and a larger wood volume in all three reaches (Table 10). In L1_comp the placement of the wood pieces is very similar between the methods, but in Mjö_comp placement of the wood pieces is totally different. In Storfall some larger wood pieces is located at the same place in the data from the field survey and the GIS analysis, but the large difference in total number of wood pieces makes it hard to conclude if there is any systematic difference between the methods.

Table 9. Mean and standard deviation (SD) for the values derived from the field survey and the GIS analyze (*n*=4).

	Method		
	Field	GIS	*p*-value
Total wood pieces	61 (96)	26 (37)	0.4116
Wood volume (m^3)	6.38 (10.48)	3.92 (6.57)	0.3894
Bankfull area	0.75 (1.31)	0.68 (1.16)	0.4188
Bratio	1.072 (0.049)	1.065 (0.015)	0.7169

In L1_comp the bankfull edges drawn in the GIS analysis is located closely to the one drawn in the field survey, although in some places it is not drawn as far up on land, which results in a 0.013 ha smaller bankfull area from the GIS analysis. The largest discrepancy is approximately 3 m between the lines. The quantified Bratio in L1_comp, on the other hand, is almost identical between the methods. In L2_comp the bankfull edge from the GIS analysis is almost consistently drawn outside of the field survey bankfull edge, with a discrepancy of approximately 2.5 m at most. This results in a larger bankfull area and Bratio quantified from the GIS analysis. In Mjö_comp the bankfull edges from the two methods crosses each other on some places and no systematic discrepancy between the methods is detected. The largest discrepancy is approximately 3 m. The quantified bankfull area in Mjö_comp is almost identical between the different methods, despite the differences in placement of the bankfull edge. However, the value of Bratio differs between the methods. In the lower left corner of the Storfall reach the GIS analysis placement of the bankfull edge deviates largely from the field survey. The field survey placed the line approximately 30 meters further up on land compared to the GIS analysis. The discrepancy of the placement is approximately up to 5 meters in other parts of the reach, but the lines also crosses each other on several places. The bankfull area quantified with data from the field survey is approximately 0.3 ha larger than the bankfull area quantified in the GIS analysis. The Bratio derived from the field survey is also larger in Storfall.

Table 10. The measured values from the field survey and the GIS analyzes. Columns denoted with 'Field' show values from the field survey and the columns denoted with 'GIS' the values from the GIS analyzes of the UAV photos of the reaches.

	Reach length	Total wood pieces		Wood volume (m^3)		Bankfull area (ha)		Bratio	
Site	(m)	Field	GIS	Field	GIS	Field	GIS	Field	GIS
Storfall	361	172	69	18.48	11.51	2.719	2.415	1.142	1.084
L1_comp	89.76	4	4	0.13	0.03	0.090	0.077	1.055	1.054
L2_comp	94.49	0	0	0	0	0.091	0.116	1.059	1.069
Mjö_comp	98.66	8	6	0.53	0.22	0.098	0.100	1.030	1.051

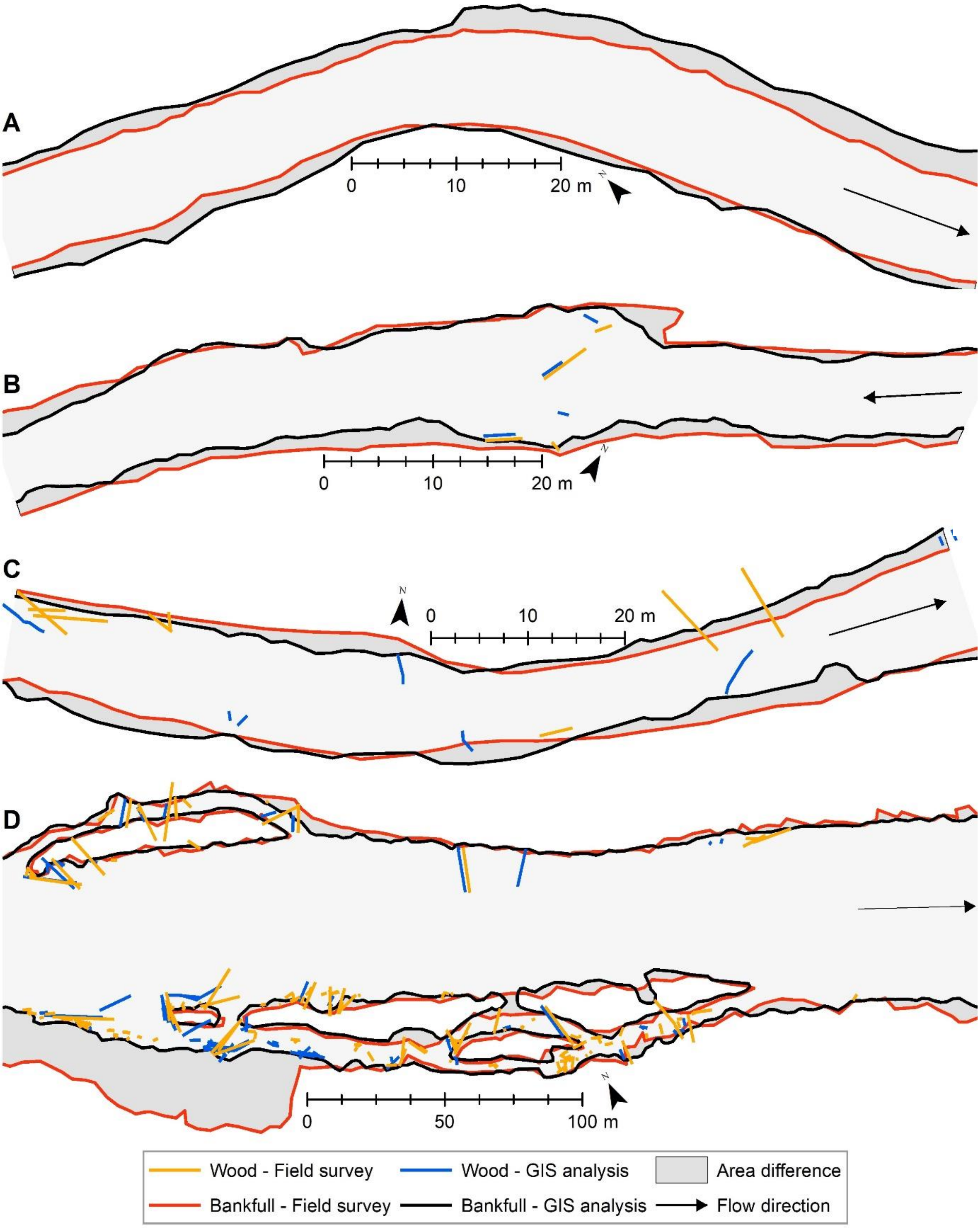

Figure 2. The features digitized in the GIS analysis and with field survey data in (A) L2_comp, (B) L1_comp, (C) Mjö_comp, and (D) Storfall.

3.4 Review of the photo quality

All three photos of the reach Storforsen in channelized condition were taken in July during cloudy weather. The photos are sharp, and many details are detectable, which made it easy to identify the features of interest (Figure 3A). The three photos of Storforsen in restored condition vary greatly in quality. They were taken at different days and with different settings (Appendix, Table 3). Storforsen 1 and Storforsen 3 in restored condition are similar in quality as they both were taken in October, after the defoliation. The weather was cloudy or just weak sunlight (Figure 3C). Boulders and instream wood were easy to identify and measure in the photo. However, the quality of the photo of Storforsen 2 in restored condition is very blurry and noisy (Figure 3B). A possible explanation to the low photo quality is that the shutter speed appears to have been set to 1/320, and to compensate for the low amount of light the ISO value varied between 535-1037. Details in the photo are lost and it was difficult to distinguish where the bankfull edge was located, and if the boulders were located above or below the water surface.

The quality of the photos of the reach Gunnarsaggan in both its channelized and restored condition is comparable to the photos of Storforsen 1 and Storforsen 3. The weather conditions and camera settings were similar. However, there were some difficulties when identifying and measuring the size of boulders and instream wood in the photo of the restored condition, due to a combination of sunlit areas, shadows, and visible tracks from the excavator used in the restoration. The pixel size of 6.3 cm also contributed to a loss of details in the photos (Appendix, Table 3).

The photos of Lögdån 1, Lögdån 2 and Mjösjöån in its channelized condition were taken in sunny weather in June. The pictures are very sharp and generally the features of interest were easy to identify. However, there is also dark shadows in which features were difficult to identify, especially in the photo of Mjösjöån which was taken in late afternoon with a lot of long shadows (Figure 4A and 4C). The canopy of the trees obscured the ground and at some places it was difficult to distinguish the location of the bankfull edges, boulders, and wood pieces. The photos of Lögdån 1, Lögdån 2, Mjösjöån and Storfall in restored condition were taken in November. These photos are blurry, probably because of deficient light conditions. The weather was cloudy in Lögdån 1 and Lögdån 2, and weak sunlight in Mjösjöån and Storfall. The shutter speed was relatively long (1/12 to 1/100 fraction of a second), and the ISO relatively low (between 100 and 240) (Appendix, Table 3). As the UAV photos were taken in late autumn, ice had formed in the channel, which complicated the identifying and measuring of the channel edge, wood pieces and boulders (Figure 4B and 4D). Boulders and wood pieces were in some places covered by snow on land, and covered by ice in the water.

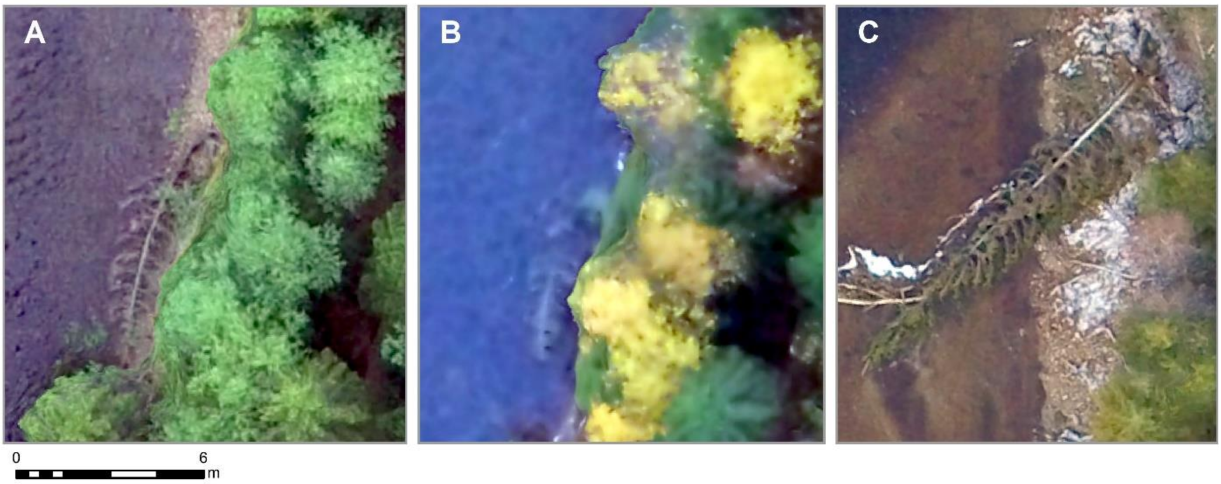

Figure 3. The quality of the UAV photos of (A) Storforsen 2 in channelized condition, (B) the same area of Storforsen 2 in restored condition, and(C) Storforsen 3 in restored condition. All panels have the same resolution. The digitized features are not shown in this figure.

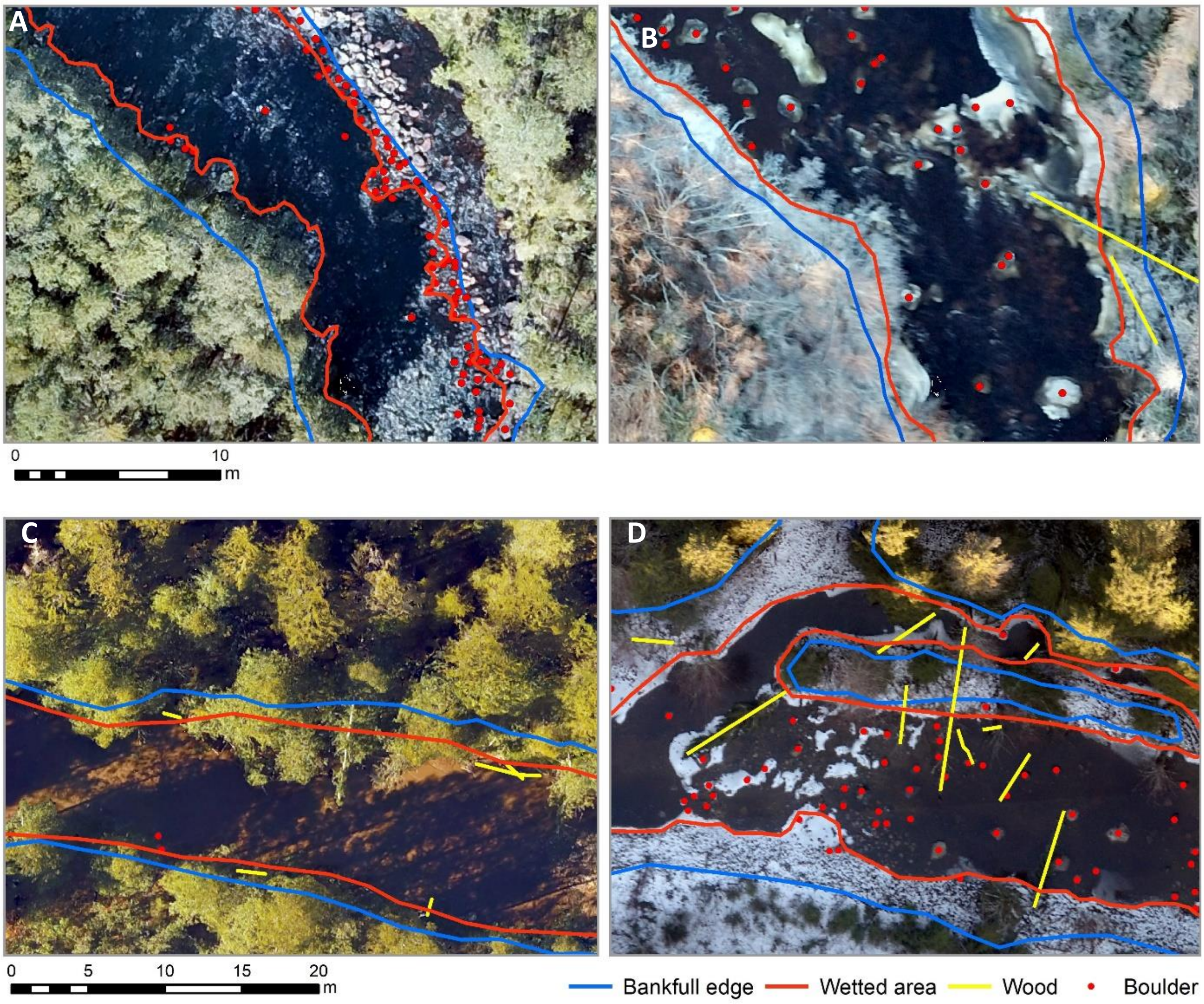

Figure 4. (A) Lögdån 1 in channelized condition, (B) the same area of Lögdån 2 in restored condition, (C) Mjösjöån in channelized condition, and (C) the same area of Mjösjöån in restored condition.

4 Discussion

4.1 Pre and post-restoration

4.1.1 Descriptive metrics

When restoring streams, the CAB specifically aims to increase the amount of instream dead wood and the number of boulders in the stream channel, and to enlarge the wetted area in the reaches. These actions are done to reduce the water velocity and improve the habitat for many aquatic species, for example brown trout *(Salmo trutta L.)* (Zika and Peter 2002). This study showed that the restoration effort significantly increased the mean width, bankfull area and wetted area in the reaches. The wood volume also increased in all reaches: however, the change is not statistically significant, which is probably due to the low number of reaches used in this study (n = 5).

The restoration had the largest effect on the geometry in Storforsen and Gunnarsaggan, as all descriptive metrics increased. In Lögdån 1 and Lögdån 2, the number of boulders is decreased after restoration, and in Mjösjöån the total wood pieces decreased. One reason for this decrease is the quality of the UAV photos. The photos of the restored condition in these reaches are dark and blurry, and in all three reaches there was ice and snow on the ground. A second reason for the reduction in number of boulders in Lögdån 1 and Lögdån 2 is likely due to differences in discharge on the day when the UAV photos were taken. In the UAV photos of these reaches it is visible that the discharge was much higher in the photo of the reach in the restored condition, compared to the channelized condition. Boulders added to the stream by the CAB may be located under the water surface in the photo of the restored condition. Unfortunately, no discharge data from 2018 is available on SMHI. There is no apparent visible difference in discharge in the photos of Mjösjöån, but even small changes in discharge and, thus, water surface level may affect the number of wood pieces that are visible in the UAV photo.

4.1.2 Complexity metrics

The hypothesis of an increased complexity after restoration is confirmed for three of the seven complexity metrics quantified in this study. The restoration had a significant effect on the Bratio and MTI, which describe the planform, and the B_D, which describes the sediment spatial distribution. The sample size in this study was only five reaches, and one should not draw the conclusion that the restoration does not have an increasing effect on the other complexity metrics that were quantified. Several of the complexity metrics increased after restoration, even though it was not statistically significant. In the Storforsen reach and Gunnarsaggan reach, all the seven complexity metrics increased, and in Lögdån 2 all metrics except for the MTI increased, as no additional side channels were created within that reach. However, in the Lögdån 1 reach and Mjösjöån reach the total effect on complexity after restoration is not as clear, as some of the metrics increased and some decreased.

The total number of wood pieces is lower after restoration in the Mjösjöån reach, with a following decrease in the metric W_100m. This is probably not a long lasting effect as the amount of wood pieces will likely increase with time by recruitment from the surrounding riparian forest. Despite the loss of wood pieces in Mjösjöån, the wood volume and W_ha increased after restoration, which means that the size of the wood pieces within the reach is larger than prior to restoration. Large wood pieces have a greater effect on stream flow and velocity than smaller pieces and are more likely to form log jams that trap sediment and organic matter, which may lead to avulsions and multithreading of the channel (Dahlström and Nilsson 2004; Wohl 2013). This leads to a higher complexity in the cross section, longitudinal, and planform dimensions as the stream bed and channel form become more variable (Wallace, Webster and Meyer 1995). During restoration, an addition of large wood pieces (>30 cm in diameter) is prioritized due to both the wood pieces shaping effect on stream morphology, and the low occurrence of large woody debris in channelized streams (Degerman 2007). However, an addition of small wood pieces (< 2 cm in diameter) is also important as these trap the largest amount of leaves, which contributes to a major part of energy input to the stream (Fisher and Likens 1973; Muotka and Laasonen 2002).

The reason for the decreases of the metrics CVw and B_D in Mjösjöån, and the metric W_ha in Lögdån 1, can be deduced from the changes of the mean width and bankfull area in the reaches. The decrease in the metric CVw in Mjösjöån is derived from a relatively large increase in the mean width (47%), compared to the increase of SDw (19%), which the metrics are based on. The metric B_D in Mjösjöån decreased for the same reason, as the boulders distance to the bankfull edge increased, but not as much as the mean width. In Lögdån 1, the metric W_ha decreased, because the increase in bankfull area is relatively larger (39%), than the increase in wood volume (15%). The restoration effort is, on the other hand, the cause of the decrease in the metrics SDw and CVw in Lögdån 1. The variation in channel width became lower after restoration, as expressed by the reduction of the SDw. This led to a following decrease of the metric CVw, as the metric is based on the values of SDw and the mean width.

The consequences of the changes in spatial complexity for biodiversity is hard to predict in the reaches used in this study, even in the ones were all complexity metrics increased. A dominant paradigm in stream restoration is that increased spatial complexity enhances the biodiversity, but there are studies showing no effect on biodiversity after restoration, despite an increased complexity (Palmer, Menninger and Bernhardt 2010, Helfield et al. 2012, Nilsson et al. 2017).

Field surveys of the biota are therefore needed to evaluate the restorations effect on biodiversity. In addition, as the restoration is a disturbance in itself, it may take years before the ecosystem recovers and reach equilibrium after the restoration.

4.1.3 The ReBorN project goals

The specific ReBorN project goal of an increase in wetted area of 0.12 ha per restored kilometer is met in all reaches. As this goal was very clearly specified, it was easy to quantify with data from the GIS analyzes. There are no requirements specified to achieve the ReBorN project goal of a more heterogeneous stream channel geometry mentioned in the project description (LIFE15 NAT/SE/000892). Hence, the interpretation is that the goal is met in a reach if one of the complexity metrics has increased after restoration. The goal of a higher heterogeneity is clearly met in the reaches Lögdån 2, Storforsen and Gunnarsaggan. The goal is also considered met in Lögdån 1 and Mjösjöån as well, even though not all complexity metrics increased after restoration.

The ReBorN project goal of an increased hydraulic roughness was harder to quantify using UAVs and GIS as a method. The hydraulic roughness is a measure of the frictional resistance the water is exposed to in a stream channel, and is commonly expressed as the friction factor 'n', which is determined with the Manning's equation. The water velocity, channel bed slope, width, and depth of the stream must be known to use the equation and determine 'n'. The hydraulic roughness is also affected by the variation in channel shape; obstructions such as wood and boulders, the channel vegetation, and the degree of meandering (Jarret 1985). In this study it is only possible to give an indication of the change in hydraulic roughness, as it was not possible to retrieve data on the water velocity, channel bed slope, and depth of the stream from the UAV photos. In this study the complexity metrics W_100m, W_ha, Bratio and B_D were quantified. An increase in these metrics could indicate an increase in hydraulic roughness. The Bratio express the bank irregularity, thus a higher value means that the bankfull edge is more variable. The B_D value is the average distance of the boulders to the bankfull edge divided by the mean width of the stream. A higher B_D value after restoration means that the boulders are placed further from the bankfull edge and are more spread out in the stream channel, thus having greater impact on the water velocity than the boulders prior to restoration. The metrics W_100m and W_ha describes the number of wood pieces per 100 m and the wood volume per hectare of bankfull area. Large structures placed in a stream channel, such as boulders and wood pieces, will obstruct the stream flow and thus increase the hydraulic roughness (Wallace et al. 1995; Gardeström et al. 2013; Wohl 2013). In the reaches Lögdån 2, Storforsen, and Gunnarsaggan all the four metrics mentioned above increased after restoration, and the hydraulic roughness likely increased as well. In Lögdån 1 the metrics W_100m and B_D increased, W_ha decreased, and Bratio was unchanged after restoration. In Mjösjöån two of the metrics increased, W_ha and Bratio, and two decreased, the W_100m and B_D. The number of boulders increased in Mjösjöån, and the wood pieces in this reach are larger after restoration, which probably impacts the water flow. However, it is necessary to take measurements *in situ* to be able to evaluate if the goal of an increased hydraulic roughness after restoration is met.

4.2 UAV and GIS data as a monitoring method

When developing alternative methods to use instead of field surveys, it is important to verify the new method with field data to validate its accuracy. In this study, data derived from a simple method using UAV photos and feature digitizing in GIS were compared to data from field surveys. This study showed no significant difference between the two methods. However, the sample size used in the statistical test was only four and one should therefore examine the results visually to interpret the result. It is important to recognize the temporal difference in data gathering between the field survey and UAV photography in some of the reaches, as the natural dynamics of the streams may have altered the features identified in the reach. In the L2_comp and Mjö_comp reaches, the field surveys were conducted one year prior to the UAV photography, and in the Storfall reach, the field survey was conducted five months prior to the

UAV photography. L1_comp is the only reach where the time between the field survey and UAV photography is unlikely to have affected the results, as it was only one week between the occasions.

4.2.1 Bankfull edge

The placement of the bankfull edge will affect the size of the bankfull area and the metrics that depends on either the size of the bankfull area or the placement of bankfull edge, i.e. all the reach-scale descriptive metrics and all the complexity metrics quantified in this study, except for the wetted area and the W_100m. When comparing the GIS analysis with the field survey data the placement of the bankfull edge differs somewhat between the methods. No systematic discrepancy is seen, as the bankfull edge is placed between the lines from the field survey in L1_comp, outside the lines in L2_comp, and it crosses the field survey lines in several places in Mjö_comp and Storfall. The largest discrepancies in the placement of the bankfull edge is noticed in L2_comp and Storfall. In L2_comp the placement differs approximately 2.5 m along a longer part of the left bank, and in Storfall the difference in placement is up to 30 m at most in the upper right bank of the reach. The canopy cover made it difficult to identify the location of the bankfull edge in some UAV photos. The bankfull edge is usually identified by a change in elevation from a flat floodplain to a steeper channel bank, and by a change in vegetation from perennial up-land species to annual water-tolerant species. A change in the sediment texture from newly disturbed sediment within bankfull to more soil development and lichens on boulders is also an indicator of the bankfull edge. These small-scale changes in physical features are easier to detect when being out in the field close to the objects, compared to the 100 m distance that the viewer of the UAV photos got to the features. While digitizing in GIS, the upper boundary for the bankfull edge was determined by the presence of large trees, bushes, and visible sediment. The UAV photos in this study does not contain any elevation data, hence differences in elevation was only detected via visual interpretation of the photos. In the area in Storfall, where the measured lines of bankfull edge from the field survey and the GIS analyze differs, there is a stand of large spruces visible in the UAV photo. The reason why the person who performed the field survey chose to include these spruces inside the bankfull area is unknown, but there may be features that are detectable in the field but not in the UAV photo, that reveals that the flow reaches that high up on land during bankfull discharge.

The discrepancy of the field- and GIS- delineated bankfull edge results in differences in size estimation of the bankfull area in the reaches. In the reaches L1_comp, L2_comp and Mjö_comp, which are approximately 90 to 100 m long, the size estimation differs with -0.013 ha, + 0.025 ha and + 0.002 ha, respectively. In Storfall, which is approximately 360 m long, the GIS analysis estimated the bankfull area to be 0.304 ha smaller compared to the field survey, due to the large discrepancy in the placement of the bankfull edge in one part of the reach. Since two of the reaches got a larger bankfull area and two got a smaller bankfull area with the GIS analysis compared to the field survey, no conclusion can be drawn about whether the GIS method overestimates or underestimates the size of the bankfull area. The same goes for the Bratio, as the GIS analysis got a higher value for two reaches and smaller values for two reaches, compared to the field survey data. Thus, a larger sample size is needed to fully evaluate the accuracy of the method. The UAV and GIS method works well on a large scale (ten to hundreds of meters and larger), as a generalized estimate of where the bankfull edge is located and a generalized size estimation of the bankfull area can be done. On smaller scales (tens of meters and smaller), field surveys are more accurate, as it is easier to detect variations in vegetation cover and elevation under the canopy, when in field.

4.2.2 Wood

The size and placement of instream wood is interesting due to its channel shaping capacities and importance for stream biota (Crook and Robertson 1999; Zika and Peter 2002; Wohl 2013). Wood was only found in three of the four reaches, and the difference in time between the field survey and UAV photography in two of the reaches complicates the comparison of the data. In the reach Mjö_comp the placement of the identified wood pieces differs between the methods. The UAV photography was done in the summer of 2018, one year after the field survey was done. The spring flood of 2018 was the largest since 1995 in northern Sweden and was described as a 10- to 50-year flood (SMHI 2018b). The wood pieces in Mjö_comp have probably moved between the field survey and UAV photography in the spring flood. It is unlikely that it is the same wood pieces that has been measured, therefore the accuracy of the length and width measurements in the GIS analysis was not compared to the field data for this reach. In the Storfall reach, the difference in the number of quantified wood pieces is large, as the data from the field survey contains about 100 more wood pieces than found in the GIS analysis. The UAV photos were taken in November 2018, five months after the field survey. Some smaller wood pieces that were identified in the field survey may have been flushed away during high autumn flows. There is unfortunately no discharge station located within the in Lögde River catchment, but there is one discharge station in the Gide River, located south of the Lögde River, and one in the Öre River, located north of the Lögde River. When looking at data from these stations for the dates June 24th to November 1th 2018, there was a distinct peak in flow on July 31th in 2018 in both rivers (SMHI 2019b, SMHI 2019c), and one can assume that the discharge in the Lögde River had a similar peak. The difference in number of identified wood pieces can also be due to it being easier to identify individual wood pieces in the field survey. For example, it is easier to count all the wood pieces in logjams in the field, than in the UAV photo, as only the top laying pieces will be seen in the UAV photo. The UAV photo was taken when ice had formed in the channel, and is slightly blurry and dark, which made it hard to identify and accurately measure the width of wood pieces in the GIS analysis. By visually comparing the digitized wood pieces in the upper left bank of Storfall, it is visible that the canopy covered the wood pieces laying on the ground, making them appear shorter in the GIS analysis. The L1_comp reach is the only reach where the wood pieces identified with the two methods can be compared to each other, as the time between the field survey and UAV photography was only one week. Four wood pieces were identified with each method, and they are located within 0.7 m to each other. The wood volume quantified with data from the field survey is larger than the wood volume quantified in the GIS analysis. Examination of the measured width and length of the wood pieces in L1_comp showed that the measured lengths are larger in the field survey for three pieces. For the remaining piece, the length is measured to the exact same length with both methods. The measured width was larger on all wood pieces in the field survey compared to the GIS analysis.

The minimum width of the wood pieces was set to 5 cm when doing the GIS analyzes, which corresponds to the conditions used when manually measuring the size of wood pieces in a study by Polvi, Nilsson and Hasselquist (2014), where they quantified the spatial complexity in channelized, restored, and natural streams. The use of a minimum width of 5 cm in the GIS analysis was optimistic, considering that the pixel sizes is 1.7 cm to 6.3 cm in the UAV photos used in this study (Appendix, table 3). In a study by Niedzielski, Witek, and Spallek (2016) where they used UAV photos to map stream features, the UAV photos had a resolution of approximately 3 cm and they determined the accuracy of the digitizing to be 10 cm. The UAV photos of the Gunnarsaggan reach got the largest pixel size of 6.3 cm, and the estimate of the wood volume in that reach is thus quite rough. Based on the comparison of the measurements of the wood pieces in the reaches L1_comp and Storfall, and observations from when digitizing the wood pieces in the reaches used in the evaluation of stream restoration, the conclusion is drawn that the GIS analyzing method generally underestimates the number of wood pieces and wood volume in streams, due to loss of accuracy in the cm scale, and by being obscured by other objects. However, more studies with field surveys and UAV photos taken during the same day, should be done to evaluate the accuracy of quantifying the number of wood pieces and wood volume with UAVs and GIS. Although, the UAV photo and GIS method is sufficiently accurate to use for mapping the placement of the wood in the stream channel and of the wood pieces' orientation against the water flow.

4.2.3 Other observations

Data from field surveys were only available for parts of the reaches Lögdån 1, Lögdån 2, Mjösjöån and Storfall, and only the bankfull edge and the wood pieces within the reaches were surveyed. Even though there are no field data for the number of boulders and the wetted area, conclusions can still be drawn on the accuracy of the digitizing of these features, from observations done during the digitizing of all the reaches used in this study. The wetted area was easy to digitize as the boundary between water and dry sediment is easy to see in the UAV photos. Difficulties only occurred when trees and bushes obscured the ground and when ice had formed in the water. In the UAV photos of Lögdån 1, Lögdån 2 and Mjösjöån in the channelized condition there was also some difficulties in shaded areas, where the extent of the wetted with was hard to distinguish. The estimates of the wetted area are probably more accurate than the estimates of the bankfull area, as the bankfull edge is defined by changes in vegetation, sediment texture, and elevation which more likely to be obscured by vegetation in the UAV photos, compared to the view of the extent of the water surface. However, the size of the wetted area is highly dependent on the discharge, meaning the size of the wetted area will differ between low flow and high flow.

The CAB were interested in the number of boulders in the stream channel that is visible above the water surface, as the boulders were moved from the channelized stream edge into the stream channel during the restoration. In this study, boulders larger than 25 cm were counted within the bankfull area, and not only the wetted area, to reduce the influence of potential differences in water flow on the number of boulders. Any differences in bankfull area between the channelized and restored state will only be due to the restoration effort. Despite this, the discharge likely affected the result in Lögdån 1 and Lögdån 2. There are some areas within these reaches that were not altered during restoration, and boulders that are seen within that area in the UAV photo of the channelized state, are not visible in the photo of the restored condition, due to a higher water flow. The total of number of boulders should be seen as a rough estimate, as the size of smaller boulders was hard to estimate in some of the reaches. The reasons for this are the same as mentioned earlier for the wood pieces: blur, snow, and a large pixel size in the photos of some reaches. However, this method gives a good view of the spatial distribution of the boulders. The differences in placement of the boulders after restoration is clearly seen in the UAV photos.

4.3 Future implementation

To create the best conditions for the GIS analysis, it is important to take UAV photos of good quality. The GIS digitizing method will determine the reaches as less complex than they really are, if details of features, such as wood and boulders, are hard to identify in the UAV photos. The water discharge affects the size of the wetted area and how many boulders and wood pieces that are visible within the bankfull area. If the reach is monitored and the photos will be used to quantify data for comparative purposes, the aim should be to take photos during days with as equal water discharge as possible, to avoid biased data. The photos should be taken during days with cloudy weather to avoid bright sunlit areas and areas in dark shadows, as details of features may be lost in those conditions. If it is cloudy, the camera settings must be adjusted to the light conditions to avoid dark and blurry photos. A suggestion is to set the shutter speed to at least 1/100 and use the automatic setting for the ISO value, so it adjusts itself to a sufficiently high value. The best season to photograph the reaches would be before leafing of trees or after the defoliation when there is no snow, to avoid any obscuring of the view of the ground. However, the bankfull edge may be harder to identify with a lack of green vegetation, but wood pieces and the wetted area will be easier to see. The problem with trees and other objects obscuring the view for the UAV has been recognized in other studies (Atha 2014; Ortega-Terol et al. 2014; Niedzielski, Witek, and Spallek 2016, Wohl 2018). To get a better view of the stream banks, one suggestion is to take oblique and horizontal photos with the UAV, as described in Rusnák et al. (2018), to be able to capture features below the canopy. This could be especially be useful if the aim is to quantify instream wood. If the purpose with the UAV photos is to quantify the volume of the instream wood, the resolution of the photos should be as high as possible to be able to accurately measure the length and the width of the wood pieces.

4.4 Conclusion

This study tested a simple method using UAV photos and digitizing in GIS, to quantify the spatial complexity of streams. The physical complexity was altered during stream restoration, and pre- and post-restoration changes of physical features was easily detected with the use of UAVs and GIS as a monitoring method. The restoration effort had a significant effect on three of six reach scale descriptive metrics, and on three of seven complexity metrics that were quantified with this method. However, the sample size was only five reaches. When looking at the reaches individually, three reaches increased in five of six reach descriptive metrics, and in two reaches all reach descriptive metrics increased. All reaches got a higher spatial complexity as at least one complexity metric in the reaches increased after restoration. In two reaches all complexity metrics increased, and in one reach all but one complexity metric increased after restoration. The remaining two reaches increased in complexity in three and four complexity metrics, respectively.

Large scale features, such as the extent of the wet area and the mean number of channels, and also the spatial distribution of boulders and instream wood, was easily detected by the use of UAV photos and GIS. However, the accuracy when digitizing small scale features, such as the location of the bankfull edge and small wood pieces, was low. The method is likely to underestimate the number of wood pieces and boulders, and the wood volume, within the streams. These assumptions are based on comparisons with field data, and observations during the digitizing process. However, the sample size was low, and more studies are needed to evaluate the accuracy if the digitizing method. In some of the UAV photos the ground was occasionally obscured by the tree canopy or snow, and some UAV photos was not sharp enough to allow easy detection and measuring of the features of interest. This complicated the digitizing process. This can be avoided by taking the UAV photos during favorable weather, and by adjusting the camera settings for the prevailing light conditions.

Acknowledgements

I would like to start to thank my supervisor Lina Polvi Sjöberg, for guiding me and keeping me on the right track during this project. You are an inspiration. I would also like to thank Henrik Karlborg at the County Board of Västerbotten, for giving me the permission to use their UAV photos in this project.

If it wasn't for all the lovely people I've met during my studies in Umeå, who knows if I would have made it this far. Thanks to you, this has been the best years of my life. Viktor Gydemo Östbom and Jenny Olsson, thank you for an amazing friendship. You have been there in times of studies, parties, and heartbreaks, and for that I am forever grateful. Adrian Andersson Nyberg, late nights at your place and long phone calls have been the best in times of doubt. You always know how to cheer me up. Thank you.

Finally, I would like to thank my family. In ups and downs you have always been there to support me, and I know you always will be.

References

Atha, J.B. 2014. Identification of fluvial wood using Google Earth. *River Research and Applications* 30: 857-864.

Cadenasso, M.L., Pickett, S.T.A. and Grove, J.M. 2006. Dimensions of ecosystem complexity: Heterogeneity, connectivity, and history. *Ecological complexity* 3:1-12.

Crook, D.A. and Robertson, A.I. 1999. Relationships between riverine fish and woody debris: implications for lowland rivers. *Marine Freshwater Research* 50: 941–953.

Degerman, E. 2008. *Ekologisk restaurering av vattendrag*. Naturvårdsverket and Fiskeriverket, Stockholm and Göteborg, Sweden.

Elosegi, A., Díez, J. and Mutz, M. 2009. Effects of hydromorphological integrity on biodiversity and functioning of river ecosystems. *Hydrobiologica* 657(1):199-215.

ESRI 2018. *ArcGIS Desktop*. Environmental Systems Research Institute.

European Commission, LIFE *project ReBorN* - Restoration of Boreal Nordic Rivers: LIFE15 NAT/SE/000892.

Fisher, S.G. and Likens, G.E. 1973. Energy flow in Bear Brook, New Hampshire: An integrative Approach to stream ecosystem metabolism. *Ecological Monographs* 43: 421-439.

Frainer, A., Polvi, L.E., Jansson, R. and McKie, B.G. 2016. Enhanced ecosystem functioning following stream restoration: The roles of habitat heterogeneity and invertebrate species traits. *Journal of Applied Ecology* 55: 377-385.

Fredén, C., 1994. National Atlas of Sweden: Geology. SNA Publishing, Stockholm.

Frissell, C.A., Liss, W.J., Warren, C.W. and Hurley, M.D. A Hierarchical Framework for Stream Habitat Classification: Viewing Streams in a Watershed Context. *Environmental Management* 10(2): 199-214.

Gardeström, J., Holmqvist, D., Polvi, L.E. and Nilsson, C. 2013. Demonstration Restoration Measures in Tributaries of the Vindel River Catchment. *Ecology and Society* 18(3): 8.

Gooseff, M.N., Hall Jr., R.O. and Tank, J.L. 2007. Relating transient storage to channel complexity in streams of varying land use in Jackson Hole, Wyoming. *Water Recourses Research* 43(1): 1-10.

Havs- och Vattenmyndigheten. 2018. Limniska ekoregioner. https://www.havochvatten.se/hav/samordning--fakta/kartor--gis/karttjanster/karttjanster/limniska-ekoregioner.html (Retrieved 2019-04-29)

Helfield, J.M., Engström, J., Michel, J.T., Nilsson, C. And Jansson, R. 2012. Effects of river restoration on riparian biodiversity in secondary channels of the Pite River, Sweden. *Environmental Management* 49: 130-141.

Ivarsson, H., 2007. Glacial dynamics and till genesis in hilly terrain: a study in the Tallträsk area, central–northern Sweden. (Ph.D. Dissertation) Umeå University, Umeå, Sweden.

Jarret, R.D. 1985. *Determination of roughness coefficients for streams in Colorado*. US Geological Survey Water-Resources Investigations Report 85/4004.

Junk, M.J. and Wantzen, K.M. 2004. The Flood Pulse Concept: New aspects, approaches and applications – An update. In Welcomme R. L. & T. Petr (eds), Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries, Vol. 1. Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/16: 117–140.

Laub, B.G., Baker, W.D., Bledsoe, B.P. and Palmer, M.A. 2012. Range of variability of channel complexity in urban, restored and forested reference streams. *Freshwater Biology* 57: 1076-1095.

Lepori, F., Palm, D., Brännäs, E. And Mamqvist, B. 2005. Does restoration of structural heterogeneity in streams enhance fish and macroinvertebrate diversity? *Ecological applications* 15(6): 2060-2071.

Lindén, M., Möller, P., Björck, S., Sandgren, P., 2006. Holocene shore displacement and deglaciation chronology in Norrbotten, Sweden. *Boreas* 35: 1–22.

Lorang, M.S., Whited, D.C., Hauer, J.S., Kimball, J.S. and Stanford, M.S. 2005. Using Airborne Multispectral Imagery to Evaluate Geomorphic Work across Floodplains of Gravel-Bed Rivers. *Ecological Applications* 4: 1209-1222.

Marcus, W.A. and Fonstad, M.A. 2010. Remote sensing of rivers: the emergence of a subdiscipline in the river sciences. *Earth Surface Processes and Landforms* 35: 1867 – 1872.
McHugh, S. 2019. Camera exposure. *Cambridge in Colour*. https://www.cambridgeincolour.com/tutorials/camera-exposure.htm (Retrieved 2019-04-17)
Muotka T. and Laasonen P. 2002. Ecosystem recovery in restored headwater streams: the role of enhanced leaf retention. *Journal of Applied Ecology* 39:145–56.
Niedzielski, T., Witek, M. and Spallek. 2016. Observing river stages using unmanned aerial vehicles. *Hydrology and Earth System Sciences* 20: 3193-3205.
Nilsson, C., Lepori, F., Malmqvist, B., Törnlund, E., Hjerdt, N., Helfield, J.M., Palm, D., Östergren, J., Jansson, R., Brännäs, E. and Lundqvist, H. 2005. Forecasting Environmental Responses to Restoration of Rivers Used as Log Floatways: An Interdisciplinary Challenge. *Ecosystems* 8: 779-800
Nilsson, C., Sarneel, J.M., Palm, D., Gardeström, J., Pilotti, F., Polvi, L.E., Lind, L., Holmqvist, D. and Lundqvist, H. 2017. How do biota respond to additional physical restoration of restored streams? *Ecosystems* 20: 144-162.
Ortega-Terol, D., Moreno, M.A., Hernández-López, D. and Rodrígez-González, P. 2014. Survey and Classification of Large Woody Debris (LWD) in Streams Using Generated Low-Cost Geomatic Products. *Remote sensing* 6: 11770-11790.
Norris, R.H. and Thoms, M.C. 1999. What is river health? *Freshwater Biology* 41: 197-209.
Palmer M.A., Bernhardt E.S., Allan Lake P.S., Alexander, G., Brooks, S., Carr, J., Clayton, S., Dahm, C.N., Follstad Shah, J., Galat, D.L., Loss, G.S., Goodwin, P., Hart, D.D., Hassett, B, Jenkinsson, R., Kondolf, G.M., Lave, R., Meyer, J.L., O'Donnell, T.K., Pagano, L. and Sudduth, E. 2005. Standards for ecologically successful river restoration. *Journal of Applied Ecology*. 42 (2): 208–217.
Palmer, M.A., Menninger, H.L. and Bernhardt, E. 2010. River restoration, habitat heterogeneity and biodiversity: a failure of theory or practice? *Freshwater Biology* 55: 205-222.
Pickett, S.T.A. and Cadenasso, M.L. 1995 Landscape Ecology: Spatial Heterogeneity in Ecological Systems. *Science* 269: 331-334.
Poff, N.L. and Ward, J.V. 1990. Physical habitat template of lotic systems: Recovery in the context of historical pattern of spatiotemporal heterogeneity. *Environmental Management* 5: 629-645.
Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R. E. and Stromberg, J. C. 1997. The natural flow regime. *Bioscience* 47(11): 769-784.
Polvi, L.E. and Wohl, E. 2012. The beaver meadow complex revisited – the role of beavers in post-glacial floodplain development. *Earth Surface Processes and Landforms* 37: 332–346.
Polvi, L.E., Nilsson, C. and Hasselquist. 2014. Potential and actual geomorphic complexity of restored headwater streams in northern Sweden. *Geomorphology* 210: 98-118.
Rusnák, M., Sládek, J., Kidóva, A. and Lethoský, M. 2018. Template for high-resolution river landscape mapping using UAV technology. *Measurment* 115: 139-151.
SMHI, 2018a. Vattenwebb. *Hydrologiskt nuläge*. https://vattenwebb.smhi.se/hydronu (Retireved 2018-12-04)
SMHI, 2018b. *Maj 2018 – Den kraftigaste vårfloden sedan 1995*. December 4 2018. https://www.smhi.se/klimat/klimatet-da-och-nu/manadens-vader-och-vatten-sverige/laget-i-sveriges-sjoar-och-vattendrag/maj-2018-den-kraftigaste-varfloden-sedan-1995-1.134783. (Retrieved 2019-05-14)
SMHI, 2019a. *Klimatdata*. http://www.smhi.se/klimatdata (Retrieved 2019-02-16)
SMHI, 2019b. Vattenweb. Mätningar. Station 2376. http://vattenweb.smhi.se/station/# (Retrieved 2019-05-28)
SMHI, 2019c. Vattenweb. Mätningar. Station 2506. http://vattenweb.smhi.se/station/# (Retrieved 2019-05-28)

Stanford, J.A., Lorang, M.S. and Hauer, F.R. 2005. The shifting habitat mosaic of river ecosystems. *Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen* 29: 123-136.
Tarolli, P. 2014. High-resolution topography for understanding Earth surface processes: Opportunities and challenges. *Geomorphology* 216: 295-312.
Törnlund, E. and Östlund, L. 2002. Floating Timber in Northern Sweden: The Construction of Floatways and Transformation of Rivers. *Environmental History* 8: 85–106.
Wallace, J.B, Jackson, R.W. and Meyer, J.L. 1995. Influence of log additions on physical and biotic characteristics of a mountain stream. *Canadian Journal of Fisheries and Aquatic Sciences* 52: 2120-2137.
Ward, J.V. 1998. Riverine landscapes: Biodiversity patterns, disturbance regimes, and aquatic conservation. *Biological Conservation* 83(3): 269-278.
Ward, J.V. 1989. The four-dimensional nature of lotic ecosystems. *Journal of the North American Benthological Society* 8: 2–8.
Wheaton, J.M., Garrard, C., Whitehead, K. And Volk, C.J. 2012. A simple, interactive GIS tool for transforming assumed total station surveys to real world coordinates – the CHaMP transformation tool. *Computers and Geosciences* 42: 28-36.
Wohl, E. 2013. Floodplains and wood. *Earth-Science Reviews* 123: 194-2012.
Wohl, E. 2016. Spatial heterogeneity as a component of river geomorphic complexity. *Progress in Physical Geography* 40(4): 598-615.
Wohl, E., Scott, D.N. and Lininger, K.B. 2008. Spatial Distribution of Channel and Floodplain Large Wood in Forested River Corridors of the Northern Rockies. *Water Resources Research* 4: 7879-7892.
Woodget, A.S., Austrums, R., Maddock, I.P. and Habit, E. 2017. Drones and digital photogrammetry: from classifications to continuums for monitoring river habitat and hydromorphology. *WIREs Water* 4: 1222.
Zika, U. And Peter, A. 2002. The introduction of woody debris into a channelized stream: effect on trout populations and habitat. *River Research and Applications* 18: 355-366.

Appendix

Table 1. Measured reach-scale descriptive metrics in each reach. Columns denoted with a 'C' show values for the channelized condition and the columns denoted with an 'R' the restored condition.

	Lögdån 1		Lögdån 2		Storforsen		Gunnarsaggan		Mjösjöån	
	C	R	C	R	C	R	C	R	C	R
Mean width (m)	14.19	19.74	14.41	16.7	41.1	60.84	40.46	77.68	13.58	19.91
Bankfull area (ha)	0.99	1.39	1.07	1.30	5.04	7.93	1.73	3.94	1.81	2.74
Wetted area (ha)	0.59	0.92	0.64	0.99	3.45	5.61	1.45	2.94	1.15	1.43
Total wood pieces	90	99	46	110	350	1120	56	272	326	221
Wood volume (m^3)	3.45	3.95	1.21	4.17	14.32	64.3	5.66	13.07	9.82	24.82
Boulders	1528	528	811	698	423	474	12	27	1806	1851

Table 2. Complexity metrics in each reach. Columns denoted with a 'C' show values for the channelized condition and the columns denoted with an 'R' the restored condition.

	Lögdån 1		Lögdån 2		Storforsen		Gunnarsaggan		Mjösjöån	
	C	R	C	R	C	R	C	R	C	R
W_100m	25.37	27.91	6.39	15.28	27.32	119.41	12.96	62.93	24.8	16.81
W_ha	3.47	2.85	1.14	3.2	2.84	8.11	3.26	3.32	5.42	9.07
Bratio	2.207	2.211	1.102	1.122	1.343	1.457	1.051	1.282	1.136	1.250
SDw	10.99	9.21	3.96	4.86	14.57	21.94	7.8	24.45	4.96	5.58
CVw	0.775	0.467	0.275	0.291	0.354	0.361	0.193	0.328	0.346	0.280
MTI	1	1.095	1	1	1	1.286	1	1.381	1	1.333
B_D	0.125	0.231	0.186	0.254	0.156	0.302	0.107	0.267	0.339	0.292

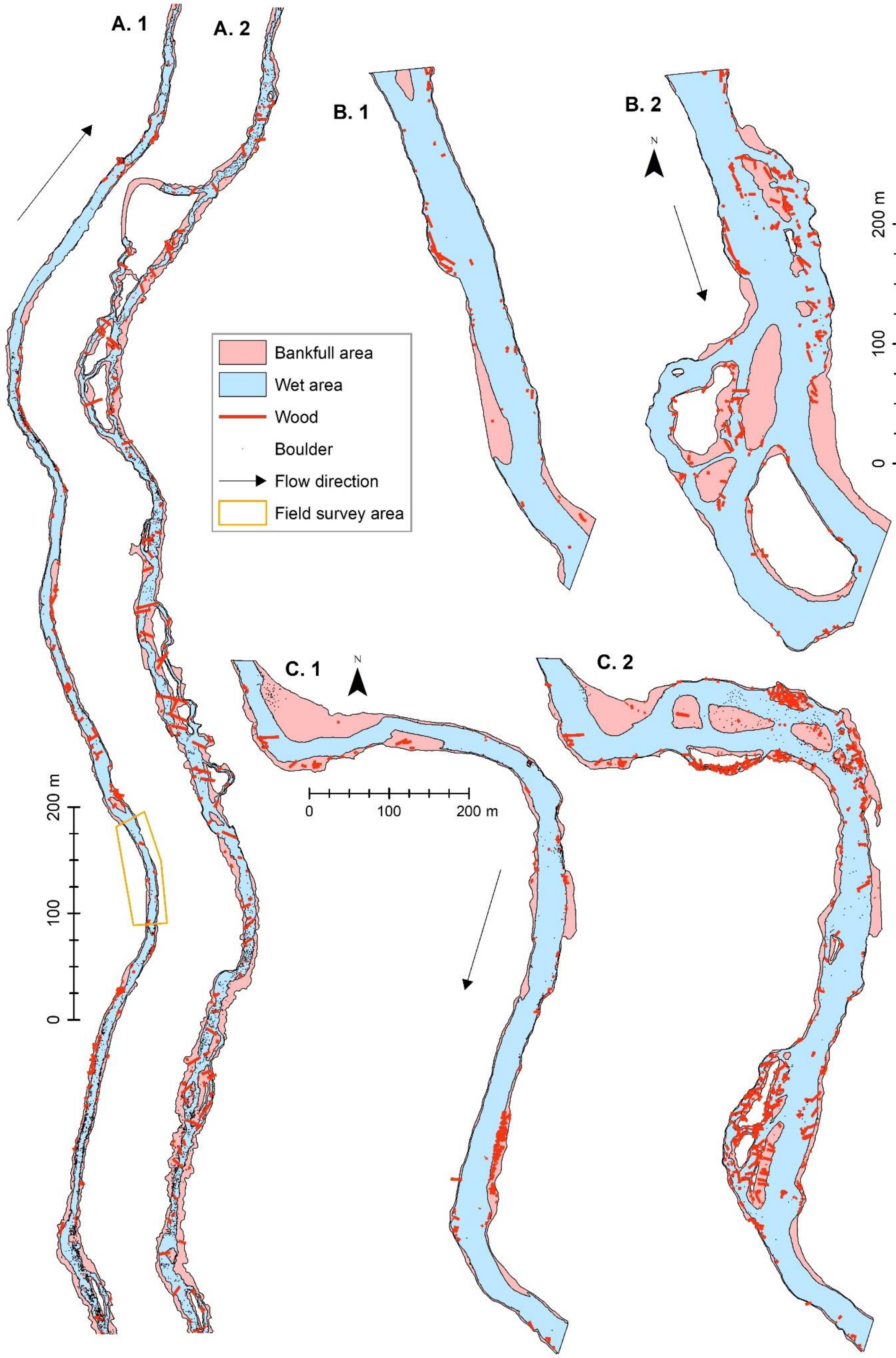

Figure 1. The digitized features in A.1 Mjösjöån channelized, A.2 Mjösjöån restored, B.1 Gunnarsaggan channelized, B.2 Gunnarsaggan restored, C.1 Storforsen channelized, C.2 Storforsen restored, D.1 Lögdån 1 channelized, D.2 Lögdån 1 restored, E.1 Lögdån 2 channelized, and E.2 Lögdån 2 restored.

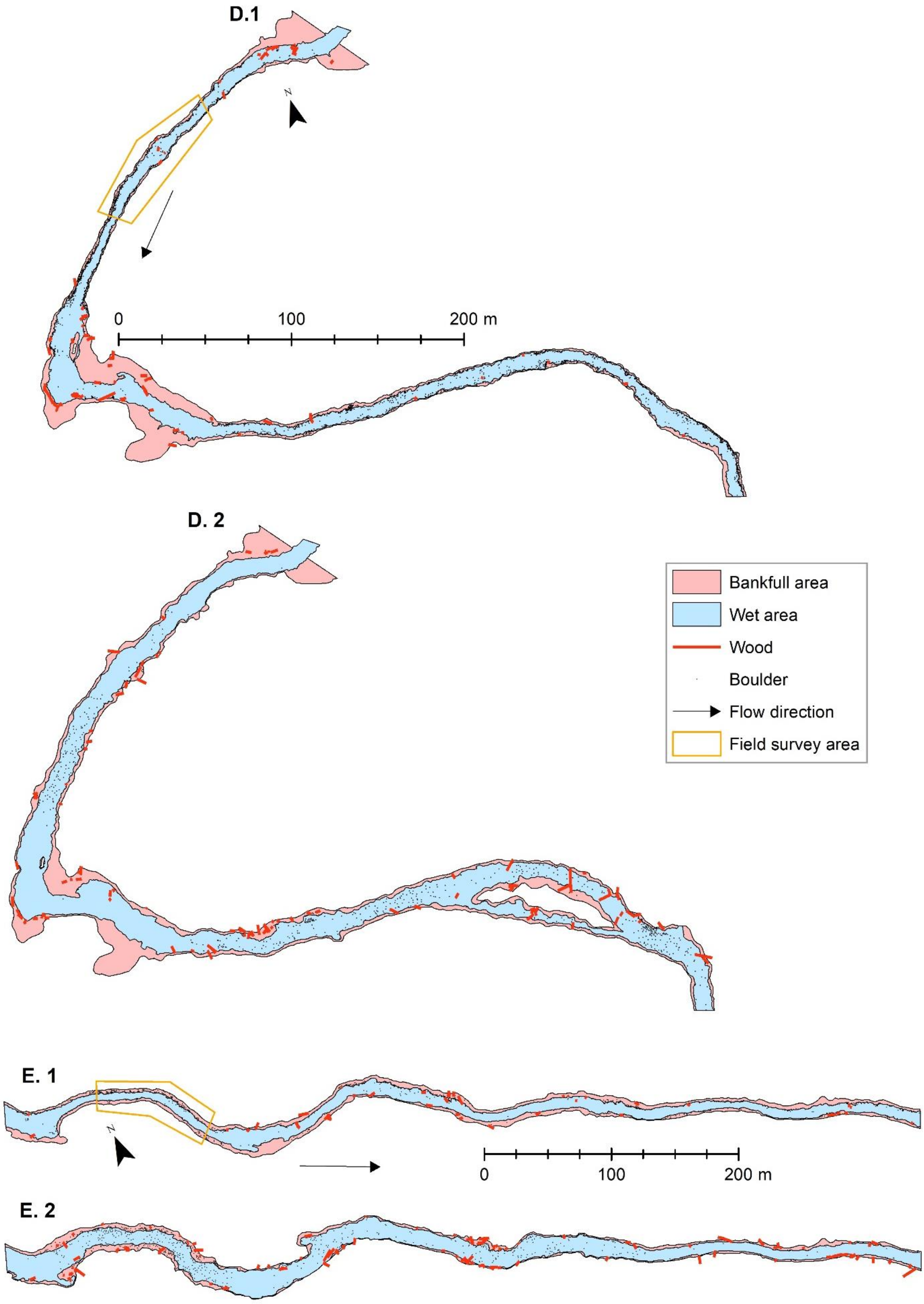

Figure 1, continued. The digitized in A.1 Mjösjöån channelized, A.2 Mjösjöån restored, B.1 Gunnarsaggan channelized, B.2 Gunnarsaggan restored, C.1 Storforsen channelized, C.2 Storforsen restored, D.1 Lögdån 1 channelized, D.2 Lögdån 1 restored, E.1 Lögdån 2 channelized, and E.2 Lögdån 2 restored.

Table 3. Information about the time of restoration and camera settings used when photographing each reach. C = channelized, R = restored. Q = water discharge on the day of photography from modulated data (SMHI 2018a). n.a. = not available.

Reach	Photography date	Weather	UAV model	Camera settings	Pixel size (cm)	Q (m^3/s)
Lögdån 1, C	26/6 2018 2:02 - 2:12 pm	Sunny	Mavic Pro	ISO: 100-172 Shutter: 1/100-515	2	n.a.
Lögdån 1, R	20/11 2018 1:03 – 1:25 pm	Ice Cloudy	Mavic Pro	ISO: 100-198 Shutter: 1/25-100	2	1,3
Lögdån 2, C	26/6 2018 2:30 - 2:49 pm	Sunny	Mavic Pro	ISO: 100 Shutter: 1/175-353	4.5	n.a.
Lögdån 2, R	20/11 2018 1:38 - 1:45 pm	Ice Cloudy	Mavic Pro	ISO: 103-240 Shutter: 1/12-100	4.5	1,3
Storforsen 1, C	14/7 2017 8:49-8:53 am.	Cloudy	Inspire 1	ISO: 200 Shutter: 1/200	2.4	9
Storforsen 2, C	7/7 2017 2:18 -2:22 pm.	Cloudy	Inspire 1	ISO: 100 Shutter: 1/200	1.7	9
Storforsen 3, C	14/7 2017 8:03 -8:05 am.	Cloudy	Inspire 1	ISO: 200 Shutter: 1/200	2.5	9
Storforsen 1, R	19/10 2017 10:39-10:47 am.	Sunny	Inspire 1	ISO: 200 Shutter: 1/240	2.4	n.a.
Storforsen 2, R	24/9 2017 2:35-2:38 pm.	Cloudy	Inspire 1	ISO: 535-1037 Shutter: 1/320	1.7	20
Storforsen 3, R	18/10 2017 1:31-1:47 pm	Cloudy	Inspire 1	ISO: 200 Shutter: 1/160	2.4	n.a.
Gunnarsaggan, C	8/8 2017 4:00 – 4:06 pm	Cloudy	Inspire 1	ISO: 100-195 Shutter: 1/100-120	6.3	12
Gunnarsaggan, R	23/10 2017 12:23 – 12:34 pm	Sunny	Inspire 1	ISO: 200 Shutter: 1/320	6.3	20
Mjösjöån, C	27/6 2018 4:36 - 4:57 pm	Sunny	Mavic Pro	ISO: 100-121 Shutter: 1/100-313	3.6	n.a.
Mjösjöån, R	1/11 2018 11:44 am - 12:04 pm	Ice Sunny	Phantom 4 Pro V2	ISO: 100 Shutter: 1/30-80	3.6	0,4
Storfall, R	1/11 2018 10:46-11:46 am	Ice Sunny	Inspire 1	ISO: 100 Shutter: 1/30-80	2	7,8