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Temporal Development of Macroinvertebrate Communities and their Responses to Restoration Measures in Bognelv, Norway.

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Preface

The present study was conducted at the Faculty of Environmental Sciences and Natural Resource Management (MINA) at the Norwegian University of Life Sciences (NMBU) as a part of my master's degree in biology at the Faculty of Biosciences (BIOVIT).

I would like to thank you my supervisors, Thrond O. Haugen and Jonathan Edward Colman at the Faculty of Environmental Sciences and Natural Resource Management (MINA) for the chance to write this master thesis. Experiencing Bognelv after hearing so many stories and the history of the river was interesting and special. I would like to thank you both for the guidance through the planning of field work, the data analysis, and writing process. A special thanks to you, Thrond O. Haugen for helping me with the statistical analysis and a special thanks to you, Jonathan E. Colman for helping during the writing process.

I would like to thank The Norwegian Water Association (Norsk Vannforening) for funding the field work in Bognelv. Furthermore, I would like to thank Andreas Lium for helping me with the identification process. A Special thanks to Per-Fredrik Rønneberg Norhov for the support and the knowledge about his experiences from earlier field work in Bognelv and data from his study. Lastly, the covid-19 situation made the writing process extra challenging – so I want to give a special thanks to my family and partner for the enormous support during this period.

Photographs without crediting are taken by the author.

Abstract

Human activities drive degradation and biodiversity loss of freshwater rivers globally. One of the major threats to rivers are channelization, which straightens the river and eliminates the heterogenic habitats as opposed to a natural river system. In the timespan of late 1930s to early 1990s experienced Bognelv, heavy modifications to prevent erosion, increase adjacent land and to control the water level during flood. The present study is the second study identifying the macroinvertebrate community in Bognelv down to species, and thus, the first study to evaluate and quantify the temporal development of the macroinvertebrate community composition and their responses to the restoration measures conducted to Bognelv in Finnmark County, Norway. The restoration process of Bognelv started in 2006 and has since experienced several restoration measures and adjustments of existing measures. The latest adjustment was conducted in 2019, before my visit in Bognelv. Following the study from 2015 I sampled macroinvertebrates by means of kick-sampling.

My study found a higher Shannon-wiener index diversity in 2019 compared to 2015. Furthermore, the environmental variables influencing the macroinvertebrate community in 2019 was found to be large woody debris, vegetation coverage of the river closest to the shoreline, moss coverage, depth, velocity, and pools. Similar to 2015, water depth and velocity of current was found to be among the important influential variables. Regarding the restoration measures, I compared macroinvertebrate density and diversity between restoration measure and control. I found side channels to have the highest species richness *potential*, stations with pools had the highest density. Moreover, the modified channelization station and the channelized control stations followed the same density trend, but channelization showed a significant higher species richness *potential*. Thus, the overall results showed tendencies towards the restoration measures not providing enough effect on the heterogeneity to support a higher diversity and density compared to the channelized stretches in Bognelv. Moreover, I tested two different sampling methods which both gave similar results.

Sammendrag

Tidsutvikling av bunndyrssamfunn og deres respons til restaureringstiltak i Bognelv

Menneskelige aktiviteter driver degradering og tap av biodiversitet i ferskvannselver globalt. En av de største truslene til elver er kanalisering, som retter ut elveløpet og eliminerer heterogeniteten av habitater i motsetning til et naturlig elvesystem. I perioden sent 1930 til tidlig 1990 ble Bognelv utsatt for store strukturendringer for å forhindre erosjon, øke nærliggende arealer og kontrollere vann-nivået ved flom. Dette er det andre studiet som identifiserer bunndyrssamfunnet i Bognelv ned til art, og dermed det første til å vurdere og kvantifisere tidsutviklingen av bunndyrssamfunnets artssammensetning og deres respons til restaureringstiltakene utført i Bognelv, Finnmark. Restaureringsprosessen i Bognelv startet i 2006 og i løpet av årene har det blitt gjennomført flere tiltak og justeringer av eksisterende tiltak. I 2019, før mitt besøk i elva, ble det foretatt justeringer av to sideløp. Likt som studien i 2015, samlet jeg inn bunndyr ved bruk av sparkehåv.

Min studie fant en høyere Shannon-wiener indeks diversitet sammenlignet med 2015. Videre, fant jeg at miljøvariablene dybde, hastighet, død ved, vegetasjonsdekket over elvekant, mosedekke på elvebunn, og kulper påvirker sammensetningen av bunndyrssamfunnet i Bognelv. Likt med 2015, viste vanndybde og -hastighet seg å være viktige påvirkninger. Angående restaureringstiltakene, sammenlignet jeg bunndyrstetthet og diversitet mellom restaureringstiltakene og de kanaliserte kontrollstasjonene. Min studie fant stasjoner i sideløp til å ha høyst artspotensial, stasjoner med kulper hadde den høyeste tettheten, mens stasjonene med modifisert kanalisering og kanalisering (kontroll) fulgte samme tetthetstrend, men kanaliseringsstasjonene hadde et signifikant høyere artspotensial. Min studie fant tendenser til at restaureringstiltakene ikke har hatt nok effekt på heterogenitet i elva, som støtter en høyere bunndyrstetthet og diversitet sammenlignet med de kanaliserte områdene i Bognelv. Til slutt testet jeg to ulike innsamlingsmetoder, som begge ga like resultater.

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1. Introduction

Freshwater rivers are threatened (Dudgeon et al., 2006) and heavily degraded ecosystems worldwide (Allan & Flecker, 1993; Nakano & Nakamura, 2006; Allan & Castillo, 2007; Miller, Budy & Schmidt, 2009). Human activities drive biodiversity loss and degradation in rivers on a global scale (Malmqvist & Rundle, 2002). A paradox is that many of these “negative” activities are a necessity for society, such as freshwater, flood control, sources of food and for agricultural purposes (Malmqvist & Rundle, 2002; Allan & Castillo, 2007; Kennedy & Turner, 2011; Gleick, 2003). More than 70 % of major rivers in the northern hemisphere are altered by human made structural constraints in one way or another (Dynesius & Nilsson, 1994; Kennedy & Turner, 2011). Agricultural pollution and hydrological engineering are the major activities preventing the European river basins from reaching good ecological status (Menendez et al., 2006; Schneider & Petrin, 2017). Furthermore, in Europe, hydrological alteration of river basins alone is responsible for approximately 50 % of the rivers not reaching acceptable ecological status (Theodoropoulos, 2020). Raunio et al., referred to in Suurkuukka et al., (2014) reports that only a small proportion (< 5 %) of headwater streams in northern Europe remain in pristine conditions. The impact of human activities in freshwater rivers involve a variety of physical alterations that homogenize the hydraulic and geomorphological features of the river channel (Lepori et al., 2005). In present study, I will focus on the impacts of channelization.

Channelization is among the major threats to habitat loss and degradation in rivers and streams globally (Allan & Flecker, 1993; Muotka et al., 2002; Nakano et al., 2008; Rambaud et al., 2009). Emerson (1971) defines channelization as an artificial straightening of the stream, and one reason to implement this to rivers is to hinder the water level from reaching surrounding areas during floods (Emerson, 1971; Lennox III & Rasmussen, 2016). Channelization affects the river ecosystem in two fundamental ways, (1) directly through physical changes in habitat, such as increased sedimentation, erosion, and velocity (Lepori, Palm & Malmqvist, 2005; Lau, Lauer & Weinman, 2006). Moreover, (2) indirectly by changes in energy and nutrient dynamics (Lepori, Palm & Malmqvist, 2005) as allochthonous input reduce (Lau, Lauer & Weinman, 2006). The straightening of the river eliminates the natural heterogenic features of the river (Negishi, Inoue & Nunokawa, 2002; Nakano et al., 2008), and thus,

reduces the structural complexity. This in turn decreases the number of microhabitats available for flora and fauna and simplifies the flow pattern (Muotka et al., 2002). Due to this, a channelized river is commonly referred to as physically homogenous (Rambaud et al., 2009; Lennox III & Rasmussen, 2016), and both macroinvertebrates and fish are reported to be negatively affected by the homogenization of habitats by channelization (Bis, Zdanowicz & Zalewski, 2000; Nakano & Nakamura, 2006). Moreover, studies have reported negative consequences of channelization on stream biota and show there is a significant threat overall to river function and biodiversity (Negishi, Inoue & Nunokawa, 2002; Nakano et al., 2008; Lennox III & Rasmussen, 2016).

Macroinvertebrates and fish have been used as quality indicators to assess the ecological conditions in rivers and streams (Kilgour & Barton, 1999; Theodoropoulos, 2020). The range in tolerance among macroinvertebrates toward pollutants and water quality makes them great indicators for measuring water quality and the ecological condition of freshwater rivers (Leunda et al., 2009; Direktoratsgruppen vanndirektivet, 2018). Especially, Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) species – known as the EPT-orders – are of special interest because of their high sensitivity to humanmade stressors (Gál et al., 2019). Kilgour & Barton (1999) describes benthic macroinvertebrates as better quality indicators because of their lack of mobility, compared to fish, and thus, better reflectlocal conditions. Furthermore, the sampling procedure of macroinvertebrates is relatively easy, even though the taxonomic identification process can be more time consuming (Kilgour & Barton, 1999). Macroinvertebrates tend also to respond rapidly to disturbance because of their shorter life cycles compared to fish (Kilgour & Barton, 1999).

Aquatic macroinvertebrates live in the substrate layer or near the bottom of freshwater rivers and other aquatic ecosystems part of or through their entire life cycle (Direktoratsgruppen vanndirektivet, 2018; Khudhair, 2019). They are important for ecosystem services in the river, as they assist in nutrient recycling and processing of organic matter (Collier, Probert & Jeffries, 2016; Ncube et al., 2018). They are also involved in decomposition of allochthonous input from the riparian vegetation. This is

especially important in northern streams, as this serves as a major part of the detritus-based food webs in these streams (Falkegård, Elliot & Klemetsen, 2016). They are also important food sources for e.g., fish, and are thereby strongly involved in trophic interactions (Ncube et al., 2018). The composition of the macroinvertebrate community is influenced by several environmental variables, such as depth, velocity of current, wetted width and substratum composition (Leunda et al., 2009; Leigh, 2013; Karaouzas et al., 2019) – where flow regimes are associated with being the master variable that affect the diversity and density of the biota in rivers (Poff et al., 1997). Moreover, flow also affects the macroinvertebrate community by increased physical pressure, increased water temperature and decreased concentration of dissolved oxygen – depending on whether it is high or low flow (Hart & Finelli, 1999; Karaouzas et al., 2019). Scrimegeour et al., (1988) found that major floods reduced the density, richness of taxa and biomass of macroinvertebrates, but that there was a rapid recovery of 132 days to reach pre-flood levels of the fauna.

Despite low diversity and density of macroinvertebrate communities in channelized rivers, they improved rapidly in the Danish river Gelså within two years after remeandering of the river (Friberg et al. 1998). The levels of diversity and density are assumed to reach a higher level than pre-restoration because of the increased heterogeneity in habitats in the first few years after restoration measures (Minshall, referred in Friberg et al., 1998). Friberg et al., (1998) found that the macroinvertebrates reached a peak in density approximately 2 years post-restoration, and then decrease and began to stabilize after approximately 3-4 years. Furthermore, Friberg et al., (1998) found the diversity of macroinvertebrates to have a similar response to restoration as density, but instead of peaking after 2 years, the diversity reached a higher level than pre-restoration and continued to increase slowly. The increase in diversity over time is assumed to be connected to species with low dispersal abilities colonizing (Milner, referred in Friberg et al., 1998) the restored heterogenic habitats.

The current study system is the river Bognelv in Alta municipality in Finnmark county. The lower 3.5 km of the river was channelized during the time period 1946 to 1990s (Hoseth & Josefsen, 2005; Colman, Hoseth & Dønnum, 2010). The restoration process of the river Bognelv began in 2006 (Colman, Hoseth & Dønnum, 2010). The restoration practice used in Bognelv is a commonly known practice called in-stream restoration and focuses on increasing or creating structure and heterogenic habitats to increase the diversity and density of biota in the river (Lepori et al., 2005; Miller, Budy & Schmidt, 2009). An important assumption for practicing this type of restoration practice is that local diversity and density is controlled by physically heterogenic habitats (Lepori et al., 2005, Scealy, Mika & Boulton, 2007). The types of measures used in in-stream habitat restoration can be for instance, the addition of large woody debris (LWD) and or boulders, with an aim to restore habitats in homogenous rivers at the reach-scale (< 60 x bankfull width) (Miller, Budy & Schmidt, 2009). Both addition of LWD and boulders were used as parts of the measures carried out in Bognelv. The restoration measures I focused on in this study were the side channels, pools and where the channelization was remedied by removing large boulders along the river edge and “restarting” the processes of erosion and sediment transport. I will also include several control stations – as they represent impaired habitats that have not (yet) been restored.

This is, to my knowledge, the first master thesis conducted in Bognelv that solely investigated the macroinvertebrate community within the river and their temporal response to restoration measures conducted in the river. Studies report a knowledge-gap within the cold-water river systems, as most of the studies have focused on warm-water communities and on lowlands – there is also a gap surrounding the long-term recovery of these communities (Lennox III & Rasmussen, 2016). Furthermore, Kennedy & Turner (2011) report that macroinvertebrate communities affected by channelization are often neglected and in need of more research. Thus, I aimed to investigate the temporal changes in diversity and density of macroinvertebrate in Bognelv since 2015 (Nordhov & Paulsen, 2016), and estimate how the macroinvertebrates responded to specific restoration measures over time. I compared and investigated the re-opened side channels, areas with created pools and where the channelization of the riversides were modified. Controls stretches were sampled in the channelized areas. I also estimated how some environmental variables influenced the

macroinvertebrate composition in Bognelv. A goal for this thesis is to create a fundament for future master thesis in Bognelv and to contribute to reducing the knowledge-gap in cold-freshwater ecosystems and to be able to look into the long-term effects of channelization on macroinvertebrates within Bognelv. It will also be important knowledge to continuing to provide enough food to keep reintroducing anadrome fish - the role of macroinvertebrates as a food source and interactions between trophic levels is to my knowledge an important key role to achieving this goal and will continue to be so in the future.

1.1 Objectives

The objectives are structured in a typical top-down structure, where I will present the broader objectives looking into the entire river, and then narrow them down to specific restoration measures within the stations. I tested three expectations.

(1) By comparing temporal trends between 2015 and 2019 in river-level macroinvertebrate diversity, I expected to find a higher diversity of macroinvertebrates in 2019 compared to 2015, supporting earlier studies from other river systems.

(2) Through estimating environmental variables that affected the macroinvertebrate community independent of restoration measures, I expect velocity and bottom substrate to be of greatest influence on the macroinvertebrate community.

(3) By comparing stretches with restoration measures with control stretches – as they represent impaired habitats that have not (yet) been restored – I estimated effect of specific measures on species richness and density. I expected that the stretches without measures would overall have a lower diversity and density because of the homogenous conditions. Conversely, I expected to find an overall higher diversity and density within the stations with measures because of the increased heterogenous habitats in these systems.

I also tested the common methodology used (kick sampling) when collecting macroinvertebrates in many earlier studies by estimating how sensitive some of the analyses are towards combining three replicas into one sample instead of using the three samples separately.

2. Methods

In an attempt to prevent erosion, increase the surrounding agricultural land and to control the water level during floods, the river Bognelv experienced several heavy modifications since the late 1930s (Hoseth & Josefsen, 2005; Colman, Hoseth & Dønnum, 2010). I briefly describe the history of the river. The first attempt to secure the river's outer edges from erosion started in the late 1930s and finished in 1950 – but as the attempt failed and the river continued to erode the agricultural land closest to the river, the Norwegian Water Resources and Energy Directorate (NVE) proposed that the lower 2.1 km of the rivers was to be channelized to prevent further loss of agricultural land (Hoseth & Josefsen, 2005). The canalization of the river started in 1956 and finished in 1975. Hoseth & Josefsen (2005) describes the channelized river as streamlined, which indicated a straightened river with few turns and the same dimension throughout the channelized parts of the river.

During the time span of 1946 to 1972, the lower 2.1 km parts of the river were transformed tremendously, as seen in figure 1. The natural shape of the main river and its side channels were lost due to heavy modifications. Channelization also included placing large boulders along the riverbanks to confine water flow, lowering and hardening the river bottom with uniform, large rocks and maintaining an equal width and height of the riverbank along channelized stretches. Thus, the river became more homogenous and important processes, e.g., supporting habitat for fish and invertebrates, were lost (Colman, Hoseth & Dønnum, 2010).

Figure 1. Changes of the shape of the river before and after the canalization of the river. In 1946, the river had a more natural shape with turns and side channels – while in 1972, the river is straightened, and the side channels are closed off as a consequence to the canalization.

Due to a massive flood during the spring in 1978, an additional kilometre was channelized between 1980-90 (Hoseth & Josefsen, 2005). Furthermore, in the beginning of the 1990s, a new road (E6) replaced the existing road (E6) along the fjord Langfjorden, and as a result, the area between the new and old road was channelized (Hoseth & Josefsen, 2005). The total distance of channelized river was 3.5 km and was located at the lower parts of the river (Hoseth & Josefsen, 2005). I will not discuss the prework leading up to the restoration in this study – I recommend Hoseth & Josefsen (2005) or Colman, Hoseth & Dønnum (2010) for further reading. The restoration of the river started in 2006 (Colman, Hoseth & Dønnum, 2010) – and the goal of the restoration project was to increase existing, yet extremely low populations of anadrome fish, increase the groundwater level and overall level of biodiversity in the river valley (Colman, Hoseth & Dønnum, 2010).

2.1 Study system

The river Bognelv is located in the western parts of Finnmark county (70º01'22''N, 22º17'46''E) in the Alta municipality. Bognelv is a small river flowing through the valley Bognelvdalen with an outlet into the inner parts of the fjord Langfjorden (Figure 2). The study area stretches over the lower 3.5km parts of the river and includes stretches representing different restoration measures and control stretches still channelized. Hoseth & Josefsen (2005) describes Bognelvdalen-valley as a typical U-shaped valley, with steep hillsides and a flat bottom with marine soil (Figure 3). The lower parts of the valley consist of scattered settlement and agricultural activity. The area along the river is defined as an LNF-area, agricultural, nature and recreation area (Hoseth & Josefsen, 2005). In 1980, the river was granted protection status in "Verneplan II" against further development against hydropower (Sæle & Bjordal, 2019).

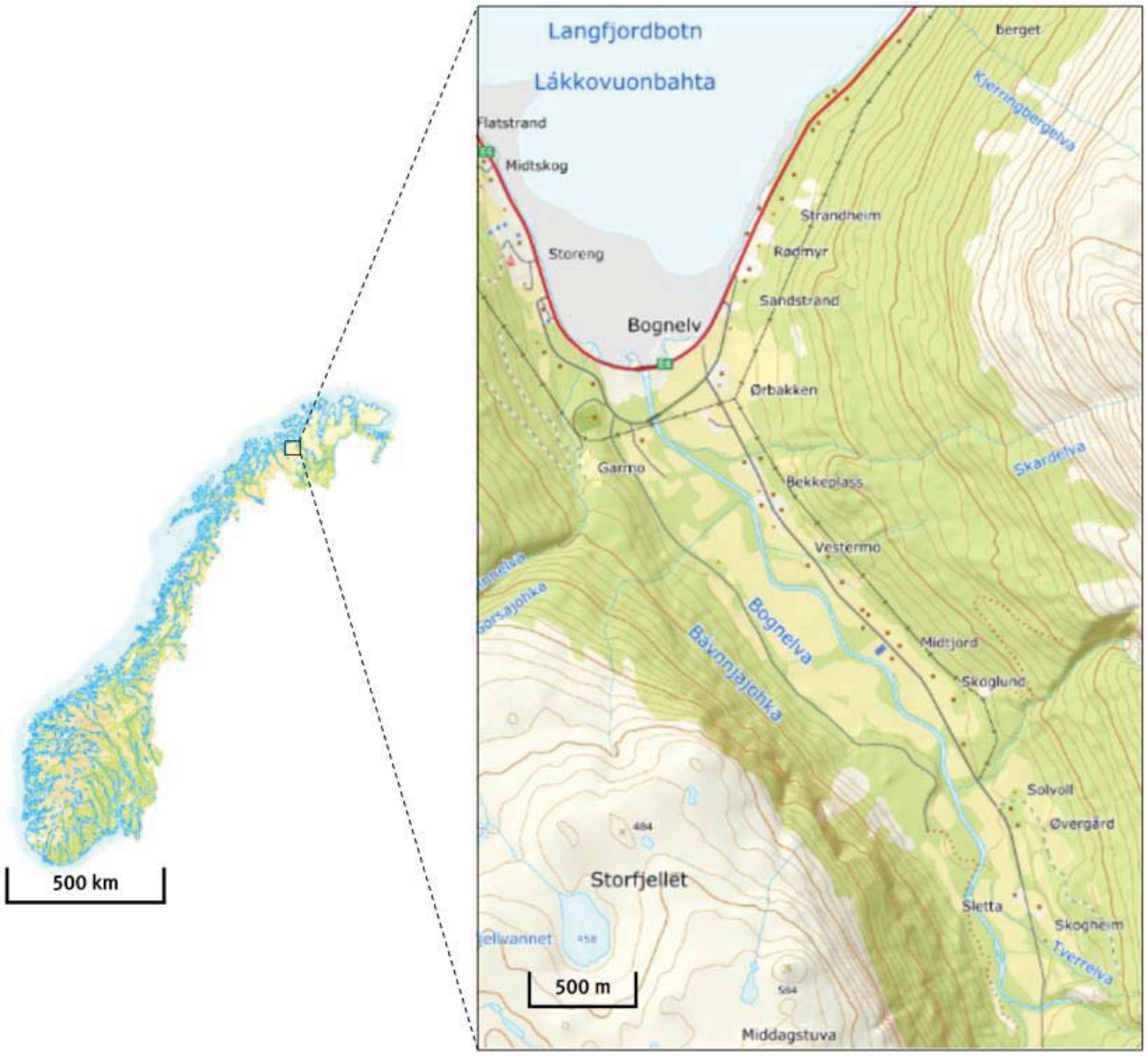

Figure 2. The location of the river Bognelv, located in the valley Bognelvdalen in the Alta municipality, Finnmark County. The study area was in the lower 3.5 km parts of the river (Norgeskart.no).

Figure 3. Parts of the Bognelv valley with the typical U-shape and flat bottom as described by Hoseth & Josefsen (2005).

Bognelv has a total length of 18.5 km and a catchment of 88.5 km^2 (Hoseth & Josefsen, 2005). The major parts of the catchment are located 500-600 meters above the treeline in the alpine zone, providing stable conditions during the winter season (Hoseth & Josefsen, 2005). Because of this, the river experiences great runoff from snow melting during the latter parts of June, which results in early summer floods (Hoseth & Josefsen, 2005). Usually, the river does not experience major floods during the rest of the summer and autumn (Hoseth & Josefsen, 2005). The average streamflow during July is about 7 m^3/s, and 3 m^3/s in August, September, and October (Hoseth & Josefsen, 2005). Calculations estimate the 100-year flood to be 58 m^3/s and the mean flood to be 27 m^3/s (Hoseth & Josefsen, 2005).

2.1.1 Study design

In total, 12 stations were selected in the present study. The stations are presented in figure 4 and table 1, and the coordinates can be retrieved in appendix 1. Four different types of stations were chosen (Table 1); channelized representing the control stations without measures, and pools, side channel and modified channelization representing stretches that have received restoration measures conducted in Bognelv. The side channel stations involve reopening closed side channels. Additional measures done in connection with this were the placement of rock clusters and weirs in the main river to increase water level and flow into the side channel. For the stations with modified channelization, the measures included removal of large boulders on the riverbanks and thus removing the erosion control system and placement of rock clusters in the main river. Stations with the restoration measure “pool”, involved the creation of new pools or the extension of old pools. To read more about the measures, I recommend Hoseth & Josefsen (2005) and Nordhov & Paulsen (2016).

The selection of stations was based on the same stations as the electro fishing study conducted in the river at the same time, which included eight stations. Four additional stations were selected to include stations with modified channelization, as well as two more side channels and another channelized control. This was to provide additional representative data for the macroinvertebrate community in Bognelv. For each station, environmental variables were measured and used to describe the key characteristics for each station (Table 1).

Table 1. Key characteristics and treatment level for the 12 stations in Bognelv 2019. Restoration measure = describe the measure conducted at the station, Time = time since the measure was conducted or modified, Substrate and depth shows mean value for the station, riverbed vegetation measures both algae and mosses where the dominating type are shown in the table, LWD and pools were counted along the entire station and divided into three. Velocity = mean velocity for entire station. *channelized stations have no time as they represent impaired habitats that have not (yet) been restored.

Station	Restoration measure	Time	Substrate (mm)	Depth (cm)	LWD	Pools	Velocity (ms^{-1})
P1	Pools	2014	265	20	6.33	1	0.25
P2	Pools	2014	262	27.1	0	1.3	0.34
C1	Channelized (control)	*	100	31.2	0	0	0.4
C2	Channelized (control)	*	123	22.2	0	0	0.08
C3	Channelized (control)	*	201	22	0	0	0.08
S1	Side channel	2006	194	55.1	16.67	0	0.20
S2	Side channel	2009	116	22.3	0.33	0.33	0.38
S3	Side channel	2019	106	27.2	21.67	1	0.06
S4	Side channel	2009	70	11.4	10.33	0.33	0.21
S5	Side channel	2019	94	7.8	0.33	0	0.1
S6	Side channel	2009	128	20.4	0.33	2	0.1
M1	Modified channelization	2009	197	22.6	0	0	0.28

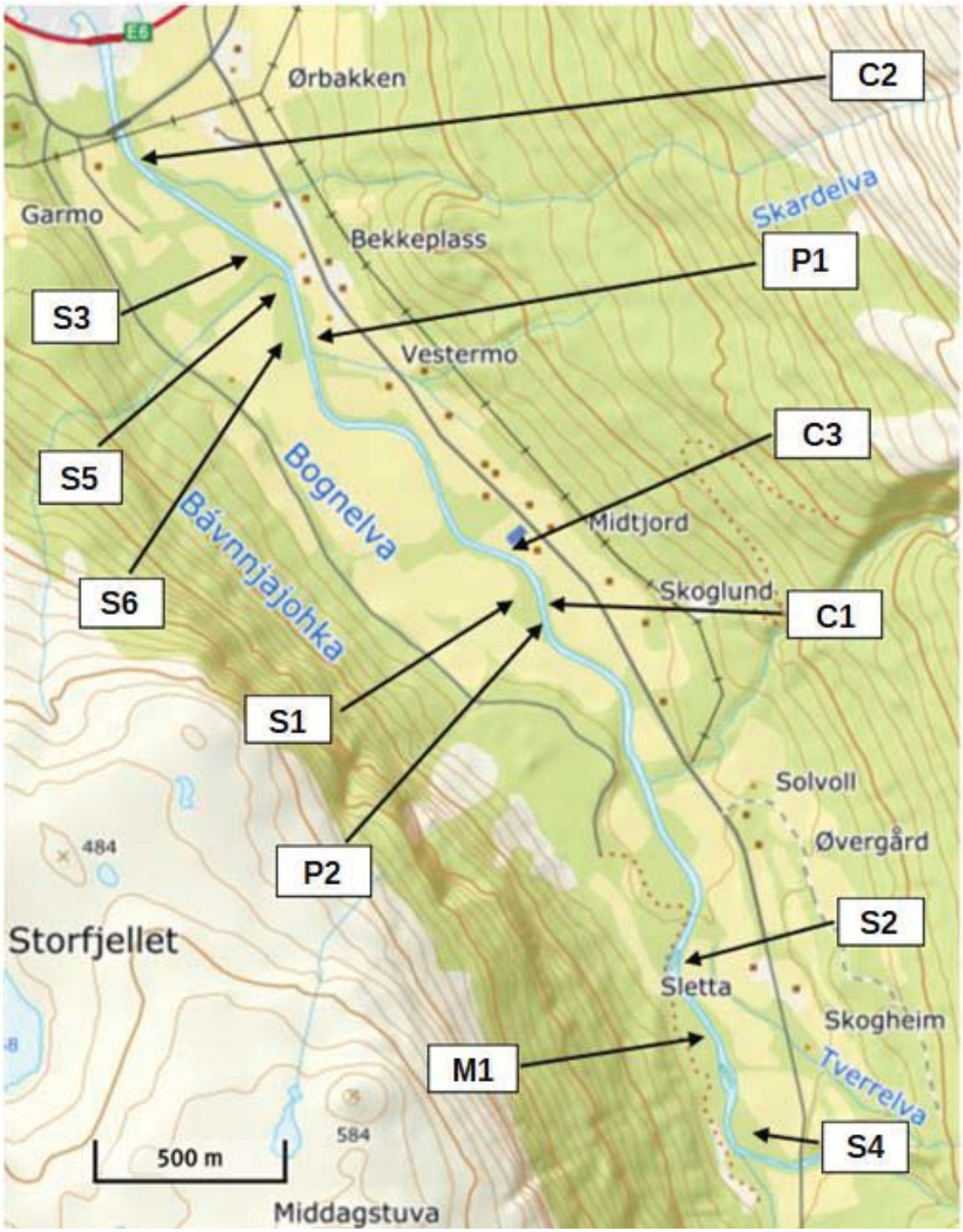

Figure 4. An overview of the 12 sampling stations used in the present study. C1-3 is channelized control stations, P1-2 is stations with the restoration measure pools, S1-6 is stations located in side channels and M1 is station with modified channelization.

2.2 The data collection of macroinvertebrates

The present study analyses new data collected in 2019 along with data collected in 2015 (Nordhov & Paulsen, 2016). I classified the macroinvertebrates down to species or to the lowest taxonomic order possible. This is the same procedure as Nordhov & Paulsen (2016) did for their master thesis back in 2015. Earlier master thesis investigating the macroinvertebrates in Bognelv only classified the macroinvertebrates to their taxonomic order (Sødal, 2014) or counted the number of invertebrates present in their samples (Austivik, 2012).

I sampled macroinvertebrates between the 15th and 18th of October in 2019. This was later in the season compared to fieldwork in 2015. The reason for this was to give the macroinvertebrates a chance to grow larger in size and easier to identify. Another reason was the timing of the fieldwork of other master projects in the same river. My sample design constituted 12 stations of 50 meters with three cross transects at 0 m, 25 m and 50 m, while Nordhov & Paulsen (2016) had 56 stations of 15 meters with cross transects at 0 m, 7,5 m and 15 m in 2015. The reason for reducing the number of stations and increasing the length of each station was to overlap with the other studies occurring in 2019 that included a new study design adapted new sampling techniques for juvenile fish (Strand, 2020).

The macroinvertebrates were sampled using the kick-sampling method as defined by Hynes (1961). The hand-held kick net had a dimension of 25 cm x 25 cm, a mesh size of 250 µm and a 1.5 m handle. I performed three replicas at each sub cross transect. The kick-sampling method was manageable by one person with waders on. The net was placed into the river downstream the person (Figure 5) and by moving upstream while kicking the river bottom for 20 seconds, the macroinvertebrates loosened and drifted into the net. For each sample, leaves, sticks and stones were investigated for invertebrates that were retrieved before the sample was collected into a plastic bag and added ethanol. The samples were transported to NMBU, Campus Ås to be examined.

Figure 5. The net was placed into the river downstream and then kicking the bottom to collect specimens that flow into the net.

The river was divided into two halves for each station –shown as the dotted line in figure 6. Within each substation, I sampled three replicas at each sub cross transect (from the riverside to the middle of the river). Each station had a total of five samples as shown in figure 6. For the subsamples at 0 m and 50 m, the three replicas were collected into one combined sample (the common method employed in most studies), while for the subsamples at 25 m, I collected the three replicas into three separate samples along the transect (Figure 6). The mid-transect subsamples were deliberately not pooled in order to assess if pooling samples would affect conclusions when analyzing the data.

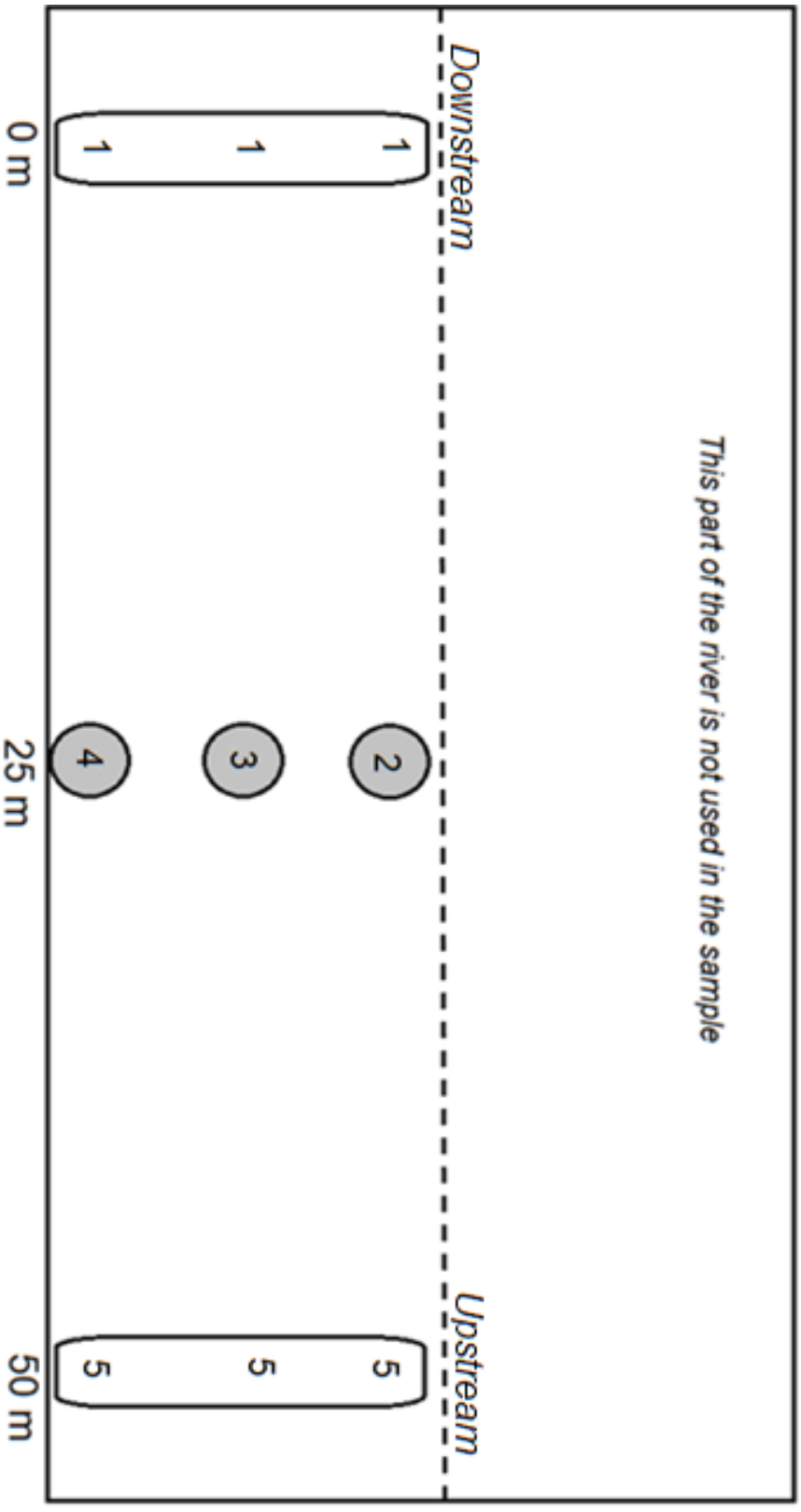

Figure 6. An outline of the station layout and how samples were collected. A station contained three sub cross transects. The replicas at 0 m and 50 m were collected into one combined sample, while the three replicas at 25 m were collected into three separate samples as indicated by the figure.

2.2.1 Environmental variables

The environmental variables were measured in all 12 stations. The categories measured were canopy coverage, riverside vegetation, substrate composition, water velocity, depth, algae and moss coverage, number of pools and number of large woody debris. The canopy coverage was measured from 0 %, indicating zero coverage and an open area to 100 %, indicating full coverage of the area from the edge of the riverbank and 2 meters over the river. This area comprises of only wet area. The riverside vegetation was measured at the same transects, and were categorized as 1 = 0 % coverage, 2 = 1-25 % coverage, 3 = 26-50 % coverage, 4 = 51-75 % coverage, 5 = 76-90 % coverage and 6 = ≥ 91 % coverage. The substrate composition was categorized by the size of the substrate (the rocks at the riverbed). The categories ranged from 1-5. Category 1 = 0-2 mm, 2 = 2-20 mm, 3 = 20-100 mm, 4 = 100-250 mm and 5 = > 250 mm.

The surface water velocity was obtained by measuring time spent for drifting 1 m using a floating leaf. The variables depth, length and width were all measured using measuring tape. Algae and moss were obtained by visual assessment of mean percentage cover of the riverbed. The categories within each of these variables ranged from 1-4, where 1 = 0 % coverage, 2 = 1-33 % coverage, 3 = 34-66 % coverage and 4 = > 66 % coverage. The number of pools was based on the large-scale characteristic of the entire station, while the large woody debris were counted if the diameter was ≥ 10 cm and the length was ≥ 1 m.

The environmental variables were measured at three sub cross transects at each station. The depth and substrate were measured at five different points (at 10, 25, 50, 75 and 90 % of the total length of the transect) across the transect, and then I calculated the mean depth and substrate for each substation. The large woody debris were counted along the entire station and then divided into three (each sub cross transect). The same applies for the number of pools within the station. The total number of pools were counted and then divided into the three substations. Pools were defined as mirror-surfaced areas larger than 1 m^2.

For further details, I recommend Nordhov & Paulsen (2016).

2.3 Statistical analysis

The data processing and preparation was done in Microsoft Excel (Microsoft Office 2004) for samples from both 2015 and 2019, and then imported into the statistical software R version 3.5.2 (R Core Team, 2018) as CSV-files. R was used to conduct all the statistical analysis and create figures. All statistical tests were based on significance level alpha = 0.05. The packages used in data modelling and to create figures were 'ggplot2' (Wickham, 2016), 'stringr' (Wickham, 2019), 'dplyr' (Wickham et al., 2018) & 'directlabels' (Hocking, 2020). The 'vegan' (Oksanen et al., 2019), 'BiodiversityR' (Kindt & Coe, 2005) and 'AICcmodavg' (Mazerolle, 2019) package were used to analyses and for testing prediction. I used Akaike's information criteria (AIC) for model selection (Akaike, 1974).

2.3.1 Changes in diversity and density at a river-level

The macroinvertebrates were to the best ability classified down to the lowest taxonomic level possible and this is the second time all the EPT-orders were classified down to species in Bognelv. The first was in 2015 (Nordhov & Pauslen, 2016), and this is the data I will use to compare my data with. The overall distribution of macroinvertebrate taxa found in Bognelv 2019 was presented using a bar plot in R. To investigate the species composition in the river, I ran the dataset through a detrended correspondence analysis (DCA) to decide which analysis to proceed with. Principal components analysis (PCA) was chosen because the DCA yielded an axis length of DCA = 1.89 (i.e., smaller than 3). This estimated the loading of each species and how they correlate to each other at a river-level. The loading of the macroinvertebrate species was presented in biplot.

To analyse the temporal changes in macroinvertebrate diversity in Bognelv between 2015 and 2019, data from Nordhov & Paulsen (2016) was used. To estimate the diversity, the function Shannon-Wiener index (SW-index) from the vegan package (Oksanen et al., 2019) was used. This index represents species diversity and the higher SW-index, the higher diversity. Moreover, a one-way anova test was performed to estimate the differences between 2015 and 2019 and presented in a boxplot created in R.

Further investigation of diversity of the macroinvertebrates in Bognelv 2019 amongst the sampled stations was done using model selection to describe the explanatory variables using SW-index as the response variable. The candidate models and the parameter estimates were presented and from this a prediction plot of the SW-index was created.

2.3.2 The affecting environmental variable

The environmental variables measured in 2019 and used in my analysis were based on Nordhov & Paulsen (2016) and were measured like those in 2015. The measuring process of the environmental variables was conducted at five different points along the entire station. When I started processing the environmental data, I chose to use only three of these points, as they were measured at the exact same point where I sampled macroinvertebrates. The two other measuring points of environmental variables in 2015 were located between my sub cross transects in 2019 and were excluded. For pools and LWD from 2015, the total number for each station were divided into three (for each of the three sub cross samples) in the same way as for data from 2019.

The environmental variables were processed in Microsoft Excel, where I calculated the mean value for each variable at each sub transect. The statistical analyses were conducted in R. To estimate the superior correlation between the environmental variables and the macroinvertebrate community in Bognelv, a mantel test was performed in R. Furthermore, a PCA was performed to find the loading of each environmental variable and how they correlate to each other. This was illustrated using a biplot.

2.3.3 The measures influence on the macroinvertebrate community

The macroinvertebrates were sampled at different parts of the river. The stations included the restoration measures ‘pools’, ‘side channel’ and ‘modified channelization’, as well as control stations with remaining ‘channelization’. To investigate how each of the measures work (affects the macroinvertebrate diversity and density), a model selection with the macroinvertebrate density as a response was performed. The

predicted density for the measures and control was illustrated in a prediction plot with a 95 % confidence interval using the parameter estimates of the candidate model. Further test of the macroinvertebrate diversity was predicted and illustrated as plots by comparing the species richness *potential* for the different measures and by comparing the evenness vs dominance for the measures compared to the control stations, as well as the analyses presented above in section 2.3.2. Moreover, I used model selection to investigate how environmental variables and restoration measures (pools, side channel, modified channelization, and channelization (control)) influenced the macroinvertebrate community structure in Bognelv. The response of the macroinvertebrate community to the parameter estimates of the most supported model were illustrated using a prediction biplot.

2.3.4 Testing the sampling practice of macroinvertebrates

To test whether important variation might be lost in combining samples from each sub cross transect versus keeping them as three separate samples, the vegan package (Oksanen el al., 2019) was used. In R, a list of all sub cross transects was created and then one of each sub transect for each station was randomly picked. The beta diversity was measured and compared for each sub transect using the 'betadiver' function. One-way anova was used to test for a significance difference between the two methods.

3. Results

3.1 Objective 1 – Changes in diversity and density 2015 vs 2019

A total of 8.843 individuals were sampled and identified into 31 different taxonomical levels. Seven families of Diptera, five species of Ephemeroptera, ten species of Plecoptera, four species of Trichoptera and five families of other taxonomic levels as shown in figure 7.

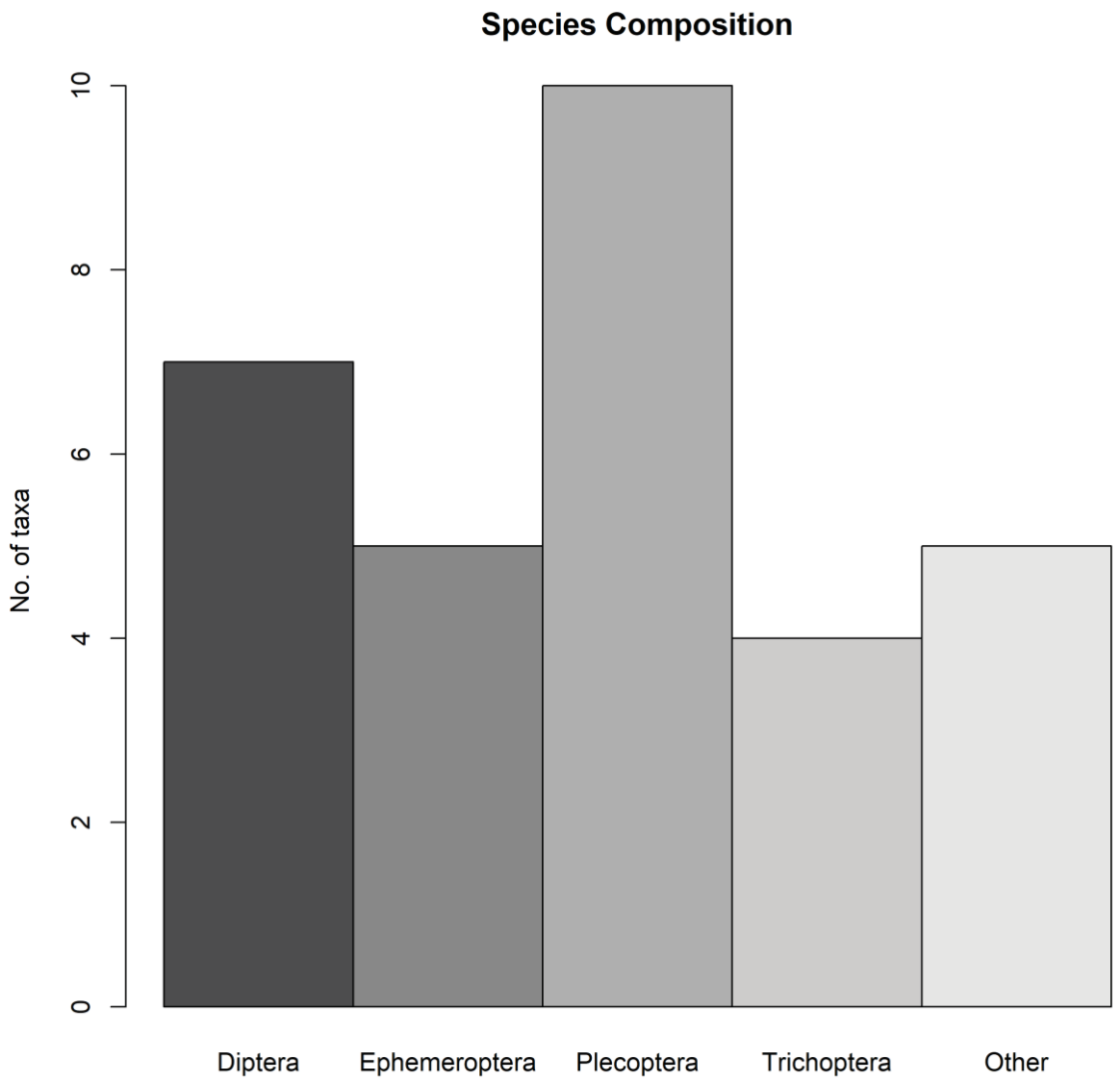

Figure 7. Composition of taxonomic ranks found in Bognelv 2019. Diptera were identified down to family level, while Ephemeroptera, plecoptera and trichoptera were identified down to species. The group 'others' include collembola, dytiscidae, enchytraeidae, lumbricidae and hydrachnidia.

The inter-species correlation structure in Bognelv was analyzed using a principal component analysis (PCA). The species composition was mainly centered between the intersection of the two axis and along the negative PC1-axis with a few exceptions (Figure 8). This indicates that the macroinvertebrate community along the different parts were similar. The loading of PC2 reveals a stronger impact and reveals differences in species composition. For instance, the loading of PC2 reveals that at a given site in the river with a high amount of Simuliidae, it can be expected to observe no or few of *A.zonella*.

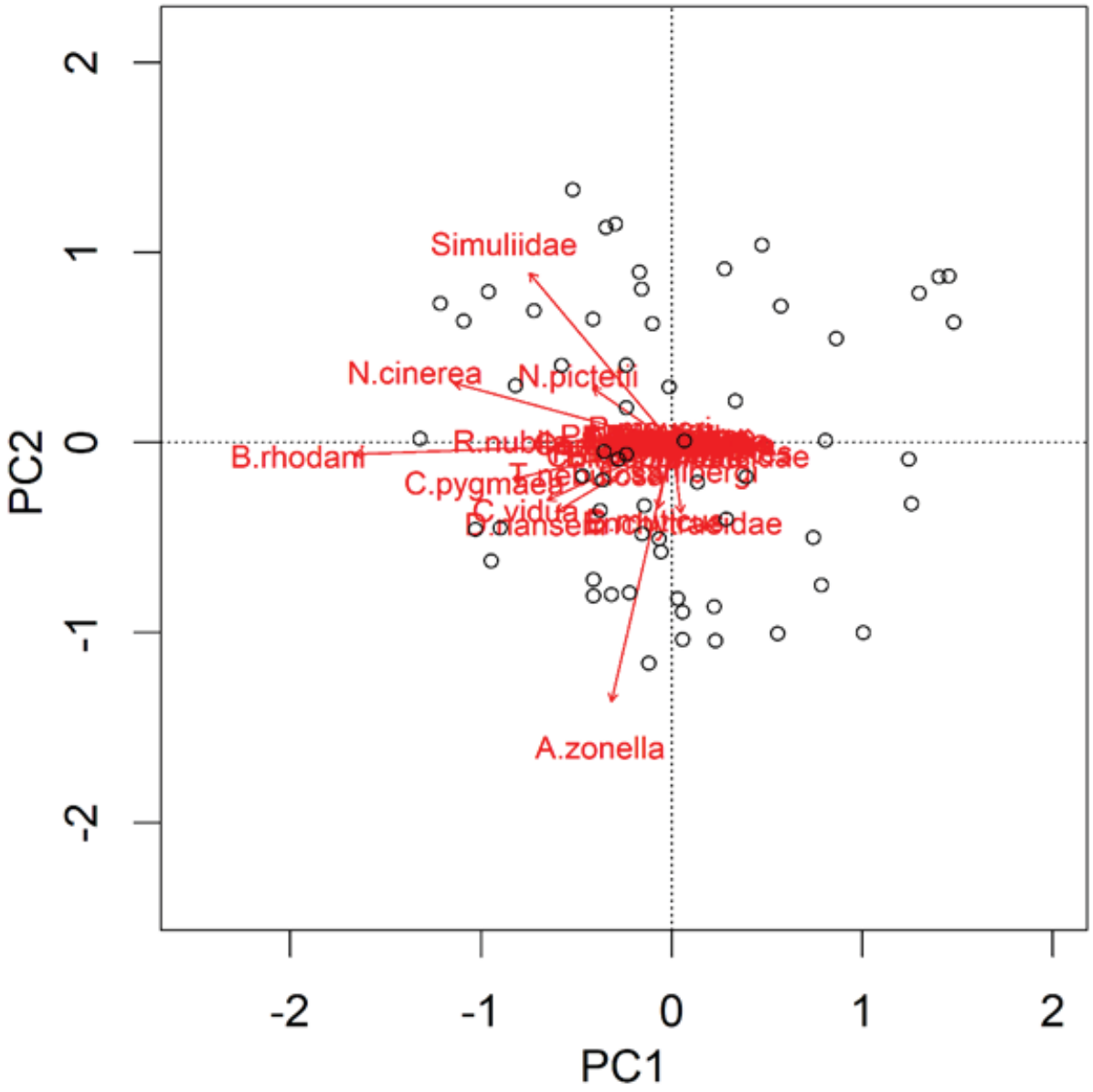

Figure 8. Biplot of PC1 and PC2 loadings for the macroinvertebrate samples in Bognelv. The nine species with highest factor loadings are named, whereas others are only displayed with arrows. Dots represent station loadings.

There was a significant (F = 150.92 & p < 0.0001) difference between SW-index in 2015 and 2019 (Figure 9). The overall macroinvertebrate diversity was measured at the river-level and included all samples for each sampling year. Mean SW-index were higher in 2019 with ~ 1.75 as opposed to ~ 1.0 in 2015, giving an ~ 0.75 increase in four years (Figure 9). The total length of river sampled was 840 m (15 m x 56 stations) and 600 m (50 m x 12 stations) in 2015 and 2019, respectively.

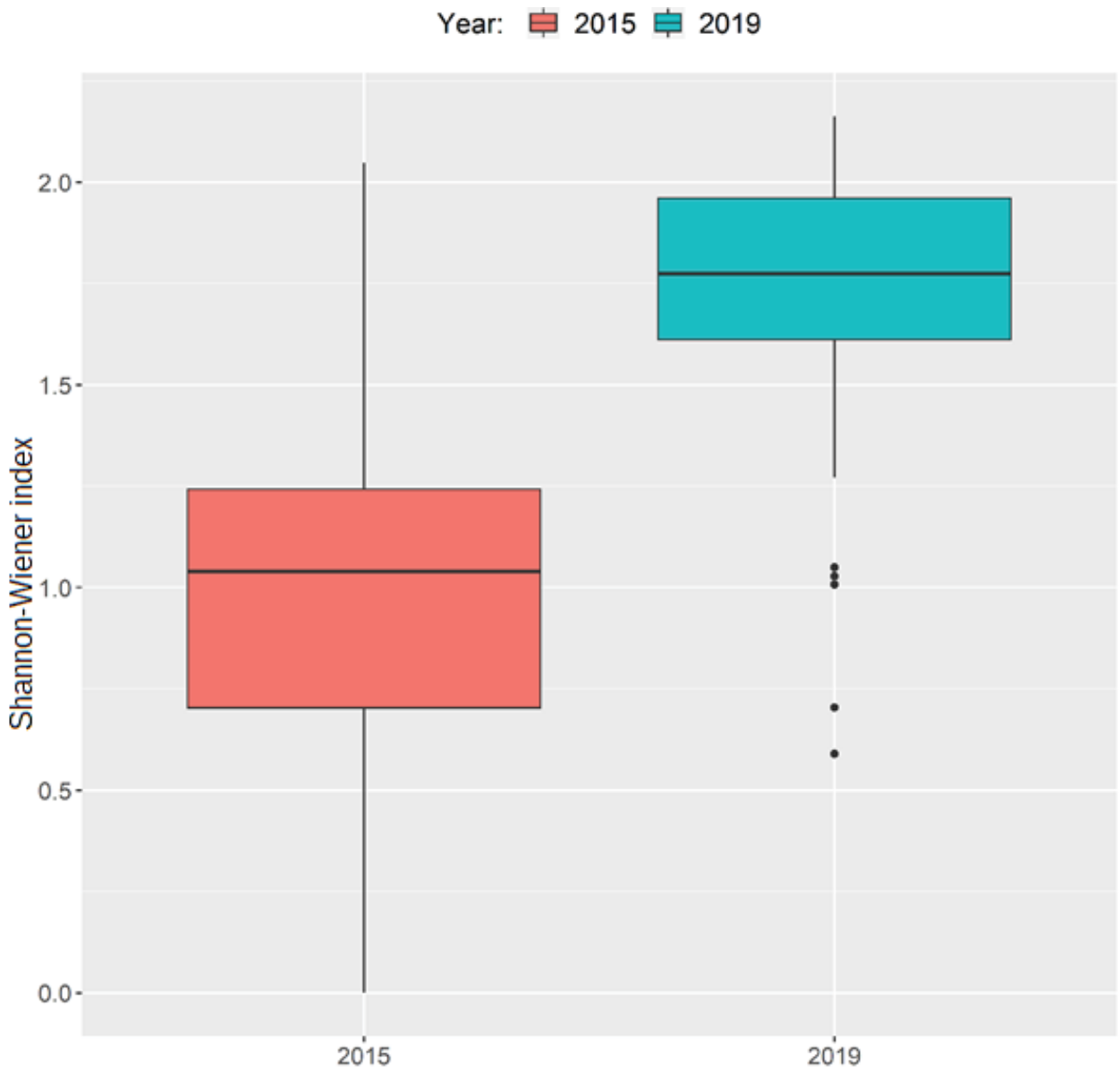

Figure 9. The river-level diversity (SW-index) in 2015 vs 2019. The black horizontal line represents the median for each year. Black dots represent outliers, which in this case are observations below the lowest mean SW-index for 2019.

Model selection among candidate linear models fitted to SW-index values describing the macroinvertebrate diversity favored a two-way interaction between PC1 and time^2 (Table 2). This model attained an AIC score at 1.39 units lower than the second most supported model. The seven top-ranked models all ranged between 1.39 to 3.88 units from the selected model. The common theme for the seven most supported models is the explanatory variables PC1, Time and PC2. The model that most efficiently explained the macroinvertebrate diversity predicts that SW-index changes over time and PC1 (Figure 10). The model had 31 % support (AICcWT = 0.31) and explained approximately 28 % of the variance observed. The adjusted R-squared was 24 %.

Table 2. AICc-based model selection for candidate models fitted to SW-index values of the macroinvertebrate diversity in Bognelv. The top ten best fitted models are shown (total n. of mod. 22). K = number of estimated parameters, AICc = the corrected Akaike's information criterion, ΔAICc = difference between the most supported model (with lowest AICc score) and any given model, AICcWt = the model AICc weight/ the relative support & LL = model log likelihood. Timerecent is time since last adjustment of the measure, while Timefirst is time since the measure was conducted.

Explanatory variable	**K**	**AICc**	**ΔAICc**	**AICcWt**	**Cum.Wt**	**LI**
PC1+Timerecent^2	5	33.15	0.00	0.31	0.31	-11.02
PC1+PC2+Timerecent^2	6	34.55	1.39	0.16	0.47	-10.48
PC1+PC2+Timefirst^2	6	35.32	2.16	0.11	0.58	-10.87
PC1+PC2+Timefirst	5	35.35	2.19	0.10	0.68	-12.12
PC1+PC2	4	36.06	2.91	0.07	0.75	-13.67
PC1+Timefirst^2	5	36.99	3.84	0.05	0.80	-12.94
PC1+PC2+Treatment	7	37.03	3.88	0.05	0.84	-10.44
PC1+PC2+Timerecent	5	37.40	4.24	0.04	0.88	-13.14
PC1+Treatment	6	37.71	4.56	0.03	0.91	-12.06
PC2+Timefirst	4	38.40	5.25	0.02	0.94	-14.84

Predictions (Figure 10) based on the selected SW-model (Table 3), indicates a reduction in diversity (SW-index) with increasing PC1 and at any PC1 level, the diversity peaks around 6 years (T = 5.95) post-restoration and then decrease as time since most recent habitat restoration increase.

Table 3. Parameter estimates for the selected model (i.e., lowest AIC score in Table 2) fitted to predict SW-index for macroinvertebrate data from Bognelv 2019. R-squared = 0.28.

	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	1.619790	0.060148	26.930	< 2e-16
PC1	-0.225157	0.063420	-3.550	0.000788
Time	0.100685	0.031438	3.203	0.002247
$Time^2$	-0.008466	0.002738	-3.092	0.003101

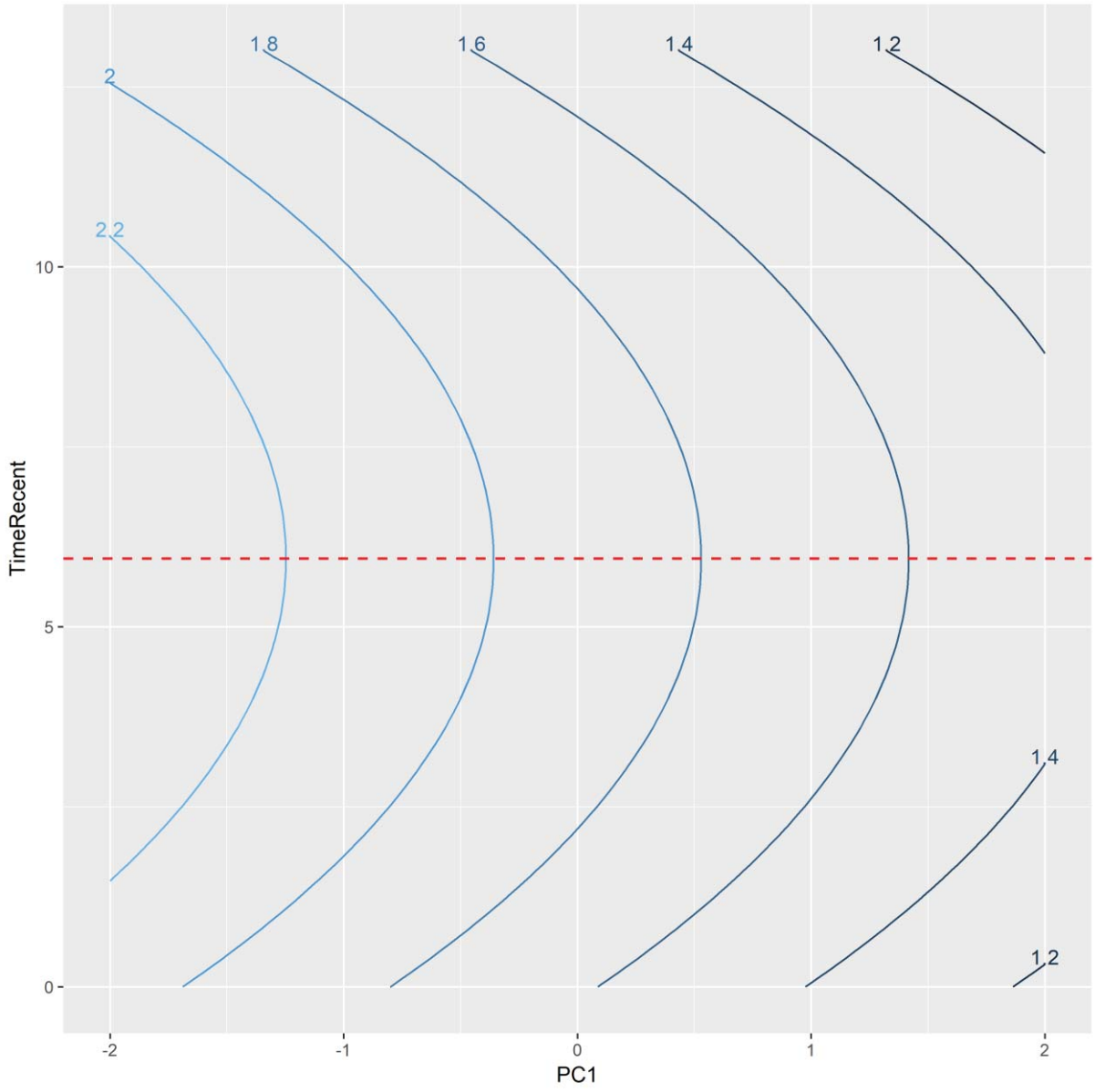

Figure 10. Prediction plot of the most supported model (Table 3) showing the SW-index of macroinvertebrate diversity in Bognelv. The explanatory variables are PC1 and time (timerecent). The diversity (SW-index) is illustrated by numbers, and the higher number, the higher diversity. The diversity peaks after approximately 6 years post-restoration.

3.2 Objective 2 – The influential environmental variables

A Mantel test showed a significant ($p = 0.001$) correlation between environmental variables and the macroinvertebrate community in Bognelv and accounted for almost 25 % of the macroinvertebrate variation ($r = 0.246$).

PCA-analysis of the environmental variables yielded a PC1 explaining approximately 20 % of the environmental variation, while PC2 explained 17 %. The loading of an environmental variable depends on the length and direction of the arrows (Figure 11). The environmental variables strongest (longest arrows) associated with PC1 are velocity for a negative PC1 and LWD for a positive PC1. Depth is the variable strongest associated with a positive PC2, while moss coverage is associated with a negative PC2. Figure 11 indicates that a negative PC1 is associated with the physical environmental variables of the river, such as fast running water and coarser substrates. While a positive PC1 expects the opposite of this, i.e., slow running water with organic components and pools. On the other hand, a positive PC2 is associated with increased velocity, depth, finer substrate, and more algae. While for a negative PC2, one would expect to find moss instead of algae, coarser substrate, and pools. The environmental variable most fitted to explain the observed variation depends on the strength of the PC1 and PC2.

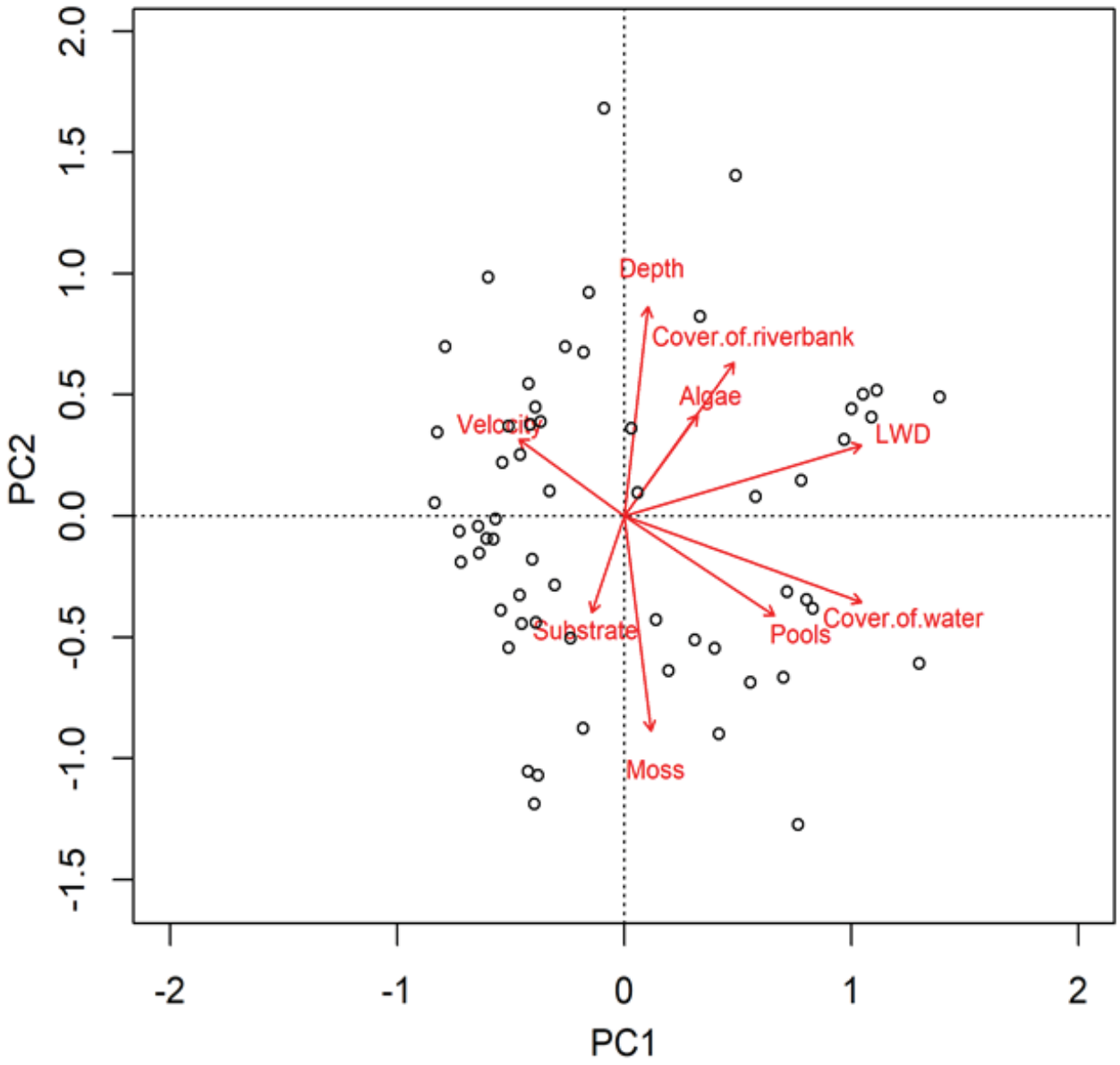

Figure 11. Biplot of principal component analysis (PCA) of the environmental variables measured in Bognelv 2019. The axes show PC1 and PC2 loadings. The length of the arrow displays the strength of loading per variable. Dots represent station loadings. LWD = large woody debris, Cover.of.water = canopy coverage of the area from the edge of the riverbank and 2 meters over the river (only wet area), Cover.of.riverbank = riverside vegetation, Moss = moss coverage of the riverbed, Algae = algal coverage of the riverbed, Substrate = riverbed substrate composition, Velocity = surface water velocity, Depth = depth of the river, Pools = number of pools within each station.

3.3 Objective 3 – The response of macroinvertebrates to measures

Model selection amongst candidate linear models fitted to macroinvertebrate density data favored a two-way interaction explanatory effect model consisting of the environmental variable PC1 and treatment (type of measure) (Table 4). The selected model attained an AIC-score at 1.61 units lower than the second most supported model. The two most supported models both contained the explanatory variables PC1 and type of measure. The model that most efficiently explains the macroinvertebrate density predicts that the density differs with different loadings of PC1 and differ between measures (Figure 12). The model has 63 % support (AICcWt = 0.63) and explains approximately 46 % of the observed variance. The adjusted R-squared was 42 %.

The selected model predicts that stations with increasing amounts of pools have the highest macroinvertebrate density at any environmental PC1 score. The stations with removed channelization have the same density as the control stations, while the side channel stations have the lowest density.

Table 4. AICc-based model selection for candidate models fitted to the macroinvertebrate density in Bognelv. The top ten best fitted models are shown (total n. of mod. 22). K = number of estimated parameters, AICc = the corrected Akaike's information criterion, ΔAICc = difference between the most supported model (with lowest AICc score) and any given model, AICcWt = the model AICc weight/ the relative support & LL = model log likelihood.

Explanatory variable	K	AICc	ΔAICc	AICcWt	Cum.Wt	Ll
PC1+Treatment	6	80.36	0.00	0.63	0.63	-33.39
PC1+PC2+Treatment	7	81.97	1.61	0.28	0.91	-32.91
PC1+PC2+Time	5	87.18	6.81	0.02	0.93	-38.03
Pc1+Pc2+Time^2	6	87.29	6.93	0.02	0.95	-36.85
PC1+Time^2	5	87.70	7.34	0.02	0.96	-38.30
PC1+Time^2	5	88.12	7.75	0.01	0.98	-38.50
PC1+Time	4	89.72	9.36	0.01	0.98	-40.50
PC1+PC2+Time^2	6	89.79	9.43	0.01	0.99	-38.10
PC1+PC2	4	90.21	9.84	0.00	0.99	-40.74
PC1	3	91.34	10.98	0.00	1.00	-42.46

Table 5. Parameter estimates for the supported model (i.e., lowest AIC score in Table 4) fitted to predict macroinvertebrate density data from Bognelv. Default type of measure (intercept) is channelization (control) sites. R-squared = 0.46.

	Estimate	Std.Error	t value	Pr(>|t|)
(Intercept)	4.85456	0.12483	38.890	< 2e-16
PC1	-0.44984	0.11221	-4.009	0.000185
Measure P	0.50204	0.19458	2.580	0.012577
Measure S	-0.20779	0.16123	-1.289	0.202880
Measure M	0.00743	0.22847	0.033	0.974174

The selected model estimated the macroinvertebrate density 4, at any PC1 score, stations with pools to have the highest density of macroinvertebrates, while stations from the side channels had the lowest density for any PC1 score (Table 5 Figure 12). The confidence interval for each measure overlap, but overall density for each measure is highest at a negative PC1 score and decreases parallel to an increased PC1 score. All of the restoration measures follow the same trend, with the highest density at a negative PC1 score and the lowest density at a positive PC1 score, which indicates that one will expect to find a higher density at all the stations when the environmental conditions is more physical and less organic (as in a positive PC1).

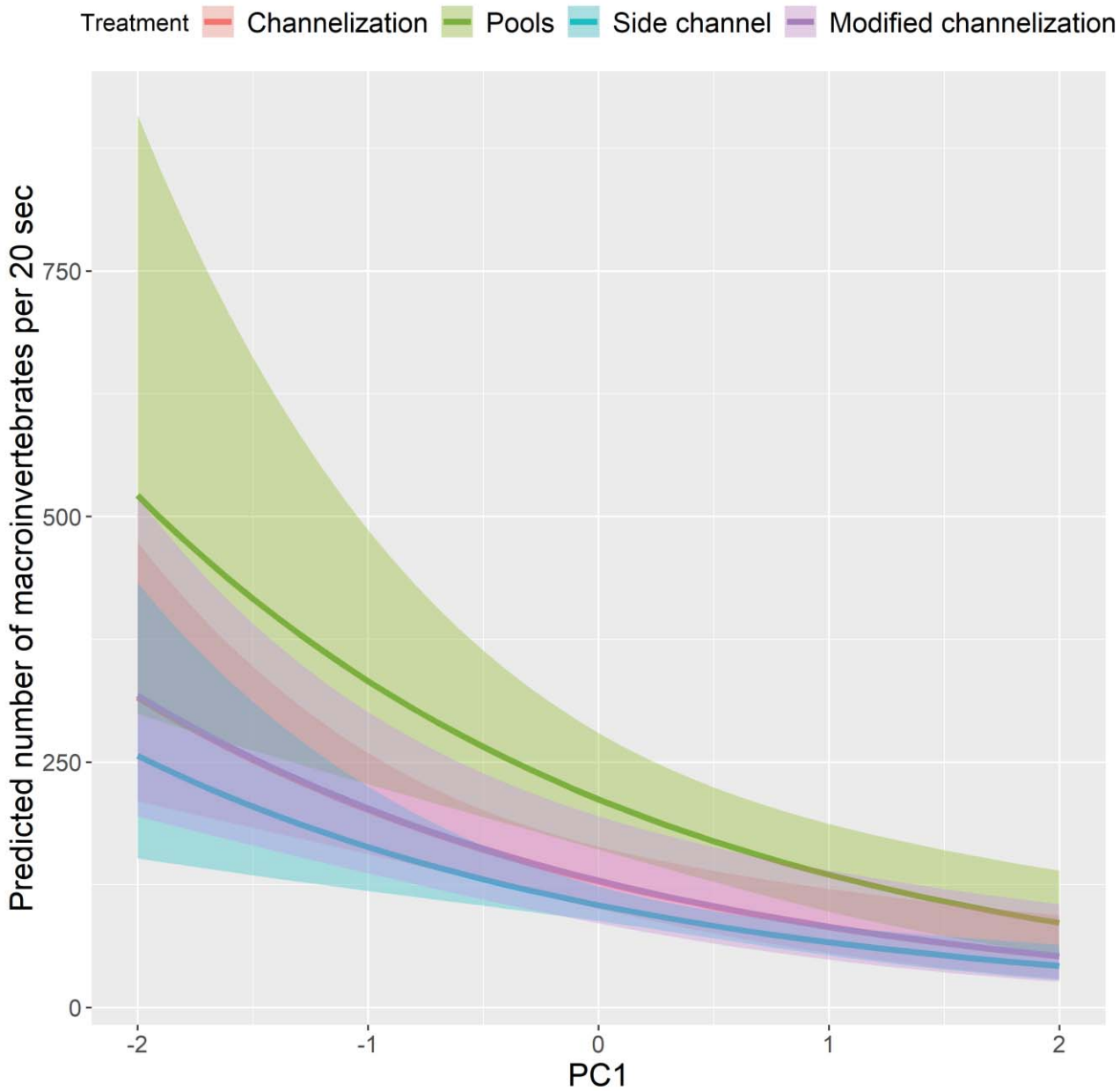

Figure 12. Prediction plot of the most supported density model (Table 5) showing the density of macroinvertebrates as function of the environmental PC1 and restoration measures.

Side channel and control stations seemed to have the same and highest species richness *potential* compared to the two other measures (Figure 13).

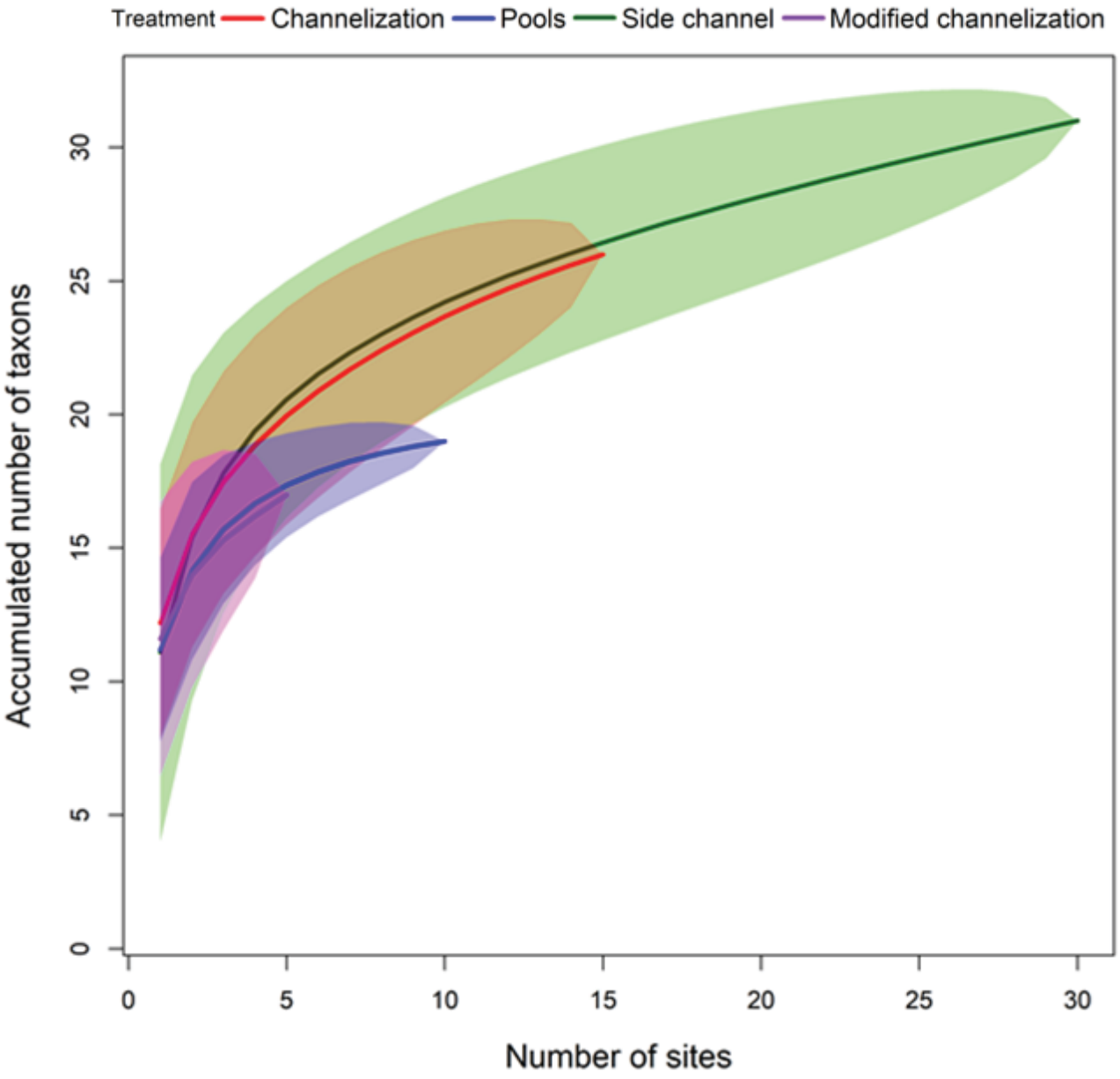

Figure 13. Species richness *potential* for each measure. The accumulated number of taxa is shown on the y-axis, while the number of sites (= stations) to reach the saturation point of estimated species within each restoration measure is shown along the x-axis.

The relationship between evenness and species dominance amongst the restoration measures are presented in figure 14. Modified channelization stations showed the highest dominance signature (L-shape) in the macroinvertebrate samples and side channels the highest evenness pattern (diagonal line) (Figure 14). The figure shows the same tendencies as figure 13, where the modified channelization stations support the lowest evenness and highest species dominance, which is indicated by the low saturation point in figure 13. Furthermore, side channel has the highest evenness in figure 14 and the highest potential species richness in figure 13.

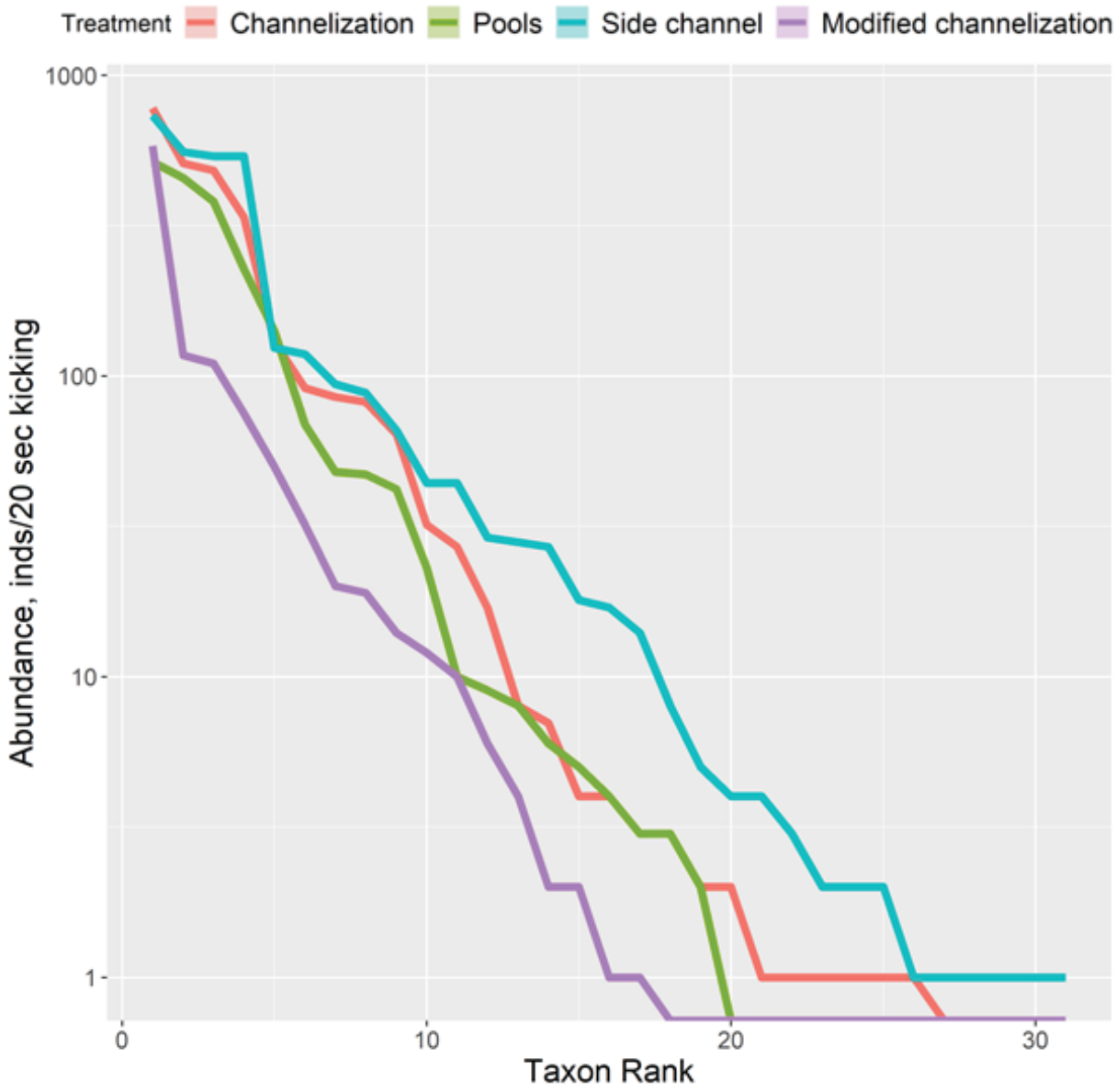

Figure 14. Rank-abundancy plot for each measure. Shows the trends (evenness vs species dominance) in rank-abundancy for each measure. An L-shape indicates high dominance while a diagonal line indicates high evenness.

Model selection of candidate constrained PCA-models fitted macroinvertebrate abundance composition data favored a model consisting of additive effects of PC1, PC2 and the measures (Table 4). This model had 0.25 units lower AICc-values than the second-most supported model. The top ten models all ranged from 0.25 to 3.96 units from the most supported candidate model. The common theme for the top ten fitted models was PC1 and measure. The most supported model predicts that the macroinvertebrate community changes by the loading of PC1 and PC2 and by type of measure (Figure 15). The model explains approximately 28 % of the variation. The adjusted R-squared was 20 %.

Table 6. AICc-based model selection for candidate models to describe the macroinvertebrate composition in Bognelv using the environmental variables as response. A total of 14 models was tested. npar = number of estimated parameters, AICc = the corrected Akaike's information criterion, ΔAICc = difference between the most supported model (with lowest AICc score) and any given model & AICcWt = the model AICc weight/ the relative support.

Explanatory variables	**npar**	**AICc**	**ΔAICc**
PC1+PC2+Measure	6	146.1660	0.00
PC1+Measure	5	146.4119	0.25
PC1+PC3+Measure	6	146.4903	0.32
PC1+PC2+PC3+Measure	7	146.6874	0.52
PC1+PC2+PC3	4	147.4940	1.33
PC1+PC3	3	148.0348	1.87
PC1+PC2	3	148.3298	2.16
PC1	2	148.7556	2.59
PC2+PC3+Measure	6	150.1292	3.96
PC2+PC3	3	155.0443	8.88
PC3	2	155.2179	9.05
PC2	2	155.4711	9.31
With intercept only	1	155.5600	9.40

Selected constrained PCA (Table 6) show that benthic invertebrate community is different in pools compared to the other measures. Modified channelization and channelization show an overlap, while side channels is the only measure with a macroinvertebrate community that is positively associated with both of the environmental PC1 and PC2 axes.

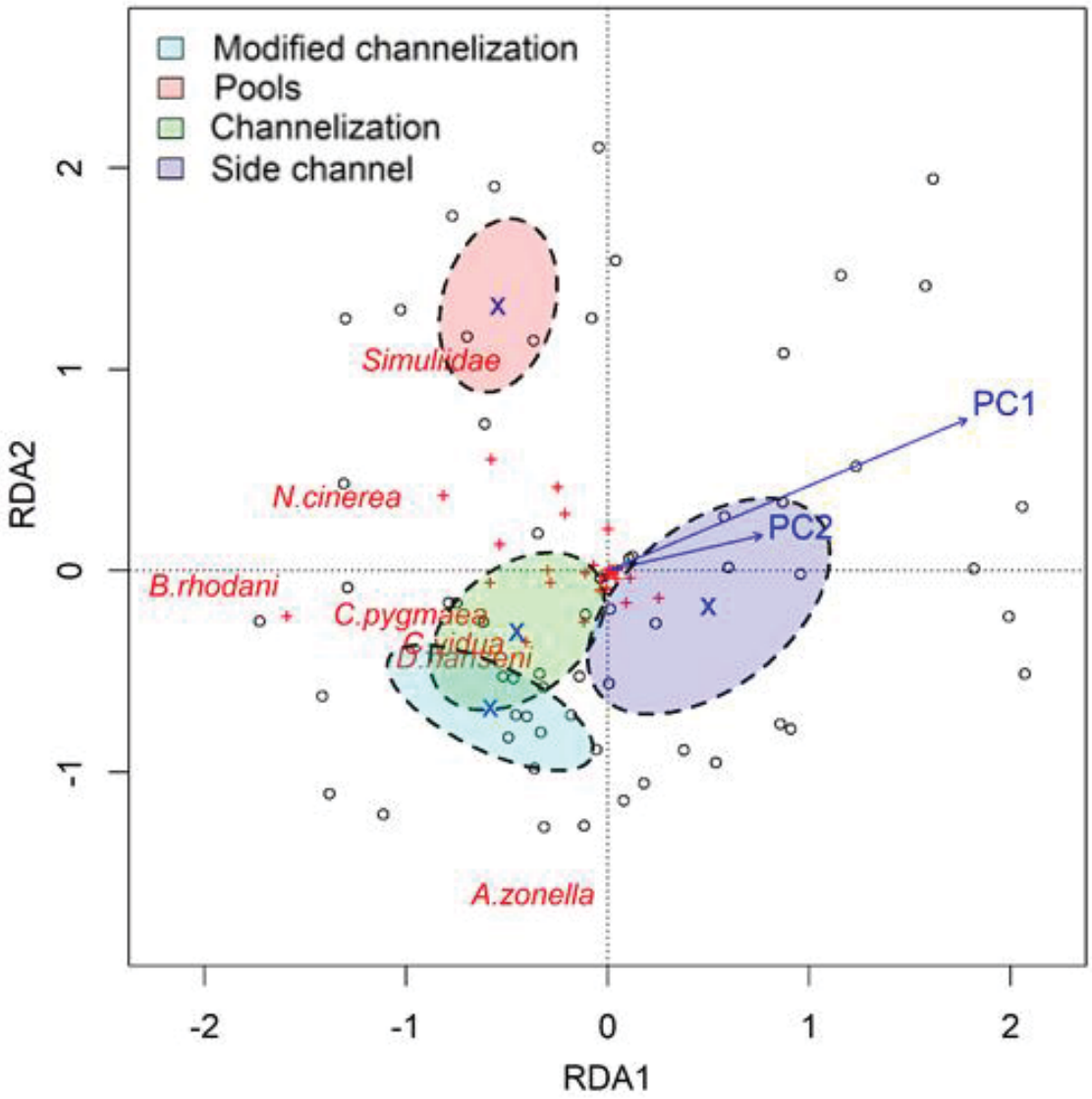

Figure 15. Prediction plot of the most supported model explaining the macroinvertebrate composition. The top seven macroinvertebrates are highlighted as well as the loading of the environmental PC1 and PC2. The dots are station loading and red crosses are loading of the rest of the macroinvertebrates.

3.4 Testing the two sampling methods

When comparing test results from the one-way anova testing for effect of measure level on beta diversity, using the combined sample (three replicas combined into one sample) provided a lower statistical significance level of the effect ($p = 0.03$) compared to a test using three separate samples ($p = 0.0008$). However, both approaches showed that there were statistically significant differences among measure levels on the beta diversity.

4. Discussion

4.1 Objective 1 – Changes in the community structure in Bognelv

I found a higher diversity in 2019 opposed to 2015 (Figure 9). This was as expected and in accordance with Friberg et al., (1998), as they found the macroinvertebrate to have a steady increase in diversity post-restoration. Other studies report the same trends, but over a shorter time span, such as Pedersen et al., (2007), who found that macroinvertebrate diversity reached pre-restoration levels already two years after restoration, while Niemi et al., (1990), found it to be three years post-restoration.

The rapid recovery after restoration is reminiscent of the natural recovery response after floods, where Scrimegeour et al., (1988) found the fauna reached pre-flood diversity after 132 days. The recovery process after conducted restoration measures would inflict strong disturbance to an already disturbed ecosystem (in this case channelized). It would be logical for the system to respond slower, even though, Friberg et al., (1998), Pedersen et al., (2007) and Niemi et al., (1990) all found rapid recovery. The rapid recovery of the natural disturbance is due to colonization from the refuges and possible flying egg-laying imagos (Palmer, Bely & Berg, 1992; Schneider & Petrin, 2017). Studies show that channelization affects invertebrates negatively, such as decreased ability to retain woody debris and organic matter and the lack of flow refugia (Negishi, Inoue & Nunokawa, 2002; Lennox III & Rasmussen, 2016). So, the reason for an increased diversity in 2019 compared to 2015 can be due to the fact that some of the measures conducted the year before sampling in 2015 influenced the refuges and slowed down the colonization of new macroinvertebrates. Even though minor changes were done to two of the side channels the same year as sampling in 2019, this seems not to have affected the diversity. Since both Pedersen et al., (2007) and Niemi et al., (1990) only measured short-term effects, it might be expected that if they continued their study, they might have found a steady, slow increase in diversity such as Friberg et al., (1998) and the present study. However, the results from the present study and Friberg et al., (1998) can indicate that there are potentially a higher number of immigrating insects from upstream or a higher level of refuges upstream the restored areas.

According to figure 10, the diversity of the macroinvertebrate community in Bognelv was shown to increase after the conducted restoration measure and reached a peak in diversity after 6 years, and then slowly decreased. This trend is similar to what Laasonen, Muotka & Kivijärvi (1998) found - that the species richness was similar to natural streams and highest after approximately one to three years post-restoration, and then started to decrease. This seems to be following a typical trend of succession (Begon, Townsend & Harper, 2006; Primack, 2012; Krebs, 2014) which involves a few colonizing species that settle in the beginning giving a high dominance of few species, and as additional species colonize, the diversity and evenness of species increases. And then, as the specialists start to establish themselves, the habitat will eventually consist of fewer, dominating species. This correlates to the findings from chapter 3.3 which I will discuss further in chapter 4.3. On the other hand, Friberg et al., (2013) revisited the same river as Friberg et al., (1998) and concluded with little change in the macroinvertebrate community, indicating high community persistence. According to this, Friberg et al., (2013), assumed that the species composition of the river was already close to its saturation point in 1998.

The overall macroinvertebrate composition in Bognelv from 2015 and 2019 is provided in appendix 2. The composition differed slightly with a total of 35 different taxonomic levels in 2015 opposed to 31 in 2019. I found 20 similar taxa in 2019 as in 2015. Nordhov & Paulsen (2016) found Chironomidae spp., to be associated with slow-running water, increasing water depths and to the restoration measure weirs. I found, on the other hand, Chironomidae spp., to be in the entire river system as I found large numbers of Chironomidae spp., in every station. The functional feeding groups associated with the macroinvertebrates found in 2015 and 2019 are similar, as most of the macroinvertebrates are associated with being predators or a combination of gatherer/collectors, grazers and shredders (Schmidt-Kloiber & Hering, 2015; Buffagni et al., 2020; Graf et al., 2020). Because of the broad feeding range in many of the species in Bognelv, one would expect the macroinvertebrate community to consist of many generalists. Furthermore, Nordhov & Paulsen (2016) found high numbers of Gammaridae spp., in the lower shallow brackish parts of the river – these stations were excluded from my surveys and thus, also in the comparison of SW-index (Figure 9). I will continue to discuss the findings in 2019 and 2015 in chapter 4.3.

4.2 Objective 2 – Environmental effects on the macroinvertebrates

I expected current and substrate to be the most influential environmental variables (Leunda et al., 2009; Leigh, 2013; Li et al., 2016; Karaouzas et al., 2019). Surprisingly, the environmental variables with the strongest effect on community structure (via loading on the environmental PC1 and PC2-axes) were large woody debris (LWD), vegetation cover of the river closest to the shoreline (Cover.of.water in Figure 11) and moss coverage of the riverbed. Studies report considerable differences in the influence of different environmental variables. Zhang et al., (2014) found that velocity, dissolved oxygen, and total phosphorus influence the macroinvertebrate community. Other studies have shown substrate and the current velocity to be important influential factors to the diversity of the local macroinvertebrates (Wallace & Webster, 1996). Moreover, Liu et al., (2016) found the physical features of the stream habitat (e.g., substrate), as well as pH, to affect the macroinvertebrate composition the most, while Nordhov & Paulsen (2016) found depth and velocity to have significant effect on the macroinvertebrate community composition, as well as river zone and type of measure.

If I only focus on the instream variables and exclude the surrounding environmental variables, the variables depth, LWD, velocity, pools and moss coverage all point out as influential to the macroinvertebrate composition in the PCA (Figure 11). All the variables correlate to the flow regime in one way or another. Velocity is connected to flow regime and affects the physical features in the river and thus, also the substratum (Khudhair et al., 2019). Velocity affect the macroinvertebrate community by directly influencing the biotic interactions within the river (Poff et al., 1997; Allan & Castillo, 2007). Substrate composition is important, as most macroinvertebrates spend their life on the bottom of the river or stream (Khudhair et al., 2019). Degani et al., (1993) found water depth to influence the macroinvertebrates in their study, as they preferred the range between 5-60 cm, but most of the taxa were found at ≥ 30 cm with high surface velocity. Whereas pools create more heterogeneity and thus increase diversity (Li et al., 2012). Furthermore, LWD are reported to be involved in colonization of macroinvertebrates as well as serve as an energy source and a refuge from predators and flow (Hrodey, Kalb & Sutton, 2008), even though this research is done in warmer water than Bognelv.

As studies show such variation in the influence of environmental variables on macroinvertebrate communities is according to Melo (2009) and Li et al., (2012) expected. Environmental variables affect the macroinvertebrate assemblage of a river differently according to type of ecosystem and the spatial scale (Melo, 2009; Li et al., 2012), and because of this I cannot confirm or dismiss the findings of the present study, as there are too many factors involved to interpret which environmental variable affects the macroinvertebrate composition the most. On the other hand, depth and velocity have been shown to influence the macroinvertebrate community composition in Bognelv in 2015 and 2019. So, it seems like both environmental variables can be of great influence on the macroinvertebrates within Bognelv as an ecosystem. Since the sampling methods of 2015 and 2019 differ, this could have influenced the scale of the study and thus, how the result of the environmental variables (Figure 11) affected the macroinvertebrates in Bognelv.

4.3 Objective 3 – Difference in macroinvertebrate community between restored and control stations

The third objective aimed to estimate the effect of restoration measures on macroinvertebrate diversity and density by comparing stations with measures against control stations without. With the assumption that areas without measures would have a lower diversity and density because of homogenous condition in the channelized stations, I expected to find an overall higher diversity and density in stations with measures as they support more heterogenous conditions. My study found no significant evidence that the restoration measures conducted in Bognelv have increased the heterogenic conditions within the river and so on the diversity and density of macroinvertebrates.

Regarding density, model selection was performed as an attempt to find the explanatory variables which revealed environmental variables associated with PC1 and type of measure to have highest support. From this, I found density to be highest in pool stations, while modified channelization and channelized control stations showed similar trends in density. The side channel stations had the lowest density of macroinvertebrates. Even though there is an overlap between the confidence interval for all station types, the trend described above is similar for all PC1 scores, and highest at a negative PC1. My findings from figure 12 and 13 corresponds, as density was highest for pool stations, it was also the measure with the lowest species richness *potential*, which indicates high density with few dominating species. This is indeed further supported in figure 14, which shows the pool stations tending towards a more L-shaped signature than a diagonal line, indicating a higher dominance in a few species. On the other hand, the measures showing the lowest densities of macroinvertebrates were the side channels (Figure 12). As opposed to pool stations, the side channels held the highest species richness *potential* (Figure 13). This correspond to the findings in figure 14, which reveled tendencies towards a diagonal line, indicating evenness in the species richness in side channel stations, and thus, a higher diversity compared to pool stations. Moreover, the modified channelization stations and the channelized control stations followed the same trend in macroinvertebrate density (Figure 12). On the other hand, this was not the case for species richness potential. Modified channelization had the lowest species richness

potential (Figure 13), and the most L-shaped signature in figure 14. All of which indicated a macroinvertebrate composition consisting of few dominating species with surprisingly low density. On the other hand, channelized control stations experience the opposite trend in species richness *potential*, as the channelized stations show the second highest species richness *potential* (Figure 13). According to figure 14, the curve tends towards a more diagonal line.

Studies report a higher species richness in habitats with more complex physical features (Allan & Castillo, 2007), and reduced density and diversity of macroinvertebrates in channelized rivers (Friberg et al., 1998; Bis, Zdanowicz & Zalewski, 2000; Negishi, Inoue & Nunokawa, 2002; Nakano & Nakamura, 2006; Nakano et al., 2008; Lennox III & Rasmussen, 2016). Moreover, dominant more tolerant species are known to increase in density as habitats degrade (Allan & Flecker, 1993) and as a consequence to channelization (Allan & Castillo, 2007). As mentioned in chapter 4.1, the temporal changes in diversity follows the typical successional path. The succession in rivers are dependent on the dispersal from surrounding communities (Godoy et al., 2016). Moreover, the succession process of insects is determined by mainly two factors: (1) age and (2) other extrinsic factors (e.g., season) (Godoy et al., 2016). Studies show that if age is the determinator of the succession process, then, the biggest changes in species composition will be caused by temporal changes. Contrary, if season and other extrinsic factors are the main driver of the succession, the differences in species composition will be between sites (Godoy et al., 2016). This correlates with the findings of the present study, where figure 9 and figure 10 both show temporal changes in the species composition which suggest age or time to be the driver of succession. While figure 12, 13, 14 & 15 all show differences between the sites (pools, side channel, modified channelization, and the channelized control stations), suggesting other extrinsic factors promote the succession.

Furthermore, a model selection of the environmental variables describing the macroinvertebrate composition favored the combination of the explanatory variables PC1, PC2 and type of measure. The environmental variables associated with PC1 (cf. Figure 11) had the strongest influence on the macroinvertebrate community in the sampled stations in Bognelv 2019. As mentioned above, I found that pools differ the most from the other measures, with Simuliidae spp., clearly associated with this measure, showing the results regarding pools station to correlate. The environmental habitat in pools showed the opposite of what would be expected, and instead indicate that this habitat holds physical features such as fast-running water and coarser substrate. This could be because the pool measure was part of the entire station and the station also included a certain amount without pools. Moreover, modified channelization and channelization overlap and indicate habitats with physical features (a negative PC1). The fact that they overlap is not surprising, as the habitats are similar and need more time to change. Side channel stations are the only measure with a positive association to PC1 and PC2, which indicates an organic-dominating habitat with deeper water. From figure 15, side channel and channelization are closes to the cross section of RDA1 and RDA2, showing the highest species representation, and correlates with the species richness potential in figure 13. Furthermore, the species richness of the measures is associated with a negative PC1 and PC2, giving the expectation to not find any or very few of the highlighted top seven macroinvertebrates, Simuliidae spp., *Nemoura cinerea, Baetis rhodani, Capnia pygmaea, Capnia vidua, Diura nanseni & Apatania zonella,* in side channels. All seven macroinvertebrates, expect *A. zonella*, were also found in Bognelv in 2015.

Nordhov & Paulsen (2016) found *B. rhodani* to be a habitat generalist that preferred stations with riparian modifications, side channels and without restoration measures. According to my findings (Figure 15) was *B. rhodani* associated with negative PC1 and PC2 values rather than a specific measure. From this, one could expect to find *B. rhodani* in any stations and measures if they possess strong physical habitat features such as high current velocity and larger gravel. Studies support my findings, showing *B. rhondai* to be associated with faster running water and rocky substrates (Kraabøl & Johnsen, 2012). As *B. rhodani* are common species within the European freshwater systems (Kraabøl & Johnsen, 2012), it was not surprising to find it in both 2015 and

2019. Furthermore, Nordhov & Paulsen (2016) found *C. vidua* to prefer habitats with deep and slow running waters. In contrast, I found *C. vidua* to be associated with shallow, fast-running waters and to the restoration measure modified channelization as well as the control stretches. Most species found in Bognelv 2019 were centred near origo (Figure 15), indicating further support towards the lack of changes to the habitat by the measures conducted in Bognelv. Moreover, from my dataset I found large numbers (≥ 20 individuals) of *B. rhodani, C. pygmaea* & *A. zonella* in every station and measure except in two of the side channel stations (which had less than 20 individual per species per station). This could indicate that the measures are too similar to the channelized stretches or simply that these three species are generalists, even though they are associated with A. zonella are found in stony streams (Johanson, 2015), and C. pygmaea are associated with high velocities (Fjellheim & Raddum, 1996; Fjellheim et al., 1992).

According to Miller, Budy & Schmidt (2009) only the species richness of macroinvertebrates are affected by the restoration of homogenized rivers to heterogenized river, the density is not enhanced. Furthermore, Lepori et al., (2005) found that the diversity of macroinvertebrates and fish were similar between restored and channelized sites, even though there was a clear difference in heterogeneity between restored and channelized sites of their study. From my expectations, the results of the present study were surprising, as channelized control stations show high density and species richness *potential* as well as tendencies towards evenness. Thus, the findings of the presents study struggle to find a correlation between the measures and the density and diversity of the macroinvertebrates, which suggest that the conducted measures in the restoration of the river acted at scales of structural heterogeneity that are irrelevant to macroinvertebrates and fish (Lepori et al., 2005). This means that the measures have not created enough changes, and thus, new structural habitats compared to the channelized section of the river that would encourage the colonization of new species are still needed (Lepori et al., 2005).

4.4 Comparison of the two sampling methods in Bognelv 2019

As an additional part to this study, I aimed to test the two sampling methods used to collect the macroinvertebrates in Bognelv 2019. I estimated how sensitive the analyses were towards combining three replicas into one sample compared to using the three replicas separately. My findings suggested that choosing one sampling strategy over the other will not affect the results, as the conclusion would be the same for both strategies in the present study. In other words, one would not be able to draw different conclusion from the two sampling methods in my study, and thus, I recommend using the one combined sample strategy, as this saves time in the field and in the laboratory. On the contrary, if one were to investigate macroinvertebrate composition on a more local scale, the three separate sampling method would be preferable as the combined sampling method has lower power and thus, could potentially fail to detect differences between macroinvertebrate groups that are being compared within station replicas and between stations.

4.5 Potential sources of errors

After finishing my thesis, I found some sources of error in my study.

Regarding the study design, the selection of stations should have been solely based on the previous study and not been adjusted to the new telemetry study conducted in the river at the same time. Even though this saved time for both of us, it would have been better when comparing my data to 2015 and for future studies to use the same exact locations as previous years. In addition, evaluating whether the number of stations used in 2019 was a valid representation of the river and thus, comparable to previous datasets, was difficult.

Furthermore, the classification of macroinvertebrates and environmental variables are potential sources of errors. Certain groups of macroinvertebrate species can be difficult to distinguish from one another, and as the identification was conducted mainly by students, this gives room for misidentifications of species. Furthermore, the measuring process of the environmental variables has been done by different people, potentially having interpreted the classification differently.

Lastly, the overall amount of existing and available literature on long-term studies of macroinvertebrates in cold-water river systems in Scandinavia are poor, giving difficulties when researching comparable studies.

4.6 Suggestions for improvement

I recommend continuing the same sampling procedure as in 2019, as this was manageable by one-person waring waders. An improvement would be to include more stations with modified channelization, as there only was one station with this restoration measure represented in 2019. This will give a better and more representative selection of the river to compare the temporal effects of the measures, as well as contributing with a long-term study of macroinvertebrates in cold-water systems. Moreover, I would recommend conducting a survey in another river with similar conditions to use as a reference site when assessing the macroinvertebrate assemblage present in Bognelv.

Furthermore, I would recommend the fish survey to be conducted in the new stations so that the macroinvertebrate studies could benefit from the information gathered in the fish studies in Bognelv. As I found the highest macroinvertebrate densities in stations with the restoration measure pools, it would be interesting to see the density of fish in these stations. Furthermore, pools serve as an important role as nutritional hotspots for fish, so, monitoring the pools and making sure the river holds enough pools to support the fish community would be recommended to continue in the future.

As the taxonomic identification process was conducted mainly by students in 2019 and 2015 and not by experts (however, the species lists were controlled by experts), the number of identified taxa affecting the diversity SW-index might have been misidentified, and therefore, provide misleading results. On the other hand, differences in species could be explained by seasonal changes, so I would recommend conducting the sampling at the same time so, time of year do not influence the samples (Friberg et al., 2013). I assume the identification process was correct for both 2015 and 2019 but recommend following the same procedures to see how the diversity trend evolves, and if possible, I recommend receiving help from experts. Furthermore, the number of stations differed from 2015 and 2019 (56 stations giving 840 m sampled river vs 12 stations giving 600 m sampled river). It might also be questionable whether 12 stations are enough to provide representative data as a river-level scale. As one person conducting the fieldwork and identification process, I found 12 stations to be manageable, so I think fewer stations with longer station length saved time both in the field and at the laboratory is the way to go in future studies in Bognelv. Nonetheless, the number of modified channelization stations could preferably be increased to give a better sample for the river as a whole.

5. Conclusion

My first objective was supported, as I found a higher diversity in 2019 compared to 2015. The macroinvertebrate composition differs slightly, but the general trends of functional feeding groups and habitat preference associated to the river are similar. According to my findings, time and environmental variables associated to PC1 has an essential influence on the macroinvertebrate community and according to my findings the diversity should be expected to follow the typical succession path, resulting in fewer dominating species.

Furthermore, the second objective were not supported as I found several environmental variables to be strongly influential to the macroinvertebrate community. Similar to previous studies in 2015, I found depth and velocity to be of special importance to the macroinvertebrate community composition in Bognelv system.

My third objective were partly supported, as I found differences within the measures and between stations with and without measures. From my findings, I predict that the reason for not observing a bigger difference in diversity between the stations with measures and without, are because the restoration measures are not extreme enough. Meaning the addition of restorations have not successfully increased the heterogeneity in these sections of the river enough.

As I tested the sampling methods used in my study I conclude that sampling one big combined sample was enough for this type of study, but as one want to investigate the macroinvertebrate community at a smaller scale one can possibly fail to detect differences between the replicas.

As freshwater rivers are threatened ecosystems worldwide, and channelization is among the major threats to the habitat loss and degradation globally, the present study provides important insight towards the recovery process of restored systems and the macroinvertebrate respond.

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7. Appendix

Appendix 1 - Coordinates for the selected stations in Bognelv 2019

Station code	Start downstream		End upstream		Measure
	North	East	North	East	
P1	70,01528333	22,30745	70,01481667	22,30753333	Pools
P2	70,00821667	22,32095	70,00783333	22,32091667	Pools
C1	70,0084	22,32126667	70,00801667	22,32126667	Channelization
C2	70,01739196	22,30301698	70,01979296	22,29720999	Channelization
C3	70,00975002	22,31815201	70,009574	22,31932003	Channelization
S1	70,00851667	22,31935	70,00803333	22,3204	Side channel
S2	69,99845	22,32931667	69,99813333	22,32988333	Side channel
S3	70,01778333	22,30261667	70,01736667	22,30325	Side channel
S4	69,9954	22,33223333	69,99501667	22,33295	Side channel
S5	70,01702199	22,30454198	70,01671303	22,30552501	Side channel
S6	70,01594299	22,30667702	70,01554099	22,30618701	Side channel
M1	70,00957299	22,31926203	69,99773498	22,32906701	Modified channelization

Appendix 2 – Macroinvertebrate composition in Bognelv 2019 & 2015

Macroinvertebrate composition in Bognelv 2019

Diptera

Ceratopogonidae *spp*
Chironomidae *spp*
Limoniidae *spp*
Pediciidae *spp*
Psychodidae *spp*
Simuliidae *spp*
Tipulidae *spp*

Ephemeroptera

Baëtidae *Baetis muticus*
Baëtidae *Baetis rhodani*
Ephemerellidae *Ephemerella aurivillii*
Ephemerellidae *Ephemerella mucronata*
Siphlonuridae *Ameletus inopinatus*

Plecoptera

Capnidae *Capnia pygmaea*
Capnidae *Capnia vidua*
Nemouridae *Nemoura cinerea*
Nemouridae *Nemurella pictetii*
Nemouridae *Protonemura meyeri*
Perlodidae *Diura nanseni*
Perlodidae *Diura bicaudate*
Perlodidae *Isoperla difformis*
Perlodidae *Isoperla obscura*
Taeniopterygidae *Taeniopteryx nebulosa*

Trichoptera

Apataniidae *Apatania zonella*
Limnephilidae *Chaetopteryx sahlbergi*
Polycentropodidae *Polycentropus falvomaculatus*
Rhyacophilidae *Rhyacophila nubila*

Other

Collembola *spp*
Dystiscidae *spp*
Enchytraeidae *spp*
Lumbricidae *spp*
Hydrachnidia *spp*

Macroinvertebrate composition in Bognelv 2015

Diptera

Ceratopogonidae spp
Chironomidae spp
Limonidae spp
Pediciidae spp
Simuliidae spp

Ephemeroptera

Baëtidae *Baetis bundyae*
Baëtidae *Baetis muticus*
Baëtidae *Baetis rhodani*
Baëtidae *Centroptilum luteolum*
Ephemerellidae *Ephemerella aurivillii*
Ephemerellidae *Ephemerella mucronata*
Heptageniidae *Heptagenia dalecarlica*
Siphlonuridae *Ameletus inopinatus*
Taeniopterygidae *Taeniopteryx nebulosa*

Plecoptera

Capnidae *Capnia pygmaea*
Capnidae *Capnia vidua*
Chloroperlidae *Xanthoperla apicalis*
Nemouridae *Nemoura cinereal*
Nemouridae *Nemoura viki*
Nemouridae *Protonemura meyeri*
Perlodidae *Arcynopteryx compacta*
Perlidae *Dinocras cephalotes*
Perlodidae *Diura bicaudate*
Perlodidae *Diura nanseni*
Taeniopterygidae *Taeniopteryx nebulosi*
Taeniopterygidae *Brachyptera risi*

Trichoptera

Glossosomatidae *Glossosoma intermedium*
Lepidostomatidae *Lepidostoma hirtum*
Limnephilidae spp
Phryganeidae spp
Rhyacophilidae *Rhyacophila nubile*

Other

Collembola spp
Gammaridae spp
Hemiptera spp
Lumbricidae spp

Appendix 3 - Raw data macroinvertebrates

station	Ceratopogonidae	Chironomidae	Limoniidae	Pediciidae	Psychodidae	Simuliidae	Tipulidae	*B. muticus*	*B. rhodani*	*E. aurivillii*	*E. mucronata*	*A. inopinatus*
P1-0		29		5				4	19			1
P1-25A		57				7		6	28			2
P1-25B		40				14			20			5
P1-25C		43				1			21			
P1-50		36		1					21			2
P2-0		48		1	1	16		2	65		1	
P2-25A		77			1	1		14	35			
P2-25B	3	51		1		7		11	61			
P2-25-C		83		1	2	1		6	47			
P2-50		51						5	63		1	
C1-0	1	103				3			103		1	
C1-25A		26		1		1			40			
C1-25B		23			1	12			30			
C1-25C		23				3			29			
C1-50		33			1	23			70			1
C2-0		26		1				1	27			
C2-25A		20						5	4			
C2-25B		27						3	12		1	
C2-25C	1	30	1	2				4	11			
C2-50	1	20		1		2			41			
C3-0	1	34				14		1	121			
C3-25A		34		1				8	46	1		
C3-25B		8						2	22			
C3-25C		19			1	1		3	73			
C3-50		56		1		32			150	2		
S1-0		20						8	3			2
S1-25A		34						1				
S1-25B		34	1					3				
S1-25C		28						4				
S1-50		67		1				7	3			
S2-0		26		1		11			26	1		
S2-25A	1	33		1		2		7	19			
S2-25B	1	26				7		2	32			
S2-25C		12		1	1	4		2	38	1		
S2-50		13		1	1	15		2	46			
S3-0		21		1		4			10			
S3-25A		46	3	3			1					
S3-25B		49	1	2		1		1				
S3-25C		35										
S3-50		22										
S4-0		4				2		18	12			
S4-25A		6		4		4			2			
S4-25B		9				12		1	4			
S4-25C		17		1	3	22		1	3			
S4-50		16		1	1	3		2	5			
S5-0		33				4	1	2	108		2	
S5-25A		26		2					10			
S5-25B		13	1	4	2				10			
S5-25C		12				1			9			
S5-50	1	33		3					7			
S6-0		13	1		1				33	1		
S6-25A		38	1			2		3	42	1		
S6-25B		17			5			1	48	1		
S6-25C		4							53			
S6-50		28		2	3			1	15			
M-0		18				1		5	87			
M-25A		30		2		10		1	79			
M-25B		10						1	27			
M-25C		19		1		5		2	93			
M-50		40		1		3		3	297	1		

station	*C. pygmaea*	*C. vidua*	*N. cinerea*	*N. pictetii*	*P. meyeri*	*D. nanseni*	*D. bicaudata*	*I. difformis*	*I. obscura*	*T. nebulosa*
P1-0		14	13			7				1
P1-25A	19	6	20							
P1-25B	5	6	9	1						
P1-25C	8	1	8	1						
P1-50	56	17	3			6				6
P2-0	20		27	1		5				
P2-25A	17	4	5			2				
P2-25B	55	10	29	1		1				1
P2-25-C	22	8	22							
P2-50	25	3	5	1		2				
C1-0	106	16	8			10				5
C1-25A	21		7	1		2				2
C1-25B	12	5	25	1	1	1		1		1
C1-25C	10	8	18	2		1				
C1-50	43	10	39	5		3				
C2-0	31	5				13				3
C2-25A	8					4				
C2-25B	22	3	1			9				3
C2-25C	25	3				5				1
C2-50	12	5	1	1		15				2
C3-0	63	5	13	2	1	4				5
C3-25A	65	7	1			4				4
C3-25B	19	2	1			1				1
C3-25C	21	9	2	1		4				
C3-50	52	4	14	4		9	1			5
S1-0	6	4				1				
S1-25A	3	1								
S1-25B		4	1							
S1-25C	11	3								1
S1-50	18	4				7				2
S2-0	15	4	6	3	1	3				4
S2-25A	13	7	6			2				3
S2-25B	19	7	5	2	2	3				3
S2-25C	17	2	7	2		1				4
S2-50	22	6	17	5		3				1
S3-0										
S3-25A	3									
S3-25B	8									
S3-25C	4									
S3-50	1									
S4-0	41		3	1		3	1	1		7
S4-25A	22	3	2			1				
S4-25B	17		2			1		1		1
S4-25C	18	3	4							2
S4-50	49	11	15			8		1		2
S5-0	33	11	20			10			1	3
S5-25A	41	7	3			1				
S5-25B	40	15	8		1	1				3
S5-25C	52	8	6			5				2
S5-50	14									
S6-0	18	5	2	1		11				4
S6-25A	31	5	4			3				1
S6-25B	23	5	7			10		1		
S6-25C	8	2	6			7				
S6-50	9	1				7				1
M-0	26	11	2	1		7				1
M-25A	14	5	13	1		3				
M-25B	14	4	1			1				
M-25C	11	3	3	3		4				
M-50	45	9	31	5	2	5		2		5

station	*A. zonella*	*C. sahlbergi*	*P. flavomaculates*	*R. nubila*	Collembola	Dytiscidae	Enchytraeidae	Lumbricidae	Hydrachnidia
P1-0	110						2		
P1-25A	36	3		1					
P1-25B	9			3					
P1-25C	65								
P1-50	31			10					
P2-0	35			16					
P2-25A	19			1					
P2-25B	58			4			4		
P2-25-C	23			5					
P2-50	69			2					
C1-0	25			8			1		
C1-25A	26	1		5					
C1-25B	23			6			1		
C1-25C	2								
C1-50	17			7					
C2-0	64			5			2		
C2-25A	20	1		1			1		
C2-25B	39			3			1		
C2-25C	53	2	1	4			1	1	
C2-50	18			13					
C3-0	3			3					
C3-25A	9								
C3-25B	22								
C3-25C	9			1					
C3-50	7			8			1		
S1-0	34						2		
S1-25A	31							1	
S1-25B	15				1				1
S1-25C	98						2		
S1-50	39	1					1	2	
S2-0	1			1					
S2-25A	3	1							
S2-25B	3			3					
S2-25C	6			1			2	1	
S2-50	8			4					
S3-0	8			1			1	3	
S3-25A		3		1			1		
S3-25B	1					1		2	
S3-25C							1	4	
S3-50	2							1	
S4-0	7	1		1			1	1	
S4-25A	3								
S4-25B	2								
S4-25C	5								
S4-50	1								
S5-0	42	4		3			3		
S5-25A	55	1					7	1	
S5-25B	38	5	1				9	2	
S5-25C	29	2		1			3	6	
S5-50	10						1		
S6-0	46			3			1	1	
S6-25A	5			1					
S6-25B	12			5			2		
S6-25C	29			1			3	1	
S6-50	5			3			4	1	
M-0	55				1				
M-25A				3					
M-25B	3								
M-25C				4					
M-50	17			7					

Appendix 4 – Raw data environmental variables

station	width	depth.10	depth.25	depth.50	depth.75	depth.90	velocity	moss	algae	cover.water
P1-0	2	22	22	19	22	28	0,05	16	50	80
P1-25A	2	3	7	20	15	31	0,35	16	16	90
P1-25B	2	3	7	20	15	31	0,35	50	50	100
P1-25C	2	3	7	20	15	31	0,35	16	16	90
P1-50	2	21	26	30	32	38	0,15	16	16	100
P2-0	2	31	33	45	31	40	0,45	16	16	5
P2-25A	2	4	18	22	25	26	0,35	16	16	5
P2-25B	2	4	18	22	25	26	0,35	50	16	5
P2-25-C	2	4	18	22	25	26	0,35	16	16	0
P2-50	2	25	30	43	60	55	0,18	16	16	0
C1-0	2	5	5	10	15	20	0,3	16	16	0
C1-25A	2	30	45	30	40	40	0,4	0	50	0
C1-25B	2	30	45	30	40	40	0,4	0	50	5
C1-25C	2	30	45	30	40	40	0,4	0	16	0
C1-50	2	10	25	50	40	45	0,5	0	50	50
C2-0	4	10	18	23	28	35	0,05	0	16	0
C2-25A	4	5	15	20	30	40	0,05	0	0	0
C2-25B	4	5	15	20	30	40	0,05	0	50	0
C2-25C	4	5	15	20	30	40	0,05	0	16	0
C2-50	4	12	20	20	30	30	0,2	0	50	0
C3-0	5	30	30	25	25	12	0,05	50	50	0
C3-25A	5	10	12	20	22	30	0,05	0	16	0
C3-25B	5	10	12	20	22	30	0,05	16	16	0
C3-25C	5	10	12	20	22	30	0,05	16	16	0
C3-50	5	5	20	30	45	45	0,2	16	16	0
S1-0	2,5	46	69	80	68	38	0,12	50	16	30
S1-25A	3,2	42	60	78	62	36	0,22	16	16	10
S1-25B	3,2	42	60	78	62	36	0,22	16	16	10
S1-25C	3,2	42	60	78	62	36	0,22	0	50	10
S1-50	3	21	50	65	65	42	0,24	16	0	5
S2-0	2	35	30	35	22	20	0,5	0	16	30
S2-25A	2	20	30	30	15	5	0,3	0	16	10
S2-25B	2	20	30	30	15	5	0,3	0	16	5
S2-25C	2	20	30	30	15	5	0,3	16	16	0
S2-50	2	10	20	25	30	30	0,5	0	16	0
S3-0	2,8	8	15	21	17	10	0,08	16	16	80
S3-25A	2,8	15	35	40	32	10	0,04	16	50	10
S3-25B	2,8	15	35	40	32	10	0,04	0	16	40
S3-25C	2,8	15	35	40	32	10	0,04	0	16	30
S3-50	2,2	29	41	60	65	19	0,1	16	16	40
S4-0	2	5	10	15	10	10	0,35	16	16	90
S4-25A	2	5	10	15	5	5	0,1	16	16	90
S4-25B	2	5	10	15	5	5	0,1	16	50	70
S4-25C	2	5	10	15	5	5	0,1	16	50	80
S4-50	2	5	25	25	30	30	0,4	16	16	40
S5-0	2	2	4	5	5	2	0,1	50	0	10
S5-25A	2,3	3	8	10	6	4	0,1	16	16	10
S5-25B	2,3	3	8	10	6	4	0,1	50	16	5
S5-25C	2,3	3	8	10	6	4	0,1	50	16	10
S5-50	2,1	8	20	23	18	15	0,1	16	16	10
S6-0	3	10	20	30	30	15	0,1	16	16	20
S6-25A	4	5	20	25	30	20	0,1	16	16	20
S6-25B	4	5	20	25	30	20	0,1	16	16	30
S6-25C	4	5	20	25	30	20	0,1	0	16	20
S6-50	4	10	30	30	20	15	0,1	0	50	50
M-0	4	30	30	20	10	10	0,2	16	16	0
M-25A	4	30	30	20	25	5	0,3	16	16	0
M-25B	4	30	30	20	25	5	0,3	16	50	0
M-25C	4	30	30	20	25	5	0,3	16	16	0
M-50	4	10	20	40	50	15	0,3	0	16	0

station	cover.flom	sub.2	sub.20	sub.100	sub.250	sub.300	mean.sub	mean.depth	dead.wood	pools	measure
P1-0	83	10	10	70	10	0	60,7	0,226	6,33	1	P
P1-25A	12	5	10	20	5	60	396,9	0,152	6,33	1	P
P1-25B	12	5	10	20	5	60	396,9	0,152	6,33	1	P
P1-25C	33	5	10	20	5	60	396,9	0,152	6,33	1	P
P1-50	12	30	30	20	15	5	73,1	0,294	6,33	1	P
P2-0	33	0	5	15	50	30	284,55	0,36	0	1,33	P
P2-25A	12	0	5	35	35	20	207,8	0,19	0	1,33	P
P2-25B	0	0	5	35	35	20	207,8	0,19	0	1,33	P
P2-25-C	0	0	5	35	35	20	207,8	0,19	0	1,33	P
P2-50	12	0	5	10	30	55	402,8	0,426	0	1,33	P
C1-0	12	5	10	70	15	0	69,4	0,11	0	0	C
C1-25A	12	15	0	10	45	0	84,9	0,37	0	0	C
C1-25B	83	15	0	10	45	0	84,9	0,37	0	0	C
C1-25C	12	15	0	10	45	0	84,9	0,37	0	0	C
C1-50	33	20	20	20	20	20	174,4	0,34	0	0	C
C2-0	12	5	5	20	50	20	225,1	0,228	0	0	C
C2-25A	33	30	20	30	20	0	55,5	0,22	0	0	C
C2-25B	33	30	20	30	20	0	55,5	0,22	0	0	C
C2-25C	33	30	20	30	20	0	55,5	0,22	0	0	C
C2-50	12	5	5	20	50	20	225,1	0,224	0	0	C
C3-0	12	5	5	60	20	10	134,1	0,244	0	0	C
C3-25A	12	5	20	30	45	20	224	0,188	0	0	C
C3-25B	33	5	20	30	45	20	224	0,188	0	0	C
C3-25C	12	5	20	30	45	20	224	0,188	0	0	C
C3-50	12	0	5	30	50	15	199,8	0,29	0	0	C
S1-0	12	5	10	60	20	5	103,4	0,602	16,67	0,33	S
S1-25A	33	5	10	20	45	20	216,9	0,556	16,67	0,33	S
S1-25B	33	5	10	20	45	20	216,9	0,556	16,67	0,33	S
S1-25C	33	5	10	20	45	20	216,9	0,556	16,67	0,33	S
S1-50	12	5	10	40	20	25	216,4	0,486	16,67	0,33	S
S2-0	33	0	10	40	40	10	157,6	0,284	0,33	0,33	S
S2-25A	33	5	30	40	20	5	93,6	0,2	0,33	0,33	S
S2-25B	63	5	30	40	20	5	93,6	0,2	0,33	0,33	S
S2-25C	12	5	30	40	20	5	93,6	0,2	0,33	0,33	S
S2-50	12	0	10	30	70	0	141,6	0,23	0,33	0,33	S
S3-0	33	5	15	20	10	50	343,7	0,142	21,67	1	S
S3-25A	33	30	30	20	20	0	50,6	0,264	21,67	1	S
S3-25B	33	30	30	20	20	0	50,6	0,264	21,67	1	S
S3-25C	33	30	30	20	20	0	50,6	0,264	21,67	1	S
S3-50	33	40	30	20	10	0	33,2	0,428	21,67	1	S
S4-0	83	10	60	10	20	0	47,7	0,1	10,33	0,33	S
S4-25A	12	0	10	60	30	0	89,6	0,08	10,33	0,33	S
S4-25B	12	0	10	60	30	0	89,6	0,08	10,33	0,33	S
S4-25C	12	0	10	60	30	0	89,6	0,08	10,33	0,33	S
S4-50	12	20	30	50	0	0	33,5	0,23	10,33	0,33	S
S5-0	63	10	10	20	50	10	163,2	0,036	0,33	0	S
S5-25A	12	30	20	30	20	0	55,5	0,062	0,33	0	S
S5-25B	12	30	20	30	20	0	55,5	0,062	0,33	0	S
S5-25C	12	30	20	30	20	0	55,5	0,062	0,33	0	S
S5-50	12	8	20	23	18	15	141,33	0,168	0,33	0	S
S6-0	12	0	10	40	50	0	112,6	0,21	0,33	2	S
S6-25A	33	5	0	40	45	10	165,3	0,2	0,33	2	S
S6-25B	33	5	0	40	45	10	165,3	0,2	0,33	2	S
S6-25C	12	5	0	40	45	10	165,3	0,2	0,33	2	S
S6-50	33	20	30	50	0	0	33,5	0,21	0,33	2	S
M-0	12	10	20	30	30	10	135,3	0,2	0	0	M
M-25A	63	5	10	35	40	10	154,65	0,22	0	0	M
M-25B	12	5	10	35	40	10	154,65	0,22	0	0	M
M-25C	12	5	10	35	40	10	154,65	0,22	0	0	M
M-50	12	0	5	5	40	50	386,05	0,27	0	0	M

Appendix 5 – Photographs of each of the 12 stations in Bognelv. The pictures represent each of the three substations (0 m, 25 m & 50 m) moving downstream to upstream.

Station P1 0-meter substation

Station P1 25-meter substation

Station P1 50-meter substation

Station P2 0-meter substation

Station P2 25-meter substation

Station P2 50-meter substation

Station C1 0-meter substation

Station C1 25-meter substation

Station C1 50-meter substation

Station C2 0-meter substation

Station C2 25-meter substation

Station C2 50-meter substation

Station C3 0-meter substation

Station C3 25-meter substation

Station C3 50-meter substation

Station S1 0-meter substation

Station S1 25-meter substation

Station S1 50-meter substation

Station S2 0-meter substation

Station S2 25-meter substation

Station S2 50-meter substation

Station S3 0-meter substation

Station S3 25-meter substation

Station S3 50-meter substation

Station S4 0-meter substation

Station S4 25-meter substation

Station S4 50-meter substation

Station S5 0-meter substation

Station S5 25-meter substation

Station S5 50-meter substation

Station S6 0-meter substation

Station S6 25-meter substation

Station S6 50-meter substation

Station M 0-meter substation

Station M 25-meter substation

Station M 50-meter substation

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