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Exploring the interplay: Assessing the impact of in-stream and riparian conditions on the abundance and diversity of aquatic insects

Kåre-Jørgen Ingerø Bøe
Master in ecology

Preface

This thesis is the result of two inspirational years at NMBU, consisting of the accumulation of knowledge, friendships, and acquaintances. All have inspired me during the process of writing my 60 credit master's thesis in ecology at the Faculty of Environmental Sciences and Natural Resource Management (MINA) at the Norwegian University of Life Sciences (NMBU). The thesis reflects themes and study questions that have been guidelines of my main interests within ecology, and I am proud of the result.

I am also proud of those who have helped me along the process. It is scary to start mentioning someone, because you may then forget others. However, there are three fundamental people that deserve extra credit: Jonathan Edward Colman, Jon Museth, and Mathias Brink Kjeldgaard. It has been a dream of mine to write my master's thesis within a larger research project in collaboration with well-known research institutions. I contacted Jon Museth at the Norwegian Institute of Nature Research (NINA), and he made that dream come true when he introduced me to "SABICAS". This is an ongoing research project working with nature-based solutions in stream ecosystems (Hairabedian, 2020). I also met Mathias Brink Kjeldgaard, who is working on a PhD within the Norwegian Institute of Water Research (NIVA) and "SABICAS". Together, we defined the baseline of my master's thesis as a part of "SABICAS". I contacted Jonathan Edward Colman and asked him to be my supervisor from NMBU, which he nicely agreed to. We have been functioning great as a team, and it has always been clear what I could expect from them, and what they have could expect from me. I have greatly appreciated this. Another thing I have greatly appreciated, is the major contribution from professor Thrond Haugen with the statistics in this thesis.

There are additionally three fellow students that deserve extra credit: Emma Helen Berg, Olvar Skagseth, and Ole Eivind Fjeldstad. Since before the start of fieldwork and until delivery, we have had weekly contact, discussing everything from large fundamental concerns, to smaller details about each other's thesis. There are of course other friends and family members that deserve an extra credit who are not mentioned by name here. I hope they know who they are.

NMBU (13.05.2024)

Kåre-Jørgen Ingerø Bøe

Abstract

The intensification of agriculture and forestry the last decades have caused extensive degradation in freshwater ecosystems, primarily through morphological, physical, and chemical impacts stemming from practices like monocultural farming and clear-cutting in forestry. The riparian ecotones regulate the transmission of materials and energy between aquatic and terrestrial ecosystems. The aim of this study was to: 1) Identify environmental factors that best explain the in-stream habitat and the riparian condition in the streams included in this study, and 2) Identify the effect of these environmental factors on the abundance and diversity of aquatic insects within the same streams. Aquatic insects were collected with emergence traps at 15 different sampling sites during June, July, and at the beginning of August 2023 in Haldenvassdraget, South-East Norway. The amount of maturing riparian vegetation and woody components in-stream best explained the condition of riparian ecotones. However, the effects of these were two-fold, as the abundance of aquatic insects increased but the diversity decreased with increasing amounts of maturing vegetation and woody components. From a management perspective, these results highlight the importance of environmental factors, and the consideration of how they influence each other, along with the effect they have on living organisms within habitats.

Sammendrag

En intensivering av både jordbruk og skogbruk i moderne tid har fått store konsekvenser for akvatiske økosystemer, gjennom morfologiske, kjemiske og fysiske endringer. Endringene stammer fra blant annet monokultur i jordbruket og flatehogst i skogbruket. Utveksling av masser og energi mellom akvatiske økosystemer og tilgrensende økosystemer reguleres av kantsoner. Hensikten med denne studien var å: 1) Identifisere miljøfaktorer som best forklarer tilstanden til ferskvannshabitatet og kantsonen i et ferskvanns økosystem, og 2) Påvise effekten disse miljøfaktorene har på både forekomst og diversitet av akvatiske innsekter i samme økosystem. Akvatiske innsekter ble samlet ved bruk av såkalte «emergence traps» på 15 forskjellige stasjoner i juni, juli, og begynnelsen av august 2023 i Haldenvassdraget Sørøst-Norge. Det var mengden av aldrende kantvegetasjon og andre ved dannende elementer som best forklarte tilstanden til både ferskvanns habitatene og kantsonene. Effekten disse miljøfaktorene hadde på forekomst og diversitet av akvatiske innsekter i det samme ferskvanns økosystemet var todelt: Det var en økende forekomst av akvatiske innsekter relatert til tilstedeværelse av nevnte miljøfaktorer, mens diversiteten av akvatiske innsekter viste seg å relatere negativt til de samme nevnte miljøfaktorene. I et forvaltnings perspektiv påpeker disse resultatene viktigheten av miljøfaktorer, hvordan disse påvirker hverandre og effekten disse har på levende organismer i habitatet.

Table of content

Introduction

There are multiple causes of loss of biodiversity (McNeely, 1992). Most important are habitat loss and habitat degradation (Hanski, 2011). The global human population is increasing, resulting in natural habitats being replaced by industry and infrastructure, or converted into simpler ecosystems, like agricultural land and plantations (Meyer & Turner, 1992). Even small-scale changes in the landscape may cause large-scale ecological changes within an ecosystem (Framstad et al., 2018). Freshwater ecosystems are among the most altered ecosystems on earth. Land-use changes cause morphological, physical, and chemical impacts in streams and lakes (Carpenter et al., 2011). There are pressing concerns about these impacts, as biodiversity is vanishing at a rate unseen the past 60 million years (Wilson, 1989). These are concerns that have resulted in international agreements to preserve biodiversity and restore habitats (Pedersen, 2021). Ecological restoration is the practice of re-starting natural processes to recreate ecological functions within ecosystems (Halleraker, 2023). Nature-based solutions are often utilized when restoring freshwater ecosystems, as they are often considered long term and cost-effective (Keesstra et al., 2018). Nature-based solutions work with ecological functions within ecosystems, rather than human-made engineering, to solve challenges such as biodiversity loss (Seddon et al., 2020).

Riparian zones are frequently targeted for ecological restoration as nature-based solutions against biodiversity loss (Štrbac et al., 2023). Riparian zones consists of an ecotone - a transition between an aquatic and a terrestrial ecosystem (Turner et al., 2003). The riparian ecotone can therefore often be seen as a linear habitat-strip that differs from the surrounding matrix (Honnay et al., 2002). Riparian ecotones often function as habitats for many species, causing the potential for high biodiversity when being conserved and maintained (Johansson et al., 2013). Riparian ecotones are interesting in an ecological point of view, as they includes ecological processes from both aquatic and terrestrial ecosystems, and how they influence each other (Nieswand et al., 1990).

At the transition between terrestrial and aquatic ecosystems, the vegetation and its roots often function as nature-based solution to reinforce the soil and hinder erosion (Hubble et al., 2010). The ecotone itself regulates the transmission of energy and materials between both ecosystems (Pusey & Arthington, 2003). The riparian vegetation also has an effect on the relationship between light and shade in streams (Davies-Colley & Rutherford, 2005), which

again has an impact on the in-stream temperature (Bowler et al., 2012). These factors further have an effect on in-stream photosynthesis (Davies-Colley & Rutherford, 2005), nutrient availability (Pettit & Naiman, 2007), and defines the niches for the living organisms are the potentially most suited to live there (Naiman & Decamps, 1997).

The existence of riparian vegetation has been found to increase the number of aquatic insects within the EPT fauna (*Ephemeroptera, Plecoptera, and Trichoptera*). However, it has also been shown to decrease the diversity of species (Stewart et al., 2001). The same study indicated an increase in diversity of aquatic insects within the EPT fauna when the riparian vegetation was fragmented or absent (Stewart et al., 2001). Importantly, what characterizes the optimal riparian ecotone? Are there additional factors (other than the riparian vegetation) that affect living organisms in-stream? This study aimed to pinpoint environmental factors that best explained the condition of riparian zones, as well as their impact on the abundance and diversity of aquatic insects. Such findings may contribute valuable insight leading to more effective management or restoration projects, enabling utilization of ecological methods to conserve biodiversity.

As a part of the "SABICAS" project, in cooperation with the Norwegian Institute of Water Research (NIVA) and Norwegian Institute of Nature Research (NINA) (Hairabedian, 2020), habitat assessments were performed both for in-stream habitats and for the riparian zones. The assessments intended to register environmental factors within riparian ecotones at 15 different tributaries associated with the watershed in Halden (Haldenvassdraget). The watershed is nutrient and biodiversity rich. It is located in South-East Norway, surrounded by forest areas, peatlands, and agricultural land (Askheim, 2023). The main river was partly channelized and has been affected by human activity since the mid 1800´s, resulting in varying condition of riparian ecotones along the main stretches of the river (NVE, 2009). It was the varying conditions that made it suitable for comparative studies. Aquatic insects were chosen as bioindicators for the effect of in-stream and riparian condition on living organisms in streams in this study.

Bioindicators involve biological processes, species, or communities that will react to changes in their environment (Holt & Miller, 2011). Insects are often good bioindicators, with their small body sizes and short life cycles. As such, they are expected to respond rapidly to environmental changes (Barman & Gupta, 2015). Therefore, during the summer season of 2023, emergence traps were used to collect aquatic insects in the 15 tributaries (Figure 23, Appendix). I investigated how the abundance and diversity of aquatic insects vary with the environmental factors within the riparian ecotones in Halden. The level of biodiversity could then be compared to environmental factors in the riparian ecotones found along degraded and intact sections of the watershed. This provided insight into defining future goals for management of freshwater ecosystems and restoration of riparian zones.

Research questions and hypothesis

- What are the environmental factors that define the optimal in-stream habitat condition, and how is the abundance and diversity of aquatic insects affected by these?

    - H_0: Substrate composition and woody components causing various in-stream mesohabitats are positively correlated with the abundance and diversity of aquatic insects.
    - H_1: Substrate composition and woody components causing various in-stream mesohabitats are negatively correlated with the abundance and diversity of aquatic insects.

- What are the environmental factors that define the optimal riparian condition, and how is the abundance and diversity of aquatic insects affected by these?

    - H_0: Increasing amounts of maturing riparian vegetation are positively correlated with the abundance and diversity of aquatic insects.
    - H_1: Increasing amounts of maturing riparian vegetation are negatively correlated with the abundance and diversity of aquatic insects.

Material and methods

Study area

Haldenvassdraget (Figure 1) is a watershed consisting of many large lakes with small rivers in-between (Haande et al., 2014). The main source is at 268 m a.s.l (Dragsjøhaugen), and the outlet in the sea is 132 km downstream in Iddefjorden in Halden, South-East Norway (Askheim, 2023). The catchment area is 1584 km^2 (Figure 1) (Hairabedian, 2020), characterized by large forest areas, peatlands, and agricultural land surrounded by some small urban areas (Haande et al., 2014). The watershed and its catchment area has been affected by human activity for hundreds of years (Haande et al., 2014). It was partly channelized during the period 1850-1870 (NVE, 2009) to facilitate timber floating, shipping traffic, and as a source of energy for grain mills (Haande et al., 2014). Today, these installations are mainly used for tourism, and some of the installations are still producing electro power (NVE, 2009). The watershed has been protected against further hydropower development since 1973, in order to preserve cultural heritage and biodiversity (Askheim, 2023). The catchment of the watershed is a case area in the ongoing research project "SABICAS" (www.sabicas.no) (Hairabedian, 2020).

The watershed is both nutrient and biodiversity rich because of its distinctive location and the characteristics of its catchment area (Haande et al., 2014). Due to the good opportunities for immigration after the last ice age, nearly all freshwater fish species recorded in Norway are present in the watershed (Haande et al., 2014). Insects within the EPT fauna thrive in partly human modified watersheds (Ligeiro et al., 2013), and under the climatic conditions with the characteristics of the watershed in Halden. Furthermore, these serve as a food source for fish (Pettersen et al., 2023)

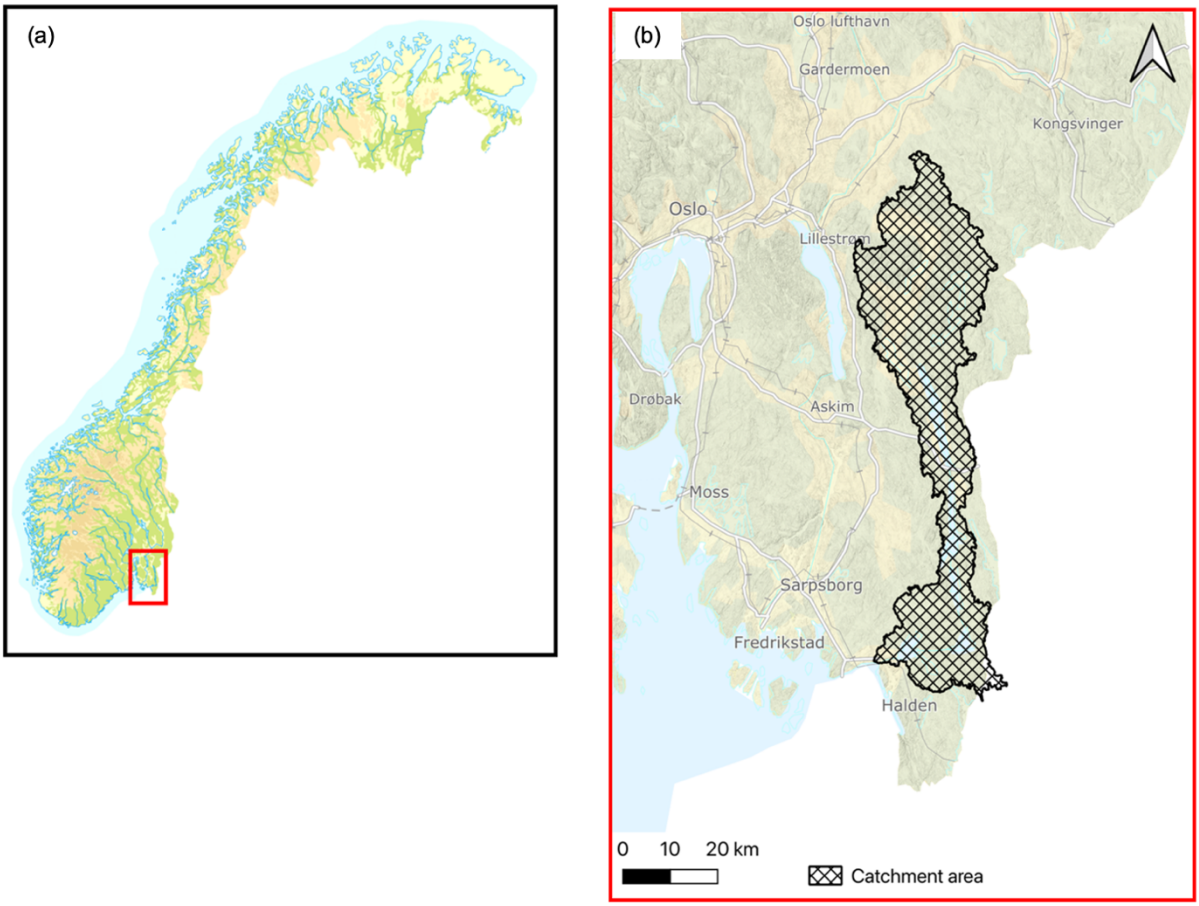

Figure 1. Location in Norway (a) and the catchment area of Haldenvassdraget (b) (produced in QGIS (3.34.1-Prizern) with maps from GEONORGE: https://kartkatalog.geonorge.no/metadata/norges-grunnkart-wms/8ecaa2d5-8b0a-46cf-a2a7-2584f78b12e2.).

Study system

Sampling sites

I sampled 15 sites in Haldenvassdraget (Figure 2), and most of them were sampled twice. The sampling sites were small wadable tributaries with varying states of riparian vegetation. The sites covered varying morphology and riparian conditions. Eight sites were characterized by more favorable riparian conditions than the last seven ones. They were therefore sampled pairwise: One site with favorable riparian conditions and one of less favorable conditions. Riparian conditions were mainly determined by the riparian vegetation, described in more detail below.

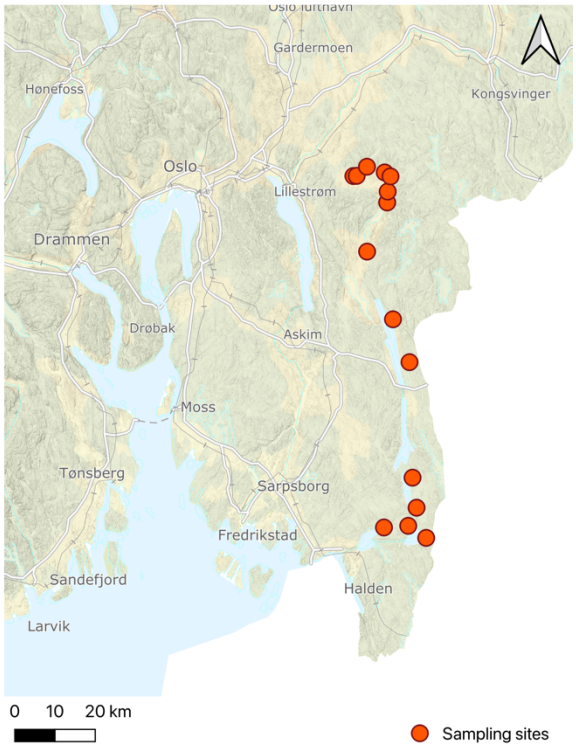

Figure 2. The study area with the sampling sites marked in red, (produced in QGIS (3.34.1-Prizern) with maps from GEONORGE: https://kartkatalog.geonorge.no/metadata/norges-grunnkart-wms/8ecaa2d5-8b0a-46cf-a2a7-2584f78b12e2.).

Emergence traps

The sites were sampled by emergence traps (Figure 3), a simple, economic, and efficient method for gathering aquatic insects in research projects (Cadmus et al., 2016). It is a pyramid shaped floating device, floating on the surface of rivers and lakes, capturing emerging insects (Figure 3) (Cadmus et al., 2016). They are designed to catch insects as they develop into their adult stage, where they "emerge" from the waterbody (Thorp & Rogers, 2015). The insects will crawl up on a rock, stick, or a water plant, before they emerge (Thorp & Rogers, 2015), making it advantageous to position the emergence trap atop of such features (Figure 3).

Figure 3. An emergence trap floating on the surface of a sampling site included in this study, photo: Kåre-Jørgen Ingerø Bøe.

Deployment of emergence traps

The sampling sites were sampled two at a time. There were sets of four emergence traps per sampling site. The aquatic insects were collected in the same period, under the same climatic conditions, but under different in-stream habitats and riparian conditions in different sites. The goal was to sample every sampling site twice. The sets of four emergence traps were switched between the first and second visit to ensure that every trap was used at each site. Each sampling site had a temperature logger in the center (Figure 4c). Two emergence traps were deployed at 10-meter intervals below and above the logger, respectively (Figure 4a & b).

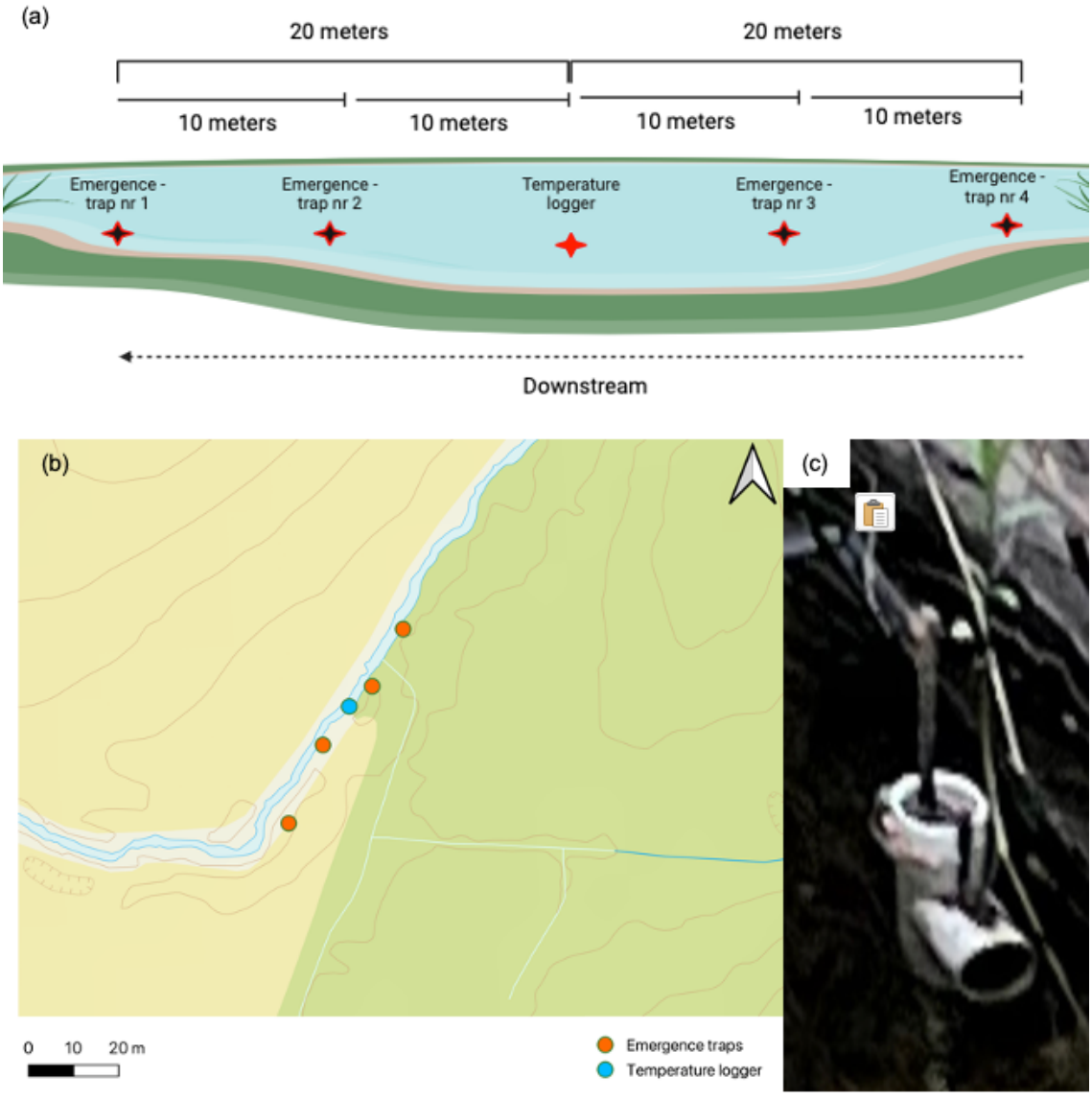

Figure 4. Illustration of how the emergence traps were deployed (a & b) in either direction of the temperature logger (c) during fieldwork for this study, made in BioRender.com.

Emptying emergence traps

The emergence traps were emptied every 4-5 days. The literature recommends every 3-5 days to avoid degradation of samples (McCauley, 1976). All equipment was disinfected between visits at different sampling sites to avoid spreading of diseases, such as crayfish plague (Johnsen & Vrålstad, 2009).

The process of emptying the emergence traps began with removing the bottle on the trap and transferring the insects into labeled glass containers marked with date, name/number of the sampling site, and number of the emergence trap (Figure 5a). Subsequently, these glasses were then frozen, typically within a few hours. Unlike the conventional methods of preserving the insects in lab alcohol for conservation (Grootaert et al., 2010), freezing the containers was preferred. This reduced costs and prevented damaging samples caused by alcohol, inhibiting future use of samples for other purposes within the "SABICAS" project (e.g. analysis of stable isotopes).

After a minimum of one hour in the freezer, the insects in the containers were dead and could be counted and identified. Subsequently, one individual of specie per sampling site was extracted and transferred in a smaller container (Figure 5b) filled with 70% alcohol for further identification in the laboratory.

Figure 5. Glasses used when emptying emergence traps (a) and conserving one individual of each species per sampling site in a container filled with 70% alcohol (b) for further identification in lab.

Study species

There are many insect species with common traits like small body sizes and short life cycles (Semb-Johansson, P. S. O. A., 2022). These traits characterize suitable functional bioindicators (Barman & Gupta, 2015). Mainly aquatic insects, like mayflies (*Ephemeroptera*), caddisflies (*Trichoptera*), and stoneflies (*Plecoptera*), were expected to be caught in the emergence traps during fieldwork.

Mayflies are among the oldest insect orders, mainly existing in standing or running freshwater habitats (Sartori & Brittain, 2015). The order consists of approximately 3000 species grouped into 37 families worldwide (Dominguez, 2006). Mayflies are registered all over Norway with 48 identified species (Semb-Johansson, A., 2022). Their life cycle starts as larvae for 1-3 years, before the first winged stage called subimago (Sartori & Brittain, 2015). The cycle ends in the mature stage called imago (Allen, 1965). Their winged life cycle lasts only a couple of days, and in this stage they emerge from the stream to reproduce (Semb-Johansson, A., 2022).

Caddisflies live in the same habitat type as the mayflies. They consist of 6000 species worldwide, where 195 of them are recorded in Norway (Ottesen, 2021). They are widely distributed all over the world, also in Norway, and they are often numerous and dominant in their habitats (Morse, 2009). Their life cycle starts as larvae for 1-2 years (Ulfstrand, 1968). At this stage, most of the species build their own portable houses of different plant materials (Ottesen, 2021). When caddisflies reach the mature stage of the life cycle, they emerge to continue their life cycle on land (Holzenthal et al., 2015).

Stoneflies also live in the same habitat types as the two other orders, with 4000 species worldwide. 35 of them are registered all over in Norway (Kringstad, 2022). Their life cycle starts as larvae for 1-4 years, before they emerge to continue their life cycle in the riparian zone of rivers and lakes (Hynes, 1976).

Insect identification

The aquatic insects were identified to family by studying morphological characteristics like body segmentation or coloration patterns through a LEICA MS5 magnifier (Figure 6a). An identification protocol (Figure 6a) outlined distinct morphological characteristics unique to each family within the insect orders. For example, whether the caddisflies had simple eyes or not (Figure 9c & d) (Pål Krogvold, 2015).

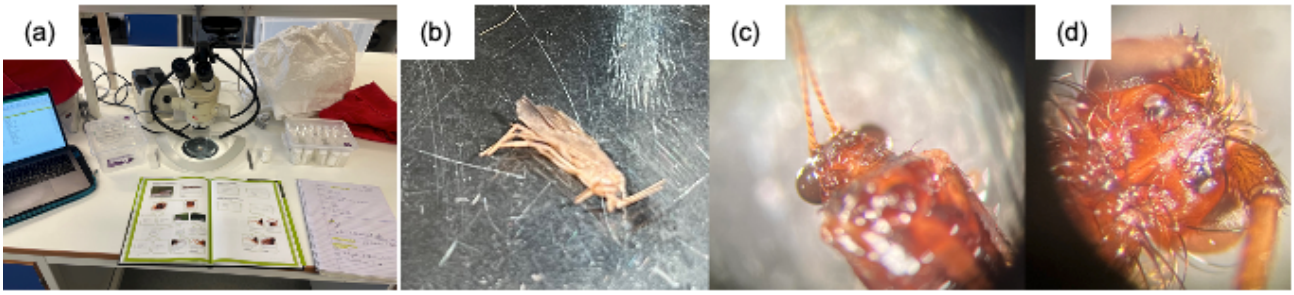

Figure 6. Insect identification in the laboratory. The LEICA MS5 magnifier (a) was used together with an identification protocol (a) to study morphological features (b, c, and d) to identify the insects to family.

Dataset

The data were plotted in Excel (version 16.78) for further analysis. Evaluation of both in-stream habitat and riparian conditions were based on the assessment protocol from Jon. S Harding 2009 (Harding, 2009), and registered by Mathias Brink Kjeldgaard in this study (Figure 7).

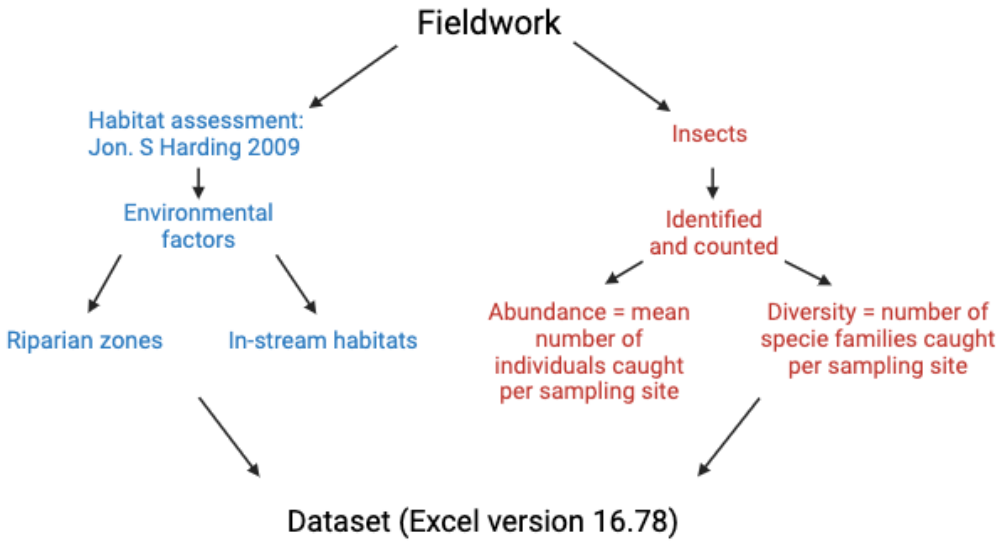

Figure 7. Illustration of dataset: from fieldwork until plotted in Excel (version 16.87), made in BioRender.com.

In-stream habitat condition

Variables registered for the evaluation of in-stream habitat condition was the “width” and “depth” of the sampling sites (Figure 8). Each sampling site was 50 meters long (I trawled within 40 of them as described above), and the “width” was registered at the beginning of the site, at 12.5 meters, at 25 meters, at 37.5 meters, and at the end of each sampling site (Figure 8a). The same positions were used to measure the site “depth” at 0, 25, 50, 75, and 100% of the site “width” (Figure 8b). The mean values of these measures were calculated as the mean site “width” and mean site “depth”. These values were used in later analysis. Further variables include woody components like percentage of “woody substrate”, number of “debris dams” larger than 0,3 m^3, and the number of “dead wood” larger than 10 centimeters in diameter per sampling site. Distribution between “emerged macrophytes” and “submerged macrophytes” were registered in percent. The geometric mean for each particle size within the substrate composition were used to calculate a “Fredle index” to gather the effect of substrate within one variable. If a habitat consists of only one particle size, the Fredle index equals the geometric mean of the particle size. A great score on the Fredle index means variation of particle sizes within the substrate composition (Sowden & Power, 1985).

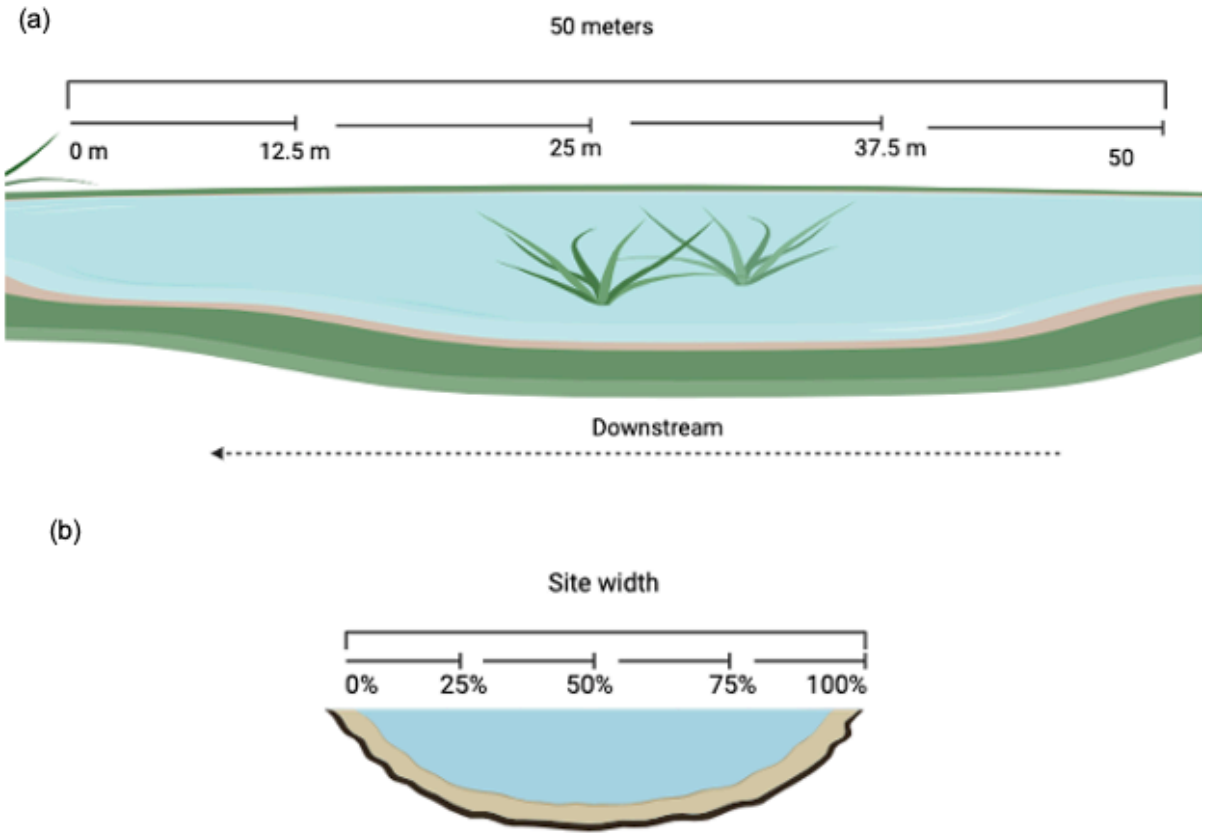

Figure 8. Illustration of measured site “width” at the beginning, 12.5, 25, 37.5 meters, and at the end of each sampling site (a). The same positions were utilized to measure the site “depth” at 0, 25, 50, 75, and 100% of the site “width” (b). Made in BioRender.com.

Riparian condition

The different variables describing the riparian condition were registered on a score from one to five for each side of the sampling sites (Table 1), seen from the beginning of the station facing upstream. “Shading” was measured in percent of canopy cover by riparian vegetation (Table 1) for each side of the sampling sites at the same positions as the widths and depths were measured (Figure 8). “Buffer width”, “bank stability”, denitrification potential of the “riparian soil”, “soil drainage” potential, amount of “groundcover”, and number of “rills and channels” were also registered on a score from one to five (Table 1) for each side of the sampling sites. “Intactness” of the riparian zones was measured as the amount (%) of gaps in the riparian vegetation (Table 1). “Dominating vegetation” was measured, where score one was short grazed, and score five was maturing forest (Table 1). The mean value of the scores from each side of the sampling sites were used in analysis.

Table 1. Environmental factors used to evaluate the riparian condition, and how they were measured on a score from one to five for each environmental factor, based on the assessment protocol from Jon S. Harding 2009 (Harding, 2009).

	Variables								
	Shading	**Buffer width**	**Intactness**	**Dominating vegetation**	**Bank stability**	**Riparian soil (denitrification)**	**Ground cover**	**Soil drainage**	**Rills and channels**
Score 1	Little or no shading	<1m	Buffer absent	Short grazed vegetation	>40% recently eroded	Dry soil >3 bypass drains per 100m	Bare	Compacted soil	>9 rills per 100m
Score 2	10-25% shading	1-5m	50-99% gaps	Vegetation 0.3-2m tall	15-40% recently eroded	Moist soil w 1-2 bypass drains per 100m	Short grazed pasture <3cm	Low permeability	4-9 rills per 100m
Score 3	25-50%	5-15m	20-50% gaps	Vegetation 2-5m tall	5-15% recently eroded	>30% soil moist. No drains	Pasture grass with bare flow paths or 2-3cm litter layer	Low-moderate permeability	2-3 rills per 100m
Score 4	50-80%	15-30m	1-20% gaps	Vegetation 5-12m tall	1-5% recently eroded	1-30% waterlogged streambank soils. With black soil. No drains	Moderate density grass or dense tree litter layer >3cm	Moderate-high permeability	1 rill per 100m
Score 5	>80%	>30m	Completely intact	Maturing forest <12m tall	<1% recently eroded	>30% waterlogged stream banks soils. No drains	High density long grass	Very high permeability	None

Abundance and diversity of insects

The abundance of aquatic insects in this study were measured as the mean number of individuals caught across the sets of four emergence traps used per sampling site. The diversity was measured as the number of different species families caught per sampling site.

Data analysis

In-stream habitat data

Correlation matrix

To check for possible correlations between the in-stream habitat variables before they were used in further analyses, I ran a correlation matrix using the "cor (name of the dataset with in-stream habitat variables)" function. I plotted this by using the "ggcorrplot" package in RStudio (version 2023.09.1+494).

Principal Component Analysis (PCA)

Principal Component Analysis is a linear unconstrained method with multiple variables suited to simplify datasets with many variables and identify which of those variables explains the variation in response variables (Wold et al., 1987). It is one of the most common statistical methods in ecological studies, where several variables often are expected to affect the response variable together (Peres-Neto et al., 2003). The in-stream habitat variables in this project include numerical, continuous variables suited for a PCA (Kolenikov & Angeles, 2004). However, to ensure that the PCA was the correct model to use, I carried out a Detrended Correspondence Analysis (DCA). The weakness of models with multiple variables is the potential sources of error when compressing large amounts of error into a simplified model. The DCA model is developed to solve such problems (Holland, 2008). The outcome of the DCA proved that the in-stream habitat data was suited for further use in a PCA (Figure 9). Both tests were performed using the "vegan" package in RStudio (version 2023.09.1+494).

Figure 9. Illustration of the PCA on the in-stream habitat data, made in BioRender.com.

Riparian data

A correlation matrix was made with the same methods for the riparian variables (based on the same reasons as for the in-stream habitat data). Then I combined them with other variables and with the abundance and diversity of aquatic insects.

Since the data on riparian condition were registered on a score from one to five, they were not numerically continuous. Therefore, they ran through a copula based ordination (Figure 10), which is another method with multiple variables suited for categorical data (Ricotta & Avena, 2006). The copula based ordination was performed using the "ecoCopula" package in RStudio (version 2023.09.1+494). Biplots of the outcome from the copula based ordination were made to see how the variables from the riparian condition affected each other along the axis called Factor 1 and Factor 2 (Figure 10). This is the simplified model used to gather all the riparian variables (Podani, 2005). All the riparian variables could be tested separately up against Factor 1 and Factor 2, in both additive and interacting relationships in the candidate models (Appendix). They ran through the Akaike information criterium (AIC) (Figure 10) to identify the model with most support in the dataset (Emad, 2015). I used the "AICcmodavg" package in RStudio (version 2023.09.1+494).

Copula based ordination

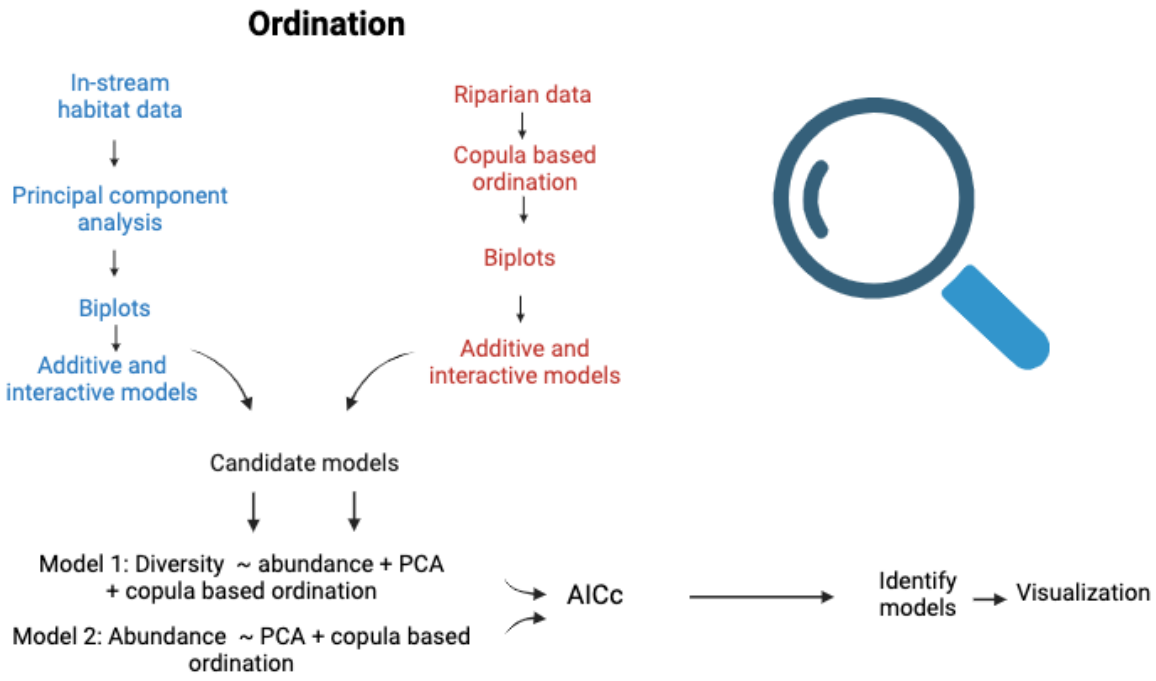

Figure 10. Illustration of the multiple component analysis performed in this study, made in BioRender.com.

When both the PCA and the copula based ordination were done, a list of candidate models (Appendix) was made for both and divided into two models: one for the abundance, and one for the diversity of aquatic insects (Figure 10). One model consisted of a list of 36 candidate models for the diversity of aquatic insects. The other model consisted of a list of 33 candidate models for the abundance of aquatic insects. All candidate models, including variables from the PCA and the copula based ordination (Figure 10) in both additive and interacting relationships, equals a list of 69 candidate models (Appendix). The reason why the number of candidate models differed between the diversity and the abundance of aquatic insects, was that both the diversity and the abundance were included as variables in the model for diversity (Figure 10). When the abundance was high during the fieldwork, the diversity was often low, indicating that some dominating species affected the abundance. This also indicated an effect from the diversity on the abundance that I wanted to correct for in the analysis. To test which of these candidate models was most supported in the dataset, they were all ran through AIC model selection using the "AICcmodavg" package in RStudio (version 2023.09.1+494). This identified the most supported model for further visualization (Figure 10). The most supported models were also run through an ANOVA analysis using the "car" package in RStudio (version 2023.09.1+494). This investigated the separate effect of every single variable within the models.

Abundance and diversity of insects

Distribution plots for both the abundance and diversity of aquatic insects were produced as histograms using the function "geom_histogram" from the "ggplot"-package in RStudio (version 2023.09.1+494). The purpose of these plots was to get to know the distribution of the abundance and diversity of aquatic insects before using them as separate response variables in further analysis and figures.

Results

In-stream habitat data

There were eight variables that determined the in-stream habitat condition for each of the 15 sampling sites. The characteristics of the sampling sites varied, e.g. the mean widths and depths varied from 1.10-7.34 meters and 4.80-56.7 centimeters, respectively (Table 2).

Table 2. Mean values of the eight environmental variables that determined the in-stream habitat condition for each sampling site.

Sampling sites	Width (m)	Depth (cm)	Debris dams	Dead wood	Woody substrate (%)	Emerged macrophytes (%)	Submerged macrophytes (%)	Substrate (Fredle index)
H36	2.11	43.84	0	1	0	0	0	10.48
H29	2.24	29.52	2	3	5	0	5	37
H30	1.94	24.28	2	1	2	0	0	8.68
H31	2.5	19.6	4	8	10	20	0	5.6
H37	6.1	32.96	5	17	20	3.5	0	31.9
H24	1.1	14.3	0	0	0	20	0	6.7
H23	7.34	13.08	4	4	5	5	10	17.87
H20	1.38	7.04	4	6	5	0	0	6.78
H21	2.52	5.06	0	2	2	0	3	27.25
H22	1.93	24.9	0	0	0	30	5	23.25
H25	2.88	4.8	0	0	0	0	0	134.35
H26	1.8	8.82	0	0	0	0	10	10.42
H34	3.26	23.92	3	19	10	10	0	5.65
H35	1.7	56.72	0	0	0	10	0	8.85
H33	2.66	17.2	0	4	10	0	0	190.13

Correlation matrix

The correlation matrix visualized both positive and negative intercorrelations between in-stream habitat variables (Figure 11). An increase in number of "dead wood" correlated with an increasing amount of "woody substrate", visualized by the positive correlation between them (Figure 11). When there was much woody components in-stream, some were registered as "woody substrate", and those who were larger than 10 centimeters in diameter were counted as number of "dead wood". There were also several variables with no correlations amongst them (Figure 11). It was therefore appropriate to involve correlations between variables in further analyses.

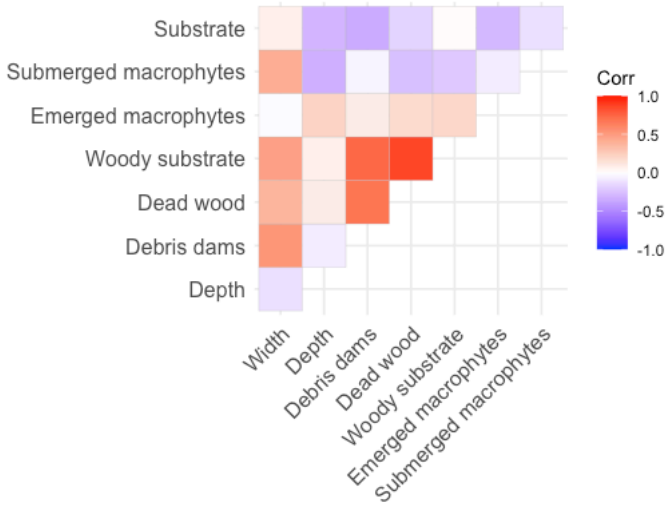

Figure 11. The correlation matrix on the variables from the in-stream habitat assessment. Red squares indicated positive correlation between variables, and blue squares indicated negative correlation between variables. White squares indicated no correlation between variables. Strength of colors indicated strength of correlations.

PCA

The PCA analysis on the in-stream habitat variables identified percentage of "woody substrate" (PC1 = 1.23), number of "debris dams" (PC 1= 1.19), number of "dead wood" (PC1 = 1.19), and the "width" (PC1 = 0.83) to be the "principal components" that best explained the in-stream habitat condition (Figure 12, (PC1, PC2, and PC3 values for every variable in Appendix)). Those were the variables with the longest vector lengths, pointing in the positive direction at the PC1 axis. This axis explained 37% of the variation within the data (Figure 12a & b). PC2 explained 21% (Figure 12a & c), and PC3 explained 17% of the variation (Figure 12b & c), respectively.

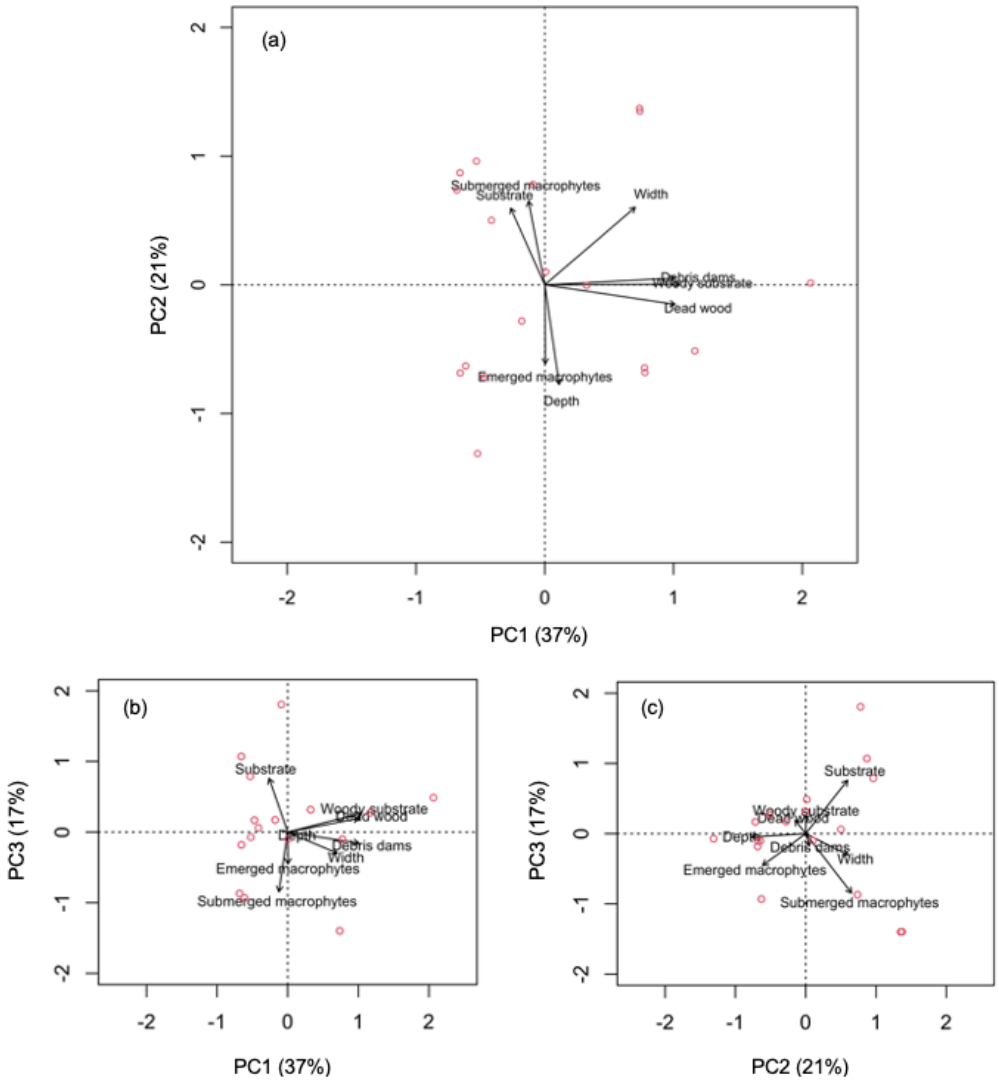

Figure 12. Plots based on the PCA analysis on the in-stream habitat variables with associated percentage of variation explained within the data. PC1 correlated PC2 on top (a), PC1 correlated with PC3 lower left (b), and PC2 correlated with PC3 lower right (c). Longest vectors on the PC1 axis pointed out as "principal components" that best explained the in-stream habitat condition, and the direction of them indicated if there was a positive or negative effect of variables. Vectors pointing in the same direction were positively correlated with each other. Vectors pointing away from each other were negatively correlated with each other. The red dots were the 15 different sampling sites.

Riparian data

There were nine variables that determined the in-stream habitat condition for each of the 15 sampling sites (Table 3). There was considerable variation between sampling sites in the nine variables that determined the riparian condition (Table 3).

Table 3. Mean values of the nine environmental variables that determined the riparian condition for each sampling site, registered on a score from one to five.

Sampling sites	Shading	Buffer width	Intactness	Dominating vegetation	Bank stability	Riparian soil	Groundcover	Soil drainage	Rills and channels
H36	1	1	1	2	1	2	2	2	3
H29	4	2	3	3	3	2	2	3	2
H30	3	2	3	3	2	2	2	3	2
H31	4	2	3	3	3	2	2	2	3
H37	4.5	3	4	5	4	3	4	3	3
H24	2	2.5	2.5	2.5	2	3	2	3	3
H23	3	5	3	3	3.5	3	4	4	2
H20	4.5	2	3	3	3	4	1.5	3	2.5
H21	5	5	4.5	5	5	4	5	4	5
H22	1.5	1.5	3.5	1.5	5	2	1.5	2	2.5
H25	1	4	2	2	5	4	3	3	5
H26	1	2	1.5	1	1	2	2	2	3
H34	4	5	4	4	5	5	4	5	5
H35	1	2	1	2	2	1	2	2	3
H33	4	4	4	3	5	3.5	3	4.5	4

Correlation matrix

The correlation matrix visualized intercorrelations between variables from the riparian data. An increasing score within the "dominating vegetation" led to more "shading" of streams, visualized by the positive correlation between these two variables (Figure 13). There were no negative correlations. However, due to several positively strong correlations, it was appropriate to involve correlations between variables in further analysis.

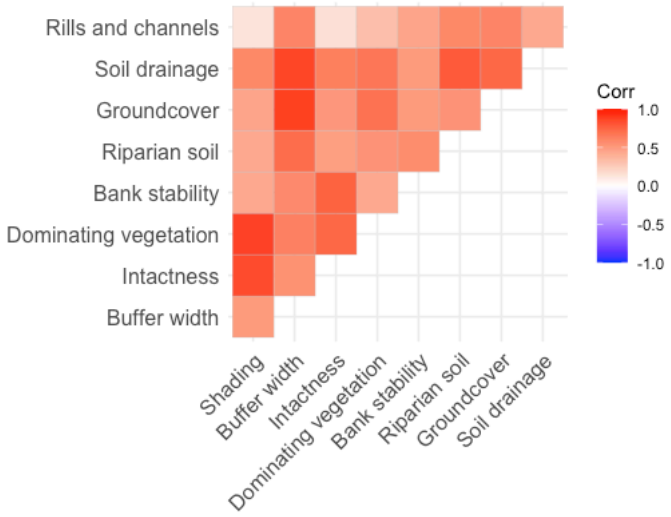

Figure 13. Correlation matrix on the variables from the riparian data. Red squares indicated positive correlations between variables, and white squares indicated no correlations between variables. Strength of colors indicated the strength of correlations.

Copula based ordination

The copula based ordination on the riparian variables identified “shading” (Factor1 = 0.88), “dominating vegetation” (Factor1 = 0.79), and “intactness” of riparian zones (Factor1 = 0.76) to be the variables that best explained the riparian condition (Figure 14, (Factor1 and Factor2 values for every variable in Appendix)). Those were the variables with the longest vector lengths, pointing in the positive direction at the Factor1 axis (Figure 14), which was the factor that explained most of the variation within the data.

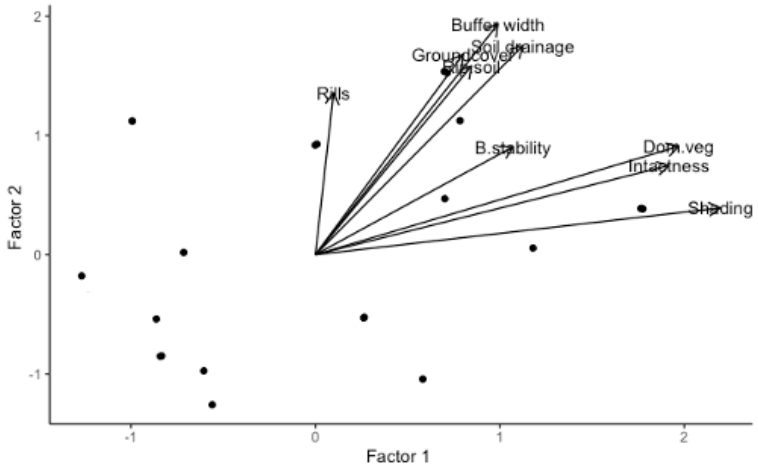

Figure 14. Copula based ordination for the variables that determined the riparian condition of sampling sites. Factor1 correlated with Factor2. The longest vector lengths pointing in the positive direction at the Factor1 axis were the variables that best explained the riparian condition. Vectors pointing in the same direction were positively correlated with each other. The black dots are the 15 different sampling sites.

Diversity of insects

Number of species families caught per sampling site was normally distributed (Figure 14). The number of specie families caught per sampling site ranged from one to a nine (Figure 15). During 16 of the 26 sampling occasions, the emergence traps caught three and four species families on eight sampling occasions each (Figure 15).

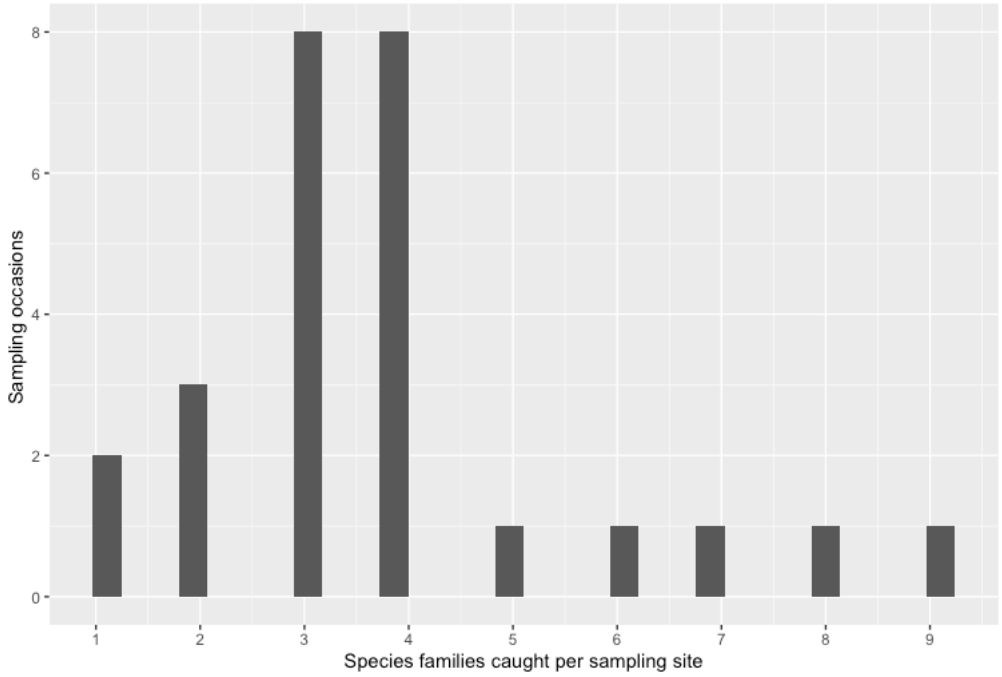

Figure 15. Distribution for the number of species families caught per sampling site with emergence traps in Haldenvassdraget during summer 2023.

Model selection after AIC

Based on the AIC model selection for the diversity of aquatic insects, model number 12 was the most supported model in the data, explaining the total effect, including both in-stream habitat condition (PC1) and riparian condition (Factor1) on the diversity of insects (Table 4). Model number 28 was an interactive model that included both PC1-values and "shading" from the riparian zones. This was the only model with a p-value below 0.05 (table 4).

Table 4. The AIC model selection on the list of 36 candidate models for the diversity of aquatic insects with associated p-values, models with a delta AIC less than three were involved.

Model number	Model variables	K	AICc	Delta_AICc	p-values
28	log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 * Mean_shading	6	43.9130189886521	0	0.04
15	log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + Mean_shading	5	45.3390722854481	1.42605329679595	0.12
12	log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + Factor1	5	46.0737945795845	2.16077559093239	0.17
25	log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 * Factor1	6	46.7724879534105	2.85946896475835	0.12

When candidate model number 12 was analyzed as a standalone unit with all variables included, there was no significant effect ($p>0.05$) of either the in-stream habitat condition or the riparian condition on the diversity of aquatic insects (Figure 16), model test statistics: $p = 0.15$ with a $R^2 = 0.10$ and $F_{3,22} = 1.96$. However, there were some trends in the data. The diversity of aquatic insects was negatively influenced by environmental variables, both the in-stream and in the riparian zones (Figure 16). This is represented by the negative Factor1- and PC1 values. As the number of species families caught per sampling site increased, the abundance of aquatic insects also decreased (Figure 16). These are trends confirmed by the parameter estimates from every variable within the model (Table 5). When the effect of variables was analyzed separately, the negative effect of environmental factors in the riparian zones was significant (Table 5).

Table 5. Parameter estimates with associated standard error (SE), degrees of freedom (Df), R^2 (SS), F-value (F), and p-value (p) after separately analyzing effects of variables within model number 12 from the AIC model selection on the diversity of aquatic insects.

Parameter estimates		
	Parameter	
	Estimate	**SE**
(Intercept)	1.2415490	0.1704021
Mean_number_of_individuals_caught_per_station	-0.05974	0.0031730
PC1	-0.09414	0.1797636
Factor1	-0.31471	0.1502230

ANOVA table				
	Effect			
	Df	**SS**	**F**	**P**
Mean_number_of_individuals_caught_per_station	1.00	0.0402	0.1638	0.6896
PC1	1.00	0.3237	1.3177	0.2633
Factor1	1.00	1.0783	4.3890	0.0479*

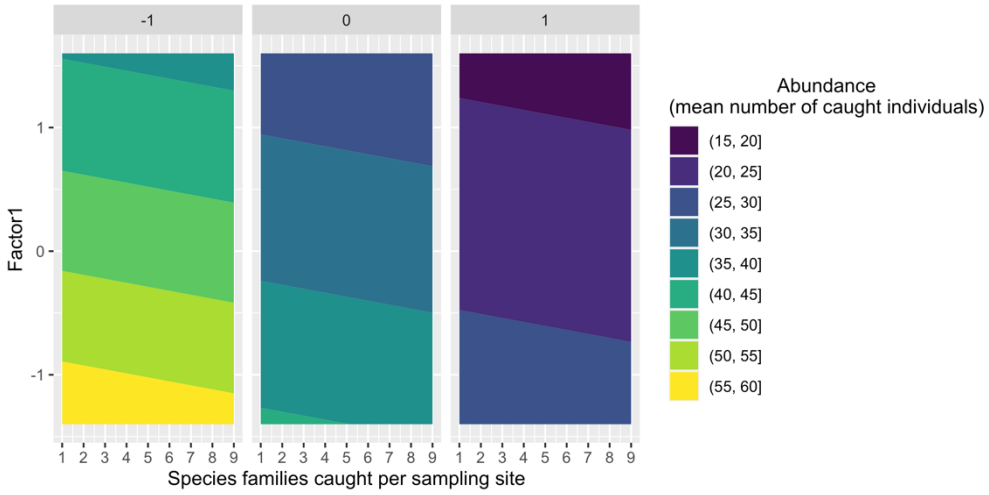

Figure 16. Prediction plot of candidate model number 12 from the AIC model selection on the diversity of insects. Including the number of species families at the X-axis, Factor1 values on the Y-axis, and one bar for each PC1 value (-1, 0, 1). The color sequences equal sequences within the abundance of aquatic insects.

When analyzing candidate model number 28 as a standalone unit with all variables included, there was a significant negative effect of environmental variables in-stream and from the amount of shade thrown into the sampling sites by riparian vegetation, represented by negative PC1 value and a low "shading" score (Figure 17), model test statistics: $p = 0.04$ with a $R^2 = 0.24$ and $F_{4.21} = 2.95$. Both the abundance and the diversity of aquatic insects were at the highest when the environmental variables in-stream and "shading" scored low (Figure 17). These are trends confirmed by the parameter estimates for every variable, but it was only the negative effect of "shading" that was significant when testing variables separately (Table 6).

Table 6. Parameter estimates with associated standard error (SE), degrees of freedom (Df), R^2 (SS), F-value (F), and p-value (p) after separately analyzing effects of variables within model number 28 from the AIC model selection on the diversity of aquatic insects.

Parameter estimates		
	Parameter	
	Estimate	**SE**
(Intercept)	2.502744	0.464734
Mean_number_of_individuals_caught_per_station	0.001274	0.003032
PC1	-0.625103	0.739984
Mean_shading	-0.387410	0.122993
PC1: Mean_shading	-0.386788	0.186446

ANOVA table				
	Effect			
	Df	**SS**	**F**	**P**
Mean_number_of_individuals_caught_per_station	1	0.0402	0.1928	0.66507
PC1	1	0.3237	1.5512	0.22667
Mean_shading	1	1.2025	5.7623	0.025*
PC1: Mean_shading	1	0.8981	4.3037	0.05051

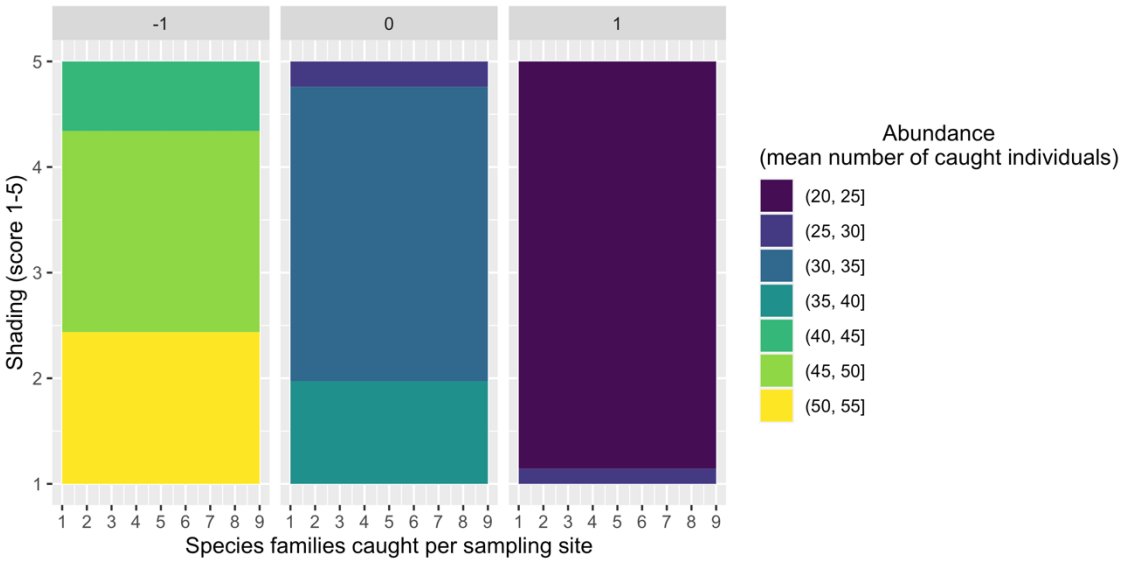

Figure 17. Prediction plot of candidate model number 28 from the AIC model selection showing a significant negative effect on the diversity of aquatic insects (p=0.04). Number of species families in the X-axis, score of "shading" on the Y-axis, and one bar for each PC1 value (-1, 0, 1). The color sequences equal sequences within the abundance of aquatic insects.

Abundance of insects

The abundance of aquatic insects caught per sampling site was normally distributed (Figure 17). It ranges between close to zero and 125 individuals caught per sampling site (Figure 18). During the 26 visits, most occasions ranged between a mean of 15 and 40 individuals caught across the sets of four emergence traps used per sampling site (Figure 18).

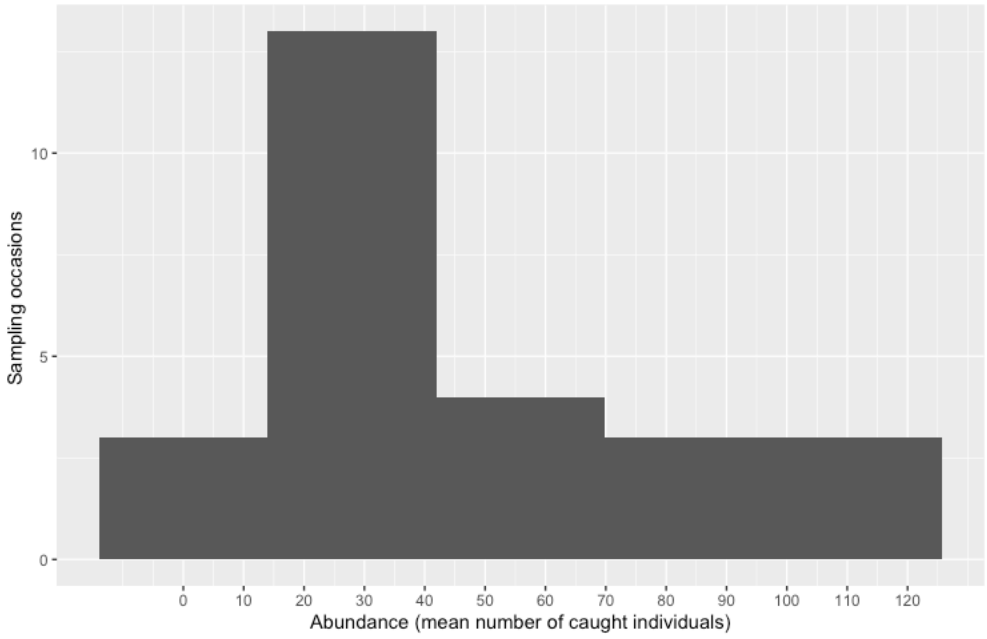

Figure 18. Distribution of the abundance of aquatic insects caught in the emergence traps in Haldenvassdraget during summer 2023.

Model selection after AIC

Based on the AIC model selection on the list of candidate models for the abundance of aquatic insects, model number 9 was the most supported model in the data to explain the total effect of both in-stream habitat and riparian condition (Table 7). It was the model with the lowest delta AIC value that still had both PC-values and Factor-values in it (Table 7).

Table 7. AIC model selection on the list of 33 candidate models with the abundance of aquatic insects as response variable. Models with delta AIC less than three were included with the associated p-value for each model.

Model number	Model variables	K	AICc	Delta_AICc	p-values
7	log(Mean_number_of_individuals_caught_per_station) ~ PC3	3	59.6752224617858	0	0.03
4	log(Mean_number_of_individuals_caught_per_station) ~ PC1 + PC3	4	61.6819047815698	2.006682319784	0.08
9	log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Factor1	4	61.8460000290674	2.17077756728156	0.09
12	log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_shading	4	62.1020875108658	2.42686504907995	0.10
19	log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_soil_drainage	4	62.1647308235641	2.48950836177826	0.10
5	log(Mean_number_of_individuals_caught_per_station) ~ PC2 + PC3	4	62.2726133957931	2.59739093400727	0.10
15	log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_rip_veg	4	62.275771972898	2.60054951111225	0.10
20	log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_rills_channels	4	62.4288195830706	2.75359712128476	0.11
10	log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Factor2	4	62.4349263749913	2.75970391320546	0.11
11	log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Riparian_condition_index	4	62.4442488497282	2.76902638794238	0.11
14	log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_Rip.intactness	4	62.4592417262003	2.78401926441452	0.11
13	log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_width_score	4	62.4632483495278	2.78802588774199	0.11
17	log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_rip_soil	4	62.4703986410541	2.79517617926827	0.11
16	log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_bank_stability	4	62.4827514875539	2.80752902576805	0.11
18	log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_buffer_groundcover	4	62.4876665042024	2.81244404241657	0.11

When analyzing the total effect of both in-stream habitat and riparian condition on the abundance of aquatic insects as a standalone unit, including all variables from candidate model number nine (not including the potential effect of dominating species), no significant effect was found (Figure 19), model test statistics: $p = 0.09$ with a $R^2 = 0.12$ and $F_{2.23} = 2.73$. There were trends in the figure. The abundance of aquatic insects was highest when environmental variables from both the in-stream habitat and the riparian zones scored high, due to positive Factor 1 and PC3 values (Figure 19). These are trends confirmed by parameter estimates of variables within the model (Table 8). The positive effect of environmental variables in riparian zones was significant when the variables were tested separately from each other (Table 8).

Table 8. Parameter estimates with associated standard error (SE), degrees of freedom (Df), R^2 (SS), F-value (F), and p-value (p) after separately analyzing effects of variables within model number 9 from the AIC model selection on the abundance of aquatic insects.

Parameter estimates				
	Parameter			
	Estimate	**SE**		
(Intercept)	3.5125	0.1371		
PC3	0.679	0.1955		
Factor1	0.208	0.1649		
ANOVA table				
	Effect			
	Df	**SS**	**F**	**P**
Mean_number_of_individuals_caught_per_station	1	0.0402	0.1638	0.6896
PC3	1	0.3237	0.32372	0.2633
Factor1	1	1.0783	1.07827	0.0479 *

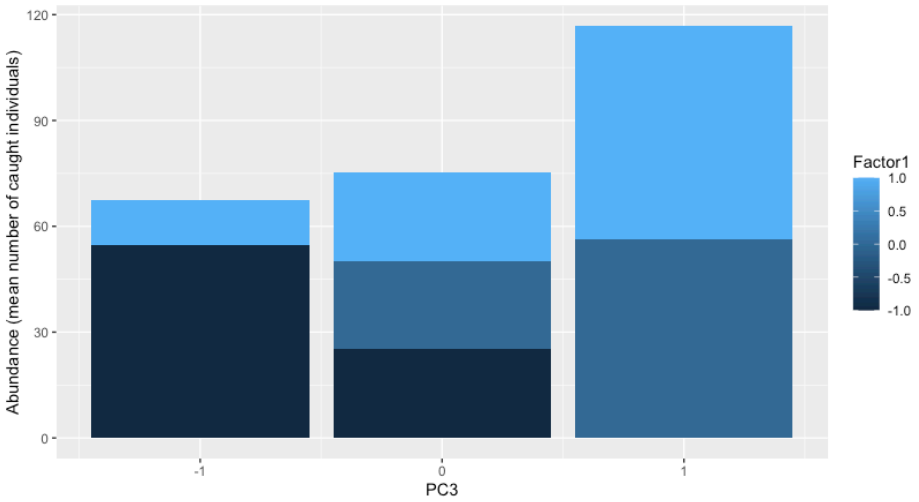

Figure 19. Visualization of candidate model number nine from the AIC model selection on the abundance of aquatic insects. Mean number of caught individuals on the Y-axis, one bar for each PC3 value (-1, 0, 1), and Factor1 values as color sequences withing the bars.

Discussion

Main findings

The aim of this study was to pinpoint environmental factors that best explained the in-stream habitat and riparian condition. Further, I evaluated how these factors affected the abundance and diversity of aquatic insects. Explanatory environmental factors on in-stream habitat conditions in this study were the percentage of "woody substrate" together with number of "debris dams", number of "dead wood", and the mean "width" of the sampling sites (Table 9, Appendix). For the riparian condition, it was the amount of shade thrown into the sampling sites by the riparian vegetation together with "dominating vegetation" and "intactness" (Table 10, Appendix). These were the variables that increased the abundance and reduced the diversity of aquatic insects in this study. This means the hypothesis was only partly supported.

The H_0 hypothesis for the in-stream habitat condition was partly supported, as the substrate composition showed no effect on either the abundance or the diversity of aquatic insects. Further, the H_0 hypothesis was partly supported, as it was only the abundance of aquatic insects that was positively correlated with woody components in-stream. When it came to the diversity of aquatic insects, the H_1 hypothesis fit best, as the diversity was negatively correlated with the presence of woody components in stream. However, the negative effect of in-stream environmental factors was not significant.

The H_0 hypothesis for the riparian condition was also partly supported, as it was only the abundance of aquatic insects that was positively correlated with the amount of maturing riparian vegetation. The H_1 hypothesis fit best for the diversity of aquatic insects, as they were negatively correlated with the amount of maturing riparian vegetation. Both results were significant.

In general, the effects of the environmental factors were weak in this study. Only some of them that were significant, and the models were not very strong, with the highest R^2 among models equaling 0.24 (Model 28, Table 4). Results indicating a positive effect of woody components in-stream on the abundance of insects were based on PC3 values. These only explained 17% of the variation within in-stream habitat data. This could result from a low number or lack of data. The dataset originates from one field season within a limited geographical area. This study also represents fieldwork and insect identification in a laboratory performed by a first-timer. This could bring some man-made sources of error in the dataset. Still, every procedure was performed by the same persons throughout this study, so potential sources of error were likely systematic.

Despite the small sample size and potential sources of error in this study, the main findings match up with findings in previous studies. For example, the main findings match with parts of the findings from Jentoft (1998). Her findings indicated an increase in both the abundance and diversity of aquatic insects with an absent in riparian vegetation (Jentoft, 1998). It was only the diversity of aquatic insects that positively correlated with the absence of riparian vegetation in this study. This coincides more with the main findings from Stewart et al., (2001). They identified an increase in abundance and reduced diversity of aquatic insects within the EPT fauna with the presence of riparian vegetation (Stewart et al., 2001).

There was a consistent trend among environmental factors in both in-stream habitat and riparian conditions. They seemed to depend on and affect each other, which is often expected in ecological studies (Robinson, 2009). Therefore, ecological studies utilize multivariate statistical analysis to include the intercorrelation between variables (James & McCulloch, 1990).Variables from different ecosystems, and how they function together at the transition between them (Ries et al., 2004), is often visualized with the use of bioindicators (Holt & Miller, 2011). The consistent trend throughout the results in this study consists of the riparian vegetation and transmission of material and energy into the tributaries in terms of “shading” and woody components in the streams. This influences the abundance and diversity of aquatic insects living there. This red line was supported by the findings of Pusey and Arthington (2003), that showed effects of the riparian vegetation to be synergistic (Pusey & Arthington, 2003). The consistent trend was also supported by Gregory et al., (1991). The riparian vegetation can to a large degree regulate organic materials in-stream (Gregory et al., 1991).

The main findings in this study were that both the in-stream habitat and the riparian condition increased the abundance and reduced the diversity of aquatic insects, possibly favoring specific species that consequently dominate the system (Gaston, 1991). All three insect orders in the dataset utilize the same habitat types. They consist of thousands of species that can be numerous and dominant (Zhou et al., 2009), especially caddisflies (Morse, 2009). For example, one emergence trap caught more than 300 caddisflies in four days. The effect of dominating species was not proven statistically in this study, but DeWalt et al. (1999) identified caddisflies to be dominant in the EPT fauna across eight large stream sites and among more than 17 000 individuals within the fauna (DeWalt et al., 1999).

Ecological impacts

One challenge with fieldwork in stream ecosystems during early summer 2023, were the varying water levels. An emergence trap could be deployed on the water surface, but due to reduced water level, the same emergence trap could be found on the dry riverbed within 4-5 days before emptying (Figure 20). In such cases, the insects may escape the traps. This results in an underestimation of the abundance and diversity. Some streams also turned into a row of small puddles that were not connected to each other, which further increased the concentration of aquatic insects in those puddles, increasing the number of individuals caught in the emergence traps.

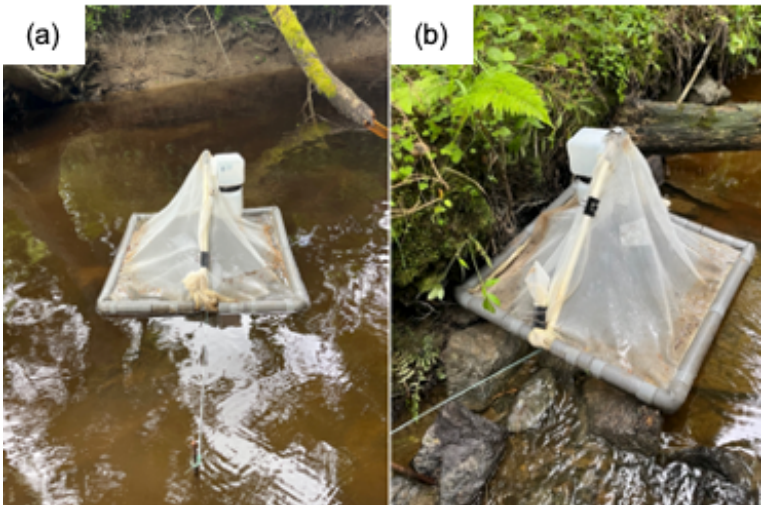

Figure 20. Pictures of the same emergence trap from different angles with four days in-between. Picture to the left (a) taken during deployment, and picture to the right (b) during emptying, showing a major difference in water level, leaving the emergence trap nearly on dry riverbed. Photo: Kåre-Jørgen Ingerø Bøe.

A major flooding event in mid-August 2023 destroyed or displaced all the emergence traps used in this study (Figure 21), in addition to some of the temperature loggers that also disappeared.

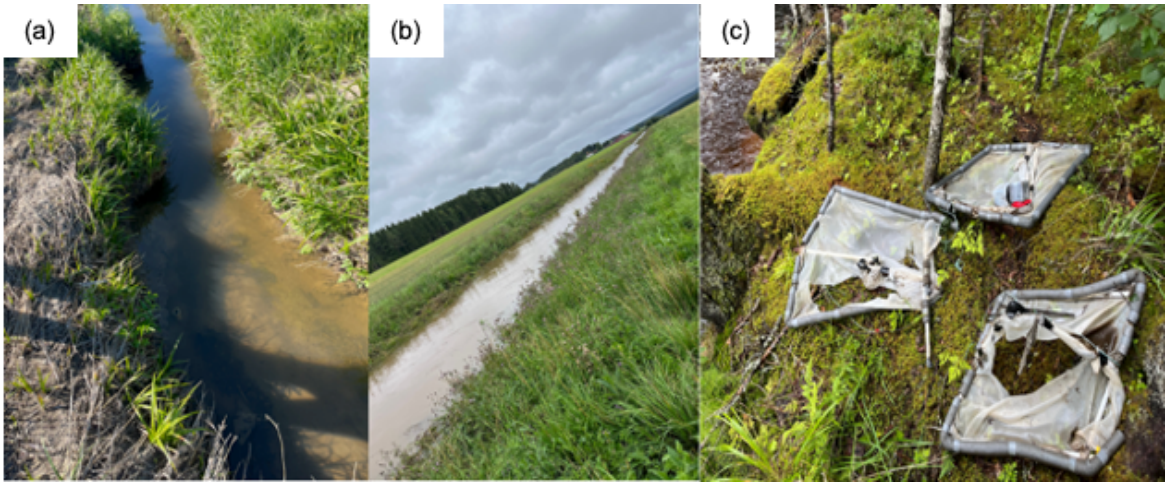

Figure 21. Pictures of the same sampling site from a different angle with four days in-between. Picture to the left taken just before deployment of the emergence traps, and picture in the middle from the day of emptying, where the flooding destroyed the emergence traps, as shown in the picture to the right, or never to be found. Photo: Kåre-Jørgen Ingerø Bøe.

There were probably additional environmental factors influencing the abundance and diversity of aquatic insects which were not covered in the dataset. Examples of such variables are wind, temperature, and stream velocity. The surface of water bodies are affected by wind, which influence insects ability to move within or emerge from a waterbody (May, 2019). Temperature regulates metabolic processes affecting growth rates and important parts of aquatic insect life cycles, like emergence and reproduction (González-Tokman et al., 2020). Even though there were temperature loggers used in this project, they were not included as part of this study.

Stream velocity creates microhabitats in streams, due to its effect on the particle sizes within the substrate composition (Hawkins et al., 1982). Different species have different preferences (BAPTISTA et al., 2001). Since this was an ecological study, it was important to remember that these were synergistic effects (Darling & Côté, 2008), which are often directly- or indirectly affected by the riparian vegetation (Dugdale et al., 2018). Lack of riparian vegetation may increase the temperature in streams, due to more sunlight. It may also let more wind into the stream, which again may also increase the stream velocity (Dan Moore et al., 2005).

The methodology in this study was also expected to serve a split answer. The sampling sites either had highly vegetated riparian zones and were rich on other woody components, or both the riparian vegetation and other woody components were nearly absent. Assessment of environmental variables also happened within 50 meters of each tributary, when the tributaries may serve varying quantities of environmental factors at other stretches. The point is: In management and ecological restoration projects, it is important to have a wider focus than this study and look at the bigger picture. Varying amounts of environmental factors, both in-stream and in riparian zones, may expand the resource availability (Grover, 2011) and serve better conditions for species coexistence (Tokeshi, 2009). Coexistence of species may increase the genetic diversity within ecosystems, which is fundamental for long-term survival and a sustainable management (Vellend & Geber, 2005). Conservation of genetic diversity is an investment in possibilities to adapt to future environmental changes (Pauls et al., 2013). Coexistence of species may also function as a nature-based solution for biodiversity loss (Clement, 2021), and conserve ecosystem services, as for instance pollination and natural pest control (Hawkins et al., 1997). These are important for the link between biodiversity and human well-being (Bennett et al., 2015).

Future considerations

For future studies within the theme of this thesis, I would consider taking some measures to increase the capture efficiency. Emerging insects develop fast, and the emergence traps need to be deployed in the exact period when the insects emerge. In this study, the goal was to perform 30 visits (twice for all 15 sites). I managed to perform 26 of them before the flood came and destroyed the emergence traps. This took a bit more than two months, meaning that there could be a lot of aquatic insects emerging from the sampling sites when the traps were not deployed. To solve this issue, the number of sampling sites could either be reduced, or there would have to be four emergence traps deployed in each sampling site during the whole season. These suggestions would require more work, but it would result in a more accurate estimates of both the abundance and diversity of aquatic insects. There are some other techniques for collecting aquatic insects in rivers and streams. However, they often requires some specific characteristics within the riparian condition, such as for instance abundant large vegetation (Cadmus et al., 2016). I wanted to study the abundance and diversity of aquatic insects across the differing environmental characteristics found in my study area. Therefore, emergence traps were found to be a suitable method.

In this study, the abundance and the diversity of aquatic insects has been tested separately against environmental factors. Alternatively, a Shannon-weaver/ Shannon diversity index could have been used to take into account the abundance and distribution of present species within one and the same variable (DeJong, 1975). This method is often used in ecological studies (Morris et al., 2014). However, due to the observed trend during fieldwork with dominant species, the abundance and the diversity were kept separate. This turned out to identify the two-fold effect with increased abundance and reduced diversity under improved in-stream habitat and riparian conditions. An alternative approach could have been to utilize both the Shannon-weaver index and the diversity separately to identify some potential ecological characteristics within insect communities with dominating species (Belamkar & Jadesh, 2014). An insect community characterized by dominating species can still get a high score on the Shannon-weaver index, but a separate test with the diversity itself may identify such characteristics (Rad et al., 2009).

The in-stream habitat and the riparian condition were measured within the length of each sampling site. It may be a good idea to expand the scale and consider in-stream habitat and riparian condition upstream from the sampling sites due to the fact that the water almost always flows in the same direction in stream ecosystems (Schneider & Petrin, 2017). This study utilized some sampling sites where environmental variables that explained the in-stream habitat and riparian condition were fragmented or absent. Some of those sites were positioned downstream from other stretches of the stream, where the explanatory, environmental variables were present. The condition of upstream habitats and riparian conditions may have influenced the abundance and diversity of aquatic insects registered at those sites. Hoover et al., (2007) examined this issue when streams with present riparian vegetation were compared to streams where the riparian vegetation was clear cut. The drift of aquatic insects was significantly higher in streams with clear cut riparian vegetation (Hoover et al., 2007). If a similar trend was present in this study, this might be the reason why a wider range of species families were caught in sampling sites with the absence of riparian vegetation.

The two-fold effect of riparian vegetation found in this study highlights the term of a goal-oriented management. A strategic approach could achieve a specific goals in conservation, ecological restoration, and sustainable management (Nute et al., 2000). A strategic approach to a specific environmental challenge is crucial for the effectiveness in both management and ecological restoration (Hobbs & Harris, 2001). The two-fold effect of riparian vegetation found in this study was indeed increased abundance and lowered diversity of aquatic insects caught in sampling sites with improved in-stream habitat and riparian conditions. These trends may be utilized in decision making when discussing environmental factors and the effect they have on the abundance or diversity of aquatic insects in freshwater ecosystems.

A more diverse population of insects will be able to pollinate a wider range of vegetation species (Ollerton et al., 2011). A diverse population of insects can also improve the foundation for a larger and wide food web (Schoenly et al., 1991). The same insect species function as bioindicators, not only for the in-stream habitat and riparian conditions as in this study, but also for predators feeding on them (McGeoch, 2007). Some insect species also function as natural predators on parasites. Therefore, they reduce the need for pesticides (Hawkins et al., 1997). Such trends are examples of both nature-based solutions and ecosystem services within a goal oriented and sustainable development (Hobbs & Harris, 2001).

More numerous populations of insects with a decreased diversity of species could be positive in more homogenous areas, as for instance forestry or agricultural land. In such cases, quantity may be more important than diversity of insects, due to the pollination of homogenous crops (Free, 1970). Another example where more numerous insect number could be positive are in spawning grounds for fish, where abundant insects serve as a food source (Barroso et al., 2014). Again, these are examples of nature based solutions to be used in management and ecological restoration projects (Hobbs & Harris, 2001).

Conclusion

What are the environmental variables that best explain the condition of riparian ecotones, and how are the abundance and diversity of aquatic insects affected by those in my study area? The answer found in this study was somewhat two-fold. The abundance and the diversity of aquatic insects were tested separately against several environmental factors. With increasing amounts of maturing riparian vegetation and woody components in-stream, came an increased abundance and reduced diversity of aquatic insects. This shows that the ecotone between aquatic and terrestrial ecosystems and the transmission of energy and material between them has several effects on living organisms in streams. These may be relevant trends to be utilized in decision making and management of resources.

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Appendix
Sampling sites

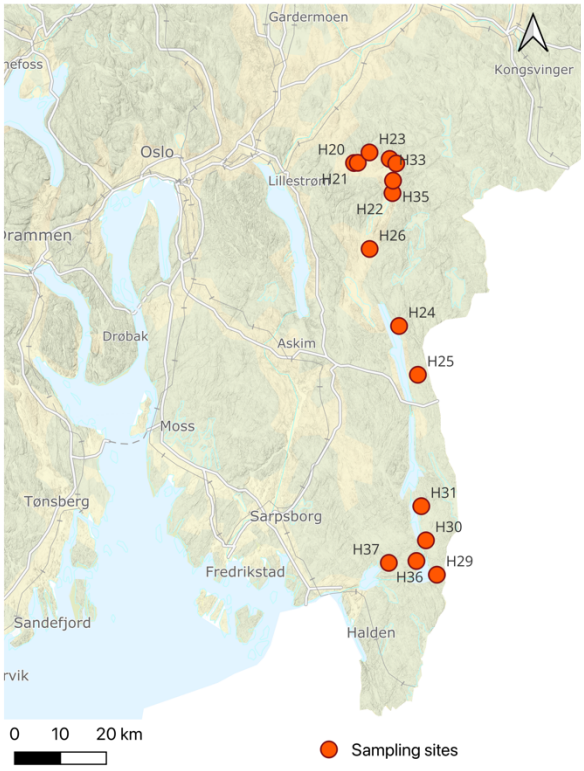

Figure 22. Sampling sites with associated site names (produced in QGIS (3.34.1-Prizern) with maps from GEONORGE: https://kartkatalog.geonorge.no/metadata/norges-grunnkart-wms/8ecaa2d5-8b0a-46cf-a2a7-2584f78b12e2.).

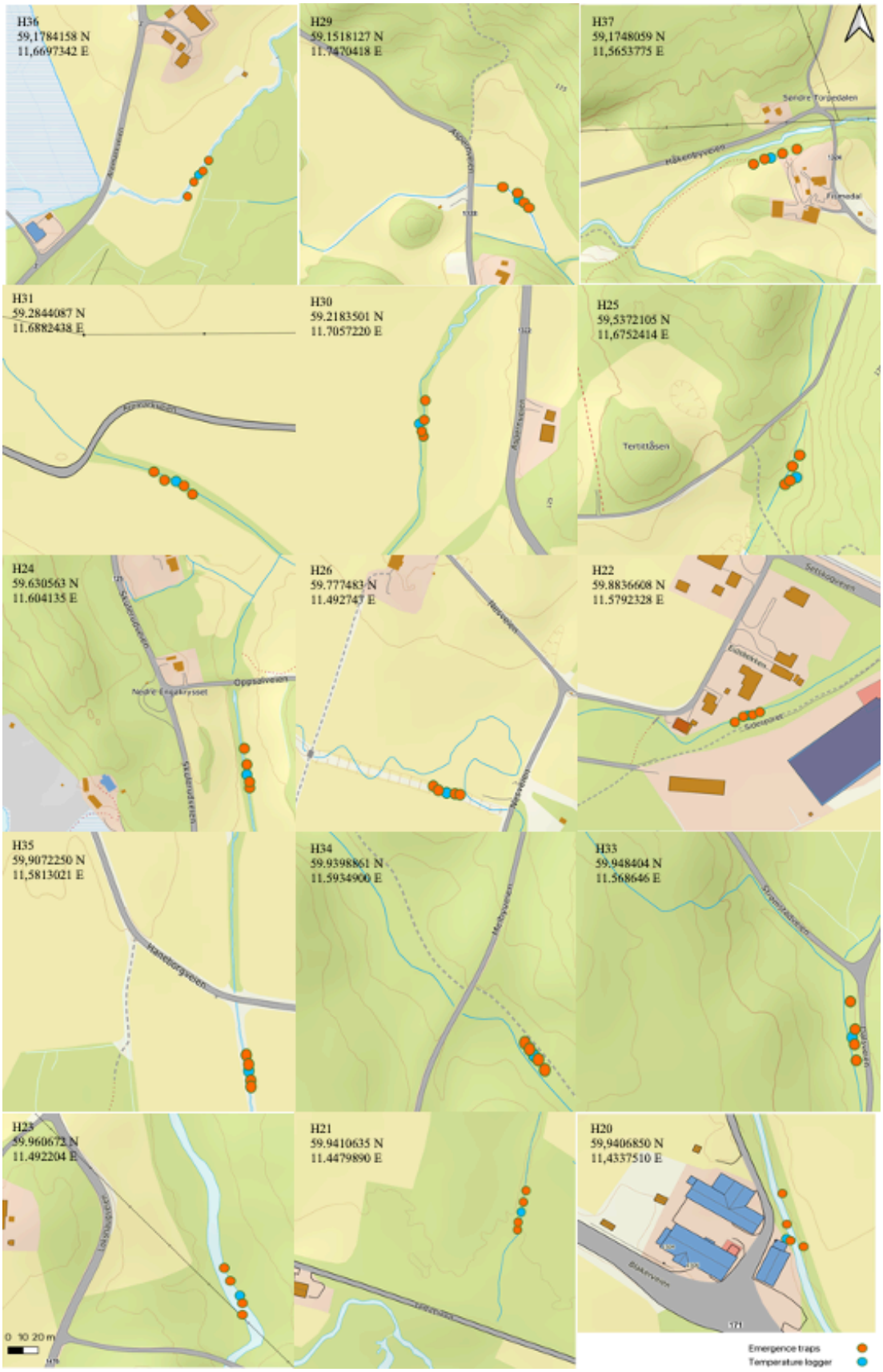

Figure 23. Detailed map of all 15 sampling sites, coordinates refer to the temperature loggers (blue dots) and the emergence traps at each site (red dots) (produced in QGIS (3.34.1-Prizern) with maps from GEONORGE: https://kartkatalog.geonorge.no/metadata/norges-grunnkart-wms/8ecaa2d5-8b0a-46cf-a2a7-2584f78b12e2.).

List of candidate models

Abundance of insects, step one

Combining the abundance of insects with PC1, PC2, and PC3 values from the in-stream habitat variables.

1. lm.abundance[[1]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC1 + PC2 + PC3, Mean_habitat.rip)

2. lm.abundance[[2]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC1 + PC2, Mean_habitat.rip)

3. lm.abundance[[3]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC1, Mean_habitat.rip)

4. lm.abundance[[4]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC1 + PC3, Mean_habitat.rip)

5. lm.abundance[[5]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC2 + PC3, Mean_habitat.rip)

6. lm.abundance[[6]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC2, Mean_habitat.rip)

7. lm.abundance[[7]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3, Mean_habitat.rip)

Diversity of insects, step one

Combining the diversity of insects with the abundance and with PC1, PC2, and PC3 values from the in-stream habitat variables.

1. lm.diversity[[1]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + PC2 + PC3, Mean_habitat.rip)

2. lm.diversity[[2]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + PC2, Mean_habitat.rip)

3. lm.diversity[[3]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1, Mean_habitat.rip)

4. lm.diversity[[4]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + PC3, Mean_habitat.rip)

5. lm.diversity[[5]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC2 + PC3, Mean_habitat.rip)

6. lm.diversity[[6]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC2, Mean_habitat.rip)

7. lm.diversity[[7]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC3, Mean_habitat.rip)

8. lm.diversity[[8]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station * PC1, Mean_habitat.rip)

9. lm.diversity[[9]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station * PC2, Mean_habitat.rip)

10. lm.diversity[[10]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station * PC3, Mean_habitat.rip)

Abundance of insects, step two

Models from step one ran through an AIC model selection. The favored models from the AIC were combined with variables from the riparian zones, including Factor1 and Factor 2 from the copula based ordination.

8. lm.abundance[[8]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Factor1 + Factor2, Mean_habitat.rip)

9. lm.abundance[[9]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Factor1, Mean_habitat.rip)

10. lm.abundance[[10]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Factor2, Mean_habitat.rip)

11. lm.abundance[[11]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Riparian_condition_index, Mean_habitat.rip)

12. lm.abundance[[12]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_shading, Mean_habitat.rip)

13. lm.abundance[[13]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_width_score, Mean_habitat.rip)

14. lm.abundance[[14]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_Rip.intactness, Mean_habitat.rip)

15. lm.abundance[[15]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_rip_veg, Mean_habitat.rip)

16. lm.abundance[[16]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_bank_stability, Mean_habitat.rip)

17. lm.abundance[[17]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_rip_soil, Mean_habitat.rip)

18. lm.abundance[[18]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_buffer_groundcover, Mean_habitat.rip)

19. lm.abundance[[19]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_soil_drainage, Mean_habitat.rip)

20. lm.abundance[[20]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Mean_rills_channels, Mean_habitat.rip)

21. lm.abundance[[21]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 + Factor1 * Factor2, Mean_habitat.rip)

22. lm.abundance[[22]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 * Factor1, Mean_habitat.rip)

23. lm.abundance[[23]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 * Factor2, Mean_habitat.rip)

24. lm.abundance[[24]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 * Riparian_condition_index, Mean_habitat.rip)

25. lm.abundance[[25]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 * Mean_shading, Mean_habitat.rip)

26. lm.abundance[[26]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 * Mean_width_score, Mean_habitat.rip)

27. lm.abundance[[27]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 * Mean_Rip.intactness, Mean_habitat.rip)

28. lm.abundance[[28]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 * Mean_rip_veg, Mean_habitat.rip)

29. lm.abundance[[29]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 * Mean_bank_stability, Mean_habitat.rip)

30. lm.abundance[[30]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 * Mean_rip_soil, Mean_habitat.rip)

31. lm.abundance[[31]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 * Mean_buffer_groundcover, Mean_habitat.rip)

32. lm.abundance[[32]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 * Mean_soil_drainage, Mean_habitat.rip)

33. lm.abundance[[33]] = lm(log(Mean_number_of_individuals_caught_per_station) ~ PC3 * Mean_rills_channels, Mean_habitat.rip)

Diversity of insects, step two

Models from step one ran through an AIC model selection. The favored models from the AIC were combined with the abundance and variables from the riparian zones, including Factor1 and Factor 2 from the copula based ordination.

11. lm.diversity[[11]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + Factor1 + Factor2, Mean_habitat.rip)

12. lm.diversity[[12]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + Factor1, Mean_habitat.rip)

13. lm.diversity[[13]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + Factor2, Mean_habitat.rip)

14. lm.diversity[[14]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + Riparian_condition_index, Mean_habitat.rip)

15. lm.diversity[[15]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + Mean_shading, Mean_habitat.rip)

16. lm.diversity[[16]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + Mean_width_score, Mean_habitat.rip)

17. lm.diversity[[17]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + Mean_Rip.intactness, Mean_habitat.rip)

18. lm.diversity[[18]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + Mean_rip_veg, Mean_habitat.rip)

19. lm.diversity[[19]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + Mean_bank_stability, Mean_habitat.rip)

20. lm.diversity[[20]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + Mean_rip_soil, Mean_habitat.rip)

21. lm.diversity[[21]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + Mean_buffer_groundcover, Mean_habitat.rip)

22. lm.diversity[[22]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + Mean_soil_drainage, Mean_habitat.rip)

23. lm.diversity[[23]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + Mean_rills_channels, Mean_habitat.rip)

24. lm.diversity[[24]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 + Factor1 * Factor2, Mean_habitat.rip)

25. lm.diversity[[25]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 * Factor1, Mean_habitat.rip)

26. lm.diversity[[26]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 * Factor2, Mean_habitat.rip)

27. lm.diversity[[27]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 * Riparian_condition_index, Mean_habitat.rip)

28. lm.diversity[[28]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 * Mean_shading, Mean_habitat.rip)

29. lm.diversity[[29]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 * Mean_width_score, Mean_habitat.rip)

30. lm.diversity[[30]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 * Mean_Rip.intactness, Mean_habitat.rip)

31. lm.diversity[[31]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 * Mean_rip_veg, Mean_habitat.rip)

32. lm.diversity[[32]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 * Mean_bank_stability, Mean_habitat.rip)

33. lm.diversity[[33]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 * Mean_rip_soil, Mean_habitat.rip)

34. lm.diversity[[34]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 * Mean_buffer_groundcover, Mean_habitat.rip)

35. lm.diversity[[35]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 * Mean_soil_drainage, Mean_habitat.rip)

36. lm.diversity[[36]] = lm(log(Number_of_species_caught_per_station) ~ Mean_number_of_individuals_caught_per_station + PC1 * Mean_rills_channels, Mean_habitat.rip)

PC values

Table 9. PC1, PC2, and PC3 values for the environmental variables in stream, from the principal component analysis performed on them.

Variables	PC1	PC2	PC3
Width	0.826756	0.709126	-0.35579
Depth	0.132472	-0.910967	-0.05789
Debris dams	1.191847	0.061761	-0.18672
Dead wood	1.191065	-0.178128	0.22967
Woody substrate	1.226546	0.006432	0.31311
Emerged macrophytes	0.004463	-0.721731	-0.53268
Submerged macrophytes	-0.148437	0.766416	-0.99510
Substrate (Fredle index)	-0.310877	0.701076	0.89606

Factor values

Table 10. Factor values for the environmental variables in the riparian zones, from the copula based ordination performed on them.

Variables	Factor1	Factor2
Shading	0.8789504	0.1510716
Buffer width	0.3989198	0.7735388
Intactness	0.7524904	0.3128646
Dom.veg	0.7962556	0.3596508
B. stability	0.4159589	0.3664206
Rip.soil	0.3485235	0.6313825
Groundcover	0.3259521	0.6706326
Soil drainage	0.4523607	0.6993701
Rills	0.0397716	0.5377822

Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway