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Macroinvertebrate colonisation of a recently deculverted urban stream

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Master of Science in Ecology

Preface

This thesis concludes my Master's Degree in Ecology at the Norwegian University of Life Sciences. I am grateful for the opportunity I had to conduct this study in collaboration with the Norwegian Institute for Water Research (NIVA). There are several people I would like to thank for helping me along the way.

Firstly, to my supervisors, Susanna Claudia Schneider and Therese Fosholt Moe, for their invaluable input and support throughout the thesis process. Thank you for always being ready to answer questions and for all that you taught me. Thank you to Jonas Persson for introducing me to the wonderful world of macroinvertebrate identification. A special thank you to NIVA for making me feel welcome, and for giving me access to the equipment and the knowledge that is to be found at the institute.

Thank you to my parents who always supported me, and who nurtured my love for the natural world. It is this love and fascination which has resulted in the writing of this thesis.

A big thank you goes to my wife, Astrid Lie Olsen, for her understanding and patience during the process of thesis writing and her unwavering support and help. I would need another thesis, or perhaps a PhD, just to say thank you.

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David Arnott

Abstract

Historically, when urban land has been developed, stream burial has been a common practice. Today, many urban communities, including the city of Oslo, are increasingly attempting to restore buried streams through deculverting. In addition to ecological and aesthetical improvements, deculverting may also be an effective management method for the removal of nutrients. However, it is largely unknown how species assemblages and ecosystems in such newly created streambeds develop and function. This thesis investigates the first year following a deculverting project in the stream Hovinbekken in Oslo, Norway. In order to determine how macroinvertebrates colonise newly created streambeds, samples were collected monthly from May to November in 2016, from six sites within the restored reach and one upstream reference site. Water chemistry samples were also taken. Similar macroinvertebrate samples were collected along a gradient of increasing urbanisation from the urban stream Akerselva. Results from Hovinbekken showed that all species found in the restored reach were also found at the reference site. The upper restored sites had both higher family richness and larger population sizes compared to downstream restored sites. They also had the species assemblages in the restored reach most closely resembling that of the reference site. This is suggestive that the initial colonisation by macroinvertebrates occurred primarily via drift and depended on the species assemblage upstream of the restored site as a source of colonists. Family assemblage comparisons using NMDS ordination between Hovinbekken and Akerselva indicated that the reference site had a similar assemblage to the lower urbanised reaches of Akerselva, suggesting the local species pool was limited to that of a highly urbanised stream. The initial colonists were those with high pollution tolerances, as indicated by low ASPT scores, and consisted mainly of *Chironomidae* and Oligochaeta. This indicated that the restored reach was affected by organic pollutants. Water chemistry showed that in the growing season, the restored reach removed nitrogen and phosphorus, while in autumn, nutrient demand declined and nutrients were released. This suggests that such restored systems may, for part of the year, remove nutrients from polluted water and function as natural water purification facilities. Based on these results, the success of restoration projects where the objective is to increase biodiversity depends on whether potential colonisers are able to disperse to the restored site, and whether there is a local species pool to disperse from. In addition, stressors in the environment, such as organic pollutants, may negatively impact successful colonisation.

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Introduction

The substantial growth in the rate and scale of urbanisation has resulted in an ever-increasing number of streams being assimilated and buried in urban areas (Meyer, Paul & Keith, 2005; Elmore & Kaishal, 2008). Streams are extremely vulnerable to the negative impacts caused by urbanisation and are highly sensitive to changes in the surrounding landscape (Paul & Meyer, 2001; Bernhardt & Palmer, 2007). The negative impacts of urbanisation on streams has been termed the urban stream syndrome. A notable feature of streams affected by the urban stream syndrome is how similar they are to one another (Booth et al., 2016).

The urban stream syndrome has consistent symptoms that include a flashier hydrograph, increased concentrations of nutrients and contaminants, changed channel morphology, reduced biological richness and negative impacts on stream ecological processes (Paul & Meyer, 2001; Walsh et al., 2005). Causes of the urban stream syndrome often comprise straightening stream channels, culverting or lining streams with impermeable surfaces, such as concrete, which reduces habitat complexity (Paul & Meyer, 2001). Urban drainage systems are often piped, allowing water and associated pollutants to flow to streams more often than under natural conditions (Walsh, Fletcher & Ladson, 2005). Increasing imperviousness and rapid drainage increases the concentrations of dissolved organic carbon, total phosphorus and total nitrogen, and thus the conductivity of stream water (Hatt et al., 2004). These physical and chemical changes in urban streams effect virtually all aspects of the ecology of streams, including macroinvertebrates.

The common practice of culverting, or stream burial, is one of the most severe consequences of urbanisation on streams, and fundamentally changes the structure and function of stream ecosystems (Meyer, Poole & Jones, 2005; Elmore & Kaushal, 2008; Beaulie et al., 2014). It can consist of directing streams into culverts, pipes, or simply paving over them. Prior to the 1980s, many waterways in Oslo were considered problematic for the sewerage system and a hindrance to efficient land use; as a result, large sections of these waterways were placed into culverts (City of Oslo, 2010). Culverts may increase the risk of flooding due to the likelihood of obstructions, and are often costly to maintain (Wild et al., 2011). For urban residents, the loss of access to the stream and its environment can represent reduced recreational opportunities and property values (Wild et al., 2011).

Urban communities, including the city of Oslo, are increasingly attempting to restore buried streams in a practice known as deculverting, also referred to as "daylighting" (Elmore & Kaushal, 2008; Oslo kommune, 2011). Daylighting consists of exposing some or all of the flow of a previously buried stream by creating a new stream bed, and may include the creation of ponds, wetlands or estuaries (Pinkham, 2000). Restoration of streams has become a common practice, especially in Europe, where the management and improvement of urban streams is required under the EU Water Framework Directive (Pinkham, 2000; Booth et al., 2016). Oslo's city plan ("Byøkologisk program") includes goals such as deculverting as many streams as possible, creating blue-green corridors and preventing pollutants from entering waterways (Oslo kommune, 2011).

Deculverting projects can hypothetically decrease the environmental effects of urbanization by reestablishing natural stream structure and opening up the stream to colonisation by aquatic fauna and flora (Neale & Moffett, 2016). The removal of culverts and the provision of a diverse range of habitats in the new stream is expected to be beneficial to the ecology and diversity of the stream, by creating the opportunity for macroinvertebrates and other biota to colonise it (Wild et al., 2011). Furthermore, deculverting may be an effective management method for reducing nitrogen and phosphorus concentrations in urban streams (Beaulieu et al., 2014; Pennino et al., 2014). Other benefits resulting from daylighting streams may include the provisioning of recreational areas, increased property values, the creation of urban green spaces and paths for pedestrians, and serving as outdoor laboratories for local schools (Bolund & Hunhammar, 1999; Pinkham, 2000; Haase, 2015).

As urban streams are often affected by pollution, which may influence the successful outcome of restoration, knowledge of these pollutants is important. However, in urban streams, pollutants are difficult to measure through periodic water samples alone. Sources of pollutants may be highly variable in time due to multiple causes of contamination, and are dependent on weather (Hatt, 2004). Additionally, streams rapidly remove and dilute these variable pollutant inputs due to the lateral flow of water. In order to avoid these problems in determining pollutant levels, macroinvertebrates are commonly used for biological monitoring of freshwater ecosystems (Metcalf, 1989; Wallace & Webster, 1996; Azrina et al., 2006).

The reasons for using macroinvertebrates for biomonitoring are that species vary in their sensitivity to pollutants, they react to pollutants quickly, they are abundant and easy to collect, they tend to have low mobility, and thus represent local conditions, and they have life-spans long enough to provide a record of environmental quality (Metcalf, 1989; Hussain & Pandit, 2012). Due to these characteristics, by using macroinvertebrates, it is possible to determine impacts of pollution not detected by water chemistry measurements alone. Using macroinvertebrates gives an overview of the whole system, chemically and biologically. As a result, macroinvertebrate biomonitoring may assist in determining whether the goals of restoration are being met.

A typical model of stream restoration is based on the assumption that if a habitat is restored or created, species will return, thereby increasing biodiversity and resulting in resumed ecological processes (Parkyn & Smith, 2011). This has come to be known as the "field of dreams hypothesis", which refers to the expectation that "if we build it, they will come" (Parkyn & Smith, 2011).

However, whether species come or not depends on colonisation from source areas; this colonisation can occur via downstream drift, upstream migration and aerial dispersal (Williams & Hynes, 1976). Colonisation of new habitats by macroinvertebrates occurs primarily by drift (Williams & Hynes, 1976; Arango, James & Hatch, 2015). Aerial dispersal of winged adult stages may also be a mechanism for colonisation of restored reaches between streams (Williams & Hynes, 1976; Gore, 1982; Parkyn & Smith, 2011). Winged adult stages may travel large distances between sites, however, the urban environment may act as a barrier, reducing the distance that such flying stages may be able to travel (Blakely et al., 2006).

Barriers to connectivity reduce the rate of colonisation both via air and water, and may consist of physical structures such as dams and weirs, distance between locations, or the intervening stream sections containing environments through which organisms are unlikely to disperse (Bond & Lake, 2004). As many restoration projects occur in disturbed landscapes, with limited regional species pools, the degree of disturbance and urbanisation of the surrounding landscape will affect how rapidly recolonisation will occur and thus the success of restoration projects (Tonken et al., 2014; Winking et al., 2014). As a result, it is uncertain how initial colonisation in a newly restored urbanised stream may occur.

This thesis examines a newly deculverted and restored stream, Hovinbekken in Oslo, Norway and its colonisation by macroinvertebrates. One of the main goals of this restoration project was to design and construct the new reach to create a natural self-purification facility to cleanse the waters of Hovinbekken, by incorporating planted wetlands and pools of standing water (Norconsult, 2015). Therefore, water chemistry samples were taken as part of this study to determine whether the restored reach removed nutrients from the water.

Such a facility is a novelty in Oslo. Very few studies have been conducted on new streambeds and how such restoration affects macroinvertebrates (Neale & Moffett, 2016). It is largely unknown whether macroinvertebrates will colonise such an urban restored stream predominantly via drift or via aerial dispersal and how the species assemblage will develop. Such a newly deculverted reach provides a setting in which to examine how initial colonisation may occur in urban environments, and may provide insights for the improvement of future restoration projects. As a result, potential sources of colonisation such as an upstream site and a comparable urban stream were investigated. If colonisation occurs predominantly via drift, the restored reach was expected to develop an initial species assemblage similar to the reference site. Should colonisation occur via aerial dispersal, the restored reach was expected to exhibit families beyond those identified at the reference site. While Hovinbekken is the main focus of this thesis, it also examines the formerly heavily polluted Akerselva river and compares it to Hovinbekken. Akerselva was selected as a comparison river as it flows through a similar urban environment and may give an indication of what might be expected to develop at Hovinbekken.

We hypothesise that in Hovinbekken:

1. Water quality will improve downstream due to self-purification in the restored reach.
2. Colonisation of the deculverted reach will occur mainly via drift from upstream habitats and less by aerial dispersal from comparable nearby urban streams (Akerselva).
3. As the deculverted stream is polluted, the initial macroinvertebrate communities will be dominated by pollution tolerant taxa.

In addition, we hypothesise that Akerselva will show symptoms of the urban stream syndrome, which may be an indication of how Hovinbekken will develop.

Methodology

Site description – Hovinbekken with Teglverksdammen

Hovinbekken is an 8.5 km long stream which begins in the vicinity of Årvoll and drains from Årvollmarka (Tønnessen, 2010). It is a small to medium sized stream with an average flow of 0.18 m^3/s over the last two decades (Bækken et al., 2011). Hovinbekken is one of the most culverted streams in Oslo and drains into the lower reaches of Akerselva (Miljødirektoratet, 2016).

A section of Hovinbekken, near the neighbourhood of Hasle, has been restored by deculverting approximately 650 meters of a formerly culverted stretch. The restored section is referred to as Teglverksdammen in this thesis. The daylighting of Teglverksdammen is one of the largest deculverting projects undertaken in Norway (Eriksen, 2014).

The main goal of the restoration project was water purification for the downstream section (Norconsult, 2015). To achieve this goal, the facility includes a number of pools, dams and riffles. These pools and dams were designed to assist in removing nutrients from the stream. To further increase the nutrient processing capabilities of the reach, emergent plants have been planted to act as a wetland. These plants have predominantly been collected from waterways in and around Oslo, and are thus adapted to local conditions. Areas of open water and vegetation were constructed, forming habitats for aquatic biota and improving the aesthetic quality of the restored reach. In this way, the secondary goals of the restoration project were incorporated: increasing biodiversity by creating habitats for biota, and improving the urban landscape by adding aesthetics of water surfaces and a park environment for recreation (Oslo kommune, 2016). A pedestrian trail has been placed along the restored reach (Miljødirektoratet, 2016). The restored site was opened in late 2015, and 2016 was the first year that samples were taken in this new system.

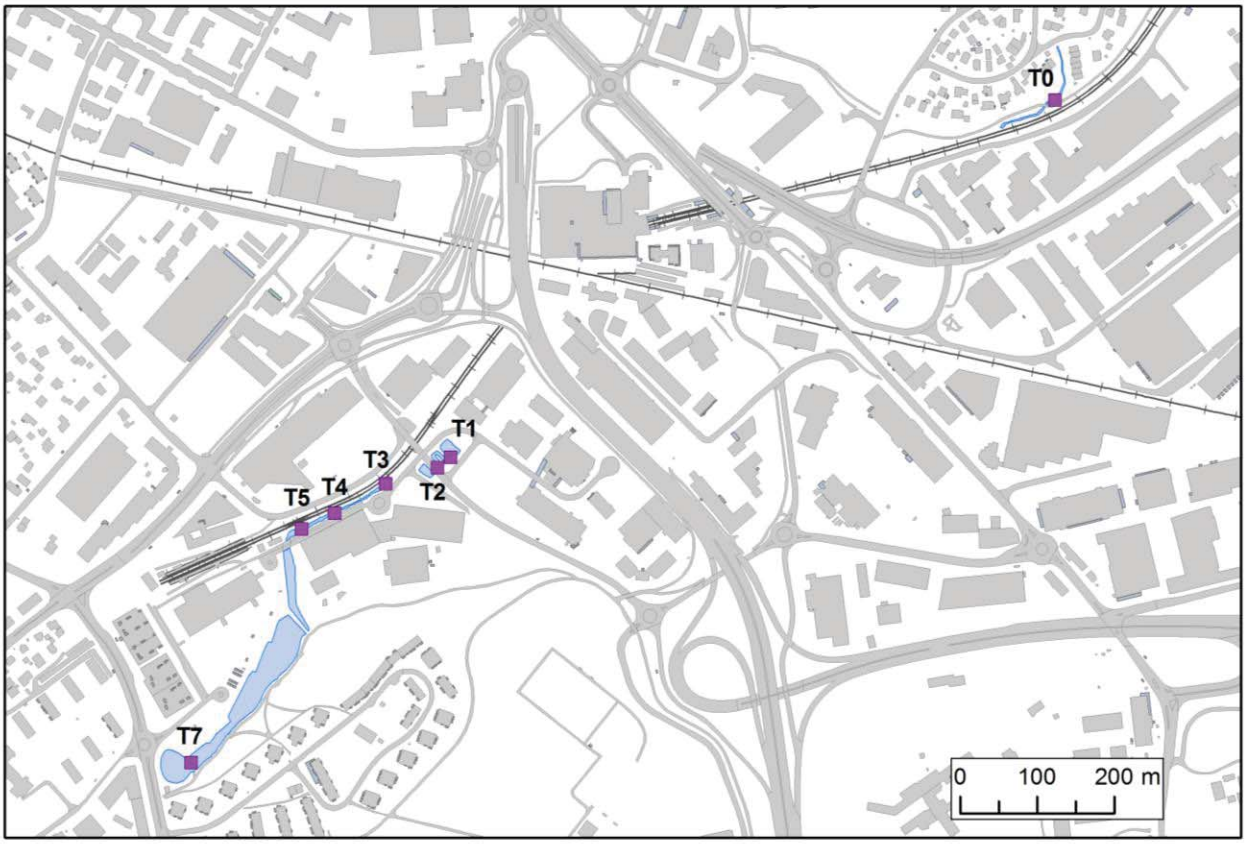


Fig. 1. Map showing sample locations at the restored area of Teglverksdammen in the stream Hovinbekken. Notice the culvert separating T0 from the restored reach. Map created by Karen Lie at The Norwegian Directorate for Civil Protection (DSB).

To collect macroinvertebrates, seven sampling sites were selected at Teglverksdammen (Fig. 1) (geographic coordinates in appendix A). As the sample sites in the restored reach at Teglverksdammen were culverted prior to restoration, data for species assemblages prior to restoration was not available.

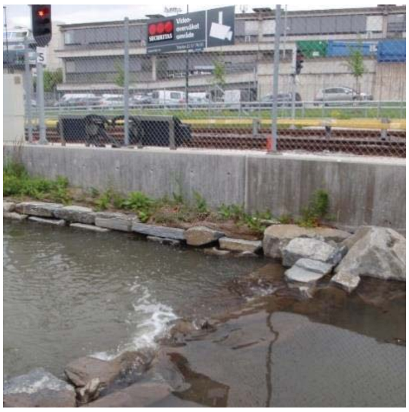
The sample sites at Teglverksdammen consisted mainly of areas with even streambeds, riffles and fast flowing water, situated between pools that were constructed throughout the restored reach (Fig. 2). The reference site (T0) was situated roughly 850 meters upstream, and is separated from the restored reach by an ~800 meters long culvert. Sites T1 and T2 were immediately downstream of the culvert exit. Sites T3 to T5 were located along the main reach. T7 was located downstream of the largest dam and a planted wetland.


T0


T1


T2


T3


T4


T5


T7

Fig. 2. Photos showing the Teglverksdammen samples sites in 2016.

(Photo credits: Therese Fosholt Moe, Karoline Myrstad and Susanna Burgess)

Site description – Akerselva

Akerselva is approximately 8 km long and drains roughly 250 km^2 of the forest area Nordmarka (Bækken et al., 2011). Akerselva is the largest stream in Oslo and was historically effected by contaminants from industry as well as sewerage (Tvedt & Svendsen, 2015). However, much of this pollution is no longer entering Akerselva, with less industry along its banks and a re-engineered storm-water drainage system to reduce sewerage overflows (Borgestrand, 2012). Akerselva drains out of the lake Maridalsvannet, which is the largest source of drinking water for Oslo. Being a source of drinking water, Maridalsvannet is managed according to a number of strict criteria, meaning the water entering Akerselva is expected to be unpolluted.

Akerselva is regulated, with a minimum flow of 1.5 m^3/s between 1st April and 31st November and at least 1.0 m^3/s the rest of the year (Bækken et al., 2011). As one progresses downstream, the surrounding landscape changes from a near pristine environment to a more urbanised one. The urban sections of Akerselva have a number of concrete embankments and fewer trees, however most of Akerselva is surrounded by a band of riparian vegetation. Additionally, a number of weirs, waterfalls and park areas are also located along Akerselva.

Seven sample sites, meeting similar criteria for flow and even streambed as at Teglverksdammen, were selected along Akerselva (Fig. 3) (geographic coordinates in appendix A). Care was taken to keep habitat type as similar as possible (Fig. 4). Sites AK1 and AK2 were located in the upper reaches of Akerselva, before the stream enters more urbanised areas. Sample locations AK3 to AK7 were located along a gradient of increasing urbanisation, with AK3 located near the area of Nydalen and AK7 located at Grønland, a neighbourhood near the city centre.

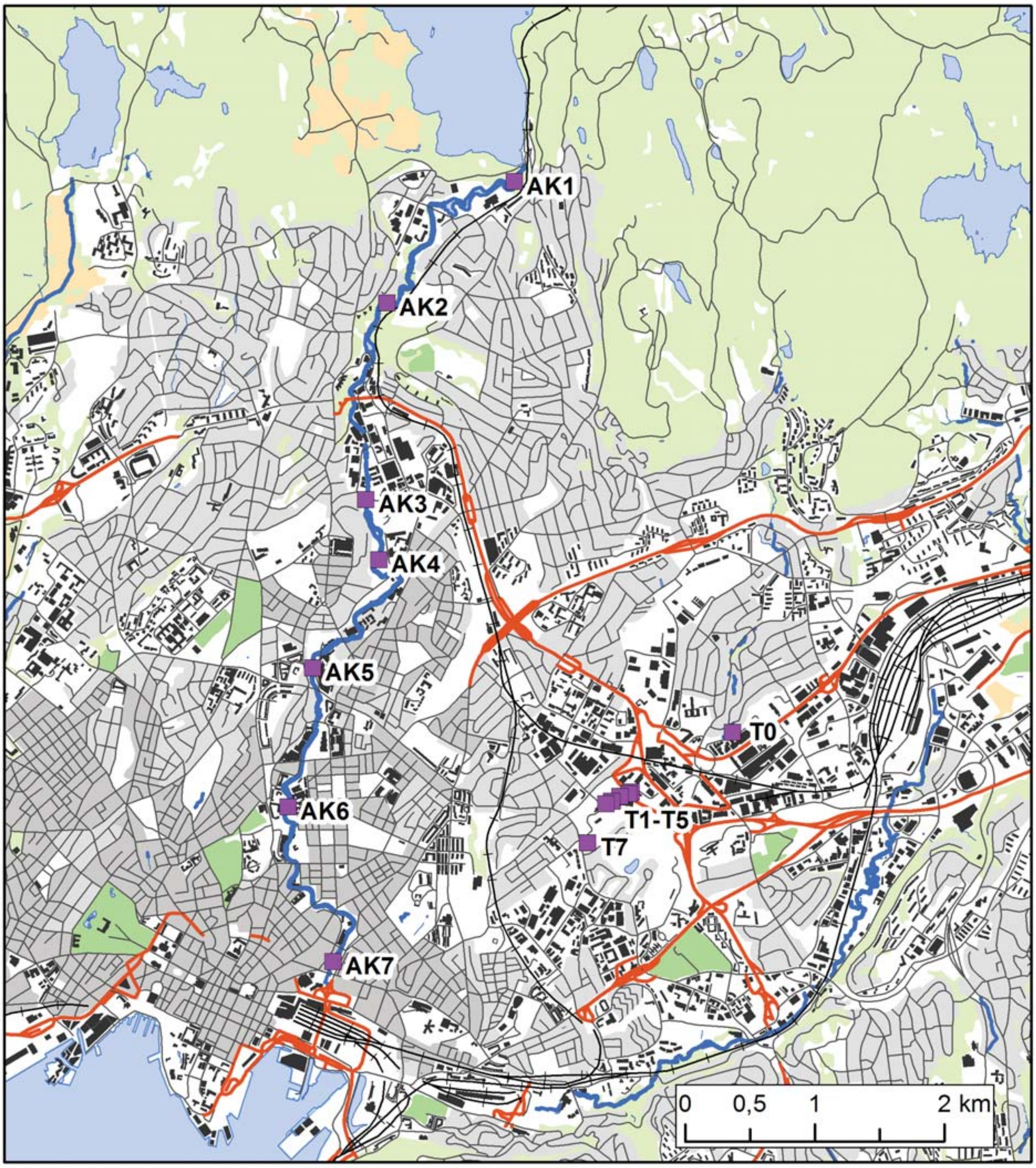
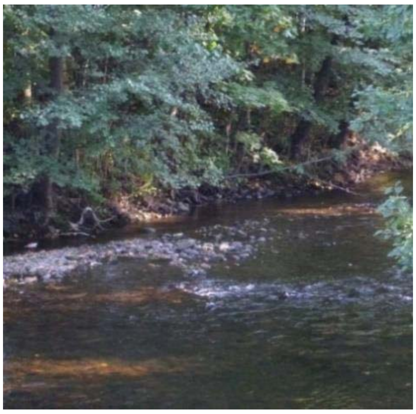


Fig. 3. Map of Oslo showing sample locations at Akerselva to the left and Teglverksdammen to the right. Map created by Karen Lie at The Norwegian Directorate for Civil Protection (DSB).

AK1

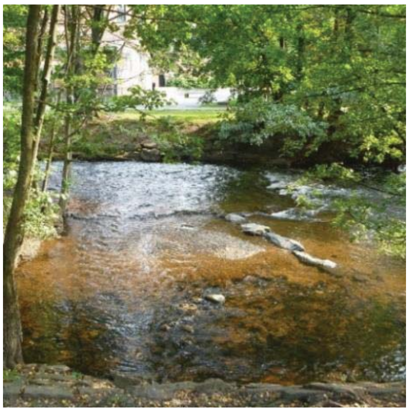
AK2



AK3

AK4

AK5



AK6

AK7

Fig. 4. Photos showing the Akerselva samples sites in 2016.

Sampling

All samples were collected using a Surber sampler (Fig. 5). The Surber sampler consists of a fine net mesh connected to a steel frame. This frame comprises an open bottom with enclosed sides. The frame is used to isolate a section of stream bed before sampling. The sides of the frame direct water flow into the net, and macroinvertebrates are retained in the base of the conical net. Macroinvertebrates were collected using a Surber sampler with a mesh size of 250 µm and a sampling area of 0.09 m^2 (30 cm x 30 cm). A review of the literature shows that Surber samplers are regularly used when sampling macroinvertebrates (Pedersen et al., 2007; Friberg et al., 2014; Verdonschot et al., 2015). The Surber sampler is well suited to sampling shallower streams, but also deeper water can be sampled, if care is taken.

Fig. 5. Photo of the Surber sampler used, illustrating its structure. Note enclosed sides and isolated section of streambed inside frame.

The following protocol, as described by Stark *et al*. (2001) and Grey (2013), was used when collecting samples: The area upstream of the sample location was left undisturbed, as the Surber sampler will collect macroinvertebrates that begin to drift. After establishing a seal between the sampler frame and the substrate and standing either downstream or to the side of the sampler, sample collection began. Sampling consisted of disturbing all sediment within the sampler frame by hand. The effort and duration of sediment disturbance was the same for all samples, with the sediment disturbed for one minute and to a depth of approximately 8 cm. When large objects, such as large stones, were encountered, the stone was brushed by hand, lifted and rolled to ensure that any macroinvertebrates on or under the stone were collected. Immediately after sampling, all macroinvertebrates retained in the net, including sediments, were transferred into clearly labelled glass jars and preserved with rectified ethanol.

Samples from Teglverksdammen were collected once a month, starting in mid-May 2016 and continuing to mid-November 2016, yielding samples covering a 7 month period from spring to autumn. Sampling from Akerselva started in early June, after which the remaining samples were collected in conjunction with sampling at Teglverksdammen. The two streams were normally sampled within a day or two of each other. The monthly period of sampling was chosen to facilitate the tracking of community changes as the restored reach of Teglverksdammen developed over time. Macroinvertebrate communities are highly variable, and may change as the seasons progress, most commonly showing changes in assemblages from spring to autumn (Šporka et al., 2006). Sampling through seasons facilitated the identification of a higher percentage of the taxa found in a particular reach.

Maintenance work caused a period of reduced flow at Teglverksdammen between approximately 11th August 2016 and 13th September 2016. This affected sampling in the restored reach. For August, no samples were collected from T1 to T7 as there was not sufficient flow to operate the Surber sampler. By September, water flow had largely been re-established, however site T7 was not sampled, as flow to this section had not yet been returned.

During October, a large amount of fine silt suspended in the water column was observed at the reference site and at the restored reach at Teglverksdammen. In November, a number of dead brown trout (*Salmo trutta fario*) were observed at the reference site. Post-mortem analysis by the Norwegian Veterinary Institute suggested that the gills had been clogged by fine sediments. As some construction work occurring further upstream was reported, this fine sediment was likely from the construction site. In contrast to the dead fish in the vicinity of the reference site, brown trout were seen spawning in the upper sections of the restored reach in November.

During sampling, a subjective assessment was done to determine the substrate sizes (sand, gravel, stone) at each of the sampling sites. This was done according to the scale in Wentworth (1922) (Table 1).

Table 1
Substrate sites, adapted from Wentworth (1922).

Silt	**Sand**	**Gravel**	**Small stone**	**Medium stone**
< 0,062 mm	0,062 – 2 mm	2 – 16 mm	16 – 64 mm	64 – 256 mm

Water quality measurements

Water quality measurements were taken at each sample site on the same day as macroinvertebrate sampling. For Teglverksdammen, this consisted of collecting 1 litre of water for chemical analysis to be conducted by Oslo's water and sewage department (Oslo Vann og Avløp). Water analysis included total organic carbon, total nitrogen and total phosphorus. Water chemistry sampling was conducted prior to macroinvertebrate sampling, as the disturbance of the sediment during macroinvertebrate sampling has the potential to influence the chemical analysis and result in a bias. Water samples were collected by submerging a freshly rinsed labelled plastic bottle upside down in the water and angling it to allow water to flow in. Water was not sampled from the surface, and the sediment was not disturbed, as it is these areas that are likely to result in false readings on the chemical analysis. Water conductivity was measured using a WTW Multi 3420 Set C, with sensor probe TC 925 at Teglverksdammen.

For both rivers sampled, Total Dissolved Solids, which is the sum of all dissolved ion particles and thus similar to the conductivity measurements, was determined using an Excelvan Digital TDS Meter. Finally, water temperature in degrees Celsius was measured for all sites.

Sample analysis

For analysing the macroinvertebrates, the sampling protocol of the Norwegian Institute for Water Research (NIVA) was used. This protocol requires analysing the entire sample, which results in all taxa in a sample being identified (Eriksen, Bækken & Moe, 2010). As this thesis investigates species richness, identifying all taxa was highly desirable. Under this sampling protocol, the abundance of plentiful taxa is extrapolated from sub-samples.

Prior to analysis, samples were washed in cold freshwater, using a sieve (mesh size: 250 µm). During washing, coarse material such as larger stones and twigs were washed and removed. The material retained in the sieve was transferred to a flat-bottomed container. Before dividing into sub-samples, the sample material was mixed to homogenise and randomise it, as washing may have resulted in organisms becoming clustered together.

Each sample was divided into eight sub-samples consisting of equal parts, following NIVA's sub-sampling protocols (Eriksen, Bækken & Moe, 2010). Of these eight sub-samples, one was randomly selected as the first to be analysed. In the first sub-sample, all individuals were identified and counted.

The second sub-sample was analysed in a similar way, however, taxa of which there were more than 50 individuals in the first sub-sample were not counted. This continued until all the sub-samples were analysed, each time not counting individuals of taxa/families when the total already counted was more than 50. For example, if a taxa reached a total of 50 individuals in sub-sample 4, it was no longer counted in the following sub-samples. After all sub-samples were analysed, the totals for those taxa of which there were in excess of 50 individuals was extrapolated. This method of analysing sub-samples has the benefit of being quicker than counting all individuals, and the entire sample is analysed, allowing for the discovery of taxa with few individuals.

Samples were analysed under a stereo microscope (Optika Lab 20). Macroinvertebrates were identified according to Hynes (1977), Edington & Hildrew (1995), Wallace, Wallace & Philipson (2003), Elliott & Humpesch (2010) and Dobson *et al*. (2012). Identification of specimens went down to species level, where possible. Only complete specimens were counted to prevent the occurrence of double-counting. Moulted skins were not counted. Only benthic macroinvertebrates were counted.

Data analysis

As not all macroinvertebrates could be identified to species level, all analyses were conducted using family levels. Biotic indices used for data analysis consisted of average richness counts and Shannon's Diversity Index (a measure of both diversity and evenness).

As a result of the maintenance work causing periods during which no samples could be collected at Teglverksdammen, and to prevent bias, August and September were excluded to create a homogeneous dataset when conducting comparative analyses between sites. However, when individual sites were analysed, the full period of available data was used. A homogeneous data set was also created when comparing Akerselva and Teglverksdammen, including only periods for which samples were collected in the same months and complete data sets existed.

Average Score per Taxon (ASPT) was calculated for each sample site according to Direktoratsgruppa (2015), which can be used to assign the site's ecological status (Table 2). The ASPT supplies the average sensitivity of macroinvertebrate families to organic pollution, and is based on the Biological Monitoring Working Party (BMWP) index (Armitage et al., 1983). The BMWP index takes into account the sensitivity of macroinvertebrates to pollution, with families receiving scores ranging from 1 to 10 (Zeybek et al., 2014). A score of 1 indicates high pollution tolerance while a 10 indicates a high sensitivity to pollution. The ASPT is calculated by dividing the BMWP score by the number of families present in the sample. The higher the final value, the less polluted the sample site.

Table 2
Organic pollutant metric based on ASPT. Adapted from Direktoratsgruppa (2015).

Condition	Natural condition	Very good	Good	Moderate	Poor	Very poor
ASPT Score	6.9	> 6.8	6.8 – 6.0	6.0 – 5.2	5.2 – 4.4	< 4.4

All statistical analyses were conducted in R Studio (R Core Team, 2013) using the "car", "mixlm", "agricolae" and "vegan" packages. All comparative analyses were done using a homogenous data set. Prior to modelling, the data was tested for homogeneity of variances using Fligner-Killeen and Levene's tests. Tukey's *post hoc* tests were conducted using an ANOVA to determine groups. Some of the data were not normally distributed, but ANOVAs tend to be robust against non-normality, and Kruskal-Wallis tests on the non-parametric data confirmed the results from the ANOVAs. Thus, only ANOVA results are shown in the thesis. All p-values below 0.001 are reported as "$p < .001$".

To compare macroinvertebrate assemblages between sites, non-metric multidimensional scaling (NMDS) was conducted, using Bray-Curtis dissimilarity from the R package "vegan". NMDS is an ordination technique that can be used to plot samples in ecology using a community dissimilarity matrix based on species composition (Hovanes, 2013). Communities that have very similar species compositions will appear as points near to each other whereas communities that differ will be placed further away from each other on the plot. The examination of community data using multivariate analysis such as NMDS provides a sensitive approach as it uses more of the multi-dimensional nature of ecological data (Dray et al., 2012 in Neale & Moffet, 2016).

Results

In the following sections, results for Teglverksdammen and Akerselva will be discussed separately.

Teglverksdammen

Water chemistry

Water chemistry varied greatly from month to month. This caused all ANOVA models to show no significant overall differences in water chemical variables between each individual sample site compared over time. Nevertheless, significant patterns occurred when models were conducted to determine changes as water progressed through the system in individual months.

For all months, with the exception of October, conductivity increased from T0 to T1 as water passed through the culvert separating these sites (Fig. 6). A similar pattern was revealed for Total Dissolved Solids. From May to August, conductivity declined as water progressed downstream through the restored reach, with the exception of T7, which showed an increase in July. In September, when there was no flow at T7, there was little change in conductivity measurements throughout the restored reach. For October and November, conductivity increased slightly as water progressed through the system. Similar patterns, though often more distinct, were observed for total nitrogen and total phosphorus.

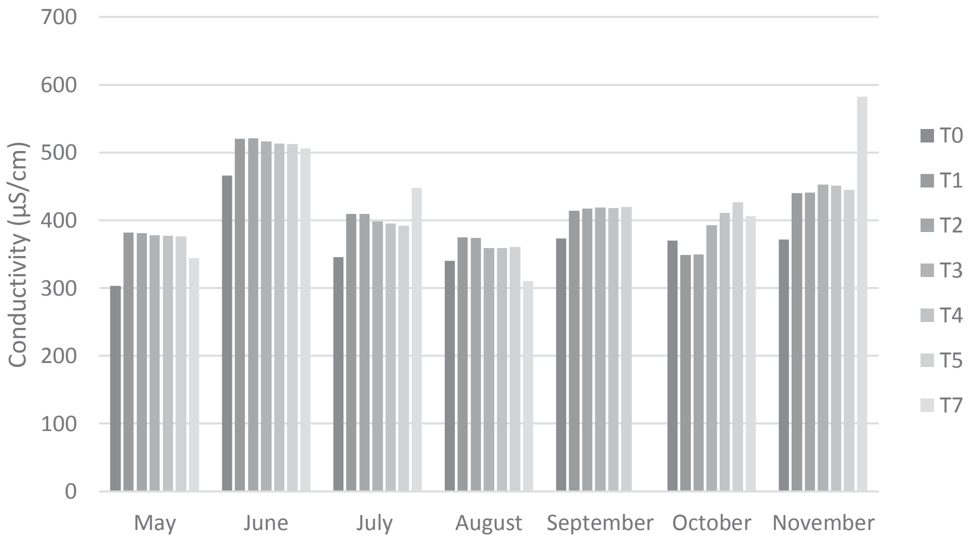


Fig. 6. Conductivity for the sample period at Teglverksdammen, plotted monthly to indicate changes in concentration as water flows through the system.

ANOVA showed significant differences in conductivity between months ($F = 17.4$, $df = 40$, $p < .001$). Tukey's *post hoc* testing indicated three groupings, with some overlap. In order of declining mean conductivity, the first group consisted of June and November, which had significantly higher mean concentrations. The second group consisted of November, September, July. The third group, which were the months with the lower means, consisted of the months September, July, October, May and August. This suggests that conductivity was highly variable at Teglverksdammen and no seasonal pattern was apparent.

Total nitrogen concentrations (Fig. 7) showed increases in 4 out of the 7 sampling periods between T0 to T1. Total nitrogen concentrations in May showed little change as water flowed through the restored system (T1 – T7). For the period June to August, total nitrogen decreased in concentration as water flowed through the system. As with conductivity, little change in total nitrogen concentration was evident in September and October. Sample site T7 showed a decrease in total nitrogen in October, indicating the dam was acting as a nitrogen sink. November exhibited a slight increase in concentration as water flowed through the system, with T7 showing elevated levels of nitrogen concentration. This suggested that the lake and associated wetland were a source of nitrogen during November.

There was a significant effect of months on the nitrogen concentration ($F = 15.3$, $df = 42$, $p < .001$). Tukey's *post hoc* testing indicated that July and November had significantly higher nitrogen concentrations, while August, September and October had the lowest. *Post hoc* testing showed that total nitrogen concentrations were highly variable from month to month, with no seasonal pattern evident.

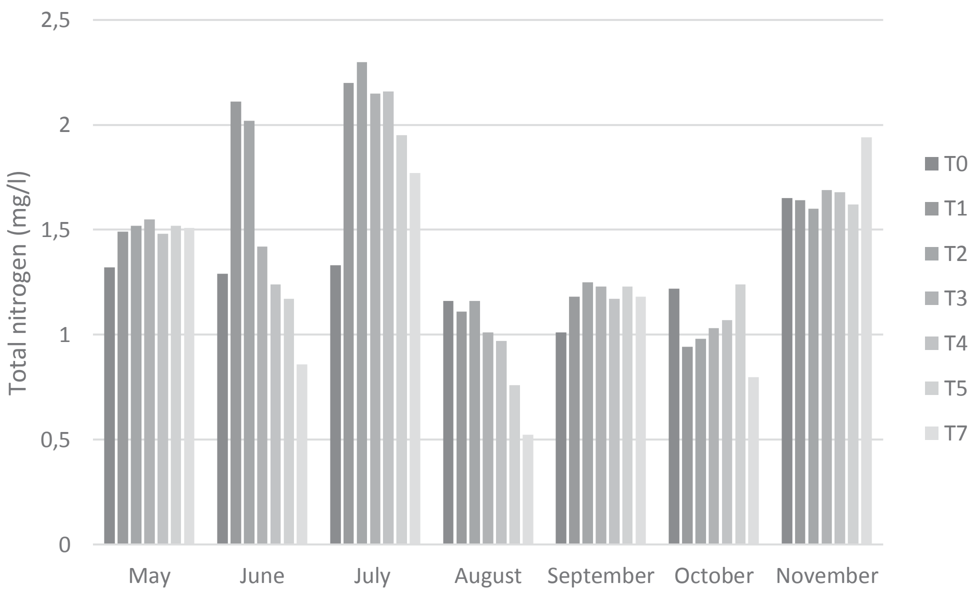


Fig. 7. Total nitrogen for the sample period at Teglverksdammen, plotted monthly to indicate changes in concentration as water flows through the system.

Total phosphorus (Fig. 8) was variable in May and no clear trend was evident. As was the case with conductivity and nitrogen concentrations, there was a substantial increase in phosphorus concentration as the water passed through the culvert between T0 and T1. For June to July, there was a trend of decreasing phosphorus concentration from T1 to T7. August showed little change in phosphorus concentration throughout the restored system. In September, phosphorus concentrations increased from T1 to T7. In October, there was an increase from T1 to T5 and a sharp decrease at T7 compared to upstream concentrations. For November, there was no clear trend in phosphorus concentration. However, in November, T7 was a source of phosphorus with a higher phosphorus concentration than anywhere sampled upstream. As with total nitrogen concentrations, the dam above T7 was a sink for phosphorus in October and a source in November.

ANOVA modelling suggested there was a significant effect of months on the phosphorus concentration ($F = 10.1$, $df = 42$, $p < .001$). Tukey's *post hoc* testing indicated three groupings, with highest phosphorus concentrations in October and July. The second group, in order of declining concentrations, consisted of July, June and September, and group three of the months of June, September, November, May and August. This suggests that total phosphorus concentrations were highly variable.

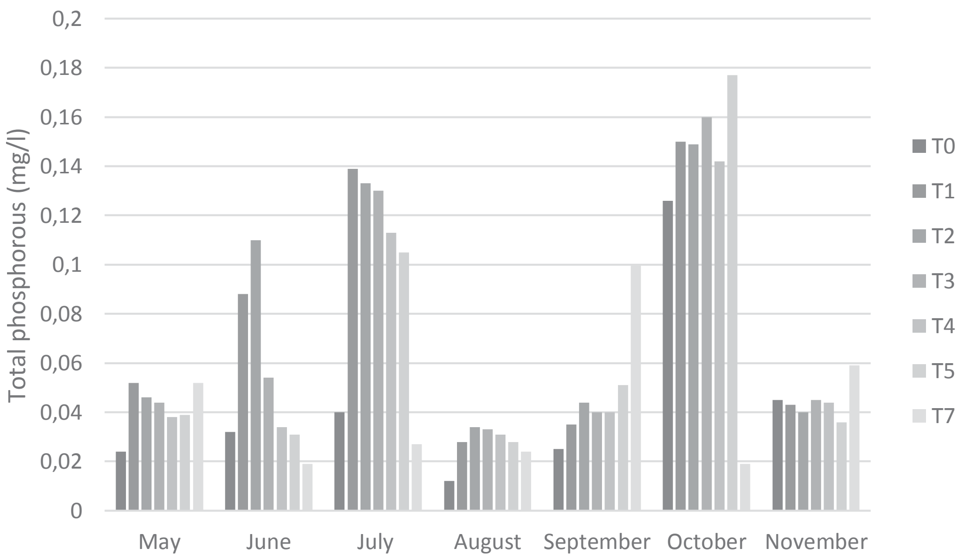


Fig. 8. Total phosphorous for the sample period at Teglverksdammen. Plotted monthly to show changes in concentration as water progresses through the system.

Total Organic Carbon (TOC) maintained relatively similar levels throughout the sampling period, with a clear spike in concentration in June between T0 and T1 (Fig. 9). This sudden increase rapidly dropped to lower levels by the time water reached T3, where it remained at similar levels for the rest of the reach. ANOVA modelling on TOC ($F = 1.4$, $df = 42$, $p = 0.24$) found no significant differences between months.

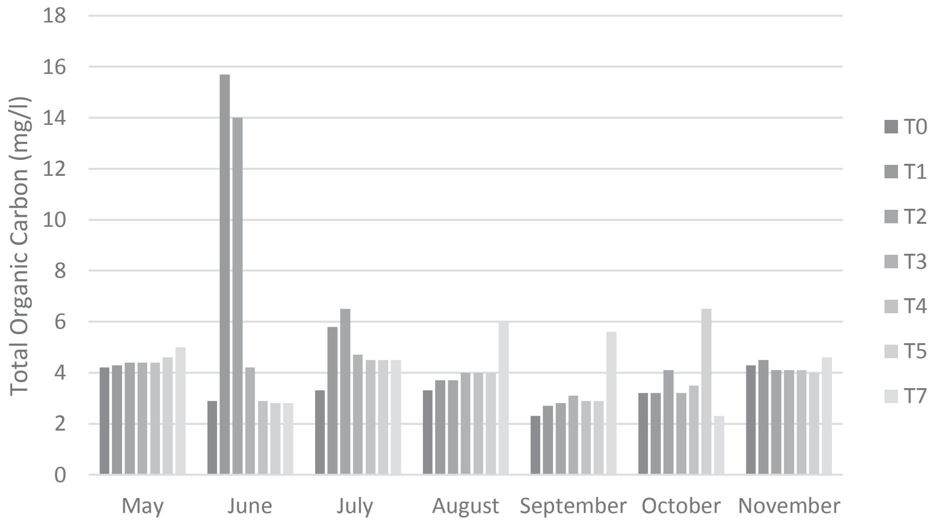


Fig. 9. Total organic carbon for the sample period at Teglverksdammen. Plotted monthly to show changes in concentration as water progresses through the system.

Water temperatures were highest in the summer months (June to September), with cooler temperatures in spring (May) and autumn (October and November) (Fig. 10). August, the month with no water flow, was the warmest month in the restored reach. The monthly pattern in water temperature was confirmed by the ANOVA model ($F = 116.4$, $df = 41$, $p < .001$) and Tukey's *post hoc* test. In the period from May to September, the water temperature increased as water progressed from T0 to T7, after which the water temperature started to decline from T0 to T7.

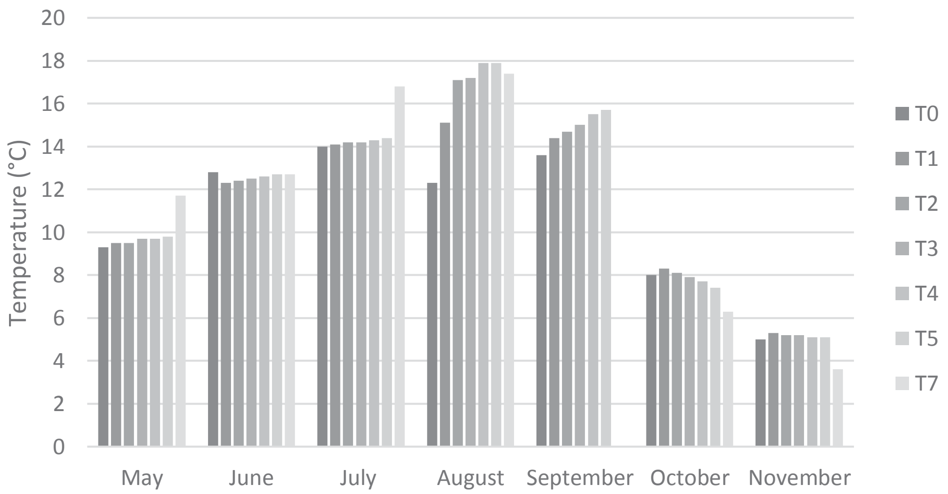


Fig. 10. Water temperature for the sample period at Teglverksdammen.

Throughout the sampled reach, sand, gravel and small stone contributed most to the substrate type, with little change in substrate exhibited throughout the restored reach (Table 3). The reference site appears to have had a somewhat more diverse substrate.

Table 3
Substrate size and composition at sample sites. Numbers in percentages.

Substrate sizes - Teglverksdammen					
Site	**Silt**	**Sand (0,063-2 mm)**	**Gravel (2-16 mm)**	**Small stone (16-64 mm)**	**Medium stone (64-256 mm)**
T0	0	20	10	30	40
T1	0	15	0	70	15
T2	0	15	0	60	25
T3	15	15	10	60	0
T4	0	15	0	60	25
T5	0	15	0	60	25
T7	30	40	0	10	20

Macroinvertebrate communities

A total of 25 macroinvertebrate families were identified at Teglverksdammen (see appendix B for full list). Throughout the study period, all benthic macroinvertebrates found in the restored reach were also found at the reference site, with the exception of individual Nematomorpha. The Dipteran order contributed most to diversity of taxa, with 8 Dipteran families identified. This was followed by 4 Trichoptera families (predominantly at the reference site), 3 Mollusca families and 2 Coleoptera families. One family from each of the following orders was also identified: Ephemeroptera, Plecoptera, Crustacea and Gastropoda. Contributing to diversity, but only identifiable to order were Oligochaeta, Ostracoda and Nematomorpha. Throughout the study period, Hydrachnidea were found in limited numbers. The restored reach was dominated by Oligochaeta and *Chironomidae* throughout the study period, and contributed most to the number of individuals. *Ceratopogonidae* was found in relatively low numbers scattered throughout the reach.

Concerning family richness, the reference site was the only site where representatives of all EPT taxa were present, and it maintained the highest level of family richness throughout the sampling period (Fig. 11). Species assemblages at Teglverksdammen in May consisted mostly of Oligochaeta and families belonging to the Diptera order (T0 to T7). Richness was similar throughout the restored reach. In May, T0 had small numbers of Ephemeroptera, Trichoptera, Plecoptera and Mollusca, contributing to richness. Only one Ephemeroptera *Baetidae* was found in the restored reach in May. *Empididae* and *Limoniideae* were only found at the first three sampling sites (T0 to T2) in May.

In June, a clear increase in family richness could be seen at T1. Individuals belonging to the Ephemeroptera order (*Baetidae)* were found at T2. Mollusca were widespread throughout the restored reach and remained so for the duration of the sampling period. In addition to the Dipteran families identified in May, *Pediciidae* were identified at T0, T1 and T2. The remainder of the Dipteran families showed little change from May.

In July, diversity at the reference site continued to increase, with additional individuals belonging to EPT taxa contributing to the increased family richness at T0. The restored reach indicated a slight increase in richness. Plecoptera *Leuctridae* was found at T1, the only time Plecoptera were found in the restored reach. The families belonging to Diptera maintained a similar pattern as for previous months, with *Simuliidae* identified at both T0 and T1. *Psychodidae* was found at T0 and also T2, the only time that *Psychodidae* was identified outside the reference site.

As sampling in the restored reach was not possible in August, no data exists on families found there, but the reference site was sampled. The reference site in August was similar to July, with an additional Trichoptera family (*Polycentropodidae*).

In September, all sites, apart from T1, showed an increase in average richness compared to July. A small number of Coleoptera were present at T0. *Ceratopogonidae* were only found at the upper three sampling sites in September. *Limoniidae* were no longer found in the reach, having been replaced by *Tipulidae,* which was found throughout samples. Both *Simuliidae* and *Psychodidae* were now found only at T0. No samples could be taken at T7 as water flow had not yet been restored.

In October, richness had again increased at T1 as well as at T7, remaining low for T3 to T5. Crustacea *Asellidae* were found in samples in October at T0 and T1. Ostracoda were found throughout the reach with the exception of T7. Plecoptera were no longer present at T0. Ephemeroptera *Baetidae* were again present at T1 and T2. *Pediciidae* were now also found at T7. Gastropoda were spread throughout the reach by this time.

By November, T1 and T2 began to resemble T0 with Ephemeroptera, Mollusca, Ostracods and Crustacea present. For the first time, Trichoptera *Hydropsychidae* was found in the restored reach at T2. Richness at T5 and T7 was at the highest levels for these sites, while sites T3 and T4 maintained low richness. In general, diversity was higher than at the start of the sampling period in May. Ostracods were found in the majority of sampling sites and were thus spread throughout the reach. Diversity of Dipteran orders through the system was lower in November, with only *Chironomidae*, *Ceratopogonidae* and *Tipulidae* found throughout the reach.

In summary, average family richness (Fig. 11) indicated a sustained increase at the reference site (T0), increasing from ten families in May to twenty families in November. Sites T1 and T2 also indicated a trend of increasing richness, with T1 and T2 exhibiting the highest richness in the restored reach. T3 to T5 showed a substantially smaller increase in richness over the sampling period. T7 indicated a slight increase in richness over time, with a final richness equivalent to T5.

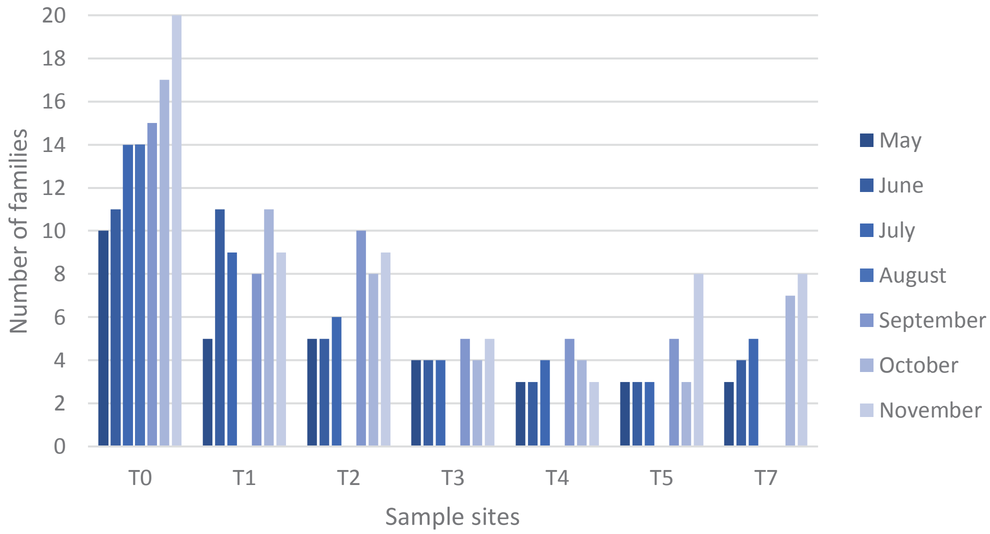


Fig. 11. Richness: total number of families found at each site during the sample period at Teglverksdammen. Note lack of data in August in restored reach due to lack of flow.

As far as population sizes are concerned, during May, the mean population size of Oligochaeta throughout the reach was 22 560 individuals per square meter (Fig. 12). The highest population of Oligochaeta occurred at T5 with a total of 43 200 individuals per square meter, and the lowest population occurred at T7 with a population of 580 individuals per square meter (see appendix C for monthly family abundance plots). Diptera *Chironomidae* numbers for May were highest between T0 and T2, while remaining low for the rest of the reach.

In June, Oligochaeta and *Chironomidae* underwent a population increase from May, with mean populations of 33 870 per square meter and 8 280 per square meter, respectively. The largest populations of both orders were observed at T1, while populations were lowest at T7.

A population increase of Ephemeroptera occurred at T1 and T2 in July. For the rest of the restored reach, the population of *Baetidae* was minimal throughout the majority of the sampling period, with July being the only month individuals were observed at T3 and T4. Populations of Oligochaeta and *Chironomidae* showed a decline compared to June.

In August, the reference site showed little change in population size. In September, the populations of Oligochaeta and *Chironomidae* showed significant reductions throughout the reach, including the reference site. As these were the dominant orders, the bar-graph indicating total population of all macroinvertebrates showed a sharp decline.

In October, populations of Oligochaeta and *Chironomidae* were still reduced, with mean populations of 750 per square meter and 1140 per square meter, respectively. Apart from T1, where Oligochaeta were dominant, *Chironomidae* remained the dominant order for sites T2 to T7. For November, populations remained low throughout the sampled reach with little change from October.

In summary, total populations of macroinvertebrates (Fig. 12) showed a large increase from May to June at the upper sites, after which population sizes showed a sharp decline and levelled off for September to November. The reference site also showed a sharp decline in population sizes.

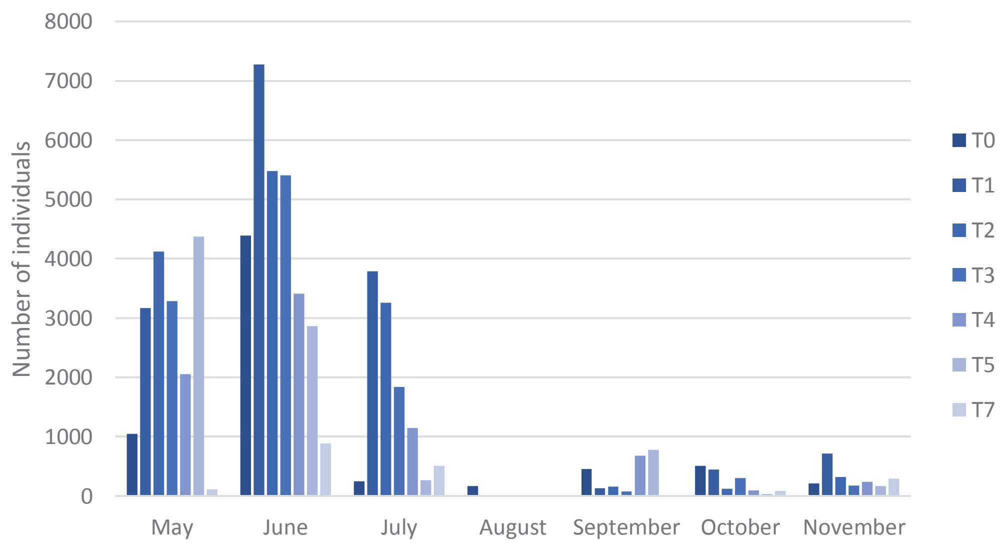


Fig. 12. Total number of individuals (population size) during the sample period at Teglverksdammen. Number of individuals per square meter were extrapolated from these numbers. Note lack of data in August in restored reach due to lack of flow.

Macroinvertebrate community models

All comparative modelling was conducted using homogeneous data, containing only months for which all sites could be sampled.

Levene's and Fligner tests showed that the assumptions for the ANOVA on the average family richness metric were met. A Kruskal-Wallis test was run on the data (chi-squared = 25.706, df = 6, p < .001), suggesting the sites were statistically different. An ANOVA was conducted, reporting a significant effect of sites on richness (F = 14.54, df = 28, p < .001, R^2_{adj} = 0.70). Tukey's *post hoc* testing on average richness suggested three grouping, with some overlap. The first group consisted of only T0, the second group consisted of T1, T2 and T7, which were the sites that had the highest mean family richness in the restored reach. The third group also included T2 and T7, in addition to T3 to T5. Within this third group, site T2 had the highest mean richness. The ANOVA model for Shannon's Biodiversity Index (F = 7.13, df =28, p < .001, R^2_{adj} = 0.52) showed a similar, though less pronounced pattern as the richness model.

There was a significant difference in macroinvertebrate population sizes between months (ANOVA F = 11.01, df = 30, p < .001), and a Tukey's *post hoc* test confirmed that June had the highest mean population, while October and November had the lowest mean populations.

Non-metric multidimensional scaling (NMDS), using Bray-Curtis dissimilarity, was conducted for the months May, June, July, October and November, to ensure a homogeneous dataset dataset (each month is shown as symbols from right to left in Fig. 13). A stressplot indicated little deviation, suggesting a successful ordination. The stress value (0.15) was below 0.2, indicating that the ordination summarised the observed distances among the samples in a satisfactory manner. The R^2 values were high (non-metric fit, R^2 = 0.98, linear fit, R^2 = 0.88), suggesting the ordination explained a large degree of the variation in the data.

The NMDS ordination (Fig. 13) show that the reference site (T0) had a different family assemblage compared to the restored reach (T1-T7), mainly due to the presence of Trichoptera families at the reference site. Site T1, the restored site closest to the reference site, most closely resembled the reference site. Sites T2-T5 showed increasing dissimilarities with increasing distance from the reference site. Site T7, which is the outlet of Teglverksdammen, showed a family assemblage more closely resembling the upper parts of the restored reach.

The NMDS ordination indicated that all sites move from right (May) to left (November), suggesting that assemblages were changing in similar directions in the NMDS space during the year. All the sites developed in much the same way to each other.

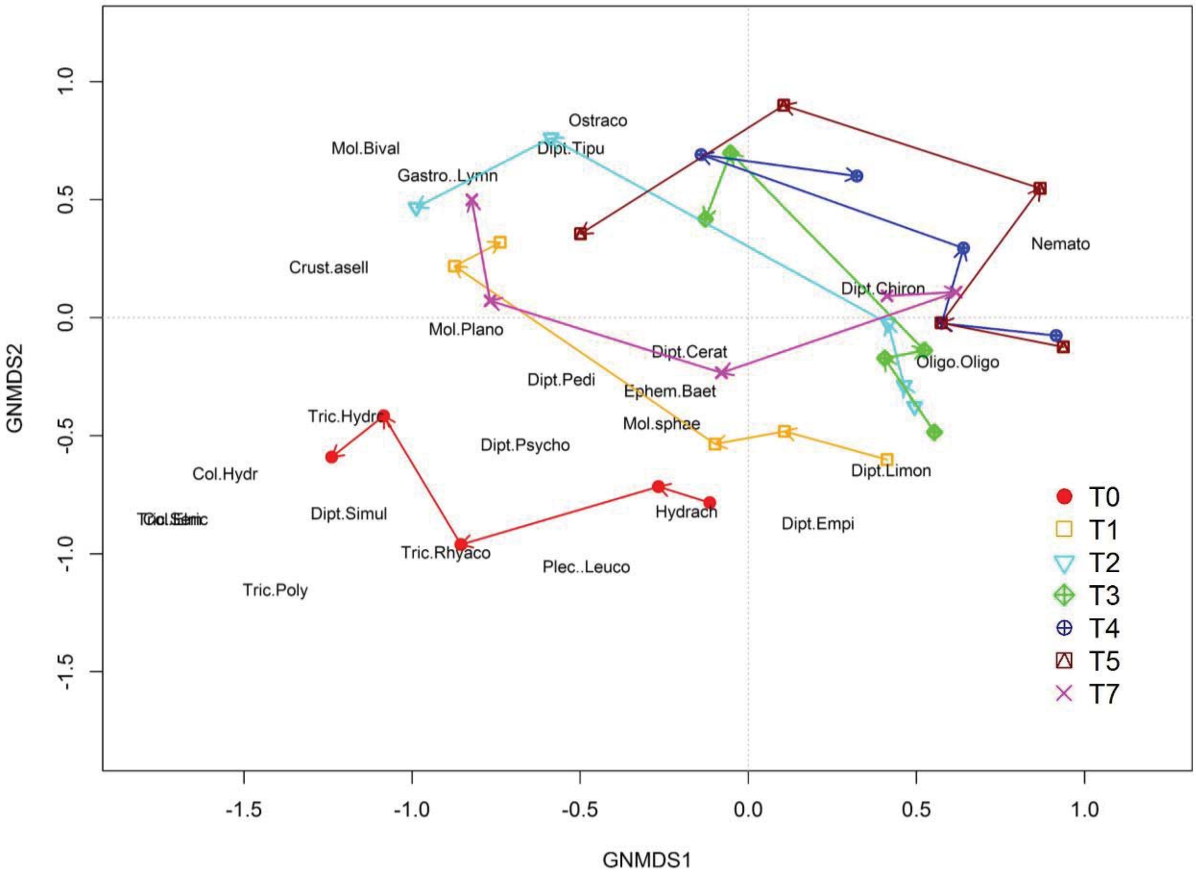


Fig. 13. NMDS ordination plot using homogenous data indicating family assemblages for the sampling periods May, June, July, October and November at Teglverksdammen. All sites show a change from right to left in the ordination plot, suggesting similar changes in assemblages may be occurring.

When plotting the mean NMDS scores from the above-mentioned ordination for the period prior to flow cease (May, June and July), and again for the period after which flow resumed (October and November), there were clear differences in assemblages for all sites (Fig. 14), including the reference site. Each site showed changes in a similar direction and distance, suggesting all changes in assemblages were of a similar magnitude.

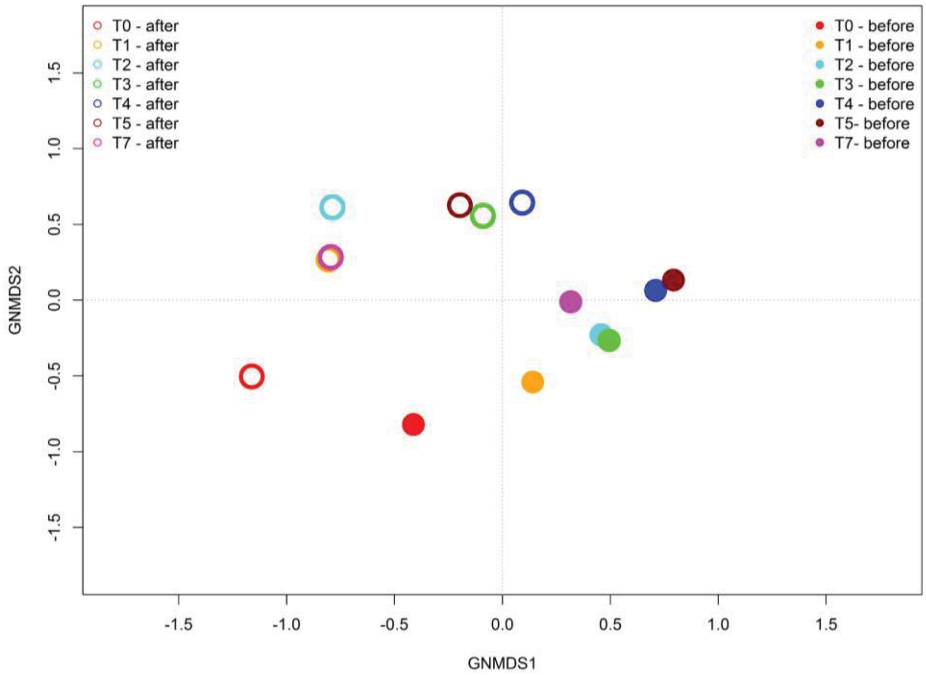


Fig. 14. NMDS ordination plot using homogenous data showing the mean family assemblages before (May, June and July) and after (October and November) flow cease.

Average score per taxon

The ASPT score (Fig. 15) stayed relatively stable at T0 over time, with a slight decline towards the end of the sampling season. Most of the sites in the restored reach showed similar values for May. From this point in May, the ASPT scores for all restored sites showed an overall increase as time progressed. Sites T1 and T2 showed the highest mean ASPT scores in the restored reach. Site T1 showed a large increase in ASPT scores for the first three months, with the ASPT score for July being at a similar level to that reported for the reference site. Site T5 maintained similar scores for the first three months, only showing an increase in September.

Levene's and Fligner tests indicated that the assumptions for the ANOVA model were met. A one-way ANOVA analysis was conducted using the ASPT score and sample site. The ANOVA indicated that there was a significant difference in means for sites ($F = 8.35$, $df = 28$, $p < .001$). Tukey's *post hoc* testing for ASPT showed no significant differences for sites T1 to T7, but a significant difference between T0 and all the downstream restored sites.

The mean ASPT score for the reference site was 4.32, while the restored reach had a substantially lower mean score of 2.36 over the full sampling period. These mean scores in ASPT classified the entire reach as very poor according to Direktoratsgruppa (2015), suggesting high levels of organic pollutants affecting the stream (Table 2). The reference site did have periods where it could be categorised as poor.

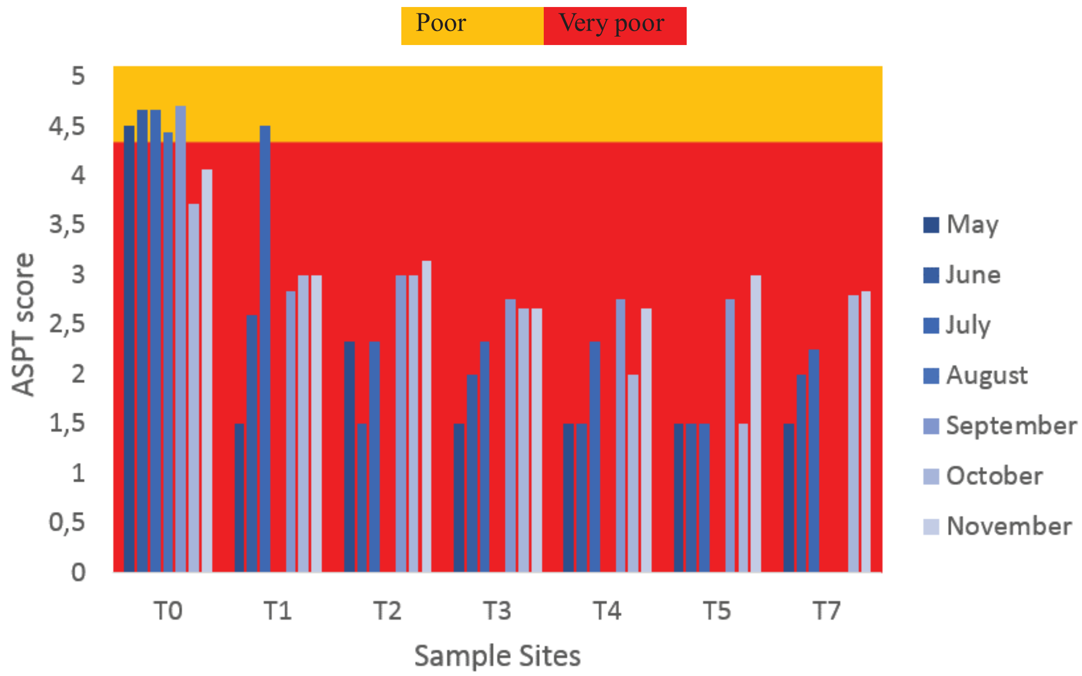


Fig. 15. Average score per taxon (ASPT) at Teglverksdammen.

Akerselva

As analysis of Akerselva was not the main goal of this thesis, it will be discussed in less detail than Teglverksdammen.

Water chemistry

As the conductivity meter was not used at Akerselva, Total Dissolved Solids (TDS) has been used (Fig. 16). A linear regression model on the Teglverksdammen data showed that TDS and conductivity were strongly correlated $p < .001$ and an adjusted R^2 of 0.96). At Akerselva, throughout the sampling period, TDS increased downstream. Site AK1 showed little variation in TDS, with a mean TDS of 10.5 ppm. AK2 showed somewhat more variation than AK1, most notably in November, though this variation is slight. Sites AK3 to AK7 showed most variation, and a clear trend of increasing TDS, with highest measurements noted in July and November. An ANOVA on TDS at Akerselva indicated that there was a significant difference in sites ($F = 5.2$, $df = 35$, $p < .001$). Tukey's *post hoc* testing showed that AK7 was grouped separately from AK1, with AK7 having the highest mean TDS and

AK1 the lowest mean confirming TDS increased downstream. The mean TDS score at Akerselva (17 ppm) was clearly lower than the mean score at Teglverksdammen (192 ppm).

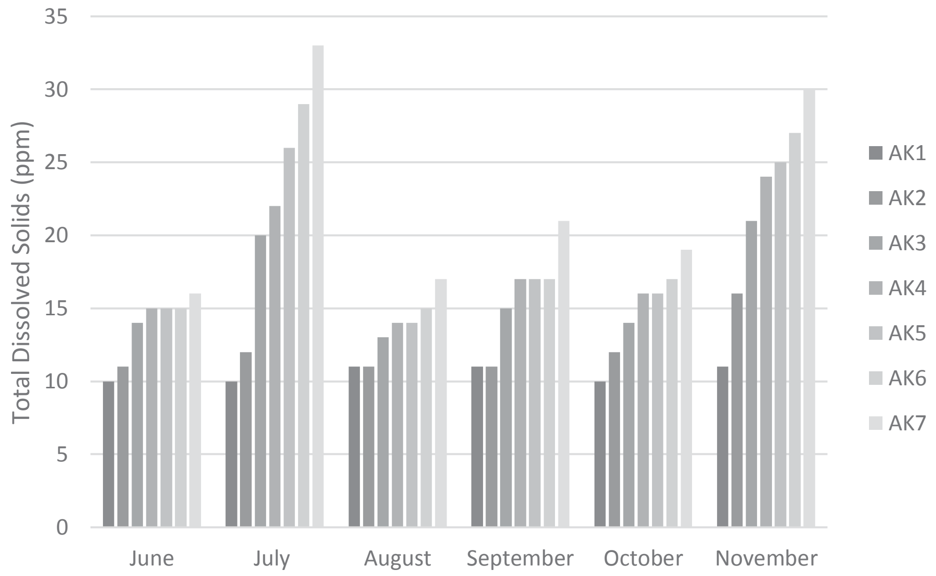


Fig. 16. Total Dissolved Solids (TDS) at Akerselva. Plotted monthly to show changes in TDS as water progresses through the system.

For individual months, as one progresses from AK1 to AK7, the temperature readings for Akerselva remained relatively stable with little variation (Fig. 17). ANOVA modelling found a significant effect of months on water temperature ($F = 655.5$, $df = 36$, $p < .001$). Tukey's *post hoc* testing indicated that July and August were the warmest months, followed by June and September, with October and November being the coldest two months. Seasonal water temperatures were thus confirmed.

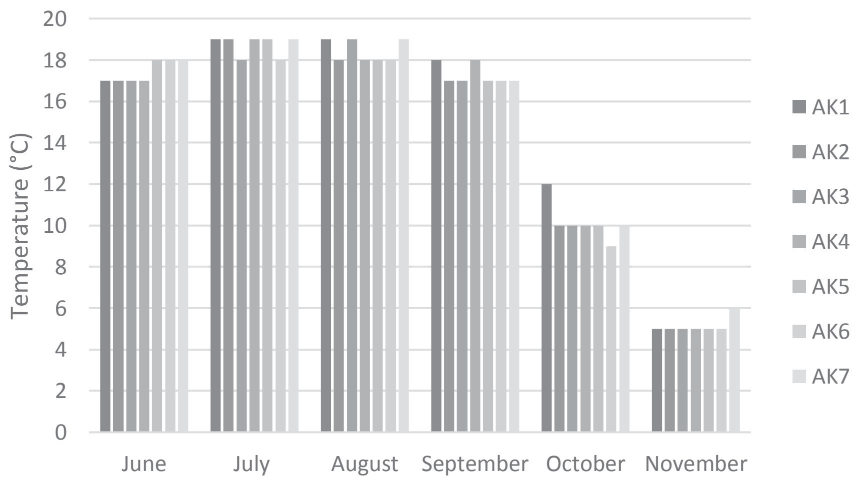


Fig. 17. Temperature fluctuations at Akerselva over the sample period.

Sediment size at Akerselva was somewhat variable, though no silt and little fine sand was present, with small stones being the most common sediment (Table 4).

Table 4
Substrate size and composition at Akerselva sample sites. Numbers in percentages.

Substrate sizes - Akerselva					
Site	Silt	Sand (0,063-2 mm)	Gravel (2-16 mm)	Small stone (16-64 mm)	Medium stone (64-256 mm)
AK1	0	10	30	30	30
AK2	0	0	20	40	40
AK3	0	0	20	50	30
AK4	0	20	40	40	0
AK5	0	0	30	50	20
AK6	0	0	30	50	20
AK7	0	0	40	40	20

Macroinvertebrate communities

Family assemblages for Akerselva were more diverse than at Teglverksdammen. A total of 32 families were identified at Akerselva (see appendix D for full list). Trichoptera contributed most to diversity of taxa at Akerselva, with 8 Trichoptera families identified. This was followed by 6 Diptera, 5 Ephemeroptera, 3 Plecoptera and 2 Mollusca. One family from each of the following orders was identified: Gastropoda, Coleoptera, Asellidae, Hydrachnidae and Hirudinea. Also contributing to diversity, but only identifiable to order, were Oligochaeta, Nematomorpha and Ostracoda. Fewer Diptera families are present in Akerselva than in Teglverksdammen. As with Teglverksdammen, *Chironomidae* were the most abundant Dipteran family, though the population sizes were smaller.

In June, Diptera were abundant throughout the river, with a mean *Chironomidae* population of 5240/m^2. AK1, which is immediately downstream of lake Maridalsvannet, had a sizeable population of Mollusca (see appendix E for family plots). Continuing downstream, diversity of families decreased (Fig. 18), with a notable decrease in Plecoptera abundance. The only families found in abundance at AK7 were Oligochaeta and Diptera with minimal Ephemeroptera and Trichoptera present.

For July, diversity at AK1 remained high. Throughout the reach, all samples indicated an increase in Ephemeroptera and Trichoptera populations, notably for *Baetidae* and *Hydropsychidae*. Diptera were dominant at all sites except for AK1, where Mollusca were dominant. Families showed an increase in richness, for example, *Ephemerellidae* and *Rhyacophilidae* were present for the first time in samples. A trend of slight decline in richness continued downstream, with AK7 again showing the lowest family richness.

August indicated a decline in population size for both Diptera and Oligochaeta throughout the reach. Mollusca remained dominant at AK1. For family richness, the majority of sites still resembled those reported for July, with little overall change.

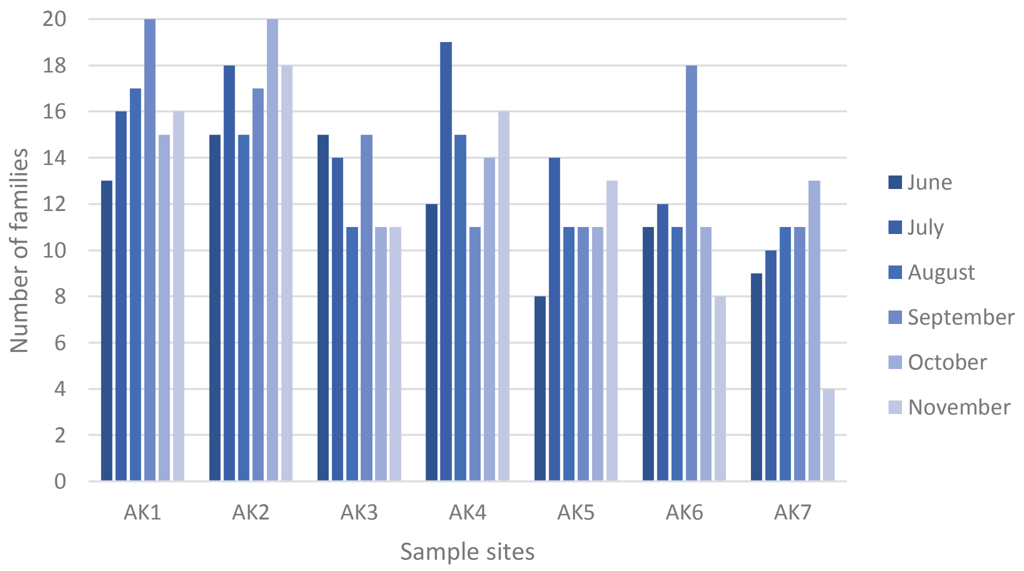


Fig. 18. Total number of families during the sample period at Akerselva

September samples indicated an increase in Trichoptera *Hydropsychidae* populations throughout the sites sampled. Ephemeroptera populations remained relatively unchanged, while Plecoptera numbers had declined compared to August. However, *Heptageniidae* populations showed an increase. *Chironomidae* populations remained stable, while *Empididae* populations increased. AK1 showed the highest level of family richness, with the observed trend of declining richness continuing downstream. Family richness of Ephemeroptera remained mostly unchanged throughout the reach compared to August.

October indicated relatively similar patterns as September, but for sites AK5 to AK7, population numbers were reduced. The number of Ephemeroptera identified in samples had increased, suggesting a population increase. Oligochaeta numbers also appeared to have increased. EPT taxa were found throughout the reach with the exception of AK7, which lacked any Plecoptera.

For November, Diptera numbers began to increase, most notably for *Chironomidae* and *Empididae*. Plecoptera populations increased compared to October. Richness for AK5 to AK7 declined from

October, with only Oligochaeta and Diptera identified at AK7, the lowest richness identified in the sample period.

In summary, in June populations were somewhat lower and family richness was lower. The reach was dominated by Oligochaeta and Diptera, though EPT taxa were already present. By July, Diptera numbers were still high, but Ephemeroptera populations were beginning to increase. By August, populations were generally not very large, but the diversity of families throughout the reach had increased. In September, Trichoptera numbers had increased, while Ephemeroptera numbers had mostly stabilised. By October/November, numbers of EPT taxa were mostly similar to September, however Oligochaeta and Diptera numbers began to increase again.

The upper two sites, which are situated in near-natural habitat, had the highest scores for both family richness and Shannon's Biodiversity Index. AK3, which was located at Nydalen, and is the first sampling site in a heavily urban environment, showed a clear decline in richness and Shannon's Biodiversity Index compared to upstream sites. This trend continued throughout the sampling period, with richness declining as one progresses downstream.

After performing successful Fligner and Levene's tests, ANOVAs were conducted on average richness ($F = 5.35$, $df = 35$, $p < .001$) and for Shannon's Biodiversity Index ($F = 6.64$, $df = 35$, $p < .001$). The ANOVA and associated Tukey's *post hoc* test for Akerselva confirmed that there was a significant decrease in richness and Shannon's Biodiversity Index between the upper sampling sites and the lower sampling sites situated near the city centre.

Average score per taxon

ASPT scores for Akerselva were generally higher than those for Teglverksdammen. ASPT in Akerselva appeared to show a slight decrease progressing downstream (Fig. 19), with AK7 showing the lowest recorded score of 1.5 in November. The sample site AK1 had a mean ASPT score of 5.15, resulting in a poor categorisation. The second sample site (AK2) had a mean ASPT score of 5.57, categorising it as moderately polluted. The lower two sites (AK6 and AK7) both had a mean ASPT of 4,47, giving them a poor categorisation.

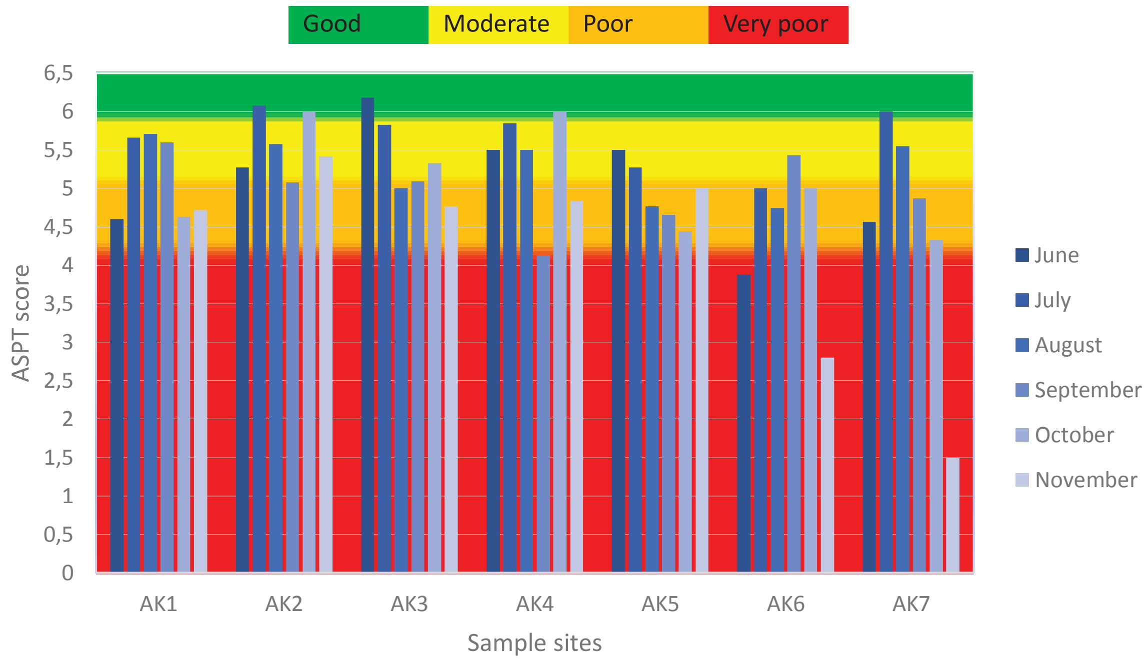


Fig. 19. Average score per taxon (ASPT) during the sample period at Akerselva.

NMDS for Akerselva and Teglverksdammen

To compare species assemblages between Akerselva and Teglverksdammen, another NMDS was conducted using a homogeneous data set from both these streams with June, July, October and November, as these were the months for which both reaches had data sets with all sites sampled. The resulting stress value (0.18) was below 0.2, suggesting a successful ordination. The ordination also had a high R^2 value (non-metric fit, $R^2 = 0.97$, linear fit, $R^2 = 0.83$) suggesting it explained a large degree of variation found in the data.

The NMDS placed Teglverksdammen and Akerselva in two separate locations in the NMDS space (Fig. 20). The distance between them is indicative of a large difference in assemblages between the two streams.

The only site at Teglverksdammen that closely resembled a section of Akerselva was the reference site. T0 most closely resembled AK6, which was close to the city centre. The site positioned furthest downstream at Akerselva (AK7) showed large fluctuations in species assemblage over the period analysed, but was relatively close to Teglverksdammen in terms of species assemblages.

The family assemblages at Akerselva tended to stay grouped quite close to one another throughout the period analysed, indicating little change in assemblages over the sample period and thus over seasons. However, the lowest and thus most urbanised site in Akerselva showed more changes in assemblages. Similarly, the family assemblages at Teglverksdammen showed much change over the period analysed.

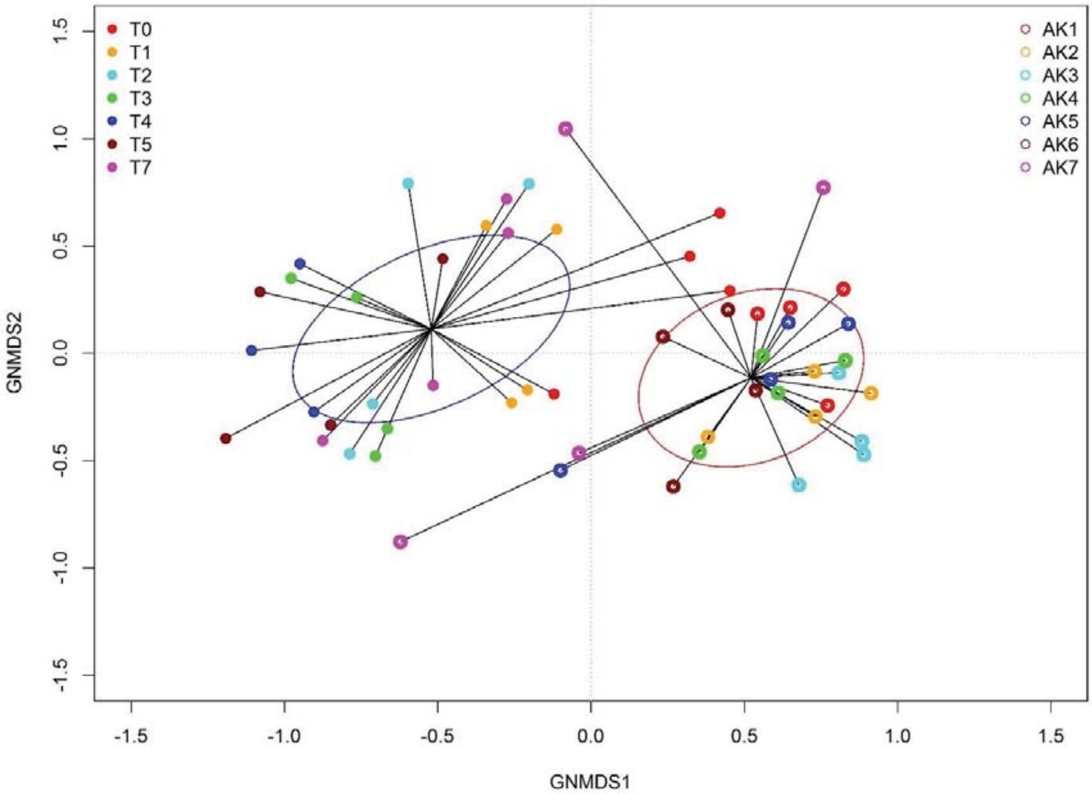


Fig. 20. NMDS plot on comparative data sets showing species assemblage comparisons between Teglverksdammen and Akerselva for the months June, July, October and November. Each point marks an individual month for the respective sites, with Teglverksdammen to the left and Akerselva to the right.

Discussion

Stream deculverting is at the far end of the spectrum of stream restoration options, representing a dramatic and near immediate change in the appearance and morphology of a stream (Neale & Moffett, 2016). As this thesis investigates a new habitat at Teglverksdammen, the macroinvertebrates reported will have arrived recently at the restored reach (Winking et al., 2014).

Teglverksdammen

Water chemistry

Large variations were observed from month to month in conductivity (Fig. 6), total nitrogen (Fig. 7), total phosphorus (Fig. 8) and total organic carbon (Fig. 9). This is likely due to Hovinbekken being culverted for much of its reach, and being situated in an urban environment. Storm-water run-off in urban environments is highly variable due to increased transport by drainage systems (Walsh et al., 2005). Urban drainage systems, including culverts, result in the direct transport of nutrients and pollutants to streams, with little terrestrial processing and removal (Hatt et al., 2004; Beaulie et al., 2014). Due to a large degree of culverting, Hovinbekken likely has little capacity to process organic pollutants, potentially causing the large variation in chemistry readings observed.

Culverting or piping of streams results in impacts downstream, such as increased nutrient inputs (Kaushal et al., 2008). This appears to be occurring in the culvert separating the restored reach from the reference site. The increase in concentrations of total nitrogen, total organic carbon and total phosphorus between the reference site and the restored reach is suggestive of some inflow or leak occurring inside the culvert. This potential source of pollutants is likely to reduce the overall success of the restoration. The additional pollutants may reduce the nutrient removal rate of the restored system by exceeding the nutrient demand. Variations in water chemistry and high levels of pollutants have been shown to decrease biodiversity in streams (Paul & Meyer 2001; Walsh et al., 2005).

Total nitrogen and total phosphorus concentrations showed a decrease in concentration from T1 to T7 in the spring and summer months, and an increase in concentration in the autumn months (Fig.7 and Fig. 8). Phosphorus and nitrogen are taken up and retained in sediments and the biota in the summer months when biotic demand is high, while these nutrients are released in autumn and winter when accumulated material decays and biotic demand declines (Mainstone & Parr 2002; von Schiller et al., 2008).

It has been suggested that slowing the flow of water may be vital for decreasing nitrogen and phosphorus concentrations in streams (Mainstone & Parr 2002; Kaushal et al., 2008). The number of small dams, which slow water flow through Teglverksdammen, should thus contribute to the removal of nitrogen and phosphorus. While there is little data on denitrification rates of restored streams, denitrification by bacteria in stream sediments is an important process for nitrogen removal

(Mulholland et al., 2008; Klocker et al., 2009). The decline in nitrogen concentrations may partly be due to bacterial denitrification.

Water chemistry results suggest that the first hypothesis is confirmed: water quality seemingly improves as water progresses through the system, at least in the growing season. As the restored ecosystem continues to develop, it is likely that ecosystem functioning will improve, leading to increased removal of nitrogen and phosphorus during the growing season. Removing the influx of nutrients in the culvert may further improve the purification capabilities of the restored reach. Lower concentrations of nutrients will result in a larger percentage of the nutrients being processed in the restored reach.

Water temperatures at Teglverksdammen show seasonal changes (Fig. 10), following the seasonal trends in mean monthly air temperature. This variation indicates that Teglverksdammen has little groundwater input, as streams with groundwater inputs tend to maintain stable temperatures (Allan & Castillo, 2009). The small dams increase water retention time, leading to increased warming. As the small stream has quite a low thermal mass, there will be rapid warming and cooling over the seasons. This may partly explain why Plecoptera, which tend to prefer cool water, were absent (apart from one individual) from the restored reach (Wenger et al., 2009).

Substrate

The substrate sizes and types do not differ to a large degree between the restored sites at Teglverksdammen, and differences in substrate is unlikely to be affecting the rates of colonisation in the restored reach (Table 3). The substrate at the restored section of Teglverksdammen shows little heterogeneity, and is less diverse than that at Akerselva (Table 4). Restoration may have little effect on biodiversity if the restoration does not include sufficient structural heterogeneity (Beisel, 2000; Lepori et al., 2005). A more diverse substrate increases the variability of habitats available, and this lack of substrate heterogeneity at Teglverksdammen may reduce macroinvertebrate richness.

Colonisation

The upper restored sites (T1 and T2) generally had higher family richness (Fig. 11) and population sizes (Fig. 12) than downstream restored sites. T1 also had the assemblage most closely resembling that of the reference site (Fig. 13). These results suggest that colonisation occurred via drift, with the highest rate of colonisation evident at the two upper restored sites. That all the families found in the restored reach were also found at the reference site, further indicates that colonisation occurred via drift. Also, other studies have shown that colonisation of new habitats occur primarily by drift, with up to 80 to 90% of colonisers arriving in this way (Williams & Hynes 1976; Gore, 1982).

Under normal conditions, the distance that organisms drift in one bound is not very far (Gore, 1982). Once an organism had drifted into a culvert, however, it is possible that it continues to drift as it tries to find a more suitable habitat. Drift over longer distances has been reported when organisms attempt to avoid unfavourable habitats (Brittain & Eikeland, 1988). This may explain the higher diversity at sites T1 and T2, as these are the first suitable habitats to be encountered after drifting through the unfavourable environment of the culvert, and they were thus the first to be colonised.

Sites T1 and T2 had relatively high numbers of Ephemeroptera compared to downstream sites, and this is indicative of colonisation occurring via drift, which is the primary way of dispersal for this group (Brittain & Eikeland, 1988). Further support for colonisation occurring via drift is indicated by the decreasing mean in richness and Shannon's Biodiversity Index, as well as reductions in population sizes, at the downstream sites. This indicates that the reference site acts as a source population, and that the lower restored sites were simply not yet fully colonised. However, *Chironomidae*, an early coloniser often found in drift and with several life cycles a year, was highly abundant throughout the restored reach, suggesting that *Chironomidae* have successfully colonised the entire restored reach via drift (Williams & Hynes, 1976, Arango, James & Hatch, 2015).

As far as aerial dispersal is concerned, it can be hampered by culverts, due to the fact that most flying macroinvertebrates use streams as corridors for dispersal (Blakely et al., 2006; Parkyn & Smith, 2011). This may explain why colonisation via aerial dispersal from nearby streams, such as Akerselva, did not seem to appear to any extent in this study; only families also found at the reference site were observed in the restored reach at Teglverksdammen. Colonisation by aerial dispersal from distant sites is possible, as flight distances of up to 20 km by winged adults has been documented (Parkyn & Smith, 2011). However, Blakely *et al*. (2006) found that, in urban environments, dispersing adults encounter multiple barriers, which may reduce dispersal distance and thus colonisation success. Flying stages of aquatic invertebrates may eventually colonise the restored reach in Teglverksdammen from nearby streams, though this appears not yet to have occurred.

These results suggest that the second hypothesis is met, that colonisation of the deculverted reach appears to have occurred predominately via drift. While the initial colonisation of invertebrates may be rapid, it may take substantially more time for the restored stream to reach maturation, i.e. when the species composition of the restored site resembles that of the source site (Winking et al., 2014; Arango, James & Hatch, 2015). The findings reported here are for initial colonisation, and it is expected that over time, richness will further increase.

The implications of this result is that species assemblages available to colonise the restored site are limited to those found at the reference site. Colonisation by macroinvertebrates is determined by their presence in the local species pool, as well as dispersal constraints such as in-stream barriers and distance between locations Lake, Bond & Reich, 2007; Tonkin et al., 2014). The NMDS ordination showed that macroinvertebrate assemblages at the uppermost restored site were most similar to those at the upstream reference site (Fig. 13). This suggests that the restored reach will come to resemble the reference site over time. This is because the biodiversity that can be expected in the restored reach is closely linked to the diversity of nearby sites (Lake, Bond & Reich, 2007; Winking et al., 2014), and it appears the reference site is the closest available species pool from which dispersal, and thus colonisation, can occur.

Despite urban barriers, aerial colonisation can be achieved by just a few females laying eggs in new habitat (Caudill, 2003). As a result, aerial colonisation of Teglverksdammen is expected to occur, though it may require time before flying individuals encounter the restored reach. When such aerial colonisation occurs, source populations are expected to come from streams in the surrounding urban environment, such as Akerselva. While this would increase diversity at Teglverksdammen, assemblages will continue to resemble those characteristic of an urban environment.

In spite of the limitations mentioned, it appears that the goal of increasing biodiversity in the restored reach is in the process of being met, though more time is needed for a more diverse species assemblage to colonise and develop at Teglverksdammen.

Pollution tolerant taxa

Large populations of pollution tolerant *Chironomidae* and Oligochaeta occurred throughout the system, and they were the dominant macroinvertebrates found in the samples. This supports the third hypothesis, that such taxa will dominate the initial macroinvertebrate communities. In practically all studies reviewed by Walsh *et al*. (2005), sensitive orders such as Ephemeroptera, Plecoptera and Trichoptera were less abundant in urbanised streams. This was also the case at Teglverksdammen.

The mean ASPT score categorised the entire restored reach as very poor according to the classification in Direktoratsgruppa (2015), suggesting the restored reach was influenced by organic pollutants (Fig. 15). Organic pollution tends to be higher in urban streams, and often results in a community dominated by *Chironomidae* and Oligochaeta (Walsh et al., 2005). Additional factors affecting the ASPT score at Teglverksdammen may have included the period of lack of flow, and fine sediments from upstream sources (observed in the October field sampling). Fine sediment, particularly clays and silts, have been shown to have detrimental effects on macroinvertebrates, such as disrupting the gills and feeding apparatus (Jones et al., 2011). These disturbances may have prevented the more sensitive taxa from being able to maintain populations in the restored reach, and thus kept ASPT low.

The improvement in ASPT score during the sample period was small, and the score was generally lower in the restored reach compared to the reference site. This may be because individuals drift down from the reference site, but cannot survive/reproduce in the restored reach due to the high levels of pollutants (input of nutrients between the reference site and T1 were apparent from the water chemistry analyses). This could explain why taxa such as Ephemeroptera were only found at the upper restored sites: they were unable to maintain populations and colonise further downstream due to the high levels of organic pollution, despite the fact that the nutrient levels seemed to decrease downstreams (at least in the summer months). It may also explain why T1 and T2 had the highest ASPT scores in the restored reach. This suggests that colonisation at Teglverksdammen was hampered by organic pollutants. However, the slight increase in ASPT over time suggests that also less pollution tolerant taxa are arriving and, at least for a short while, surviving in the system. The improvement of ASPT at the restored site cannot be explained by a natural seasonal development as the reference site remained rather stable throughout the study period. This also indicates that the calibration of the ASPT metric is correct for this stream, and that it is unaffected by seasonal variations in macroinvertebrate assemblages.

The low ASPT score suggests that higher concentrations of nutrients may have occurred in the system than what was identified in the monthly water chemistry samples. Macroinvertebrates react to pollutants quickly, and therefore may detect pollution levels not noted in water chemistry measurements alone (Metcalf, 1989; Hussain & Pandit, 2012). The site T7 in the outlet of Teglverksdammen shows a sustained increase in ASPT score over the sampling period, indicating that the dam is having a positive influence on scores. The dam may moderate and process nutrients, thereby reducing sudden variations that could negatively affect ASPT scores. As the reference site is the only source of colonists so far, and it is categorised as very poor, it is unlikely that the restored reach will show a significant improvement in ASPT categorisation in the short-term. For an improvement in ASPT in the restored reach, there must first come an improvement in the upstream parts of the stream.

Impact of flow periods

Both before and after flow interruption, biodiversity continued to increase, and population sizes showed similar changes at all sample sites. Additionally, the NMDS ordination (Fig. 13 and Fig. 14) showed changes of similar distances and direction at all sites, including the unaffected reference site. This suggests that all sites changed in similar ways over time. This suggests that the period of flow cease had little effect on the biodiversity and population sizes at Teglverksdammen. Macroinvertebrates have been shown to actively or passively track receding water, accumulating in remaining pools (Dewson, James & Death, 2007a; Chester & Robson, 2011), and the macroinvertebrates at Teglverksdammen likely moved into the dams as water levels declined. Verdonschot *et al*. (2014) found that, in a 29-day study, stagnation only resulted in minor changes in community composition, though the number of species associated with flowing waters decreased. Also, moist soils facilitate macroinvertebrate survival (Chester & Robson, 2011; Verdonschot et al., 2014), and refuges such as dams, damp sediments and the underside of stones may have permitted macroinvertebrates to survive the dry period at Teglverksdammen and to quickly recolonise when flow returned.

The species assemblage at Teglverksdammen consisted mostly of early colonising taxa that may have been better equipped to deal with the dry period. If sensitive taxa come to colonise the restored reach, such dry periods may have a negative effect. Reduced flows may alter the community composition by favouring e.g. taxa that prefer slower water (Dewson, James & Death, 2007b), thus future interruptions in flow may reduce diversity at Teglverksdammen. The highest water temperatures were noted for the period when there was little to no flow in the system, and such warm water events may affect the species compositions as some macroinvertebrate families are sensitive to high water temperatures (Wenger et al., 2009). Warmer water may also modify the species assemblage by affecting the rate of growth and maturation of macroinvertebrates (Allan & Castillo, 2009).

Akerselva

Urban Stream Syndrome

The unvarying TDS at the two upper sites (Fig. 16) is most likely due to Akerselva flowing out of Maridalsvannet, which is managed as a source of drinking water. Additionally, the catchment area of Akerselva is in a near natural condition, with water peculating through the soil, so that the water may reach chemical equilibrium with that soil (Allan & Castillo, 2009). This equilibrium will result in a stable TDS score. The water at the upper sites of Akerselva has also not been in contact with a large degree of impervious surfaces, and will therefore have acquired fewer of the pollutants associated with such surfaces (Gobel et al., 2007).

As Akerselva enters the urban environment, TDS immediately started to increase, showing the highest readings at the lowest sample site. This increase in TDS appears to be universal in urban streams and is a key feature of the urban stream syndrome (Hatt et al., 2004). The increase in TDS is likely the result of the surrounding urban landscape draining into Akerselva. This drainage water acquires pollutants from the urban environment, with little terrestrial processing occurring (Hatt et al., 2004). However, the TDS score for Akerselva remained substantially lower than for Teglverksdammen, suggesting that Akerselva was substantially less affected by pollutants.

As with Teglverksdammen, the water temperature showed seasonal changes (Fig. 17). In contrast to Teglverksdammen, the water temperature showed little change as water progressed through the system. This is most likely because Akerselva is a larger stream and has a higher thermal mass than Teglverksdammen, and will therefore not show much change. An additional factor contributing to the stable temperatures exhibited by Akerselva, is the large amount of riparian vegetation which shades the stream from solar radiation (Allan & Castillo, 2009).

The significant differences in richness between the upper site and the lower site indicated that there was a decline in richness as one progressed downstream Akerselva (Fig. 18). Streams in urban areas are often characterised by poorer species assemblage, with decreases in biodiversity most evident for Ephemeroptera, Plecoptera and Trichoptera (Paul & Meyer, 2001; Walsh et al., 2005). This is supported by the result that only Oligochaeta and *Chironomidae* were present in a sample from the lowest, most urbanised site. This decline in richness and the presence of tolerant taxa indicate that Akerselva has symptoms of the urban stream syndrome. However, this decline shows an improvement from Bækken *et al*. (2011), who found very few EPT taxa in the lower reaches of Akerselva, suggesting that diversity at Akerselva may have improved since 2010.

The mean ASPT score for the first site categorises this site as poor, while the second sample site is categorised as moderate (Fig. 19). This was unexpected, as water at AK1 is draining from the unpolluted lake Maridalsvannet, and should thus have had a higher ASPT score. This lower ASPT score at AK1 is possibly due to the lake effect, which is typically caused by the presence of more filter feeders downstream of lakes, which tend to have lower BMWP scores (Bode, Novak & Abele, 1996; N. Friberg 2017, personal communication, 24 April). The first sample site should perhaps therefore have been placed further downstream to avoid the lake effect. The ASPT scores (moderate) for the second sample site, which is further downstream, and thus not expected to be affected by the lake effect, is likely more accurate for the upper reaches of Akerselva. The lower two sample sites (AK6 and AK7) have mean ASPT scores of 4.48 and 4.47, respectively, giving these sites a poor categorisation. This decrease in ASPT score over the course of Akerselva suggests there are still sources of pollutants, most likely from non-point sources, affecting the stream. The ASPT findings reported here closely mirror those reported in Bækken *et al*. (2011), showing the upper reaches of Akerselva had higher ASPT scores, which decreased as the stream progresses.

The scores for the upper two sites in Bækken *et al*. (2011), which were in close proximity to the sites sampled for this thesis, are categorised as good for the first sample site and between good and moderate for the second sample site. This means that in 2010, the upper reaches were classified as being in better condition than in this thesis. The mean score for the uppermost site in this thesis is very close to the border for a moderate categorisation. This lower classification may be due to natural variation. When the mean of the two upper sites is taken together, they are categorised as moderate in this thesis. As Bækken *et al*. (2011) based their categorisation on two samples, and this thesis based it on seven samples, it is likely that the moderate categorisation is more accurate. In addition, Bækken *et al*. (2011) sampled shortly after a severe chlorine leak affected all of Akerselva, which may have altered the ASPT categorisations.

In 2010, the lower reaches were found to range between very poor and poor (Bækken et al., 2011). The samples analysed in this thesis show similar patterns, suggesting the system has not improved substantially since 2010. Bækken *et al*. (2011) collected samples in April, which is different from the sample dates used here, but this is not expected to severely influence the comparison. The influence of seasonal variations on ASPT scores has been found to be slight, with Armitage *et al*. (1983) concluding that samples taken in different seasons were likely to provide consistent ASPT scores.

Along its course, Akerselva shows both an increase in total dissolved ions, a decrease in richness, a species assemblage with fewer pollution intolerant taxa and a decline in ASPT scores. The data is therefore suggestive that the fourth and final hypothesis is met: Akerselva is still showing symptoms of the urban stream syndrome, even after much has been done to improve the stream. However, the costly remedial work seems to have improved the macroinvertebrate family richness of the river, compared to results in Bækken (2011).

Future prospects for Teglverksdammen

The NMDS ordination comparing Akerselva and Teglverksdammen places the reference site in the vicinity of the lower reaches of Akerselva (Fig. 20). The implication of the reference site resembling the lower reaches of Akerselva, is that given time, the species assemblage in the restored reach is expected to become similar to that of the lower urbanised reaches of Akerselva. This is due to colonisation occurring mostly via drift and the limited species pool available from the reference location. As Akerselva shows signs of the urban stream syndrome, it is likely that Teglverksdammen will not reach pristine conditions, being situated in a similar urban environment as Akerselva. It is thus expected that, while biodiversity will continue to increase in the restored reach, it will only be to the levels of biodiversity typical of streams in an urbanised environment.

The landscape surrounding Teglverksdammen is highly urbanised, and restoring sections of streams does not reduce the overall effect the drainage landscape has on the stream, which may limit the full recovery of restored streams (Walsh, Fletcher & Ladson, 2005; Neale & Moffet, 2016). This is likely due to impervious surfaces which results in increased disturbances, such as fluctuations in nutrient concentrations. Improved storm water drainage systems are likely to reduce the impacts of impervious surfaces (Walsh, Fletcher & Ladson, 2005).

While Teglverksdammen may not reach pristine conditions, it may, over time, come to have an assemblage containing representatives of the EPT taxa and be a fully functioning diverse ecosystem. The planted wetland is expected to further assist in achieving this outcome. This increase in diversity will make the system more resilient to disturbance and assist in increasing the self-purification ability of the restored reach. Finally, should the restored reach come to contain representatives of the EPT taxa, it would be the result of improved water quality, meaning the primary goal of water purification is met. It may then come to more closely resemble Akerselva.

Conclusion

The extent of drawing inferences from this study on the impact of deculverting on Teglverksdammen is limited due to the short-term nature of this study. Further limitations come from the period during which there was no flow, which may have had implications not detected here. However, as very few studies have been conducted on the ecological effect that deculverting has on restored streams (Neale & Moffett, 2016), the findings may contribute to knowledge on the initial changes that occur immediately following the deculverting of a stream in an urban environment.

The decline in nutrient concentrations at Teglverksdammen as water flows through the system suggests that the reach is acting as an open-water purification facility, meaning the primary goal of restoration is being met. This purification is expected to improve as the system develops further. Colonisation by macroinvertebrates in the system appears to be occurring mainly via drift, with family richness increasing. The macroinvertebrate community is expected to continue to develop and increase in diversity. The goal of increasing biodiversity in the system may thus be in the process of being met. The increase in ASPT score is also indicative of the goals of restoration being met, as this reflects both an increase in water quality as well as the presence of more desirable macroinvertebrates within the restored reach. However, the initial macroinvertebrate communities are dominated by pollution tolerant taxa.

Finally, onlookers have expressed satisfaction with the visual appeal of the restored reach and indicated that they receive satisfaction from it. There have even been reports of individuals fishing in the restored reach. This suggests that Teglverksdammen and its surroundings are starting to supply additional ecosystem services to the local population. Deculverting thus appears to have had positive effects on water chemistry, macroinvertebrate diversity, ASPT score and the aesthetics of the area.

While exhibiting the classic symptoms of the urban stream syndrome, Akerselva does show a higher family richness than Hovinbekken, which indicates that urban streams may host a relatively diverse array of taxa, including representatives of EPT taxa. Thus, it is possible that Hovinbekken may in future also possess such a diverse array of macroinvertebrates.

Recommendations

The restored reach at Teglverksdammen is a ground-breaking project for Oslo. As it is the first of its kind in Norway, it offers opportunities to test new methods, improve existing methods and further knowledge on how such systems should be developed and constructed. Below follow recommendations based on the findings of this thesis:

- Further restorations along Hovinbekken, as well as its tributaries, should be implemented to improve both nutrient processing and connectivity, which will assist in a more diverse species assemblage and natural flow regime. Much of Hovinbekken is culverted, meaning that further deculverting projects could be undertaken. However, as such wide-ranging restorations may be unfeasible and prohibitively costly, it should be considered to introduce local macroinvertebrate families, for example from Akerselva, to the system, and using the outcome of such an experiment to guide further restorations in isolated urban streams.
- Improvements to Teglverksdammen, and other streams in Oslo, may be facilitated by alternative drainage methods which maintain a near-natural frequency of surface run-off from the catchment area, for example by using porous pavement (Llyod, Wong & Chesterfield, 2002; Walsh, Fletcher & Ladson, 2005). Such improvements to the drainage system will reduce the severity of the urban stream syndrome and result in an overall increase in ecosystem services offered by streams in urban areas.
- It should be determined whether there is an inflow of sewerage or other pollutants occurring from inside the culvert. Should such a leak exist, removing it will reduce the quantity of pollutants entering the restored reach, which would improve both the nutrient uptake rates as well as the diversity of macroinvertebrates in the restored reach.
- To further achieve the goals of restoration, especially where the goal is to purify water, it is recommended that less disturbed upstream sections of Hovinbekken be preserved. This will both assist in creating cleaner water as well as potentially improving biodiversity throughout the entire stream, especially as restorations continue to be conducted.
- According to Pinkham (2000), most deculverting projects require continuous maintenance and planting in their initial years following deculverting, and it may be necessary to try different plantings to determine which works best for a particular site. As a result, maintenance and replanting should be ongoing and implemented when required.

- A more diverse substrate should be placed in the system, including coarse woody debris, as this will increase the variability of habitats available and improve biodiversity in the system. Coarse woody debris creates additional structure in streams and creates areas of high food resource availability (Schneider & Winemiller, 2008). By varying the types of substrates used and documenting the effects, this may assist future restorations in Oslo to select the most beneficial substrate composition.
- Dry periods are "ramp disturbances" in which environmental conditions get worse as the dry period continues (Verdonschot et al., 2015). As more sensitive taxa come to colonise the reach, sensitivity to flow interruptions may increase. Short periods of lack of flow will have less negative impacts than extended dry periods. It is recommended that maintenance work be done in such a way as to reduce the length of time that there is no flow. Where possible, merely reducing the flow of water, instead of stopping it entirely, is preferable.
- By placing a drift net in the culvert, colonisation via drift could be confirmed or rejected. Monitoring such drift and combining it with samples taken in the restored reach may give improved insights into how macroinvertebrates colonise new urban habitats. Furthermore, long-term monitoring to determine how such a system matures and develops will further improve knowledge and may give insight into how future projects may be improved. Studies may also be conducted on aerial dispersion, to determine what distance flying adult stages may travel in such an urban environment such as Oslo. Such knowledge may be beneficial when planning future restorations with the goal of increasing biodiversity.
- As *Salmo trutta fario* (Brown trout) were seen spawning in the vicinity of T3 in November, it is recommended that the population and distribution of this species be mapped to determine how fish populations will respond to changes brought about by deculverting. By researching how a diverse array of organisms respond to deculverting, a holistic view may emerge, which will be useful for future restoration projects.
- As this kind of restoration project is a novelty in Oslo, and such areas may act as natural laboratories, it is recommended that co-operation be initiated with nearby schools, for example Teglverket school, for this purpose. Such co-operation may benefit both the school, which can use the restored site to teach the fundamentals of ecology and biology, as well as the municipality, as school projects may assist in monitoring the restored reach.

These recommendations may result in an improved restored stream, as well as providing knowledge that may be used in future projects. Stream deculverting is in its infancy in Norway, and such projects create the opportunity to test ecological principles and apply these principles to new restoration projects. Stream deculverting has many benefits, including supplying ecosystem services such as water purification and creating areas of recreation for the surrounding urban population. Restoration projects improve biodiversity, which may further benefit people by reconnecting them to nature (Pinkham, 2000). To benefit future restorations, developments at Teglverksdammen should continue to be monitored and reported.

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Appendices

Appendix A: Geographical coordinates of sampling sites

Teglverksdammen geographic coordinates*		Akerselva geographic coordinates*	
T0	59.929453ºN	AK1	59.968218ºN
	010.814664ºE		010.786608ºE
T1	59.925495ºN	AK2	59.960026ºN
	010.800427ºE		010.768559ºE
T2	59.925383ºN	AK3	59.946360ºN
	010.800118ºE		010.764960ºE
T3	59.925214ºN	AK4	59.942141ºN
	010.798914ºE		010.766497ºE
T4	59.924894ºN	AK5	59.934740ºN
	010.797718ºE		010.756994ºE
T5	59.924719ºN	AK6	59.925110ºN
	010.796943ºE		010.753093ºE
T7	59.922038ºN	AK7	59.914240ºN
	010.794231ºE		010.758743ºE

* Coordinates are approximate, determined with cellphone, therefore some errors may be apparent.

Appendix B: Macroinvertabrates at Teglverksdammen

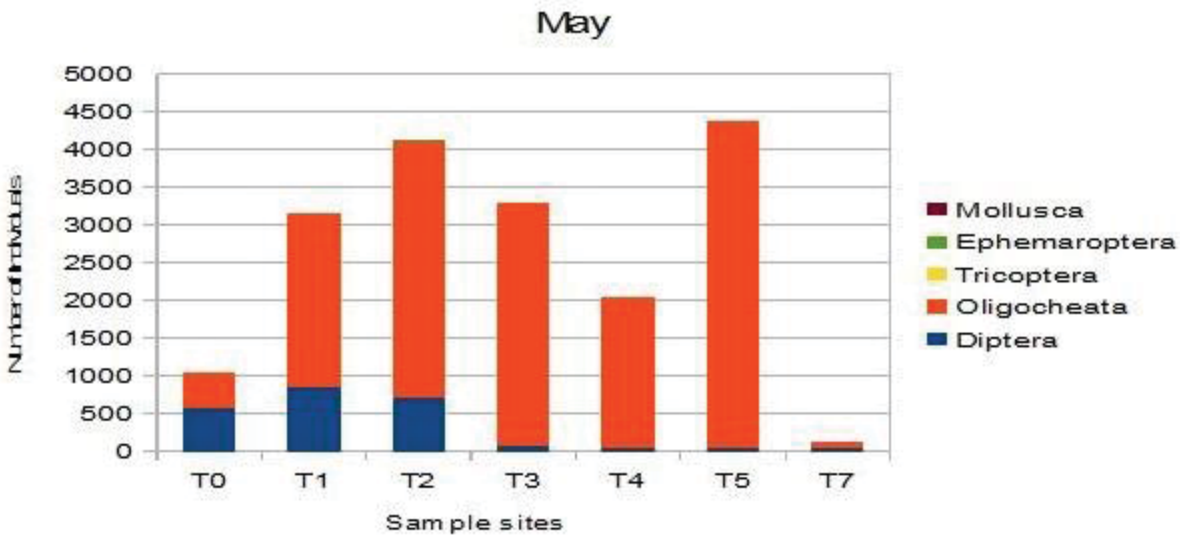
Date	Taxa/Group	Species/Family	T0	T1	T2	T3	T4	T5	T7
24.05.2016	Bivalvia	Sphaeriidae	2						
24.05.2016	Diptera	Ceratopogonidae	40	1		1			1
24.05.2016	Diptera	Chironomidae	524	840	704	63	40	52	54
24.05.2016	Diptera	Empididae	3	4	1				
24.05.2016	Diptera	Limoniidae	3	18	6	1			
24.05.2016	Diptera	Indet	24	24	17	1			
24.05.2016	Ephemaroptera	Baetidae	2						
24.05.2016	Ephemaroptera	Baetis rhodani			1				
24.05.2016	Hydrachna	Hydrachnidae	2						
24.05.2016	Nematomorpha	Nematomorpha					1	1	
24.05.2016	Oligochaeta	Lumbricidae	2				1		
24.05.2016	Oligochaeta	Oligochaeta	467	2304	3408	3224	2008	4320	58
24.05.2016	Trichoptera	Rhyacophila sp	1						
14.06.2016	Diptera	Chironomidae	1336	1480	744	552	656	624	408
14.06.2016	Diptera	Ceratopogonidae	22	8		1	1	1	
14.06.2016	Diptera	Pediciidae	13	2	1				
14.06.2016	Diptera	Empididae	1						
14.06.2016	Diptera	Limoniidae	10	13	1				
14.06.2016	Diptera	Indet							4
14.06.2016	Ephemaroptera	Baetis rhodani		2					
14.06.2016	Hydrachnidea	Hydrachnidae	7	3	1				
14.06.2016	Mollusca	Sphaeriidae	5	3		2			1
14.06.2016	Nematomorpha	Nematomorpha		3					1
14.06.2016	Oligochaeta	Oligochaeta	2976	5760	4728	4848	2752	2240	476
14.06.2016	Oligochaeta	Lumbricidae	2				1		
14.06.2016	Plecoptera	Leuctridae	7						
14.06.2016	Trichoptera	Rhyacophila sp	5						
14.06.2016	Trichoptera	Hydropsyche siltalai	4						
14.07.2016	Diptera	Chironomidae	140	1440	808	1384	1043	248	416
14.07.2016	Diptera	Ceratopogonidae	1	1					
14.07.2016	Diptera	Pediciidae	20	1	1				
14.07.2016	Diptera	Empididae	1						
14.07.2016	Diptera	Simuliidae	2	1					
14.07.2016	Diptera	Psychodidae	1		1				
14.07.2016	Diptera	Limoniidae				1			1
14.07.2016	Diptera	Indet	5	37	28		1	5	2
14.07.2016	Ephemaroptera	Baetidae	23	78	7	2	1		
14.07.2016	Ephemaroptera	Baetis rhodani	2	20	2				
14.07.2016	Ephemaroptera	Indet(CF Batidae)	10	22					

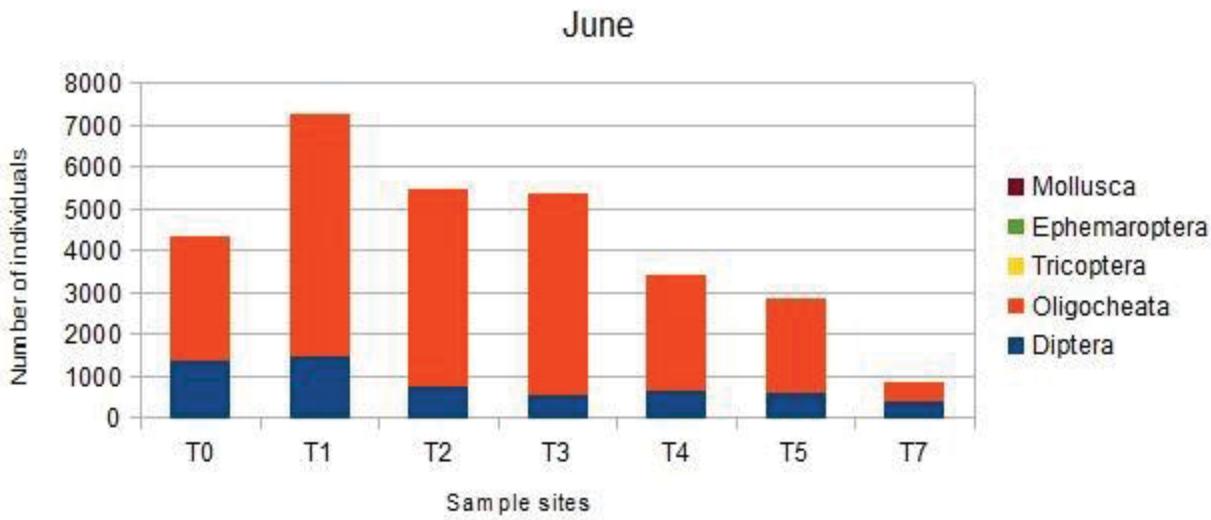
Date	Taxa/Group	Species/Family	T0	T1	T2	T3	T4	T5	T7
14.07.2016	Hydrachna	Hydrachnidae	1						
14.07.2016	Mollusca	Sphaeriidae	11	3					2
14.07.2016	Mollusca	Planorbidae	7						8
14.07.2016	Nematomorpha	Nematomorpha			3		1	9	
14.07.2016	Oligochaeta	Oligochaeta	18	2240	2432	456	104	6	78
14.07.2016	Oligochaeta	Lumbricidae					1	1	
14.07.2016	Plecoptera	Leuctridae	10	5					
14.07.2016	Trichoptera	Rhyacophila sp	1						
14.07.2016	Trichoptera	Rhyacophila nubila	10	1					
14.07.2016	Trichoptera	Polycentropodidae	1						
17.08.2016	Diptera	Chironomidae	36	NA	NA	NA	NA	NA	NA
17.08.2016	Diptera	Ceratopogonidae	2	NA	NA	NA	NA	NA	NA
17.08.2016	Diptera	Pediciidae	9	NA	NA	NA	NA	NA	NA
17.08.2016	Diptera	Empididae	3	NA	NA	NA	NA	NA	NA
17.08.2016	Diptera	Simuliidae	6	NA	NA	NA	NA	NA	NA
17.08.2016	Ephemaroptera	Baetidae	46	NA	NA	NA	NA	NA	NA
17.08.2016	Hydrachna	Hydrachnidae	4	NA	NA	NA	NA	NA	NA
17.08.2016	Mollusca	Sphaeriidae	10	NA	NA	NA	NA	NA	NA
17.08.2016	Mollusca	Planorbidae	7	NA	NA	NA	NA	NA	NA
17.08.2016	Oligochaeta	Oligochaeta	36	NA	NA	NA	NA	NA	NA
17.08.2016	Ostracoda	Ostracoda	1	NA	NA	NA	NA	NA	NA
17.08.2016	Plecoptera	Leuctridae	5	NA	NA	NA	NA	NA	NA
17.08.2016	Trichoptera	Rhyacophila sp	3	NA	NA	NA	NA	NA	NA
17.08.2016	Trichoptera	Hydropsyche	8	NA	NA	NA	NA	NA	NA
14.09.2016	Coleoptera	Hydraenidea	8						NA
14.09.2016	Diptera	Chironomidae	84	32	81	37	651	696	NA
14.09.2016	Diptera	Ceratopogonidae	13	1	4				NA
14.09.2016	Diptera	Pediciidae	6	2				1	NA
14.09.2016	Diptera	Psychodidae	4						NA
14.09.2016	Diptera	Tipulidae	2	28	24	10	8	67	NA
14.09.2016	Diptera	Indet	1	2		1	3	4	NA
14.09.2016	Ephemaroptera	Baetidae	29						NA
14.09.2016	Ephemaroptera	Baetis rhodani	13		1				NA
14.09.2016	Ephemaroptera	Indet(CF Batidae)	7						NA
14.09.2016	Gastropoda	Lymnaeidae		3	4				NA
14.09.2016	Hydrachnidea	Hydrachnidae	7						NA
14.09.2016	Mollusca	Sphaeriidae	38	4	9	3	2		NA
14.09.2016	Mollusca	Planorbidae	3	1	5				NA
14.09.2016	Nematomorpha	Nematomorpha			1				NA
14.09.2016	Oligochaeta	Oligochaeta	225	59	25	19	5	12	NA
14.09.2016	Plecoptera	Leuctridae	2						NA

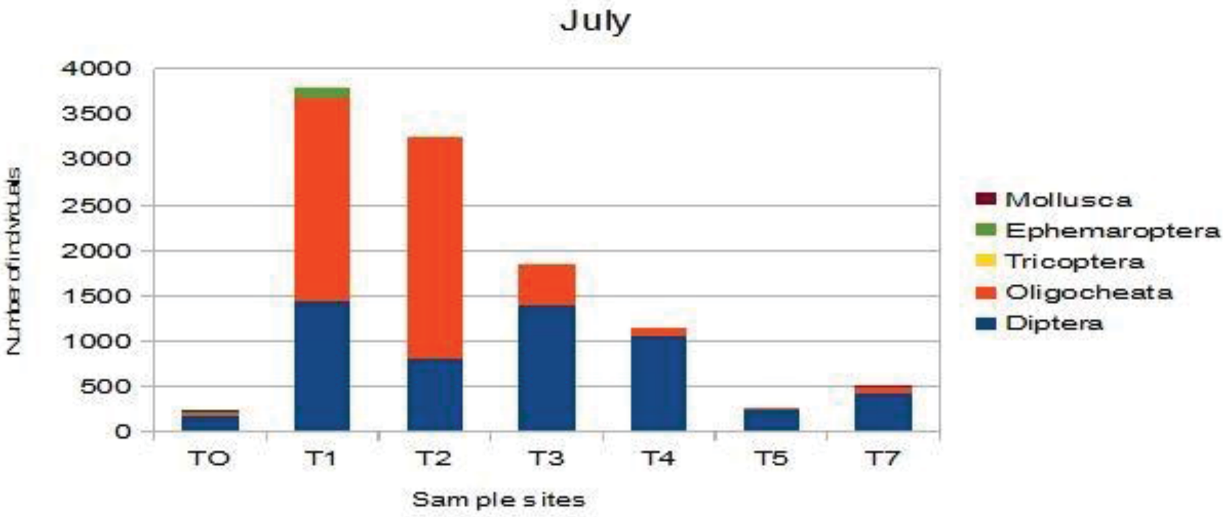
Date	Taxa/Group	Species/Family	T0	T1	T2	T3	T4	T5	T7
14.09.2016	Trichoptera	Rhyacophila sp	7						NA
14.09.2016	Trichoptera	Rhyacophila nubila	7						NA
14.09.2016	Trichoptera	Hydropsyche siltalai	2						NA
14.09.2016	Trichoptera	Polycentropodidae	1						NA
14.09.2016	Trichoptera	Indet	1						NA
12.10.2016	Coleoptera	Hydraenidea	8						
12.10.2016	Crustacea	Asellus aquaticus	2	2					
12.10.2016	Diptera	Chironomidae	208	102	44	276	91	30	44
12.10.2016	Diptera	Ceratopogonidae	6	2					9
12.10.2016	Diptera	Pediciidae	3	2	1				1
12.10.2016	Diptera	Simuliidae	17						
12.10.2016	Diptera	Psychodidae	4						
12.10.2016	Diptera	Tipulidae	4	13	24	10			1
12.10.2016	Diptera	Indet		4					
12.10.2016	Ephemaroptera	Baetidae	46	5	1				
12.10.2016	Ephemaroptera	Baetis rhodani	19	2					
12.10.2016	Ephemaroptera	Indet	4						
12.10.2016	Gastropoda	Lymnaeidae	2	6	2		1		1
12.10.2016	Mollusca	Sphaeriidae	22	7					
12.10.2016	Mollusca	Planorbidae	11	11	2				2
12.10.2016	Nematomorpha	Nematomorpha			1				
12.10.2016	Oligochaeta	Oligochaeta	136	295	43	18	5	3	30
12.10.2016	Oligochaeta	Lumbricidae	20	3					15
12.10.2016	Ostracoda	Ostracoda	5	12	3	1	1	2	
12.10.2016	Trichoptera	Rhyacophila sp	6						
12.10.2016	Trichoptera	Rhyacophila nubila	3						
12.10.2016	Trichoptera	Hydropsyche siltalai	4						
12.10.2016	Trichoptera	Indet	5						
16.11.2016	Coleoptera	Hydraenidea	1						
16.11.2016	Coleoptera	Elmidea	1						
16.11.2016	Crustacea	Asellus aquaticus	3	5	1				
16.11.2016	Diptera	Chironomidae	51	244	40	148	232	124	104
16.11.2016	Diptera	Ceratopogonidae	21	2	1	1		2	6
16.11.2016	Diptera	Pediciidae	1					1	
16.11.2016	Diptera	Simuliidae	6						
16.11.2016	Diptera	Psychodidae	5						
16.11.2016	Diptera	Tipulidae	1	10	8	1	1	8	1
16.11.2016	Diptera	Indet	2		3	4	1	2	1
16.11.2016	Ephemaroptera	Baetidae	10	2					
16.11.2016	Ephemaroptera	Baetis rhodani	1						
16.11.2016	Gastropoda	Lymnaeidae	1	12	15			1	1

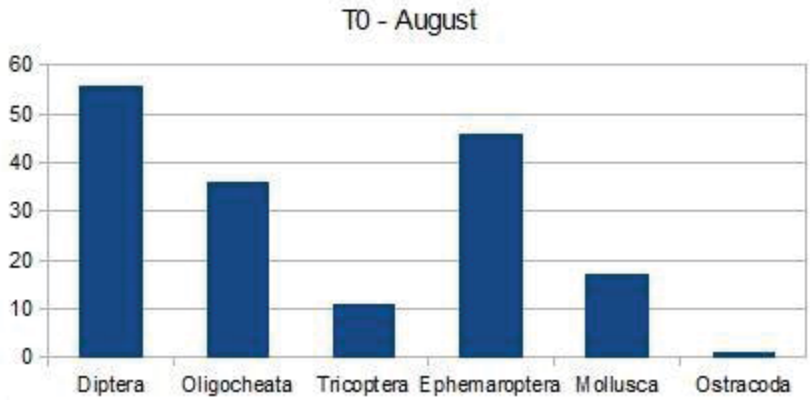
Date	Taxa/Group	Species/Family	T0	T1	T2	T3	T4	T5	T7
16.11.2016	Hydrachna	Hydrachnidae	1						
16.11.2016	Mollusca	Sphaeriidae	5						
16.11.2016	Mollusca	Planorbidae	2	1	3				8
16.11.2016	Mollusca	Bivalvia							1
16.11.2016	Oligochaeta	Oligochaeta	61	432	248	19	5	27	162
16.11.2016	Oligochaeta	Lumbricidae	25	4	1	5	1	3	
16.11.2016	Ostracoda	Ostracoda	3	1	6	2		1	6
16.11.2016	Trichoptera	Rhyacophila sp	3						
16.11.2016	Trichoptera	Rhyacophila nubila	4						
16.11.2016	Trichoptera	Hydropsyche siltalai	3						
16.11.2016	Trichoptera	Polycentropodidae	1						
16.11.2016	Trichoptera	Hydropsyche sp	1		1				
16.11.2016	Trichoptera	Sericostomatidae	3						

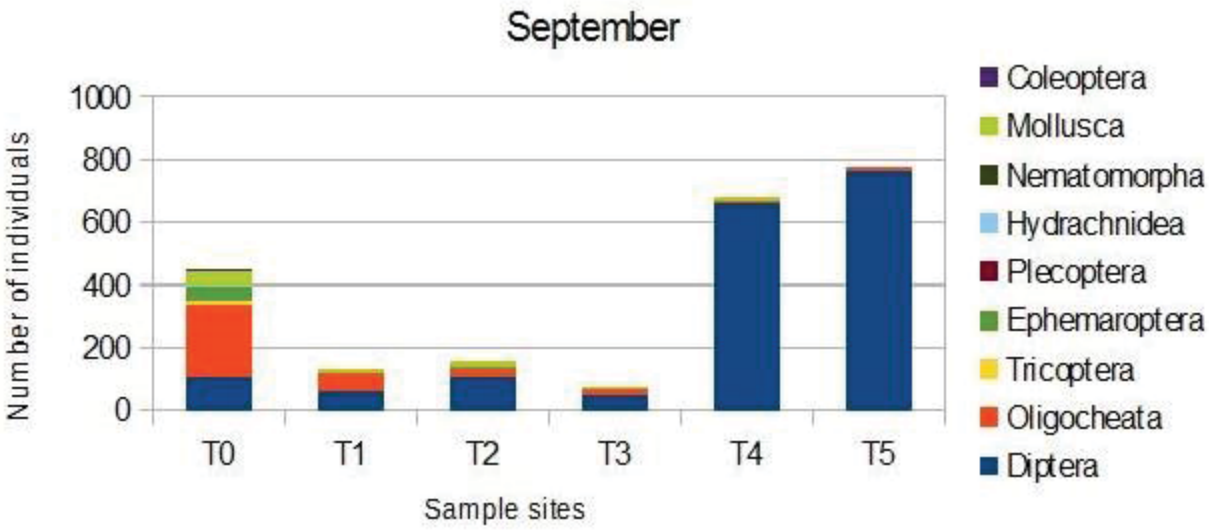
Appendix C: Family composition plots for Teglverksdammen

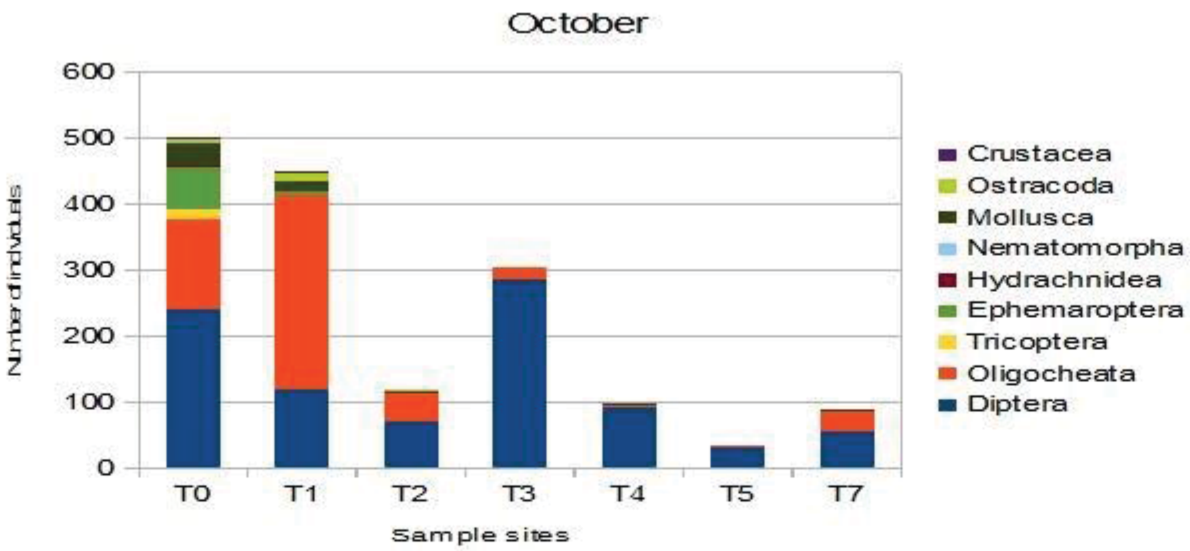


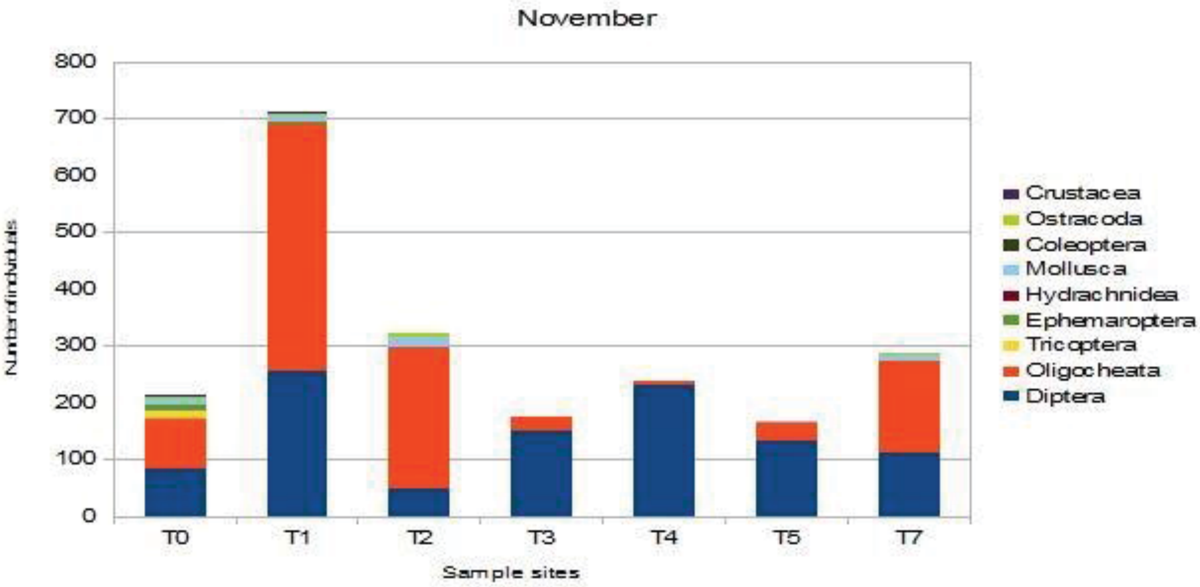



July
Number of individuals
4000
3500
3000
2500
2000
1500
1000
500
0
TO
T1
T2
T3
T4
T5
T7
Sam ple s ites
Mollusca
Ephemaroptera
Tricoptera
Oligocheata
Diptera


T0 - August
60
50
40
30
20
10
0
Diptera
Oligocheata
Tricoptera
Ephemaroptera
Mollusca
Ostracoda


September
Number of individuals
1000
800
600
400
200
0
T0
T1
T2
T3
T4
T5
Sample sites
Coleoptera
Mollusca
Nematomorpha
Hydrachnidea
Plecoptera
Ephemaroptera
Tricoptera
Oligocheata
Diptera


October
600
500
400
300
200
100
0
Number of individuals
T0
T1
T2
T3
T4
T5
T7
Sample sites
Crustacea
Ostracoda
Mollusca
Nematomorpha
Hydrachnidea
Ephemaroptera
Tricoptera
Oligocheata
Diptera


November
800
700
600
500
400
300
200
100
0
Number of individuals
T0
T1
T2
T3
T4
T5
T7
Sample sites
Crustacea
Ostracoda
Coleoptera
Mollusca
Hydrachnidea
Ephemaroptera
Tricoptera
Oligocheata
Diptera

Appendix D: Macroinvertabrates at Akerselva

Date	Taxa/Group	Species/Family	AK1	AK2	AK3	AK4	AK5	AK6	AK7
01.06.2016	Annelida	Hirudinea	10						
01.06.2016	Annelida	Rhynchobdellida	7		1		1	3	
01.06.2016	Diptera	Chironomidae	139	59	71	65	156	34	209
01.06.2016	Diptera	Simuliidae	4	23	1				7
01.06.2016	Diptera	Ceratopogonidea	1	28	4	6	2	4	3
01.06.2016	Diptera	Limoniidae		11	8	3			1
01.06.2016	Diptera	Empididae				1			
01.06.2016	Ephemeratera	Baetidae	7	1		2			2
01.06.2016	Ephemeratera	Baetis rhodani				3		2	
01.06.2016	Ephemeratera	Heptagenia sulphurea			2		1		
01.06.2016	Ephemeratera	Indet	3	1		2		3	2
01.06.2016	Hydrachna	Hydrachnidae						1	
01.06.2016	Mollusca	Planorbidea	11	3				4	
01.06.2016	Mollusca	Sphaeriddea	31	1				4	25
01.06.2016	Oligochaeta	Oligochaeta	25	55	11	44	69	68	425
01.06.2016	Oligochaeta	Lumbricidae	2	10	1	14		8	
01.06.2016	Plecoptera	Leuctridae	62	1	19	36	8	3	
01.06.2016	Plecoptera	Amphinemura sp			2	1	1		
01.06.2016	Plecoptera	Amphinemura sulcicollis		1	2		1		1
01.06.2016	Plecoptera	Isoperla		2	1				
01.06.2016	Plecoptera	Indet		2	2			2	
01.06.2016	Trichoptera	Hydrospsyche sp.	14						
01.06.2016	Trichoptera	Hydropspsyche siltalai		1	9	6		1	
01.06.2016	Trichoptera	Hydropspyche pellucidea			3	1			
01.06.2016	Trichoptera	Polycentropodidae			5	1			
01.06.2016	Trichoptera	Psychomyia pusilla			3	1			
01.06.2016	Trichoptera	Leptoceridae	5						1
01.06.2016	Trichoptera	Psychomyiidae		1					
15.07.2016	Annelida	Hirudinea	12				3	4	
15.07.2016	Crustacea	Ostracoda				1			6
15.07.2016	Diptera	Chironomidae	17	55	192	412	112	49	84
15.07.2016	Diptera	Simuliidae		22	6	5	8	1	
15.07.2016	Diptera	Ceratopogonidea		2		4	3	1	
15.07.2016	Diptera	Empididae		24	1	7	7		
15.07.2016	Diptera	Pedicidea	1	2					
15.07.2016	Diptera	Indet			1	5		1	
15.07.2016	Ephemeratera	Baetidae	9	11	31	34	120	8	1
15.07.2016	Ephemeratera	Baetis rhodani		1	5	4	19	1	
15.07.2016	Ephemeratera	Heptagenia sulphurea	3	2	1				
15.07.2016	Ephemeratera	Heptagenia sp					2		
15.07.2016	Ephemeratera	Ephemerellidae	6	1		3			9
15.07.2016	Ephemeratera	Leptophlebiidae						2	17
15.07.2016	Ephemeratera	Indet	1			2			

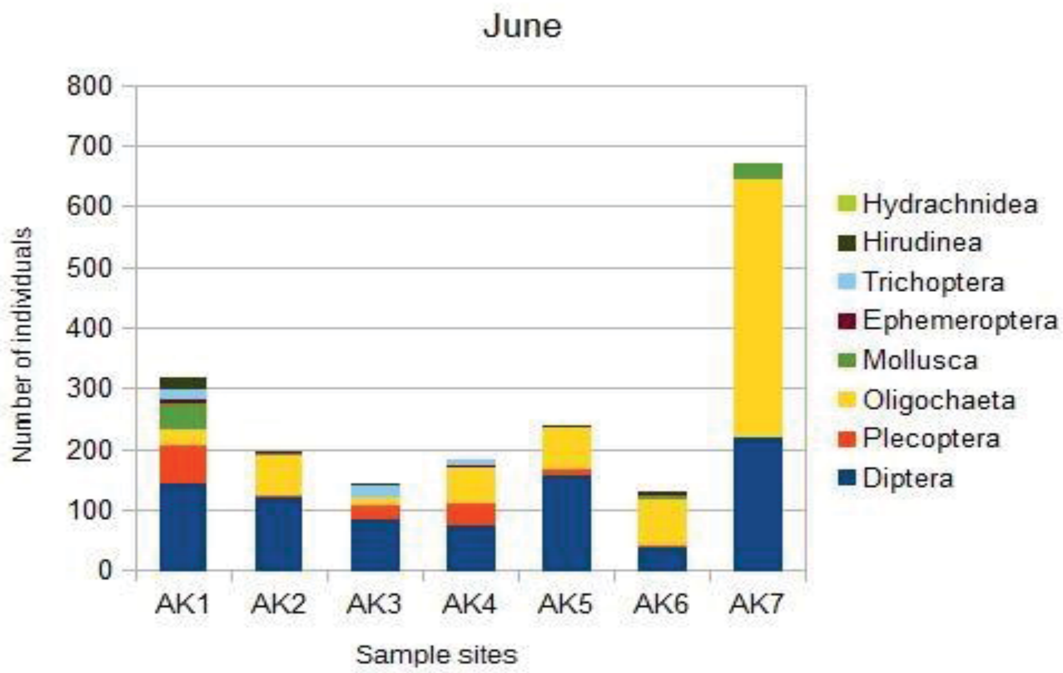
Date	Taxa/Group	Species/Family	AK1	AK2	AK3	AK4	AK5	AK6	AK7
15.07.2016	Gastropoda	Gastropoda							1
15.07.2016	Hydrachna	Hydrachnidae		3		2			
15.07.2016	Mollusca	Planorbidea	14		1	1		4	
15.07.2016	Mollusca	Sphaeriddea	25	1		1			
15.07.2016	Mollusca	Planorbidea Ancylus	1	1			1		
15.07.2016	Oligochaeta	Oligochaeta	4	32	17	51	81	15	22
15.07.2016	Oligochaeta	Lumbricidae	2	6	3	12	13	2	1
15.07.2016	Plecoptera	Leuctridae	4	22	38	37	43	7	9
15.07.2016	Plecoptera	Isoperla sp	1	2		7			
15.07.2016	Plecoptera	Indet			1	2			
15.07.2016	Trichoptera	Hydropspsyche sp.	4	22	17	33	19	1	1
15.07.2016	Trichoptera	Hydropspsyche siltalai		1	1	1	3		
15.07.2016	Trichoptera	Hydropspyche pellucidea	1	1		1	1		
15.07.2016	Trichoptera	Polycentropodidae			1	1			
15.07.2016	Trichoptera	Psychomyiidae			1				
15.07.2016	Trichoptera	Rhyacophila nubila					1		
15.07.2016	Trichoptera	Rhyacophila sp	1	5	1	1	2	1	
15.07.2016	Trichoptera	Limnephilidae				1			
15.07.2016	Trichoptera	Philopotamidae		1	16	1	1		
15.07.2016	Trichoptera	Indet	1		3	3	1		
15.07.2016	Turbellaria	Turbellaria	11						
17.08.2016	Annelida	Hirudinea	7		1	1	26	4	
17.08.2016	Coleoptera	Elmidea			1				
17.08.2016	Diptera	Chironomidae	15	24	34	38	27	4	47
17.08.2016	Diptera	Simuliidae	12	23	3		1		2
17.08.2016	Diptera	Ceratopogonidea	1				2		
17.08.2016	Diptera	Empididae		3	1	4	1	1	2
17.08.2016	Diptera	Pedicidea		6					
17.08.2016	Diptera	Indet		3	1	2	1		3
17.08.2016	Ephemeratera	Baetidae	11	8	2	11	14	9	2
17.08.2016	Ephemeratera	Baetis rhodani	1	1	5	2	6	2	2
17.08.2016	Ephemeratera	Heptagenia sulphurea	1	1		3			
17.08.2016	Ephemeratera	Heptagenia sp	2			1	1	1	1
17.08.2016	Ephemeratera	Leptophlebiidae	1	1					
17.08.2016	Ephemeratera	Ephemerellidae	2			4			15
17.08.2016	Ephemeratera	Indet	1			3			
17.08.2016	Gastropoda	Gastropoda						1	
17.08.2016	Hydrachna	Hydrachnidae	1			2			
17.08.2016	Mollusca	Planorbidea	25		1	2		3	4
17.08.2016	Mollusca	Sphaeriddea	38	2					
17.08.2016	Mollusca	Planorbidea Ancylus		4		7	1		
17.08.2016	Nematomorpha	Nematomorpha				1			
17.08.2016	Oligochaeta	Oligochaeta	10	26	19	45	55	21	10
17.08.2016	Oligochaeta	Lumbricidae	2	3		10		12	2

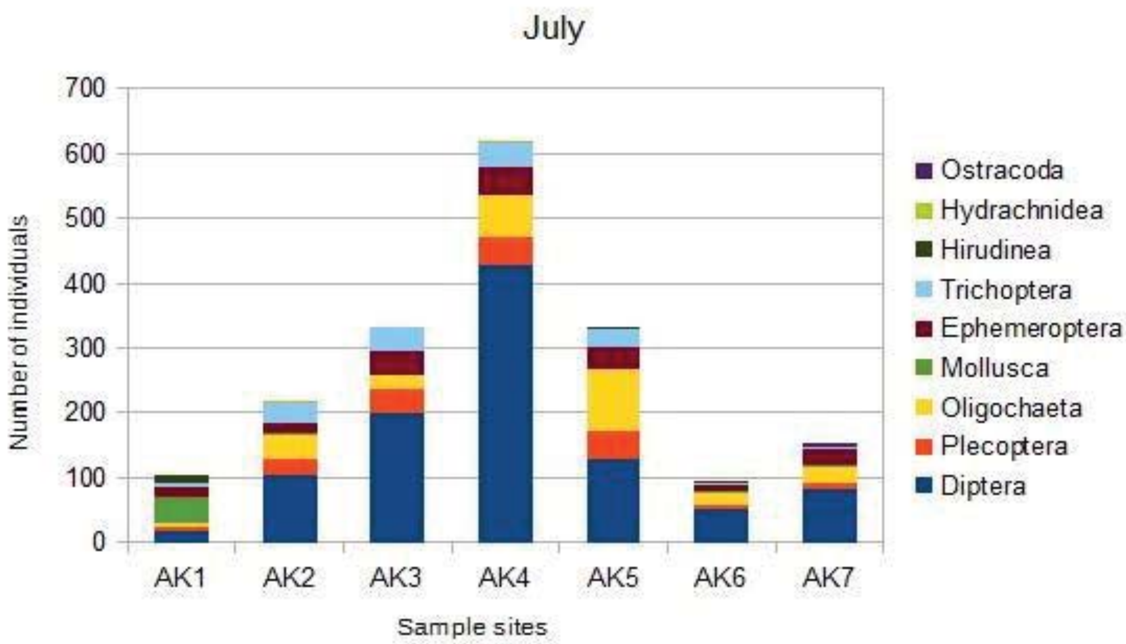
Date	Taxa/Group	Species/Family	AK1	AK2	AK3	AK4	AK5	AK6	AK7
17.08.2016	Plecoptera	Leuctridae	2	10	8	9	6	9	31
17.08.2016	Plecoptera	Amphinemura sulcicollis	1						
17.08.2016	Trichoptera	Hydropspsyche sp	1	6		11	2		1
17.08.2016	Trichoptera	Hydropspsyche siltalai		2		1	1		
17.08.2016	Trichoptera	Hydropspyche pellucidea	3			3		1	
17.08.2016	Trichoptera	Polycentropodidae	1	1					
17.08.2016	Trichoptera	Leptoceridae			1				
17.08.2016	Trichoptera	Rhyacophila sp		1		1			
17.08.2016	Trichoptera	Limnephilidae			1				
17.08.2016	Trichoptera	Indet			2	3	3		
13.09.2016	Annelida	Hirudinea	5		3	1			
13.09.2016	Coleoptera	Elmidea						1	
13.09.2016	Crustacea	Asellus aquaticus							1
13.09.2016	Diptera	Chironomidae	20	28	41	34	23	42	39
13.09.2016	Diptera	Simuliidae	1	6	3	2	1	6	
13.09.2016	Diptera	Ceratopogonidea		3				2	
13.09.2016	Diptera	Empididae	1	17	2	7	1	17	
13.09.2016	Diptera	Indet		1				1	
13.09.2016	Ephemeratera	Baetidae	3	19	7	5	12	14	
13.09.2016	Ephemeratera	Baetis rhodani	1		1		7	2	
13.09.2016	Ephemeratera	Heptagenia sulphurea	4	4	5				1
13.09.2016	Ephemeratera	Heptagenia sp	4	7	2			1	
13.09.2016	Ephemeratera	Indet		1					
13.09.2016	Gastropoda	Gastropoda							4
13.09.2016	Hydrachna	Hydrachnidae		1	1	2		1	4
13.09.2016	Mollusca	Planorbidea	8	2	1		2	2	2
13.09.2016	Mollusca	Sphaeriddea	21	17				1	
13.09.2016	Mollusca	Planorbidea Ancylus	1	8					
13.09.2016	Nematomorpha	Nematomorpha	1						
13.09.2016	Oligochaeta	Oligochaeta	17	56	52	16	8	17	7
13.09.2016	Oligochaeta	Lumbricidae	6	6	10	9	1	6	1
13.09.2016	Plecoptera	Leuctridae	1		2			2	
13.09.2016	Plecoptera	Nemouridea	2	4	2		3	1	
13.09.2016	Plecoptera	Indet		1					
13.09.2016	Trichoptera	Hydropspsyche sp.	8	47	15	35	24	66	1
13.09.2016	Trichoptera	Hydropspsyche siltalai	1	1					
13.09.2016	Trichoptera	Hydropspyche pellucidea	1	4	2	3	4	4	
13.09.2016	Trichoptera	Polycentropodidae	4	6					3
13.09.2016	Trichoptera	Leptoceridae	2						
13.09.2016	Trichoptera	Rhyacophila sp				2	2	1	
13.09.2016	Trichoptera	Polycentropus flavomaculatus	1						
13.09.2016	Trichoptera	Ithytrichia lamellaris	1	3	4	1		1	
13.09.2016	Trichoptera	Philopotamidae	1	3			2	6	1
13.09.2016	Trichoptera	Indet	1	1	1			1	

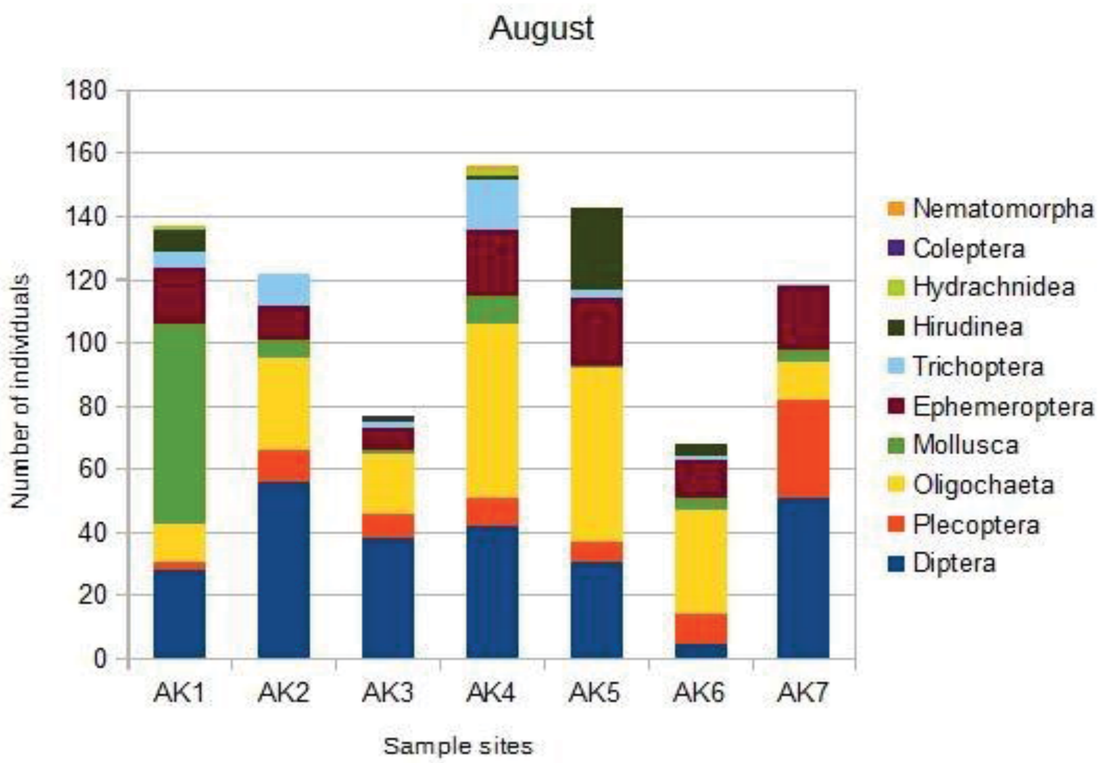
Date	Taxa/Group	Species/Family	AK1	AK2	AK3	AK4	AK5	AK6	AK7
13.09.2016	Turbellaria	Turbellaria	2						
11.10.2016	Annelida	Hirudinea	16				1		
11.10.2016	Crustacea	Asellus aquaticus							1
11.10.2016	Crustacea	Ostracoda	5						
11.10.2016	Diptera	Chironomidae	27	27	47	59	35	32	16
11.10.2016	Diptera	Simuliidae		3			1	1	
11.10.2016	Diptera	Ceratopogonidea	5	1		2		1	
11.10.2016	Diptera	Empididae	1	25	3	28		3	1
11.10.2016	Diptera	Pedicidea		6					
11.10.2016	Diptera	Indet		1	1				
11.10.2016	Ephemeratera	Baetidae	27	27	27	13	29	8	
11.10.2016	Ephemeratera	Baetis rhodani	2	9	6	2	13		
11.10.2016	Ephemeratera	Heptagenia sulphurea	5	2	5		6		
11.10.2016	Ephemeratera	Heptagenia sp	3	4	3	2	4	1	
11.10.2016	Ephemeratera	Caenis							1
11.10.2016	Ephemeratera	Indet		1					
11.10.2016	Gastropoda	Gastropoda							1
11.10.2016	Hydrachna	Hydrachnidae		1		3			1
11.10.2016	Mollusca	Planorbidea	8			1	3	1	5
11.10.2016	Mollusca	Sphaeriddea	32	22	1				1
11.10.2016	Mollusca	Planorbidea Ancylus		4		2	3		1
11.10.2016	Nematomorpha	Nematomorpha		1		1			
11.10.2016	Oligochaeta	Oligochaeta	10	44	41	75	37	11	2
11.10.2016	Oligochaeta	Lumbricidae	7	7	5	20	1	3	
11.10.2016	Plecoptera	Leuctridae		1					
11.10.2016	Plecoptera	Isoperla sp	4	7	3	2		1	
11.10.2016	Trichoptera	Hydropspsyche sp	3	46	2	35	10	5	
11.10.2016	Trichoptera	Hydropspsyche siltalai	2	13	1	13	6	4	1
11.10.2016	Trichoptera	Hydropspyche pellucidea	3	26	6	27	3	2	1
11.10.2016	Trichoptera	Polycentropodidae	3		1				2
11.10.2016	Trichoptera	Psychomyia pusilla		1					
11.10.2016	Trichoptera	Leptoceridae		6					
11.10.2016	Trichoptera	Psychomyiidae		3					1
11.10.2016	Trichoptera	Rhyacophila nubila				2	1		
11.10.2016	Trichoptera	Rhyacophila sp					1		
11.10.2016	Trichoptera	Limnephilidae		1					
11.10.2016	Trichoptera	Polycentropus flavomaculatus	2						
11.10.2016	Trichoptera	Ithytrichia lamellaris	2	4	4				
11.10.2016	Trichoptera	Indet	1	3	3		4	1	1
23.11.2016	Annelida	Hirudinea	1	4					
23.11.2016	Crustacea	Asellus aquaticus	11	16	21	24	25	27	30
23.11.2016	Diptera	Chironomidae	27	112	37	116	25	10	8
23.11.2016	Diptera	Simuliidae		9	1	3			

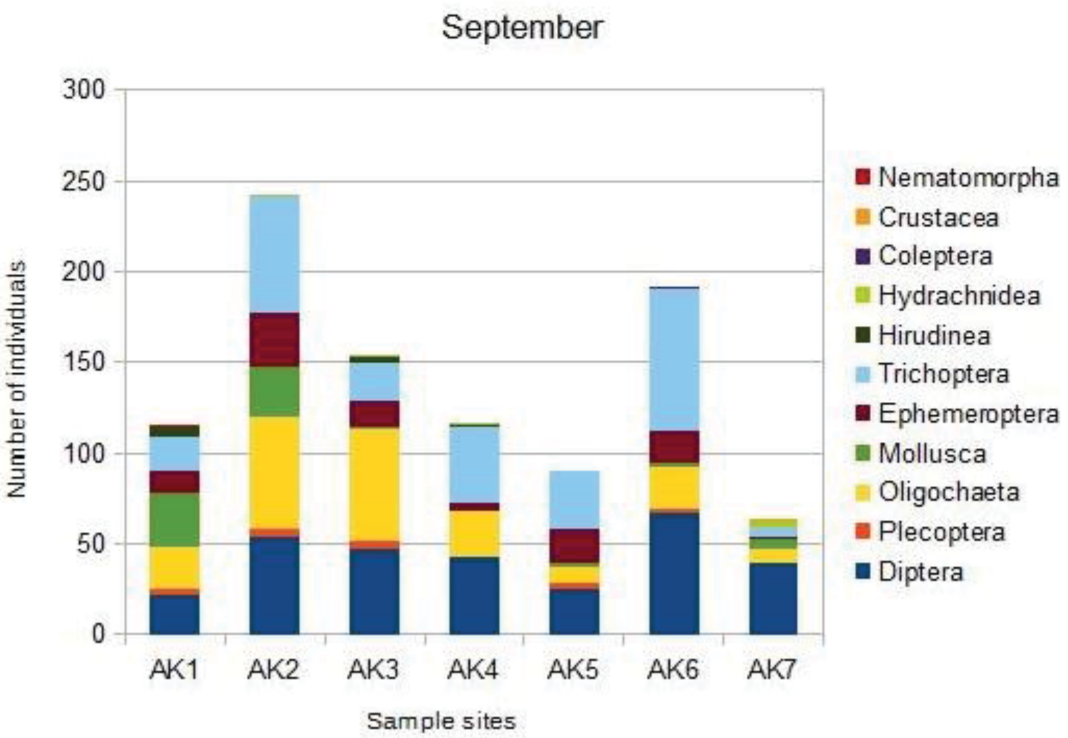
Date	Taxa/Group	Species/Family	AK1	AK2	AK3	AK4	AK5	AK6	AK7
23.11.2016	Diptera	Ceratopogonidea	5	3			1	1	
23.11.2016	Diptera	Empididae	2	29	3	11		4	2
23.11.2016	Diptera	Pedicidea		3					
23.11.2016	Ephemeratera	Baetidae	40	82	56	67	16		
23.11.2016	Ephemeratera	Baetis rhodani	19	13	9	5	8		
23.11.2016	Ephemeratera	Ephemerellidae	47	79	34	74	8	5	
23.11.2016	Ephemeratera	Caenis sp		1		5			
23.11.2016	Ephemeratera	Leptophlebiidae			1				
23.11.2016	Hydrachna	Hydrachnidae	7	11		6	9	3	
23.11.2016	Mollusca	Planorbidea	4				2		
23.11.2016	Mollusca	Sphaeriddea	5	5				2	
23.11.2016	Mollusca	Planorbidea Ancylus				4			
23.11.2016	Nematomorpha	Nematomorpha	5	5	5	5	5	5	6
23.11.2016	Oligochaeta	Oligochaeta	15	42	17	112	16	21	7
23.11.2016	Oligochaeta	Lumbricidae	3	6	9	25	2	1	1
23.11.2016	Plecoptera	Nemouridea							1
23.11.2016	Trichoptera	Hydrospsyche sp					1		
23.11.2016	Trichoptera	Hydropspyche pellucidea		1		1			
23.11.2016	Trichoptera	Polycentropodidae	10	2	2	3			
23.11.2016	Trichoptera	Psychomyia pusilla	5		3	1	3	2	
23.11.2016	Trichoptera	Psychomyiidae		2		2	1		
23.11.2016	Trichoptera	Rhyacophila sp				1			
23.11.2016	Trichoptera	Polycentropus flavomaculatus					1		
23.11.2016	Trichoptera	Ithytrichia lamellaris	1						
23.11.2016	Trichoptera	Philopotamidae			1				

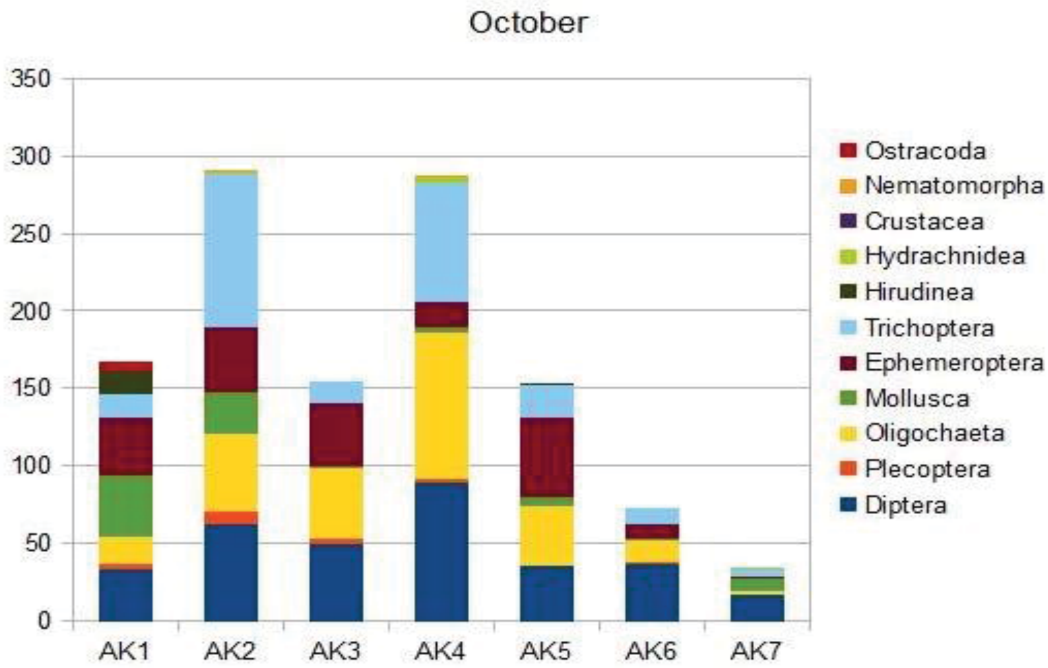
Appendix E: Family composition plots for Akerselva

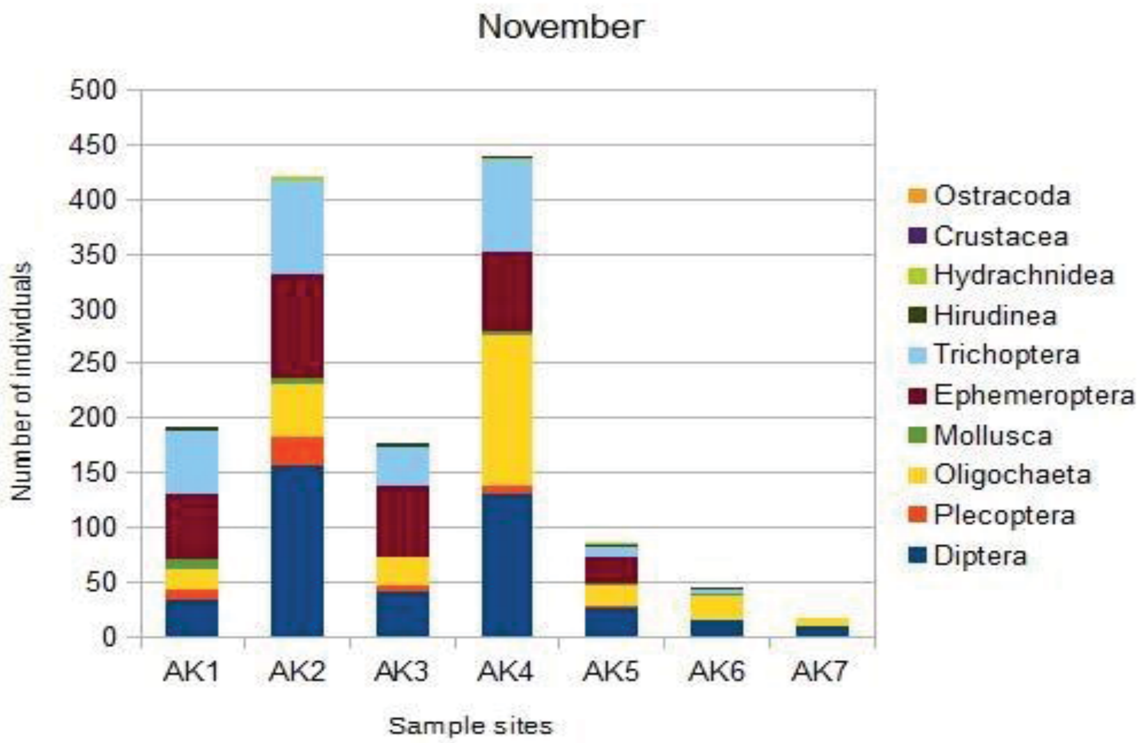





August
180
160
140
120
100
80
60
40
20
0
Number of individuals
AK1
AK2
AK3
AK4
AK5
AK6
AK7
Sample sites
Nematomorpha
Coleptera
Hydrachnidea
Hirudinea
Trichoptera
Ephemeroptera
Mollusca
Oligochaeta
Plecoptera
Diptera


September
300
250
200
150
100
50
0
Number of individuals
AK1
AK2
AK3
AK4
AK5
AK6
AK7
Sample sites
Nematomorpha
Crustacea
Coleptera
Hydrachnidea
Hirudinea
Trichoptera
Ephemeroptera
Mollusca
Oligochaeta
Plecoptera
Diptera


October
350
300
250
200
150
100
50
0
AK1
AK2
AK3
AK4
AK5
AK6
AK7
Ostracoda
Nematomorpha
Crustacea
Hydrachnidea
Hirudinea
Trichoptera
Ephemeroptera
Mollusca
Oligochaeta
Plecoptera
Diptera


November
Number of individuals
500
450
400
350
300
250
200
150
100
50
0
AK1
AK2
AK3
AK4
AK5
AK6
AK7
Sample sites
Ostracoda
Crustacea
Hydrachnidea
Hirudinea
Trichoptera
Ephemeroptera
Mollusca
Oligochaeta
Plecoptera
Diptera

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