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# A comparative study of macroinvertebrate biodiversity in highway stormwater ponds and natural ponds

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## HIGHLIGHTS

- Diversity and community composition differed between natural and highway ponds.
- Conductivity and pond surface area were associated to the observed differences.
- Highway ponds provide habitats that are otherwise unavailable along roads.

## GRAPHICAL ABSTRACT

Highway stormwater ponds support higher number of taxa than natural ponds, but different community composition.

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## ABSTRACT

The use of stormwater ponds along the highways is shown to be an effective alternative to conventional systems, which are usually sewers. These ponds have the potential to combine their primary function of pollution and peak flow control with the promotion of biodiversity. The present study focuses on comparing natural and highway stormwater ponds in terms of environmental conditions and biodiversity of macroinvertebrate communities. Twelve highway stormwater ponds and nineteen natural ponds (located within or in the vicinity of cultivated landscape) were explored for the number of taxa, community composition, and selected environmental variables: pH, conductivity, pond surface area, the number of ponds within 1 km radius, and the distance to nearest neighboring pond. Highway stormwater ponds showed much higher conductivity, which is a good proxy for chloride concentration and highway pollutants. In addition, the surface area of stormwater ponds was almost twice as big as that of natural ponds. The biological community composition was very different between the two types of ponds, and the number of taxa was slightly higher in the highway stormwater ponds. The most important variables responsible for the variation in the biological community composition were conductivity, pond surface area, and the number of ponds within 1 km radius. This study supports that, in addition to their role in pollution and peak flow control, stormwater ponds have the potential to provide a habitat that may otherwise be unavailable along the highway.

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## 1. Introduction

Ponds provide an important habitat for aquatic organisms, harbouring significant diversity of both common and rare species (e.g. Gledhill et al., 2008; Williams et al., 2008). Davies et al. (2008) found that in Europe, ponds clearly support the highest number of plant and macroinvertebrate species at the regional level (gamma diversity) compared to other water bodies, such as rivers and streams. However, although ponds may act as the most species-rich aquatic habitat, they are an overlooked freshwater habitat and received considerably less scientific attention than other freshwater bodies (Boix et al., 2012). In addition, the number of natural ponds has declined globally due to the increasing anthropogenic development, especially the expansion of agriculture and aquaculture (Galbraith et al., 2005), as well as increasing urbanization (Ellis et al., 2010; Wood et al., 2003).

In the context of the decreasing number of natural ponds and the increasing environmental impacts of urbanization, such as floods (Li et al., 2020) and water pollution (Ferreira et al., 2020), a number of artificial ponds have been established in cities and along highways. These ponds, which are usually referred to as stormwater ponds, are primarily used to control runoff peaks and flooding as well as to enhance stormwater quality through various processes, such as sedimentation (Tixier et al., 2011). Additional benefits provided by stormwater ponds, such as biodiversity conservation, are currently getting increasing attention, as their contribution to biodiversity becomes especially important in human-dominated urban landscapes (Céréghino et al., 2013). Several studies have acknowledged the functions of stormwater ponds as facilities supporting biodiversity or certain species in urban areas (e.g. Hassall et al., 2011; Hsu et al., 2011; Stephansen et al., 2016; Sun et al., 2018). Stormwater ponds may contribute to biodiversity conservation and ecological processes, such as dispersal, due to the large networks formed by ponds connected by ditches running along highways (Le Viol et al., 2009). However, other studies have pointed out that due to the proximity of road networks and urban areas, as well as the primary functions of stormwater ponds, multiple environmental stressors, such as accumulated contaminants (Gallagher et al., 2014; Grung et al., 2016; Meland et al., 2019; Sriyaraj and Shutes, 2001) and the introduction of non-native species (Ricciardi, 2015), may make these ponds act as constrained aquatic habitats or even ecological traps. Road and traffic contribute a lot to stormwater pollution through mechanical wear of pavement surface and release of chemicals into water running off the pavement surface (Müller et al., 2020). The road and traffic related pollutants, such as road salt, suspended solids and metals, play an important role in affecting aquatic biodiversity and increase the potential risks to aquatic ecosystems, such as reducing diversity and changing community composition (Carew et al., 2007). Moreover, natural ponds are located in landscapes with less impervious surfaces, resulting in differences in hydrologic regime with stormwater ponds (United States Environmental Protection Agency, 1993). Therefore, it is unclear whether such artificial stormwater ponds can act as sustainable facilities to support aquatic biodiversity, and how such ponds compare to natural ponds in this respect.

The research presented here aims to explore whether highway stormwater ponds can contribute to aquatic biodiversity in the areas along highways. We hypothesized:

(1) Physical and chemical conditions differ between highway stormwater ponds and natural ponds.
(2) Biodiversity, assessed as taxonomic richness and community composition of macroinvertebrates, differ between highway stormwater ponds and natural ponds.
(3) Physical and chemical conditions will have a significant impact on the measured biodiversity in highway stormwater ponds and natural ponds.

## 2. Material and methods

### 2.1. Study area and available data

The data used in the present analysis were obtained from two different projects. The data for 19 natural ponds were collected in 2002 for a Master thesis (Koch, 2003) on three occasions (May, July and September). The ponds were located within or in the vicinity of cultivated landscape and categorized as forest ponds, meadow ponds and farmyard ponds. However, due to a limited number of ponds within each category we have chosen to use these ponds as one single category, i.e. natural ponds, in the data analysis. The data for 12 highway stormwater ponds were collected in 2013 and 2014, four times per year (April/May, June, August and October) (Sun et al., 2019).

The natural and highway stormwater ponds are located within the same geographic region (Fig. 1) in south-east of Norway. The datasets comprised biological data, water quality, physical descriptor of the ponds, and selected landscape variables. The biological datasets included mainly macroinvertebrates, but a few amphibian species and fish were also recorded and included in the data analyses. Water quality variables included pH and conductivity. The physical descriptor of the ponds refers to the pond surface area, while landscape variables included the number of ponds within a radius of 1 km and the distance from the study ponds to the nearest neighboring ponds.

As the datasets originated from a timespan of >10 years, we initially checked whether air temperature, precipitation and days of precipitation were significantly different between sampling years (i.e. 2002, 2013 and 2014). Differences in temperature may affect growth rates and generation time, but not species composition as most of the fauna is adapted to year to year variation. One-way ANOVA on data from three meteorological stations in the studied area revealed no statistically significant differences between year (Fig. S 1). Hence, we concluded that the observed minor differences would not be a confounding factor in our analyses.

### 2.2. Data treatment and statistical analysis

The statistical analyses and ordination plots were done using the software Canoco 5, version 5.12 (Ter Braak and Šmilauer, 2018). Graphics other than the ordination plots, including linear regression and boxplot, were made in the software JMP 14.0.0 (SAS Institute Inc.).

These two datasets come from two different sources, and sampling was performed at slightly different times and by different persons. Therefore, to make these datasets as comparable as possible, we chose to use presence/absence data (i.e. binary data (1/0)) instead of abundance data in the statistical analyses. This is recommended by, for example, Legendre (2014), who also concluded that presence/absence data would provide interesting results, especially in cases when communities differ somewhat in species composition. The two datasets also have certain differences regarding the level of taxonomic determination. For example, in the natural pond dataset most Coleopterans and Heteropterans were identified to species, while these groups were identified mostly to genus in the stormwater pond dataset. Hence, we performed an initial analysis using Detrended Correspondence Analysis (DCA) on the data with different taxonomic levels: species (147 taxa), genus (98 taxa), and family (41 taxa). In addition, we performed a Canonical Correspondence Analysis (CCA) on these three taxonomic levels using pond type as categorical explanatory variable (i.e. highway stormwater ponds vs. natural ponds). The output of these initial analyses is presented in the Supplementary material (Fig. S 2). Based on the initial DCA and CCA we decided to use genus as the lowest taxonomic level. This was considered to be an adequate compromise, because the impact of uncertainties related to different levels of taxonomic determination between the two datasets is reduced without losing too much

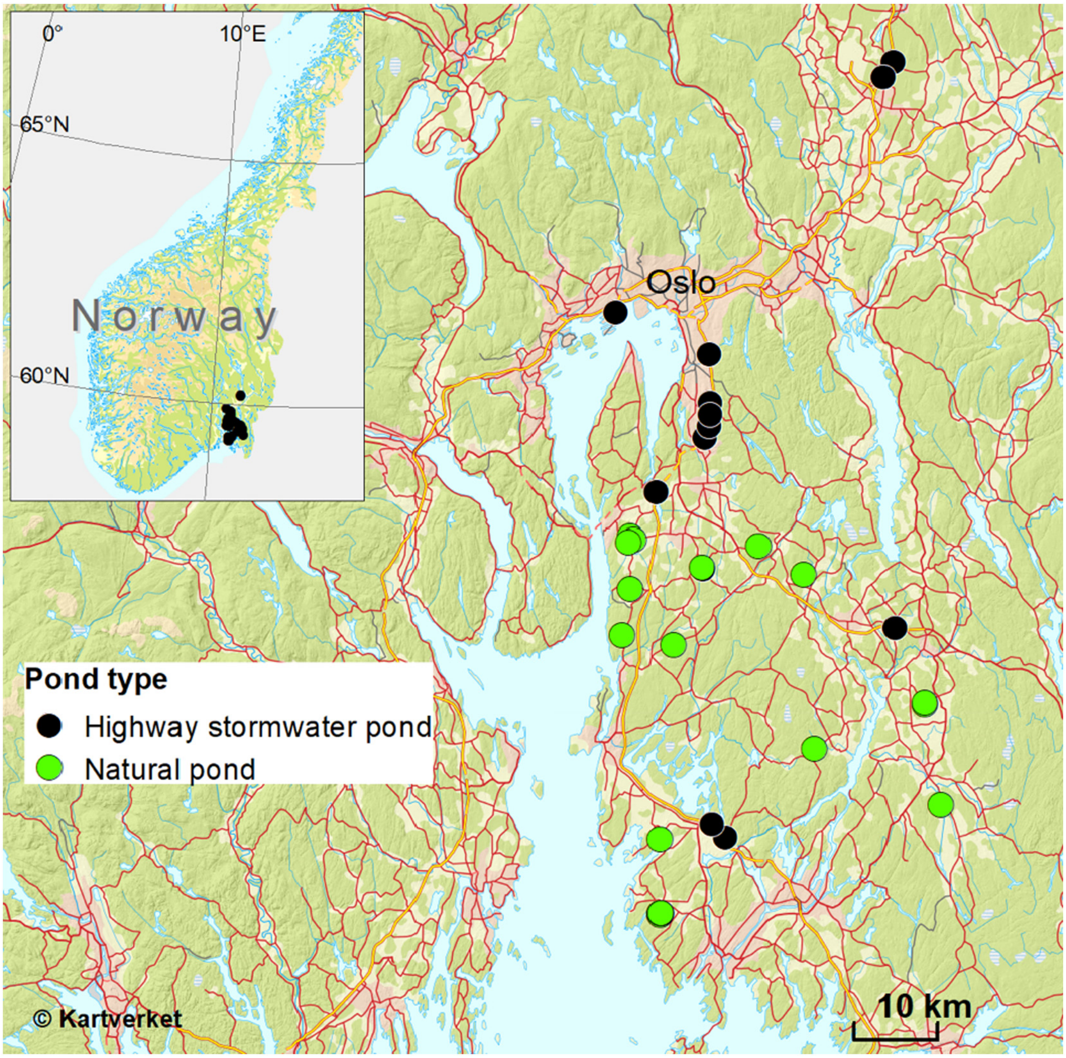

**Fig. 1.** Map showing the location of the studied ponds. The map was created in Esri ArcGIS Desktop version 10.6.1.9270 (www.esri.com), using basemaps from the Norwegian Mapping Authority (©Kartverket, www.kartverket.no).

biological information, as would have been the case if the lowest taxonomic determination were set to family level.

As the two datasets had differences in the number of sampling campaigns and in the timing of the campaigns within the year, we aggregated the data to one sample from each pond per year. Any impact of seasonality was thus removed from the data. The number of cases was therefore reduced from 153 (19 natural ponds × 3 months +12 highway stormwater ponds × 4 months × 2 years) to 43 (19 natural ponds + 12 highway stormwater ponds × 2 years). Finally, we averaged the presence/absence data to get per-year values on the scale between 0 and 1. For example, if a taxon was present in a particular pond in two sampling periods, it got a value 0.66, and if a taxon was present in all three sampling periods, it got a value 1. In this way, taxa that occurred more frequently got a higher weight in the statistical analyses compared to taxa that occurred less frequently. A drawback is however that a species which is strictly seasonal (e.g. occurring in the springtime) and cannot be sampled at a particular time of year are disadvantaged by this approach.

In the final analyses we used distance-based analysis using PCoA (principal coordinate analysis) and dbRDA (distance-based Redundancy Analysis). Hellinger distance measure was used in both analyses. By using Hellinger transformation, all essential properties for beta diversity assessment, such as minimum of zero and positiveness, and double-zero asymmetry, are included (Legendre and De Cáceres, 2013). PCoA was used to disclose any differences in community composition between highway stormwater ponds and natural ponds, while dbRDA was used to disclose any relationships between the observed biological variation and the explanatory variables. Explanatory variables common to both datasets were physical landscape variables including pond characteristics and the chemical water quality variables pH and conductivity (Table 1). Conductivity is a good proxy for pollution levels as conductivity is strongly linked to road salt concentrations in highway stormwater ponds. The numerical explanatory variables, except pH, were $\log(x + 1)$ transformed prior to dbRDA.

Comparison of various explanatory variables and the number of taxa between highway stormwater ponds and natural ponds and the assessment of any relationship between the number of taxa and explanatory variables were performed using redundancy analysis (RDA), an assumption-free alternative to the parametric *t*-test and linear regression.

In all constrained statistical analyses (i.e. CCA, dbRDA and RDA), Monte Carlo permutation tests were performed to derive pseudo-F and corresponding p-value. 1999 permutations were used and $p < 0.05$ was considered statistically significant.

The datasets used in the present paper are provided in the Supplementary material.

**Table 1**
Descriptive statistics of explanatory variables and output of the non-parametric *t*-tests using RDA to test any difference in the numeric explanatory variables between natural ponds and highway stormwater ponds. Physical variables were tested based on the 12 values for 12 highway stormwater ponds and 19 values for 19 natural ponds; while chemical variables were tested based on 12 × 2 values for 12 highway stormwater ponds (representing 2013 and 2014) and 19 values for 19 natural ponds.

| | | Descriptive statistics mean ± sd | | Test statistics | | |
|---|---|---|---|---|---|---|
| Name | Unit | Natural ponds (n = 19) | Highway stormwater ponds (n = 12) | n | Pseudo-F[a] | p-Value |
| Number of ponds within 1 km radius | – | 4.8 ± 3.6 | 4.0 ± 2.0 | 31 | <0.1 | 0.931 |
| Distance to nearest neighboring pond | m | 367 ± 360 | 322 ± 288 | 31 | <0.1 | 1 |
| Pond surface area | $m^2$ | 295 ± 267 | 551 ± 354 | 31 | 5.8 | 0.0205 |
| pH (median, min – max) | – | 6.9 (5.9–8.4) | 7.1 (6.6–8.1) | 43 | 1.1 | 0.3045 |
| Conductivity | mS/cm | 147 ± 112 | 756 ± 766 | 43 | 55.0 | 0.0005 |

[a] Pseudo F was derived by using Monte Carlo permutation test (1999 permutations).

## 3. Results

Table 1 presents the descriptive statistics of explanatory variables and the results of the non-parametric *t*-tests using RDA to examine the differences in the numeric explanatory variables between natural and highway stormwater ponds. The results showed that there was a statistically significant difference in pond area and conductivity between natural and highway stormwater ponds, while there was no statistically significant difference in the number of ponds within 1 km radius, distance to the nearest neighboring pond, and pH.

Numbers of unique and shared taxa at different taxonomic identification levels are presented in Table 2. In general, highway stormwater ponds appeared to have more unique taxa than natural ponds regardless of the taxonomic level. This pattern was, however, most pronounced at the genus level. The unique taxa in the highway stormwater ponds were mainly composed of taxa from the families Coenagrionidae (damselfly), Baetidae (mayfly), Lymnaeidae (air-breathing freshwater snails), Veliidae (water strider), Libellulidae (dragonfly), and Ephemeridae (mayfly); the unique taxa in the natural ponds were mainly composed of taxa from the families Haliplidae (crawling water beetle), Dytiscidae (diving beetle), and Hydrophilidae (water scavenger beetle).

The distribution of the number of taxa is illustrated in Fig. 2. Number of taxa determined to genus level appeared slightly higher in highway stormwater ponds compared to natural ponds. The difference was statistically significant (pseudo-F = 9.1, p = 0.006). This difference was also evident when using species and family levels (Fig. S 5).

The differences in the structure of macroinvertebrate communities in ponds were analysed using PCoA (Fig. 3A). The first and the second PCoA axes explained 18.5% and 9.7% of the variance, in total 28%. Along PCoA axis 1, the two pond types were clearly separated. This separation was not evident along PCoA axis 2.

The dbRDA using pond type (i.e. highway stormwater ponds and natural ponds) as categorical variable revealed a statistically significant difference in community composition between the two pond types (pseudo-F = 8.4, p = 0.0005). It should also be noted that there was no significant difference in community composition in the highway stormwater ponds between the two sampling years 2013 and 2014 (pseudo-F = 1.3, p = 0.22). The dbRDA, using forward selection on the various numerical explanatory variables (Fig. 3B), showed that conductivity (explained variation = 12%, p = 0.0005), surface area (explained variation = 4%, p = 0.006), and number of ponds within 1 km (explained variation = 3%, p = 0.0325) contributed significantly to the observed variation in the community composition between the different ponds. The dominant taxa in the highway stormwater ponds were positively correlated with the pond surface area and conductivity, while on the contrary, most of the dominant taxa in the natural ponds, except Dytiscidae, were negatively correlated with these explanatory variables.

Regarding the number of taxa, the result of linear regression indicated that the number of taxa determined to genus level was significantly positively correlated with conductivity (Fig. 4), but none of the other explanatory variables showed a significant relationship with the number of taxa. Similar results were obtained for species and family levels (Fig. S 6).

**Table 2**
Number of unique and shared taxa present in natural ponds and highway stormwater ponds (number in brackets shows the percentage of the total number of taxa). The numbers are derived from all three different taxonomic identification levels.

| | Number (%) of taxa present in natural and highway stormwater ponds | | |
|---|---|---|---|
| Taxa level | Unique for natural pond | Unique for highway stormwater pond | Common to both pond types |
| Species | 51 (35%) | 54 (37%) | 42 (29%) |
| Genus | 25 (26%) | 34 (35%) | 39 (40%) |
| Family | 6 (15%) | 9 (22%) | 26 (63%) |

## 4. Discussion

This study documents that highway stormwater ponds support a diverse macroinvertebrate fauna, with a slightly higher number of taxa than in natural ponds. The community composition in the highway stormwater ponds was, in addition, quite different from that in the natural ponds which may be linked to differences in environmental characteristics between the two types of ponds. Most of the dominant taxa in our highway stormwater ponds are known to be pollution tolerant, e.g. the damselfly Coenagrionidae and the dragonfly Libellulidae (Resh and

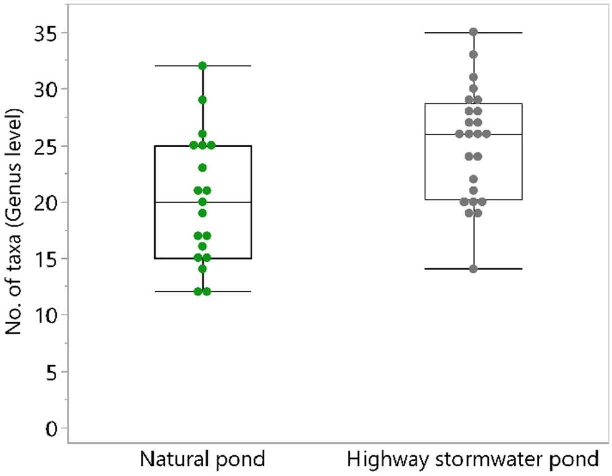

**Fig. 2.** The number of taxa depicted in boxplot showing number of taxa determined to genus level present in natural ponds (n = 19) and highway stormwater ponds (n = 24). RDA with Monte Carlo permutation test: pseudo-F = 9.1, p = 0.006. Natural ponds and highway stormwater ponds are coloured green and grey, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

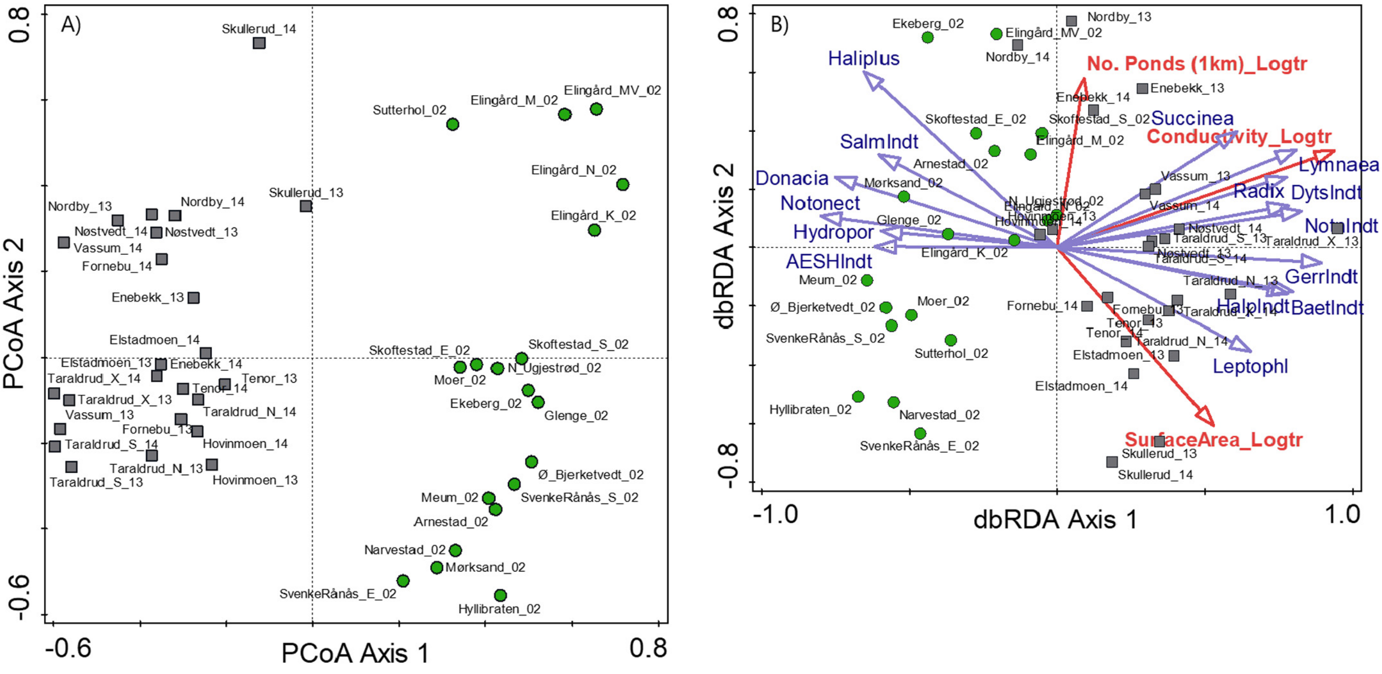

**Fig. 3.** A) Principal coordinate analysis (PCoA, Hellinger distance) and B) distance-based redundancy analysis (dbRDA, Hellinger distance) using forward selection on data with taxonomic resolution at genus level ($n = 43$ cases and 98 taxa). The complete names of ponds and taxa are available in supplementary material. The natural ponds are depicted by green circles, and highway stormwater ponds are depicted by grey squares. Explanatory variables that were statistically significant ($p < 0.05$) are depicted by red arrows, and taxa are depicted by mauve arrows. Only taxa that correlate with the ordination axes smaller than −0.5 or larger than 0.5 are displayed. Taxa abbreviations are presented in Supplementary material. PCoA and dbRDA on species and family determination level are presented in Supplementary material. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Rosenberg, 2008). In addition, the water strider Veliidae, one of the unique taxa in the highway stormwater ponds, are normally present on the water surface and are therefore likely less affected by water pollution under the water surface (Barman and Gupta, 2015). Becerra Jurado et al. (2009) also found that the community composition in constructed ponds differed from that in natural ponds due to, for example, high tolerance of certain taxa to the organic pollution.

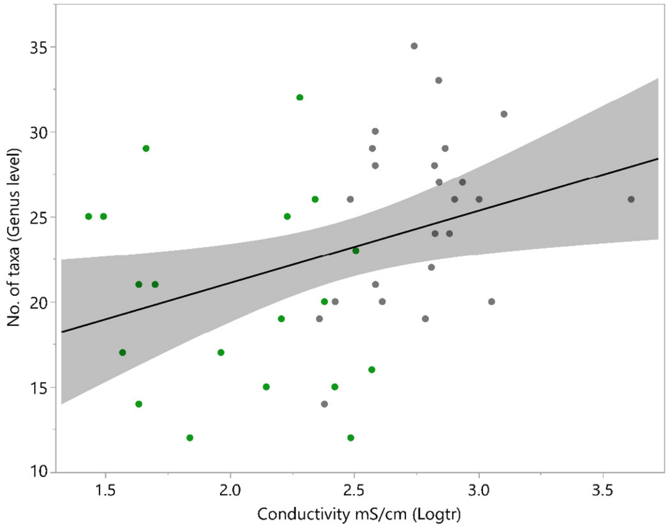

**Fig. 4.** Regression plot showing the relationship between number of taxa determined to genus level and conductivity in the ponds. Natural ponds and highway stormwater ponds are coloured green and grey, respectively. The conductivity values were log-transformed prior to the analysis. RDA with Monte Carlo permutation test: $n = 43$, $R^2_{adj} = 0.11$, pseudo-$F = 6.1$, $p = 0.0175$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In the results of dbRDA, the environmental variables that had the greatest influence on the biological community composition in the studied ponds were the number of ponds within a radius of 1 km, pond surface area, and conductivity. The latter two explanatory variables were the only ones that were significantly different between the two pond types. The dominant taxa in the highway stormwater ponds were positively correlated with these three variables, while most of the dominant taxa in the natural ponds showed the opposite response. Pond surface area and connectivity have been documented by our previous studies to be among the most important factors affecting the variation in the community composition (Sun et al., 2018; Sun et al., 2019). The reason that conductivity in the highway stormwater ponds was significantly higher than in the natural ponds is the use of sodium chloride as a deicing agent on Norwegian roads (Sun et al., 2018). Therefore, during winter and spring, the road runoff and snowmelt-induced runoff bring large amounts of chloride into the receiving ponds, significantly affecting the water quality. Several studies have demonstrated that elevated concentrations of chloride can result in lethal and sublethal effects on freshwater invertebrates (Pond et al., 2014; Soucek and Kennedy, 2005). Among the taxa that were positively correlated with the conductivity, some were mayflies (Ephemeroptera), such as Baetidae and Leptophlebiidae. Although mayfly taxa have been shown to be sensitive to salinity (Johnson et al., 2015), our results suggested that Cloeon (Baetidae) appears to be one of the ephemeropteran genera that is more tolerant to salinity than other mayflies. This finding was in accordance with the result of Timpano et al. (2018) and Pond (2010). Our finding of Leptophebiidae (mayfly) was in contrast to Dominguez-Granda et al. (2010) and Dalu and Chauke (2019), who suggested that the presence of Leptophlebiidae was characteristic of sites with low conductivity, although *Leptophlebia* spp. have been recorded in the estuary area of a coastal stream (Lingdell and Müller, 1979). Another taxon that was positively correlated with conductivity in our study was Dytiscidae. Similarly, Mereta et al. (2012) found that the taxa belonging to the order of the Coleoptera were positively correlated with conductivity, and abundance of Dytiscidae increased with increasing conductivity. Furthermore, air-breathing freshwater snail species from the genus *Lymnaea*, such as *Lymnaea truncatula*, also exhibited the positive correlation with conductivity, and this is in agreement with Costil et al. (2001) who found that *Lymnaea truncatula* survived in areas with high conductivity.

Linear regression of number of taxa and conductivity showed that the number of taxa slightly increased with elevated conductivity. This result is not necessarily consistent with Johnson et al. (2013), who suggested that increases in conductivity ultimately decreased the richness of intolerant taxa. However, the positive correlation of the number of taxa with conductivity in our study may be attributed to the presence of tolerant taxa, such as Coeagrionidae and Libellulidae. Dalu and Chauke (2019) found that Aeshnidae (dragonfly, in both natural and stormwater ponds), Coenagrionidae (mainly stormwater ponds), Corixidae (water boatmen, in both natural and stormwater ponds), and Gerridae (in both natural and stormwater ponds) were abundant at the sites characterized by high conductivity and pH. Barman and Gupta (2015) also found that conductivity was positively correlated with species richness and density of macroinvertebrates. Another explanation of the positive relationship between the number of taxa and conductivity is that the levels of conductivity did not reach a critical threshold value that causes sublethal effects, such as reduction in growth and reproduction, while further increases in salinity will lead to death (Céspedes et al., 2013). Moreover, most taxa in our study may be able to regulate osmotic exchanges under both hyperosmotic and hypoosmotic conditions, thereby mediating their broad osmotic tolerances (Céspedes et al., 2013).

In general, our results suggest that the highway stormwater ponds supported slightly higher number of taxa compared to the natural ponds. This finding is in agreement with previous studies that have shown the significant contribution of stormwater ponds to the maintenance of biodiversity (Becerra Jurado et al., 2009; Hassall and Anderson, 2015; Hill et al., 2017; Le Viol et al., 2009). For example, Le Viol et al. (2009) found that even though the abiotic conditions in highway ponds were different from those in surrounding ponds due to the pollution retention function, macroinvertebrate communities in the highway ponds were highly diverse and rich relative to surrounding ponds. Hill et al. (2017) also suggested that compared with nonurban ponds, urban ponds support relatively high alpha and gamma diversity of invertebrates, and the biological communities in these two types of ponds were markedly different.

## 5. Conclusions

The present study explored the number of taxa and community composition of mainly macroinvertebrates in highway stormwater ponds and natural ponds within and in the vicinity of cultivated landscape. The two types of ponds were different in physical and chemical characteristics. Highway stormwater ponds in this study were characterized by larger pond surface area and higher conductivity. Conductivity is a good proxy for chloride concentration and highway pollutants. The number of ponds within 1 km radius and the distance to nearest neighboring pond were not different between the pond types, nor were the pH levels. The community composition was found to be very different between the two pond types. This distinction was evident regardless of taxonomic identification level (i.e. family, genus or species level). The number of ponds within a radius of 1 km, pond surface area, and conductivity had the greatest influence on the biological community composition in the studied ponds. Finally, the number of taxa was slightly higher in the highway stormwater ponds. Hence, highway stormwater ponds have the potential to promote and even enhance biodiversity and provide a habitat that may otherwise be unavailable along the highway. The present study therefore underlines the benefit that highway stormwater ponds may have for biodiversity, in addition to their primary function as mitigation measures for pollution and peak flow control.

## CRediT authorship contribution statement

**Sondre Meland:** Conceptualization, Methodology, Formal analysis, Writing - original draft. **Zhenhua Sun:** Conceptualization, Methodology, Formal analysis, Writing - original draft. **Ekaterina Sokolova:** Writing - review & editing. **Sebastien Rauch:** Writing - review & editing. **John E. Brittain:** Conceptualization, Methodology, Writing - review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.140029.

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