



Breeding birds in wetlands: the roles of biotic and abiotic drivers

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Breeding birds in wetlands: the roles of biotic and abiotic drivers

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Abstract

Ponds and wetlands have a long history of being drained in Sweden. This has mostly been carried out by digging ditches and thus draining the fields to improve productivity of the ground for agriculture and forestry. This has led to a great loss of biodiversity amongst all groups connected to water habitats, including the loss of bird habitats. These are but a few reasons why we need to protect, restore, and create new wetlands. In order to make better cost-effective decisions regarding wetland creation, it is important to study which aspects of a pond are important for biological diversity. Can a network of restored and recreated wetlands support bird diversity and increase the populations? What aspects are most important for bird diversity? I conducted surveys of birds between the 14th and 17th of April from a set of ponds that were already characterised within the project PuddleJump, taking into account pond properties and the composition of the plant community. First, I explored variations in dissolved oxygen, pH levels, wetland size, and five macrophyte groups among five types of ponds (biodiversity, recreation, phosphorus, water retention and stormwater). Then, I analysed the variation in birds relative to wetland size and three more relevant macrophyte groups. These analyses of abiotic and biotic factors were used to determine the most relevant factors to explain the variation in bird individual abundance, species richness, and pair abundance. Biodiversity ponds were distinctly larger than the other pond categories, while phosphorus retention sites were the smallest. pH and dissolved oxygen did not clearly vary between the categories, but there was considerable variation in macrophyte composition between the pond categories. Pond size, a variable coinciding with the pond categories, was the most important factor to explain bird metrics, where the larger the wetland was, the more species, individuals, pairs and average number of species they locally had. Secondly, submergent vegetation was positively associated with species richness and tended to associate positively with the number of individuals. Lastly, emergent macrophyte cover seemed to positively associate with bird pair abundance. Filamentous algae cover and its correlation with a deficient cover of the other macrophytes and why they are prominent in phosphorus ponds was discussed. Before the conclusion error sources and future questions are presented for future research. In conclusion, size is most important for all bird measures, submerged vegetation is good for bird species richness and individual bird abundance, and emergent vegetation has been shown in this study to be good for only pair abundance.

Keywords: Macrophytes, pond restoration, pond conservation, ducks, waders, GLM, lm, pond types, waterfowl, diversity, richness

Sammanfattning

Dammar och våtmarker har en lång historia av dränering i Sverige. Det här har mestadels skett genom grävning av diken för att dränera fält, vilket ökar produktiviteten i jordbruksmark och i skogar. Detta har lett till stora förluster av biodiversitet för alla organismgrupper anslutna till dessa habitat, fåglars habitat inkluderat. Detta är bara några få exempel på varför vi behöver skydda, återskapa och skapa nya våtmarker. För att kunna ta välgrundade ekonomiska beslut kring skapandet av våtmarker, är det viktigt att studera vilka aspekter av våtmarker som är viktiga för att uppnå biologisk diversitet. Kan ett nätverk av återskapade och skapade våtmarker bära upp fågeldiversitet och öka deras populationer? Vilka aspekter är viktigast för fågeldiversitet? Jag genomförde fågelinventeringar mellan den 14:e och den 17:e april på ett antal dammar som redan karaktäriserats inom projektet PuddleJump, som inventerat dammegenskaper och dammarnas växta bestånd. Jag började mitt arbete med att undersöka lösligt syre, pH-värden, dammstorlek, och fem makrofytgrupper inom fem typer av dammar (biodiversitet, rekreation, fosfor, vattenansamling och dagvatten). Efter det analyserade jag variationen av fågelvärden jämfört med dammstorlek och tre relevanta makrofytgrupper. Dessa analyser av abiotiska och biotiska faktorer användes för att komma fram till vilka faktorer som bäst förklarar variationen i fåglars abundans, antal arter och parabundans. Biodiversitetsdammar var tydligt större än de andra dammgrupperna, samtidigt var fosforinsamlingsdammar minst. pH och löst syre hade ingen tydlig variation mellan dammkategorierna, men det fanns stor variation bland makrofytsammansättning mellan dem. Storleken på dammar var starkast faktor till höga fågelvärden, där desto större damm innebar desto fler arter, individer, par och medelvärde på par. Efter undersökning av abiotiska faktorer och makrofyt grupperna, undersöktes makrofyters korrelation med fågelvärdena. Undervattensvegetation var associerat positivt med antal arter och hade en positiv korrelation med antalet individer. Slutligen verkade det som att övervattensväxters täckning var positivt associerat med fåglars parabundans. Trådformiga algers täckning och deras korrelation med låg täckning av andra makrofytgrupper och varför de finns i stor mängd i fosforinsamlingsdammar diskuterades. Innan slutsatsen diskuterades felkällor och framtida frågor för framtida undersökningar. Sammanfattningsvis, storleken på dammarna är viktigast för samtliga undersökta fågelvärden, undervattensväxter är bra för fåglars artrikedom och fågelabundans, och övervattensväxter har i den här studien visats vara bra för parabundans.

Nyckelord: Macrophyte, pond restoration, pond conservation, duck, waders, GLM, lm, pond types, water fowl, diversity, richness

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Abbreviations

Abbreviation	Description
GHG	Greenhouse gases
GLM	Generalized linear model
Lm	Linear model
SAR	Species-area relationship
SLU	Swedish University of Agricultural Sciences
VIF	variance information factors

1. Introduction

1.1 Wetlands today

Wetland deconstruction is one of the sources of greenhouse gas emissions and loss of biodiversity (Skogsstyrelsen 2021). As the effects of global warming are becoming more apparent, people have formed political groups that use wetlands as an example of habitats with the need for restoration and recovery to save the Earth's environmental issues (*Våtmarker & Torv* 2024). This has been met with critical responses from the public because of their way of campaigning for this. Despite this, wetlands are important to our environment both from the perspective of global warming and biodiversity (Alikhani et al. 2021). Drained wetlands in Sweden were estimated to release six and a half million tons of CO₂ the year 2019 (Skogsstyrelsen 2021.). To put this into perspective, the amount of CO₂ cars in Sweden produced in the year 2023 was eight and a half million tons (Naturvårdsverket 2025). Both numbers have since then been slightly lowered, but this shows how much drained wetlands contribute to the total sum of Sweden's carbon emissions. Additionally, drainage reduces water retention and increases nutrient transport (Gramlich et al. 2018), reducing the current number of habitats available. Ponds created today are made with different aims, for instance, ponds with biodiversity as priority, recreation, stormwater retention, phosphorus retention, and water retention. These ponds are made to restore the ecological functions and ecosystem services lost from land drainage, recreating habitats, reducing overfertilization to the surroundings from agricultural land, to store water for a potential dry summer and to have beautiful nature available for people to visit.

1.2 Cause of wetland loss and its history

The source of the problem we now see with wetlands is the output of greenhouse gases and the loss of biodiversity resulting from the drainage is mainly due to two forms of land use, forestry and agriculture. This is because water-saturated soils interfere with both crop production and forestry (Landin 2022). This was done to create more land for agriculture and forestry, and to achieve a higher productivity for the land. Soils saturated with water needed to be drained through digging ditches, so the roots of the crops and trees are able to get sufficient amounts of water, air, and nutrition. However, while these developments have supported Swedish agricultural and population development, wetland drainage has become an environmental problem with them releasing GHGs and causing biodiversity loss. Sweden began drainage through ditching to lower water levels as early as the

1300s. However, it became increasingly widespread and used throughout the late 1600s, the 1700s, 1800s, and 1900s. This practice also became increasingly harmful, with the development of more efficient technology that made the ditches deeper. In 1994, making new ditches was banned because of their hydrological impact, and because the extensive network of ditches that had already been made was more than enough for its purpose. Modern agricultural techniques have since made land draining less important for agricultural success (Naturvårdsverket 2023). However, ditches still exist and are still being maintained, which leads to them continuing to drain the landscape. To reverse the extensive habitat loss, or at least to compensate for it, we currently need to create new wetlands.

1.3 Wetlands in an urban context

Apart from the roles of wetlands in agricultural and forest landscapes in supporting nutrient and water retention as well as biodiversity, wetlands can also fulfil recreational value and biodiversity in and around cities. This is relevant to mention in this paper because most people live in cities today, and the global population is forecast to increase, making sustainable cities with natural elements increasingly important. (Alikhani et al. 2021). Therefore, wetlands and ponds could be such a habitat to implement in these cities. Some of the benefits wetlands provide in cities are providing a microclimate with lower temperatures than the surrounding urban structures (Alikhani et al. 2021). Some specific effects and findings are that several small lakes have a better effect on lowering the cities' temperatures. Small ponds have been measured to lower temperatures in an area with a radius of one thousand meters. Small ponds correlate with biodiversity too, where several small patches are better for biodiversity than a single large one (Matthews & Endress 2010). Wetlands and ponds are fast to be colonized by the surrounding species pool, which means that creating wetlands in urban areas will gain fast results with all successional stages being completed within four years (Matthews & Endress 2010).

1.4 Biological effects and ecological theory

Higher biodiversity is usually associated with wetlands characterized by greater habitat diversity and better water quality. A more diverse cover of macrophytes and animal life in the ponds could lead to better habitat diversity, providing different ecological niches for diverse bird species to coexist in the same pond (Thomaz & Cunha 2010). Birds are often at the top of the ponds trophic levels and are therefore good to study to see the ponds general nature values (ibid) and ecological changes (Green & Elmberg 2014). This is due to a bottom-up

effect, if something in the pond cannot support the higher trophic level, then there are not enough elements in the pond to support birds.

The water quality of the ponds is important for macrophytes being able to grow there, worse water quality associated with being near urban areas and fields affects submerged macrophytes and floating leaves more than emergent vegetation (Akasaka et al. 2010). Turbidity, which water retention ponds, stormwater ponds or ponds near cities could experience, is a problem. This is due to sediment floating in the water from surrounding pollutants, and moving water will affect the submerged macrophytes by making the water less transparent, reducing the amount of sun light they receive. Additionally, macrophytes are negatively affected by surrounding trees shading the waters, which impairs their ability to conduct photosynthesis which in turn impairs their growth but does not completely take them away (Akasaka et al. 2010). These effects on macrophytes could in turn affect higher trophic levels such as birds, which is one reason why they are being studied.

Emergent macrophytes are important for birds, especially during spring. This is due to them being less mobile when mating and forming pairs (Paracuellos & Tellería 2004). Submerged vegetation is a big factor for bird abundance, especially for herbivorous waterfowl, and with more species of submerged macrophytes, the more different bird species could be in the pond (Mao et al. 2019). The availability of emerged vegetation could counter the disturbance of surrounding noise (Rodrigues et al. 2018) and still provide a habitat that birds are present in, which is something that could be an important factor when building ponds near cities. Floating leaves are important for invertebrates, amphibians and some fish species providing a microclimate and places to lay eggs, which in turn could be a source of food for birds and influence their richness (Lewis-Phillips et al. 2020). Filamentous green algae have competing power with a possibility of outcompeting other vegetation, that which in the case of them not being outcompeted, would attract a diverse population of herbivorous birds (Dean & Selckmann 2015).

Some of the data used for this study came from project PuddleJump, which mostly contained information about macrophytes. The data also contained measures of pond size, pH, and oxygen. Pond size has according to the species-area relationship (SAR) an important part in abundance and species richness, where the greater size of a pond means more species and individuals (Oertli et al. 2002). Measures of pH and oxygen are interesting to review in this paper because pH levels increase with higher macrophyte density in the ponds (Iacarella et al.

2018), which can be an extra thing that tells if there is a good vegetation cover in the ponds. Low oxygen levels can be correlated with low vegetation diversity (Sayer et al. 2012) and restrict the possibility of a more diverse species pool, where fish unable to be there if the water is anoxic, affecting piscivorous birds.

1.5 Main Question and purpose

The chosen ponds for this study are created for one of five purposes, which are either water retention, stormwater management, biodiversity, phosphorus retention, or recreation. Phosphorus retention ponds are located in crop fields to collect nutrients from the surrounding area, especially phosphorus that is being drained from the soil when it rains. The purpose of this is to dampen the negative effects of fertilization in the surrounding fields when the farmers enriches the soil with fertilizers (Börling 2010). Biodiversity sites are created to support specific biotic communities, most commonly birds and amphibians, but also crayfish or odonates by providing suitable habitat for them (Länsstyrelsen Upplands län 2017). Recreation ponds are made to be accessible for everyone, and for people to want to visit the area. There should be beautiful nature with birds of diverse species being present, increasing the drive to visit the pond. For this to be fulfilled, these ponds are made to support a variety of birds and vegetation, making it better for biodiversity (Projekt och åtgärder 2023). One could also think that recreational ponds needing to be available for people to visit, and thereby often located near or inside cities, would have reduced biodiversity levels because of the increased noise, human presence, and littering. Stormwater ponds are made to collect the runoff of excess water from the surroundings (Stockholmsstad 2024). Water retention has a similar purpose to stormwater ponds but is situated in areas with forestry activity. These ponds are designed to prevent substances from leaking downstream after clearcutting (*Skogsstyrelsen* 2017). These ponds have an important use during droughts too, and could be used by farmers to water the crops (Länsstyrelsen Skåne 2023), mitigating the risk of losing their harvest.

The design of these wetlands will depend on their purpose. But what are the main differences? Do they have any common features? Could they benefit other purposes than intended? This brings further questions. If the wetlands created for biodiversity work as intended, which elements could be easily implemented to increase biodiversity for the other pond types? Which abiotic or biotic variables are most important for bird diversity? Answers to these questions will be valuable for future restoration projects focusing on wetlands. Ultimately, all this boils down to the main question of this study: Which created wetland variable are most important to prioritize for conservation? Thus, the purpose of this paper is to

evaluate the relationship between breeding birds, aquatic plants, and abiotic factors in a set of small artificial water bodies of varying environmental quality.

Some outcomes of this study could be that pond size has a large effect on biodiversity according to the species-area relationship, which says that the greater the area of a given habitat, the more species and individuals there are (Oertli et al. 2002). The presence of submerged vegetation should be something that positively correlates with most of the bird measures because it provides food for most of the birds I surveyed. Emerged macrophytes are supposed to provide shelter and a place to lay eggs for the birds, meaning that their coverage should probably be closely connected with pair abundance. It is important to check if these macrophytes are important at explaining the bird community metric variation after accounting for the variation explained by the pond size.

1.6 Paper disposition in short

The introduction gives background information about ponds and wetlands, leading up to why this study is being done. Then the methods are described with a bird survey in the ponds used for project PuddleJump mainly for waders and waterfowl and later data analysis using excel for visual interpretation and R software to make linear and generalized linear models to find associations between pond attributes and collected bird data, to see what aspects of the ponds affect bird diversity. This is followed by a result section mainly describing what I have found. After this, a small literary review putting the found associations into perspective based on previous work. Lastly, the paper will end with a conclusion.

2. Material and methods

As a part of Project PuddleJump, 21 small artificial wetlands representing five types of wetlands – two water retention ponds, eight phosphorus retention ponds, five biodiversity ponds, five recreational ponds, and one stormwater management pond. These have previously been inventoried for their macrophyte communities, and data on abiotic variables, such as water chemistry and substrate characteristics. The ponds are distributed throughout the Uppland region with selected sites close to Enköping, Uppsala, and Östhammar (figure 1). These sites vary greatly, due to the purpose of the pond having an influence on its design.

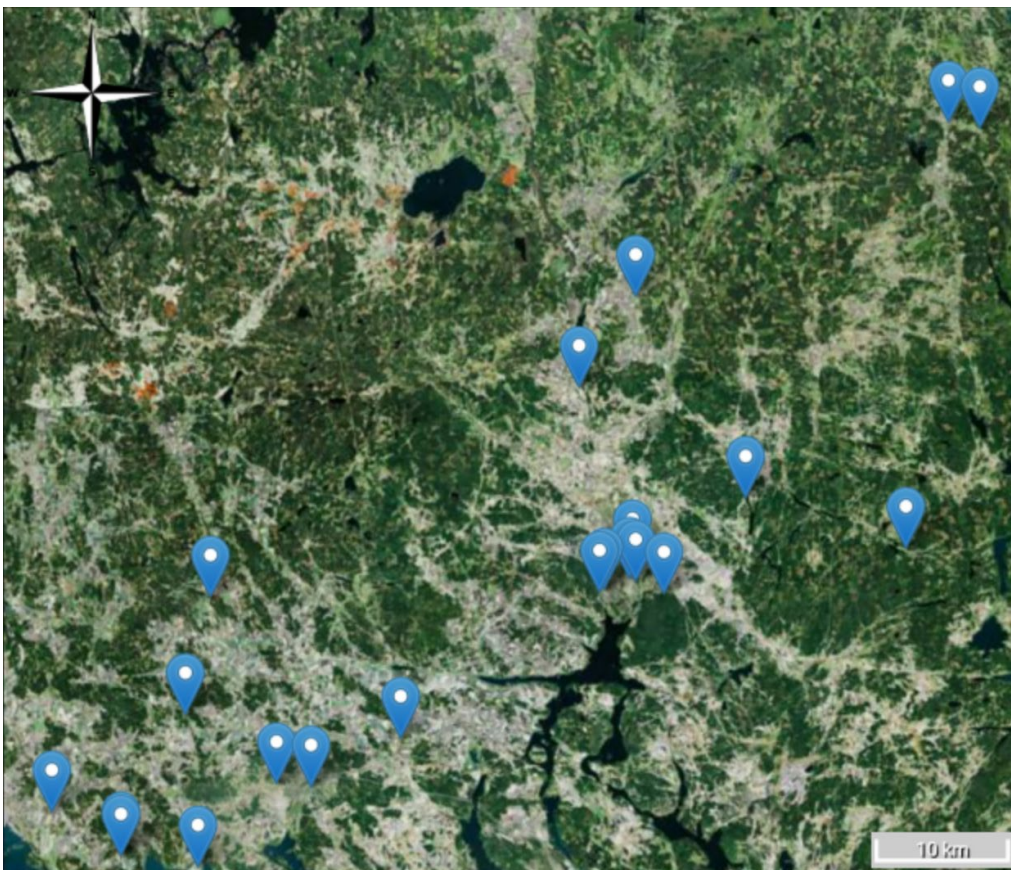


Figure 1. Ponds visited for the bird survey, and where the data from PuddleJump came from.

2.1 practical survey

The macrophyte data, which was collected before this study, was collected through walking around the entire shore of each pond. Every ten meters, a rake was used to pull in submerged macrophytes, which could reach about 1,5 meters from the shore. The species richness and percent coverage were surveyed with this method, the cover for the entire pond was then estimated from what was

earlier surveyed from the shore. This sampling method was not reliable at estimating species richness of filamentous algae, which is the reason why algae are not included in some of the plots in the results.

The survey done for this study was of breeding bird species and counting pair abundance. Each site was visited once between the 14th and the 17th of April 2025. The time of day for the surveys was within the hours of half past five in the morning, and twelve o'clock. Following the 10-minute-per-hectare rule of effort, the survey was conducted by walking a lap at a constant rate around the wetlands and counting the birds within 50 meters of the pond's shore and inside the wetland. The birds were categorised into males, females, or individuals if the sex was impossible to identify for each species. Ducks, grebes, waders, swans and passerines were counted. Pairs were identified in the field when exhibiting signs of breeding, such as courtship behaviour, or later interpreted from the notes following the Koskimies field protocol (appendix 2), which is mostly controlled by the number of males being surveyed. This pair interpretation is based on prior knowledge of bird behavior and is seen as reliable. Birds that were being flushed while walking towards the pond were also included, as well as the birds that were flying into or from the pond.

Additionally, a short 3-minute playback survey was conducted at each site, with 30-second intervals of calls from moorhen (*Gallinula chloropus*), little grebe (*Tachybaptus ruficollis*), and water rail (*Rallus aquaticus*), and 30-second pauses in between them to listen to responses. Materials used for the bird survey included binoculars, a telescope, a bird guide, a speaker, field protocols (appendix 1), and a camera for documentation and further species identification.

2.2 Advantages and disadvantages of the methods

Advantages of doing the survey this early in the season are that the birds will be easier to see and count, due to the vegetation not being fully developed yet. This will make the survey time efficient, and the possibility of surveying the birds in a way that reflects reality increases. For instance, seeing reed bunting in the reeds when there is not that much foliage to hide behind is favourable. The downside of this is that not all birds will have moved back to Sweden or have reached Uppsala yet because it is so early in the season. And the birds being surveyed could also be in the process of migrating when being surveyed, making the pair interpretation less reliable. A different approach could be using microphones placed in the wetlands to listen for bird sounds and using machine learning to count species diversity and possibly abundance. To fix the problem with migrating birds, one

could do several inventories. This is not possible in this paper because of the short time in which a bachelor's thesis has to be completed.

2.3 Data analysis

Following the practical data collection, pair interpretation based on the sightings of pairs and following the Koskimies field protocol (appendix 2) was followed to interpret pair abundance. Data analysis was done in two phases. The first phase used graphical analysis with Excel to highlight pond characteristics (size, pH, and O₂), macrophyte measures, and bird measures. One of the macrophyte groups, filamentous algae, did not have data about the species richness, only percent coverage in the ponds, and whether they were or were not present in the ponds. This is why the group filamentous algae are not included in most of the plots that include the rest of the macrophyte groups.

Part two is investigating the correlation between wetland characteristics and bird measures. With the response variables as bird species richness, bird abundance, pair abundance, and mean pair abundance as predictors, they were compared with macrophyte coverage in ponds and with pond size. Within the models, there were always three macrophyte groups and logged pond size, as predictors. These macrophyte groups were: emergent and submergent vegetation, and then rotating between floating leaf and filamentous algae to be included as predictors. Doing this made it clear that filamentous algae were always far from having good confidence values, and that is why they are not included in the tables containing data from these tests. Making it so that emergent, submergent, and floating leaf was the macrophyte groups used as predictors for the models.

The statistical program used for this was RStudio version 2024 12.0+467. For bird species richness, the number of species, a poisson generalised linear model (GLM) was used to model their relationship to pond characteristics. The number of individuals or bird abundance was also modelled with a poisson GLM. Pair abundance, the number of pairs seen during the survey and the number of pairs from pair interpretation, was modelled with a negative binomial GLM to account for overdispersion. Mean pair abundance was also used as a predictor to lessen the effects of the most abundant species, and accounting for the number of species. Mean pair abundance was calculated by dividing the total number of pairs by the number of species for each pond. The mean pair abundance was then within the model converted into a log scale with the model used being a linear model (LM). The response was transformed to a log scale to improve homogeneity and variance. The predictors for these four models were macrophyte coverage of emergent, submergent, and floating leaves, and log transformed size. Model

diagnostics included assessment of residual patterns, dispersion, and model fit, ensuring assumptions were met for each modelling framework as well as variance inflation factors (VIF).

3. Results

3.1 Pond characteristics

The four wetland creation categories were different in their sizes (Figure 2), with biodiversity ponds appearing to be the largest ponds and water retention having the smallest ponds. Oxygen content in all ponds could be interpreted as having very similar median (Figure 3), with some deviation from the median between pond types. Values of pH between pond types seemed also to be similar, with their medians having some variance (Figure 4). Biodiversity ponds have a narrow spread of pH values between sites whereas water retention ponds have a large spread between sites. Note that there are four categories of ponds in these plots, while there actually are five. This is because there is only one pond in the category of stormwater management which has been included in the phosphorus category.

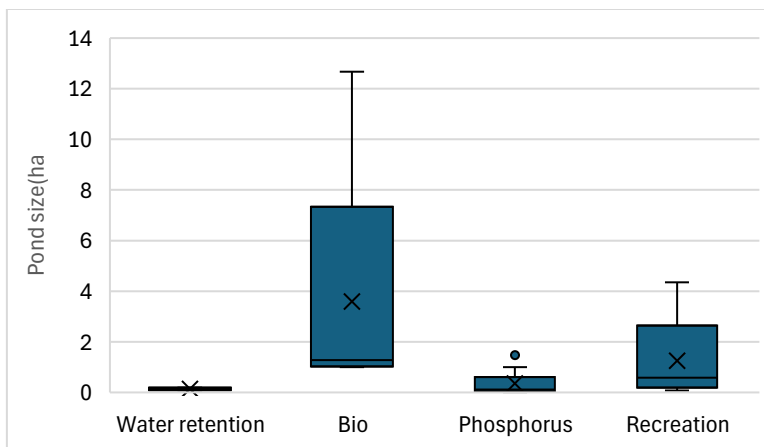


Figure 2. Boxplot showing pond size in hectares on the y axis and pond creation type on the x axis. The phosphorus category contains one wetland that has the purpose of “stormwater management”.

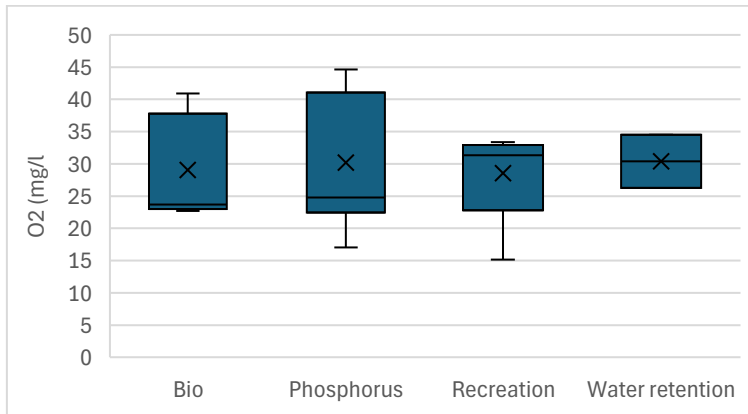


Figure 3. Boxplot showing values of oxygen available in the water in milligrams per liter on the y-axis and pond creation type on the x-axis. The phosphorus category contains one wetland that has the purpose of “stormwater management”.

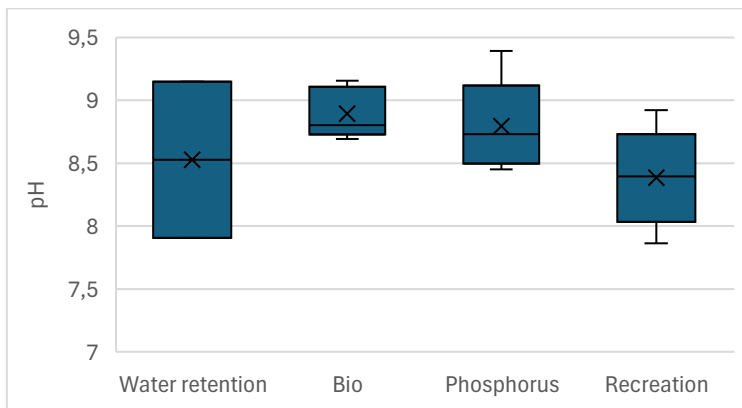


Figure 4. Boxplot showing pH values on the y-axis and pond creation type on the x-axis. The phosphorus category contains one wetland that has the purpose of “stormwater management”.

3.2 Macrophyte and bird data

3.2.1 Macrophyte data

Figure 5-7 consists of plots showing macrophyte data that provide insight into their species richness and percent coverage variation in each type of pond. The vegetation of the studied ponds has been divided into five groups: emergent, submergent, floating leaf, Sedges, and algae. Biodiversity and recreational ponds have a greater coverage of emergent macrophytes (Figure 5) with higher values of species richness and abundance with emergent and floating leaf vegetation (Figure 6 and 7). In contrast, phosphorus ponds have a large cover of submerged and filamentous algae and less cover of emergent macrophytes.

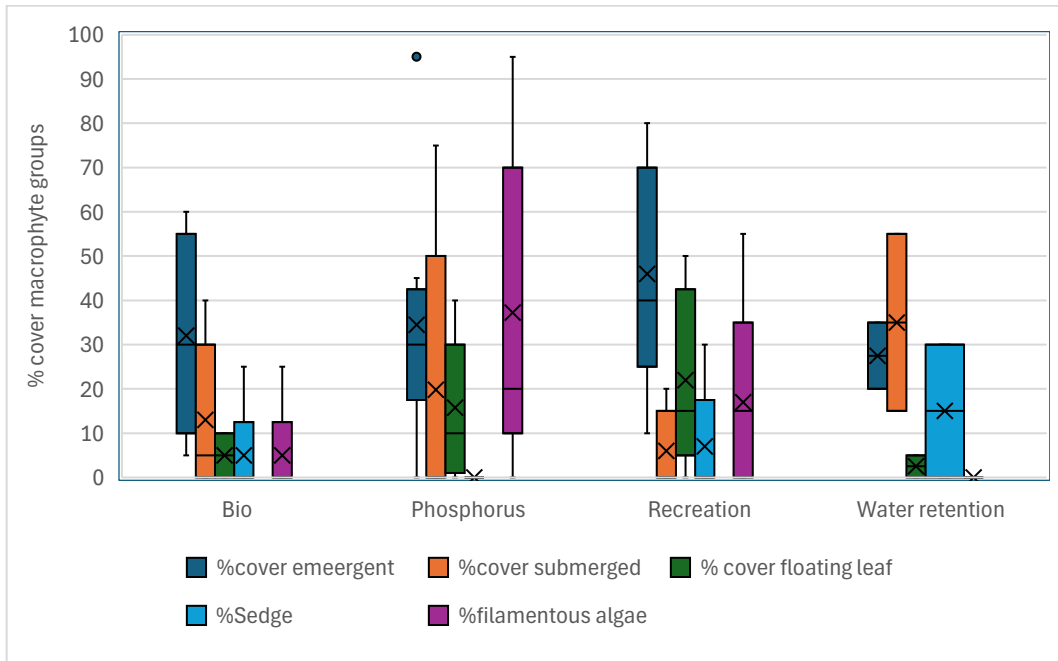


Figure 5. Boxplot showing the percent coverage emergent, submergent, floating leaf, and algae have on the y-axis, and pond creation type on the x-axis. The phosphorus category contains one wetland that has the purpose of “stormwater management”.

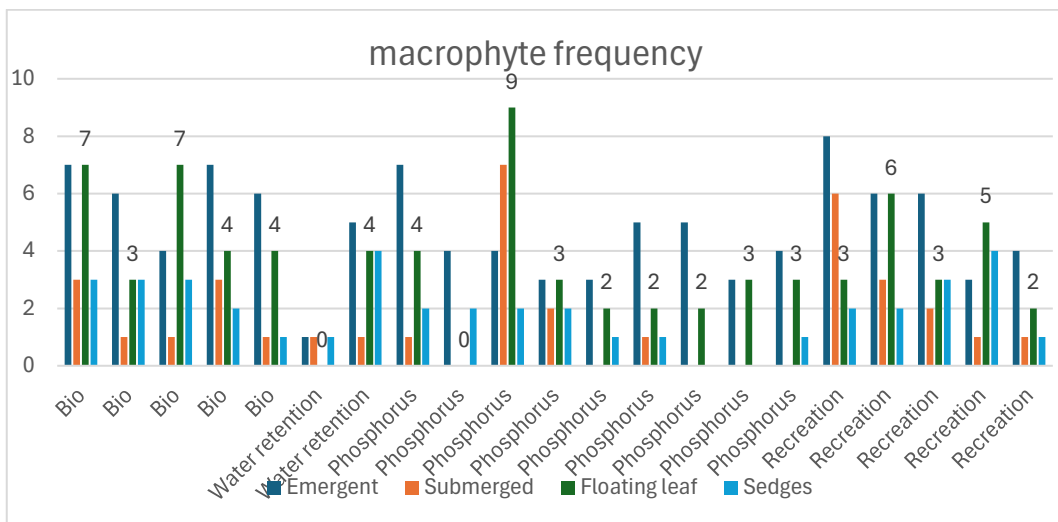


Figure 6. This bar plot shows the number of species of emergent, submergent, and floating leaf on the y-axis, and pond creation type divided into their separate sites on the x-axis. The phosphorus category contains one wetland that has the purpose of “stormwater management”.

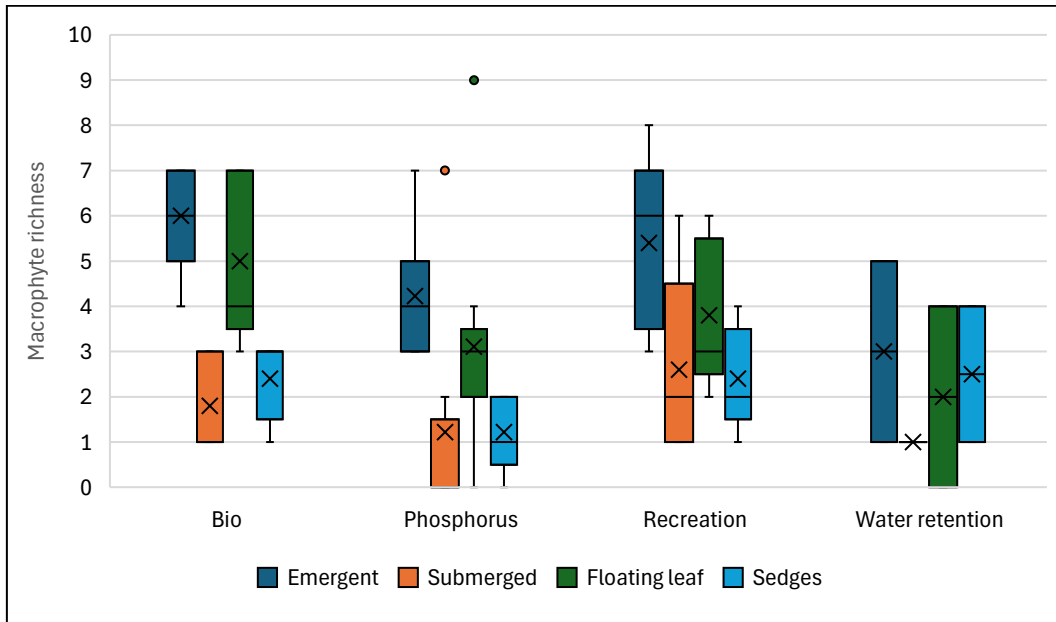


Figure 7. Boxplot showing species richness of emergent, submergent, floating leaf, and algae on the y-axis, and pond creation type on the x-axis. The phosphorus category contains one wetland that has the purpose of “stormwater management”.

3.2.2 Bird data

Of all the species observed at the site, only a few were migratory. However, 24 species (Figure 9) were observed to have signs of breeding across the 21 surveyed ponds. The most abundant species were mallards (*Anas platyrhynchos*), followed by Eurasian coots (*Fulica atra*), and common goldeneye ducks (*Bucephala clangula*) (Figure 9 and 10). The second most abundant species was the black-headed gull (*Chroicocephalus ridibundus*), though it was only the sixth most common bird across sites (Figure 10). Almost half of the surveyed species were least abundant (Figure 10), due to them being seen at one site only. Biodiversity ponds seem to have higher species richness and pair abundance than other categories, followed by recreational ponds. The fewest species and individuals were observed in nutrient retention wetlands (Figure 8).

Mallard is seen in a lot of ponds and within a great total number of individuals. Pair abundance and species richness are also shown in a plot. By comparison, a lot of birds were seen at only one site each and with only one individual present.

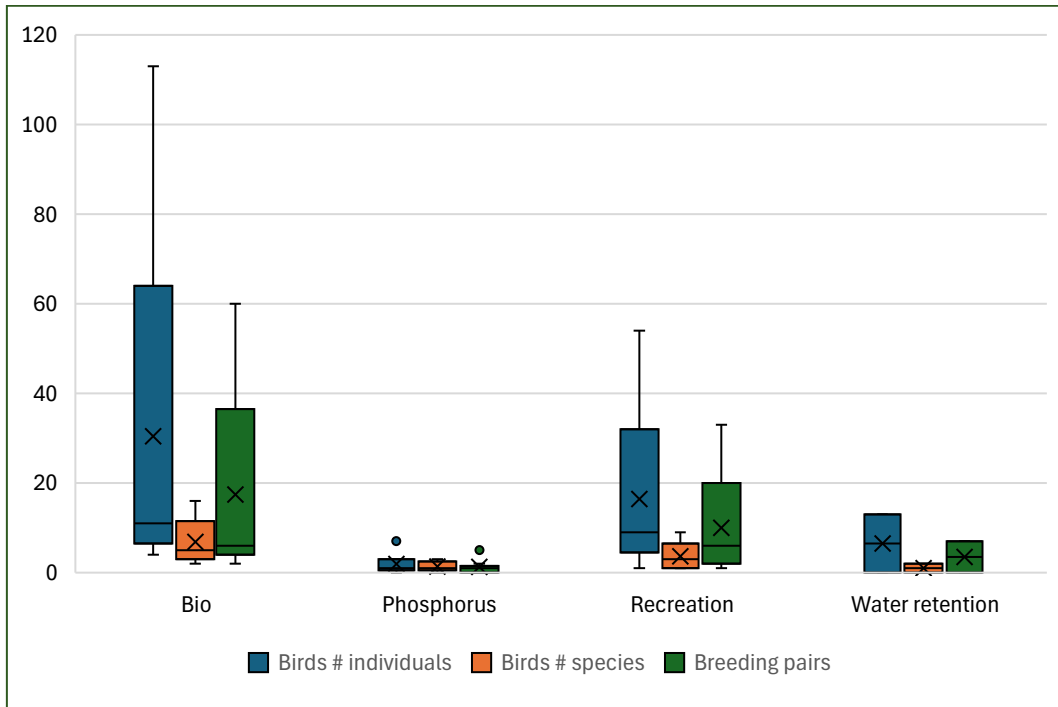


Figure 8. Boxplot showing the summaries of bird species richness, bird abundance, and bird pair abundance on the y-axis and pond creation type on the x-axis. The phosphorus category contains one wetland that has the purpose of “stormwater management”.

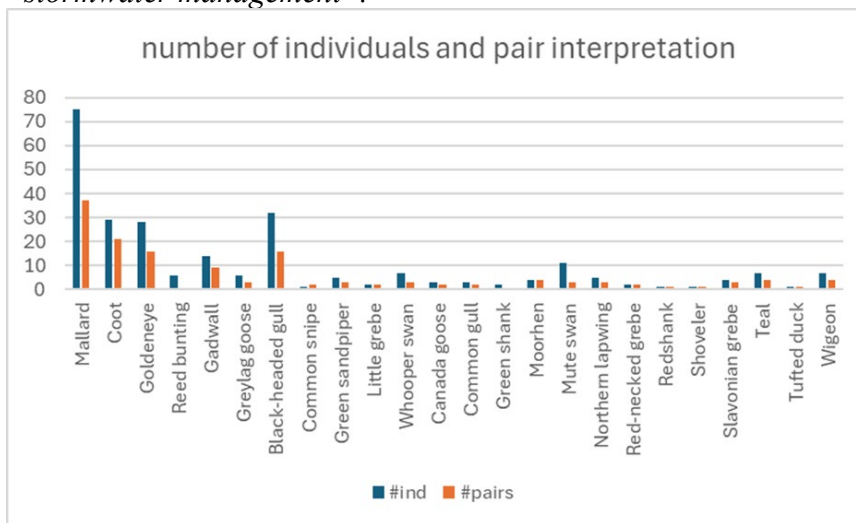


Figure 9. This bar plot shows the number of individuals and number of pairs on the y-axis and the bird species names on the x-axis.

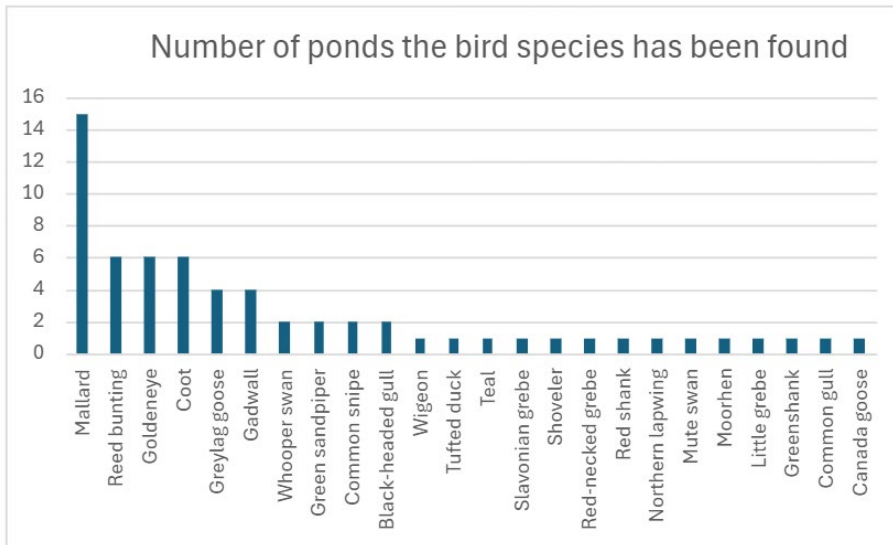


Figure 10. This barplot shows the number of ponds the species was surveyed on the y-axis and bird species on the x-axis.

3.3 Vegetation cover effect on breeding birds

This part consists of tables and plots discerning the confidence levels of the different pond aspects compared to bird species richness and abundance, and pair richness and abundance. Many of these plots and tables are made to forgo the impact pond size has on the bird data and examine how the groups of macrophytes affect the presence of birds. According to the models, wetland size is the most important variable in explaining bird metrics. As wetland size increases, so do bird species richness, total pair abundance, and mean pair abundance. Wetland size corresponded well with the four creation categories; the largest wetlands were created for biodiversity. Several macrophyte cover variables showed clear positive associations with wetland birds when wetland size was considered. Bird species richness tended to be higher in wetlands with higher submerged vegetation cover (see Figure 14 and the results table). Total pair abundance also increased with submerged vegetation cover. However, mean pair abundance did not show an association with submerged vegetation. Neither floating nor emergent vegetation showed clear associations with bird metrics. The models below contain a category called nutrient retention ponds, this category contains the same sites and the respective data of previously called phosphorus retention ponds.

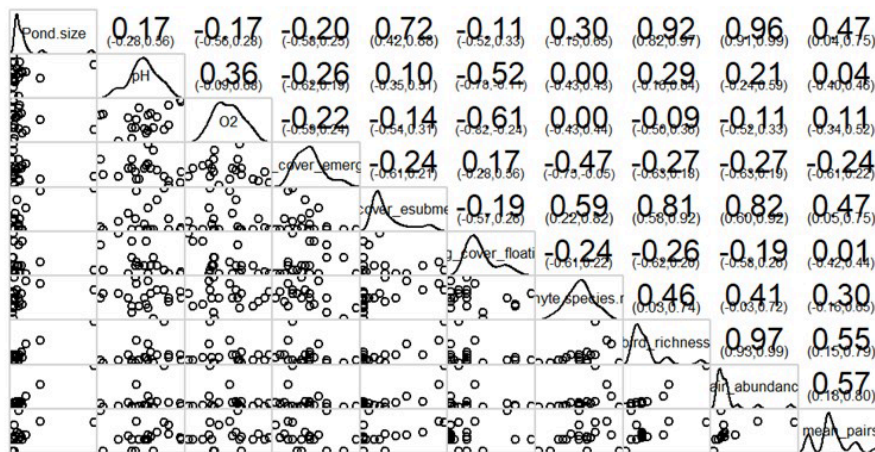


Figure 11. Correlation plot showing, from top to bottom, pond size measured in hectares, pH, oxygen amounts in milligrams per liter, percent coverage of emergent vegetation, percent coverage of submerged vegetation, percent coverage of floating leaf vegetation, macrophyte species richness, bird richness, pair abundance and in the lower corner to the right mean number of pairs. The lower triangle shows the scatterplot of the data points. The upper triangle shows the Pearson correlations between variable pairs, along with their confidence intervals. The diagonal cells show the names of the variables and the density of the datapoints.

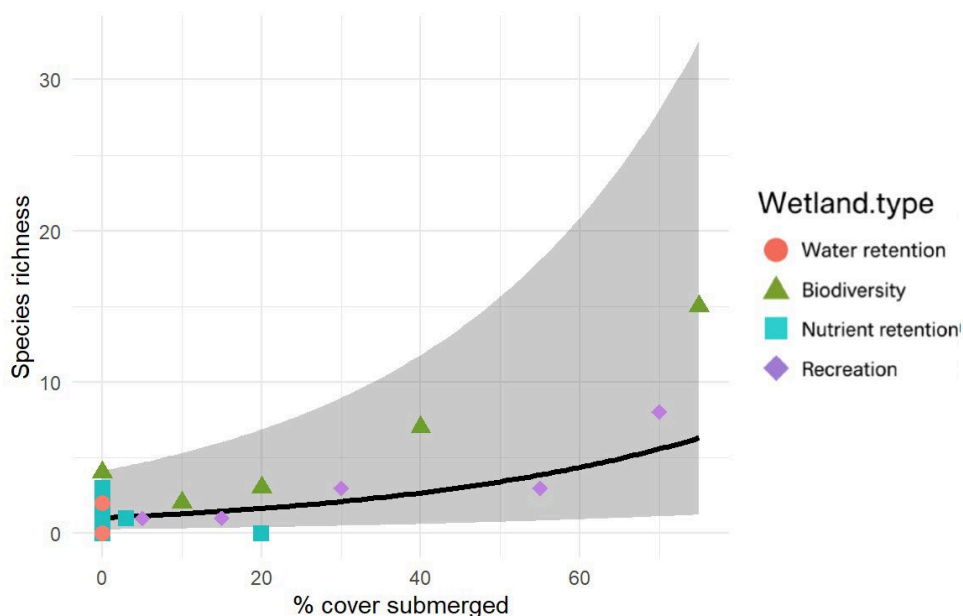


Figure 12. The effect plot shows the percent cover of submerged vegetation (on the x-axis) as the predictor variable and with bird richness (on the y-axis) as the response variable, as predicted from the LM model that included wetland size and emergent and floating vegetation. The shaded area shows the 95% confidence interval, and the data points include the wetland creation type (which was not included in the model due to overlap with wetland size). Purple diamonds represent recreational ponds, blue squares represent nutrient retention wetlands, green triangles represent biodiversity ponds, and red circles represent water retention ponds.

	Estimated std.	Error	T-value	P-value
(intercept)	2.851734	1.084968	2.628	0.01826*
log(pond.size)	0.830708	0.332861	2.496	0.02388*
% cover emergent	-0.003619	0.018731	-0.193	0.84922
% cover submerged	0.076802	0.023608	3.253	0.00499**
% cover floating	-0.028477	0.028672	-0.993	0.33540

Table 1. Standard deviation, t-value, and p-value of percent coverage, emerged, submerged and floating leaf macrophytes in relation to bird richness.

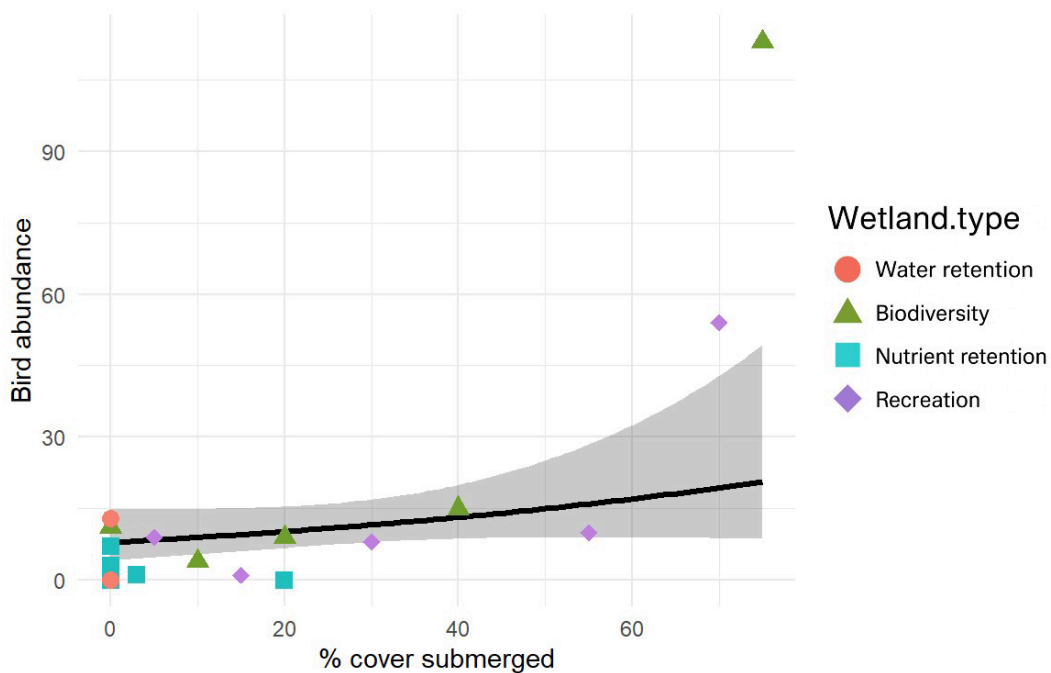


Figure 13. The effect plot shows the percent cover of submerged vegetation (on the x-axis) as the predictor variable and within-breeding bird species richness (on the y-axis) as the response variable, as predicted from the GLM model that included wetland size and emergent and floating vegetation. The shaded area shows the 95% confidence interval, and the data points indicate the wetland creation type (which was not included in the model due to overlap with wetland size). Purple diamonds represent recreational ponds, blue squares represent nutrient retention wetlands, green triangles represent biodiversity ponds, and red circles represent water retention ponds.

	Estimated std.	Error	Z-value	P-value
(intercept)	2.623536	0.404521	6.486	8.84 e-11***
log(pond.size)	0.532439	0.139746	3.810	0.000139***
% cover emergent	0.012876	0.008119	1.586	0.112752
% cover submerged	-0.015582	0.008518	-1.829	0.067358
% cover floating	-0.011183	0.012174	-0.919	0.358318

Table 2. Standard deviation, z-value, and p-value of percent coverage, emerged, submerged, and floating leaf macrophytes in relation to bird abundance.

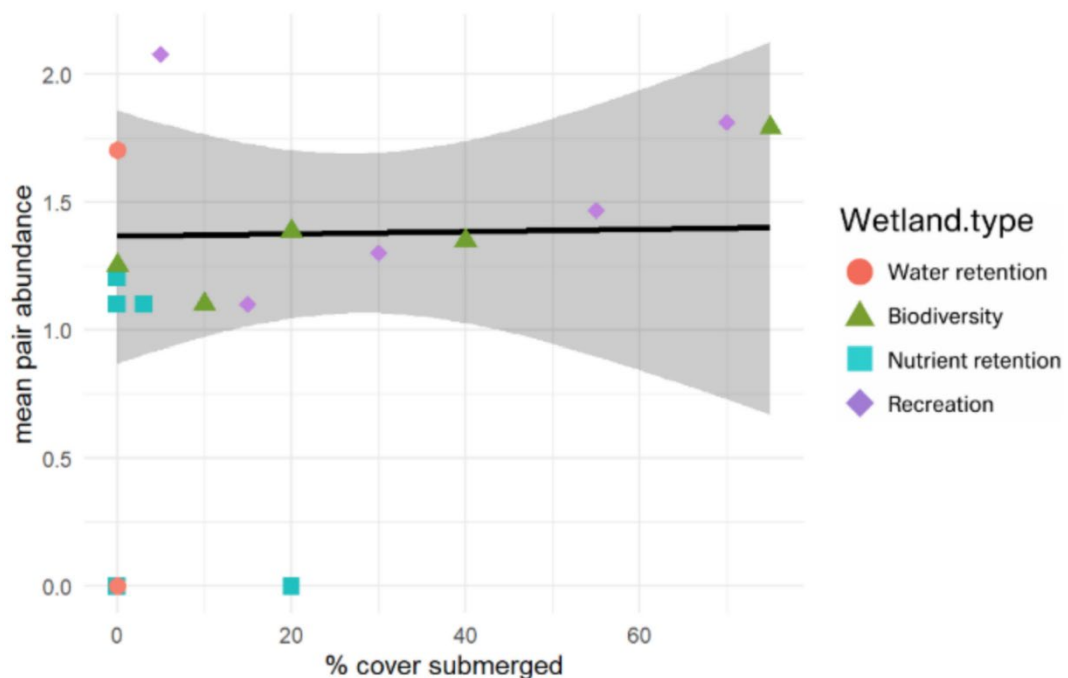


Figure 14. The effect plot shows the percent cover of submerged vegetation (on the x-axis) as the predictor variable and with mean pair abundance (on the y-axis) as the response variable, as predicted from the LM model that included wetland size and emergent and floating vegetation. The shaded area shows the 95% confidence interval, and the data points include the wetland creation type (which was not included in the model due to overlap with wetland size). Purple diamonds represent recreational ponds, blue squares represent nutrient retention wetlands, green triangles represent biodiversity ponds, and red circles represent water retention ponds.

	Estimated std.	Error	T-value	P-value
(intercept)	1.4173759	0.2939725	4.821	0.000188***
log(pond.size)	0.2124272	0.0901889	2.355	0.031599*
% cover emergent	-0.0038892	0.0050753	-0.766	0.454661
% cover submerged	0.0006761	0.0063966	0.106	0.917139
% cover floating	0.0015718	0.0077687	0.202	0.842216

Table 3. Standard deviation, t-value, and p-value of percent coverage, emerged, submerged, and floating leaf macrophytes in relation to mean pair abundance.

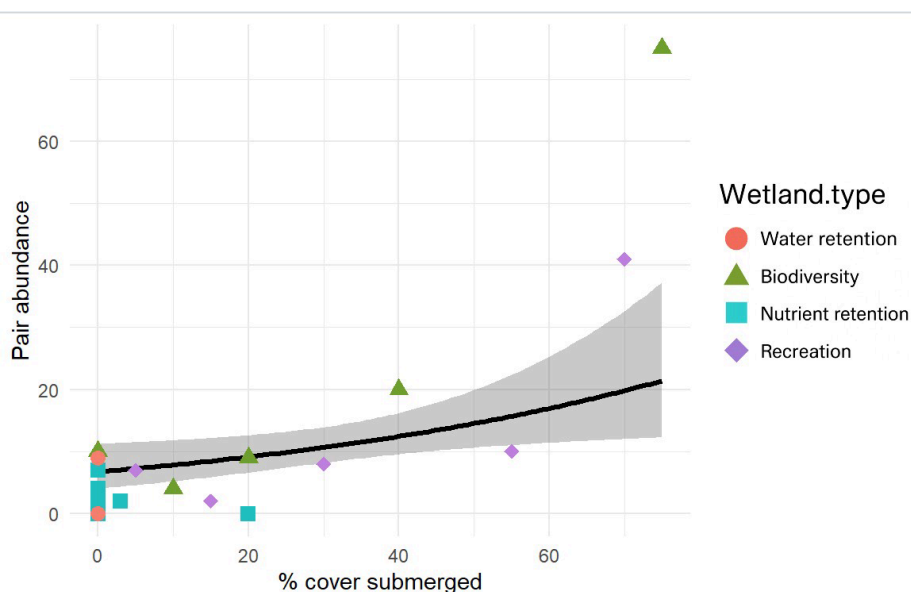


Figure 15. The effect plot shows the percent cover of submerged vegetation (on the x-axis) as the predictor variable and with pair abundance (on the y-axis) as the response variable, as predicted from the LM model that included wetland size and emergent and floating vegetation. The shaded area shows the 95% confidence interval, and the data points include the wetland creation type (which was not

included in the model due to overlap with wetland size). Purple diamonds represent recreational ponds, blue squares represent nutrient retention wetlands, green triangles represent biodiversity ponds, and red circles represent water retention ponds.

	Estimated std.	Error	T-value	P-value
(intercept)	2.233152	0.330260	6.762	4.57 e-06 ***
log(pond.size)	0.456654	0.111061	4.112	0.000816 ***
% cover emergent	0.015459	0.005878	2.630	0.018195 *
% cover submerged	-0.007022	0.006734	-1.043	0.312616
% cover floating	-0.015244	0.010519	-1.449	0.166604

Table 4. Standard deviation, t-value and p-value of percent coverage, emerged, submerged, and floating leaf macrophytes in relation to pair abundance.

4. Discussion

This study shows that pond size was the main variable explaining the investigated bird measures, which were hypothesised in the introduction. These bird measures were bird richness, bird abundance, pair abundance, and mean pair abundance. Submerged vegetation coverage was important for birds' richness (Figure 12, Table 1), while emerged vegetation was more important for abundance (Figure 13, Table 2). This was partly hypothesised in the introduction, where submerged vegetation was thought to affect both species richness and abundance. Emergent vegetation was also important for pair abundance, with no other macrophyte being significant (Figure 15, Table 4), whereas the mean pair abundance was only clearly predicted by pond size (Figure 14, Table 4). This means that the importance of cover, which emerged vegetation is thought to provide was more important for the population sizes but not bird species diversity, while the availability of submerged vegetation associated with more diverse bird community. This answered the main question being, that submerged vegetation and pond size are most important, where emerged vegetation is less important. This is due to emergent cover only being shown in the results to be important for mean pair abundance and pair abundance. For the best effect across all measures all three features should be prioritized when creating ponds.

4.1 Differences between the ponds in their abiotic variables

Part one of the results, consisting of abiotic factors, tells something about the pond's possibility of containing life. The Size of the ponds (Figure 2) according to the species-area relationship, should influence the number of birds. The plot clearly shows that there are two categories of ponds that are greater in size than the others. Both biodiversity and recreation ponds are almost always bigger, with biodiversity being the biggest of them. This should according to the connection between the statistical analyses and the size comparison across pond categories, mean that biodiversity ponds have the greatest number of species.

According to the visual analyses, it seems that oxygen and pH levels varied less across the type of created wetlands than the size. PH has little fluctuation between ponds; this is probably because they are similarly covered in macrophytes, which influences the pH (Iacarella et al. 2018), which would make the values higher. The oxygen mean values are quite similar too. Lack of oxygen should thereby not be a problem in these ponds, and it seems that neither the macrophytes nor the abiotic factors negatively affect the dissolved oxygen in these ponds. An anoxic

environment with dissolved oxygen values below 5-6 mg/l could not support life underwater (Iacarella et al. 2018). This could indirectly cause a negative effect on birds being at the site, by, for example, affecting fish, amphibians, and invertebrate development and survival.

4.2 Differences between the ponds in macrophyte cover

Five groups of macrophytes have been inventoried. Even though they have been discussed as a pair so far, biodiversity ponds and recreation ponds are not made with the same purpose, but their similarity is that they have higher amounts of emergent macrophytes than the other two groups of ponds (Figure 5).

Additionally, the same plots showing macrophyte data show the highest cover of filamentous algae in phosphorus ponds. This is probably because of the excess nutrients, leading to few species of the other groups being able to survive in these ponds and therefore giving room for filamentous algae to grow. One could think that because of the lesser amount of bird diversity in water retention ponds, the same macrophyte ratios would be seen in water retention ponds. This is not the case, water retention has more cover of sedges and almost no cover of filamentous algae, and the pond also has greater cover of submerged vegetation. The higher amounts of submerged vegetation and the not present filamentous algae, I think play a big role in having higher bird numbers in water retention ponds.

Considering that filamentous algae are often related to poorer water conditions (or even toxic) and thus might not be suitable for biodiversity (Sink 2020), this is probably a big factor. Results from a study surveying macrophytes in ponds with higher phosphorus concentration in agricultural land (del Pozo et al. 2010) showed that ponds with higher concentrations of phosphorus, which phosphorus ponds in this study have, was correlated with greater species richness values amongst the macrophytes. These results from, del pozo et al. 2010, is contradictory to the results of this study. Later, it says that with higher phosphorus levels, the cover of algae increases and outcompetes most of the other vegetation (ibid). This could be a supporting argument for enlarging the area which the phosphorus ponds are created. Currently, phosphorus ponds are small, but with a larger area, it would possibly dilute the concentration of nutrients in the pond and increase the species richness of macrophytes, which could influence higher trophic levels to arrive in the pond.

4.3 Differences between the ponds and breeding bird communities

Figure 8 confirms that biodiversity ponds and recreation ponds do have, throughout, a greater number of bird species and individuals when looking at bird metrics. However, that is also confounded to the size of the wetlands. Biodiversity and recreational ponds were much larger than nutrient and water retention ponds. The larger the habitat is, the more individuals and species it can have. Confidence measures were needed to forgo the implications of pond size, which will be discussed in connection with the third part of the results. Comparing figure 8 with figure 1 does not show an absolute correlation between size and bird biodiversity, other aspects might be in play. Pair abundance clearly shows that ponds of a bigger size also led to more pairs, which led to more breeding birds. Figures 10 and 11 are important too to show that most bird species are only seen in one pond, and these species are also seen in few numbers when being surveyed. I was expecting black-headed gulls and common gulls to be more often seen, and in higher numbers. The number of black-headed gulls being that high is mostly due to one site where 30 individuals were recorded. Interesting to note is also how often mallards were recorded in ponds, with them being in 16 of 21 ponds.

4.4 Connecting macrophyte and bird diversity metrics

Unfortunately, I was not able to test all the macrophyte groups in the same models because most macrophyte groups add up to one hundred percent, making them dependent on each other. I chose to test only submerged, emergent, and floating vegetation covers because they have been suggested to affect bird diversity metrics, as seen in the introduction. Sedges are important for wading birds, but most species in these types of ponds were ducks, to which sedges might not be as important as to the investigated three macrophyte groups. Filamentous algae were tested in some models, but did not seem to explain much of the variation and thus were omitted due to small sample size.

Biodiversity ponds and recreation ponds had higher macrophyte coverage and species richness (Figure 12-13), supporting the fact that pond size is a large driver for diversity and abundance. In line with this study, Pond size has been confirmed to have an impact on the number of bird species and individuals present in other ponds (Oertli et al. 2002). Therefore, larger ponds should be prioritized when creating new ones.

The results from pair interpretation shows, size as the most important factor for pairs being present in ponds, with submerged vegetation also being significant (Table 3-4). Previous studies show similar results to this study. For instance evaluating created wetlands for bird diversity and reproductive success ([Kačergytė et al. 2021](#)) is a bit bigger study with 89 sites being visited. This study tells us that pond size has a strong positive effect on species richness and pair abundance, matching both results. Although, it also shows results saying that emergent vegetation is negatively correlated to bird metrics.

Submerged macrophytes, which are an important food for some species of ducks and habitat for developing amphibians and invertebrates (Sibilia et al. 2022), are of importance too. The results from this study showed that bird richness, the number of species present in the ponds, had a positive correlation with the percent coverage of submerged macrophytes. One could think that this would affect all bird metrics, but also more cover of submerged vegetation probably means more species of submerged vegetation and more food available for the birds directly or indirectly through habitat provisions for bird prey. Although, this is not what the results show, phosphorus retention ponds have a large cover of submerged macrophytes (Figure 5) and low submerged species richness (Figure 7). This could be because of the higher amount of nutrients in the pond leading to fewer species able to grow in phosphorus retention ponds but those that manage to stay get a larger cover due to the lowered competition (Sibilia et al. 2022). In biodiversity ponds, there is a good cover of submerged vegetation which contributes to the site's high values with the bird measures.

I would think that emergent macrophytes would also be important, considering that they provide a place to hide and build nests for the birds (Ashworth 2023). This was probably caused by the early timing of the survey within the breeding season, where macrophyte cover is still not visible. Additionally, they could still be at their settlement stage and have not completely settled, making shelter less important than the availability of food. Seeing the results from this study tells us that emergent macrophytes seemed to be positively related to the observed bird pair abundance but not clearly related to the other bird metrics. A study found that emergent macrophytes could cause a lower detection rate of birds, thus causing the bird numbers to appear lower than they actually are ([Kačergytė et al. 2021](#)). However, they also suggested that many species require open water to forage, and 100% cover would suggest the absence of such habitats.

Floating vegetation has not been observed to have any effects on birds in this study. They generally do not provide shelter or a place to hide for birds, and they are not food for them either (Kawatsu et al. 2015). Some species use them as hunting ground or food, but this is a limited number of species (ibid). Studies show that floating leaves promote invertebrates (Lewis-Phillips et al. 2020), and

one could think that that they would be able to support birds through indirect provision of food.

It seems that pond size would be the best aspect to focus when creating ponds for birds, but the reality is that this is costly and especially hard to do in cities where there is often little space to spare. I would recommend in these cases to introduce emergent and submerged macrophytes. In that way, one could increase the biodiversity values for birds, without compromising their main use.

4.5 Error sources & future research

One of the study's weaknesses is that birds were identified using only one visit. Doing a second survey of at least some of the sites would be good for this study, but it was not possible due to time constraints. Multiple inventories of the same sites would make the data more reliable, as that increases the effort and thus species and individual detection. Additionally, not all the individuals have finished spring migration, thus increased number of visits could have helped to distinguish migrating individuals from residents in more detail, as well as detect the late migrants that could reside in these sites.

Doing the survey in mid-April was also done because of the time constraints and due to which time of year this study was done. The survey could not have been conducted during late summer because the course is set during the second half of the first semester of 2025. Because of this, the macrophyte data and pond characteristics were not done at the same time as the bird survey, which should have been from the same time of year to properly compare these different measures to each other. Additionally, later surveys within the season would have allowed surveying the number of chicks. Studying reproductive success is a very important factor for knowing what drives bird populations and what types of ponds support bird diversity in the long run. This is something that would widen the knowledge of what types of ponds are favorable. Something that has not been considered in this study is how climate change, with increasing frequency of extreme weather, should be considered when creating wetlands (Hill et al. 2021). A question for future research could be, how do we create ponds that are resilient to extreme weather and change in climate to still provide habitat for biodiversity?

4.6 Conclusions

With this work, I found that a more diverse bird species pool of birds were most often found in large created wetlands. This was not the sole factor of birds' presence and abundance in ponds. This study has provided results showing

emergent and submergent vegetation being of importance for higher bird biodiversity. This answers what kind of factors are important for bird conservation and habitat restoration. Although there needs to be more research done to get a fuller picture this knowledge could still be used for future projects of creating and restoring ponds and wetlands. In conclusion, human-made ponds are a way of mitigating a wetland loss problem we made, where some of the measures can increase bird diversity in such ponds. However, there still needs to be complementary studies conducted to get a fuller picture of what measures are best to prioritize in pond creation conservation measures.

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Appendix 1

Date _____ Time start _____ Time finish _____

Site number _____ Person _____

Weather (clear/clouds/rain/wind) _____

Species	Male	Female	Pair	Ind*	Chick	Comments
Mute swan <i>Cygnus olor</i>						
Whooper swan <i>Cygnus cygnus</i>						
Greylag goose <i>Anser anser</i>						
Canada goose <i>Branta canadensis</i>						
Wigeon <i>Anas penelope</i>						
Gadwall <i>Mareca strepera</i>						
Teal <i>Anas crecca</i>						
Mallard <i>Anas platyrhynchos</i>						
Garganey <i>Spatula querquedula</i>						
Shoveler <i>Spatula clypeata</i>						
Pochard <i>Aythya ferina</i>						
Tufted duck <i>Aythya fuligula</i>						
Goldeneye <i>Bucephala clangula</i>						
Goosander <i>Mergus merganser</i>						

Little Grebe <i>Tachybaptus ruficollis</i> #						
Gr. Crested Grebe <i>Podiceps cristatus</i>						
Red-ne. Grebe <i>Podiceps grisegena</i>						
Slavonian grebe <i>Podiceps auritus</i>						
Grey Heron <i>Ardea cinerea</i>						
Water Rail <i>Rallus aquaticus</i> #						
Moorhen <i>Gallinula chloropus</i> #						
Coot <i>Fulica atra</i>						
Common crane <i>Grus grus</i>						
Little ring plover <i>Charadrius dubius</i>						
Northern lapwing <i>Vanellus vanellus</i>						
Common snipe <i>Gallinago gallinago</i>						
Green sandpiper <i>Tringa ochropus</i>						
Redshank <i>Tringa totanus</i>						
Common sandpiper <i>Actitis hypoleucos</i>						
Black-headed gull Chroic. <i>ridibundus</i>						

Common gull <i>Larus canus</i>						
Common tern <i>Sterna hirundo</i>						
Yellow Wagtail <i>Motacilla flava</i>						
Sedge warbler <i>Acrocephalus schoenobaenus</i>						
Species	Male	Female	Pair	Ind.*	Chick	Comments
Marsh warbler <i>Acrocephalus palustris</i>						
Reed warbler <i>Acrocephalus scirpaceus</i>						
Reed bunting <i>Emberiza schoeniclus</i>						

Other wetland Species	Male	Female	Pair	Ind.*	Chick	Comments
Marsh harrier <i>Circus aeruginosus</i>						
Osprey <i>Pandion haliaetus</i>						

General Comments (visibility/ where all parts approachable?/ disturbance by humans/ predation signs/ management):

Appendix 2

INTERPRETATION OF CENSUS RESULTS. The following are counted as a breeding pair (field abbreviations in parenthesis):

In ducks (except in *Aythya* and *Bucephala* species)

- single pair ($\sigma^1\text{Q}$)
- lone male (σ^1)
- males in groups of 2-4 ($2\text{-}4\ \sigma^1\sigma^1 = 2\text{-}4$ pairs)
- small male groups chasing a female ($2\text{-}4\ \sigma^1\sigma^1\ 1\text{Q} = 2\text{-}4$ pairs)
- lone females (Q), if their total number is larger than that of males (σ^1).

In the Tufted Duck and Pochard (excess of males)

- the total number of females (QQ).

In the Goldeneye

- adult male (σ^1)
- pair ($\sigma^1\text{Q}$).

In the Coot

- lone bird (near the shore)
- pair (two birds together)
- territorial dispute (= 2 pairs)
- calls of birds unseen.

In divers and grebes

- lone bird
 - pair (= two birds together).
- In grebe colonies some birds may hide in vegetation. If you are not able to count all birds (e.g. by disturbing them), give the total number of individuals near the colony without interpreting them as pairs.

In gulls and terns

- lone bird or pair near a probable nesting site (e.g. incubating or alarmed birds).

The size of colonies can be estimated by counting nests or incubating birds, or parents leaving their nests (both the male and the female are often present). Probable non-breeding groups are not interpreted as pairs.

In all taxons

- nest (be careful not to interpret the adults as a second pair!).

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