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Research Paper

Waterfowl use of mine tailing ponds in comparison with beaver ponds in boreal eastern Canada

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ABSTRACT. Wetlands are essential for many animal and plant species. However, many of these ecosystems are being degraded. Wetland degradation affects the habitat of certain groups of species such as waterfowl, which use these environments at different stages of their life cycle. In this study, we assessed the quality of man-made wetlands, i.e., mine tailing ponds, in comparison to beaver ponds, which are natural wetlands used by waterfowl. We conducted repeated surveys of breeding waterfowl species present on 12 mining ponds and 38 beaver ponds in boreal western Quebec, Canada. We also conducted brood surveys and considered environmental variables at the sites that could affect their occupancy. Conditions at the mining ponds appear to be as favorable for the establishment of breeding waterfowl as those observed in beaver ponds. Using site occupancy models, we found that five out of the six species studied were as likely to occupy and breed in mining ponds as in beaver ponds: Mallard (*Anas platyrhynchos*), Ring-necked Duck (*Aythya collaris*), American Wigeon (*Mareca americana*), Green-winged Teal (*Anas crecca*), and Hooded Merganser (*Lophodytes cucullatus*). Both adults and broods of Common Goldeneye (*Bucephala clangula*) were more likely to use mining ponds than beaver ponds, but we did not find a direct relationship between goldeneye occupancy and environmental variables at our sites. Overall, the results of our study suggest that mining ponds have the potential to be managed for waterfowl and used by this group during the breeding season. However, further studies are required to assess the long-term effects of mining ponds on wildlife, particularly regarding contaminants such as heavy metals likely present at such sites.

Utilisation par la sauvagine de bassins de résidus miniers comparativement à celle d'étangs de castors dans la région boréale de l'Est du Canada

RESUME_. Les milieux humides sont essentiels pour de nombreuses espèces animales et végétales. Cependant, la dégradation d'un grand nombre de ces écosystèmes est en cours. La dégradation des milieux humides affecte l'habitat de certains groupes d'espèces, comme la sauvagine, qui utilisent ces milieux à différentes étapes de leur cycle de vie. Dans la présente étude, nous avons évalué la qualité de milieux humides artificiels, c'est-à-dire des bassins de résidus miniers, par rapport à la qualité d'étangs de castors, qui sont des milieux humides naturels utilisés par la sauvagine. Nous avons effectué des relevés d'espèces de sauvagine nicheuses présentes sur 12 bassins miniers et 38 étangs de castors dans la région boréale de l'Ouest du Québec, au Canada. Nous avons également mené des relevés de couvées et examiné les variables environnementales des sites qui pourraient affecter leur occupation. Les conditions des bassins miniers semblent être aussi favorables à l'établissement de la sauvagine que celles observées dans les étangs de castors. À l'aide de modèles d'occupation des sites, nous avons constaté que cinq des six espèces étudiées étaient aussi susceptibles d'occuper les bassins miniers et de s'y reproduire que les étangs de castors : le Canard colvert (*Anas platyrhynchos*), le Fuligule à collier (*Aythya collaris*), le Canard d'Amérique (*Mareca americana*), la Sarcelle d'hiver (*Anas crecca*) et le Harle couronné (*Lophodytes cucullatus*). Les adultes et les couvées du Garrot à oeil d'or (Bucephala clangula) étaient plus susceptibles d'utiliser les bassins miniers que les étangs de castors, mais nous n'avons pas trouvé de relation directe entre l'occupation par les garrots et les variables environnementales de nos sites. Dans l'ensemble, les résultats de notre étude laissent croire que les bassins miniers ont le potentiel d'être gérés pour la sauvagine et utilisés par ce groupe pendant la saison de reproduction. Cependant, d'autres études sont nécessaires pour évaluer les effets à long terme des bassins miniers sur la faune, en particulier en ce qui a trait aux contaminants, tels que les métaux lourds probablement présents à ces sites.

Key Words: *beaver ponds; Common Goldeneye; habitat use; mining ponds; reproduction; waterfowl*

INTRODUCTION

The degradation and destruction of ecosystems taking place on a global scale affects the natural habitat of many animal and plant species (Brooks et al. 2002, Cushman 2006). Wetlands are no exception, and they continue to be impacted by human activities even though these environments perform many ecological functions, such as water quality improvement, carbon sequestration, and flood control (Zedler and Kercher 2005). Wetlands are also essential for a large number of wildlife species, such as amphibians and some birds, to complete a part of their life cycle (Weller 1999, Seburn and Seburn 2000, Batzer et al. 2006). Despite the ecological importance of wetlands, their area

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is decreasing on account of activities such as agriculture, forest harvesting, or installation of hydroelectric infrastructure (Poulin et al. 2004). In North America, up to 56% of the wetland surface area has been lost in settled landscapes since the beginning of the 18th century (Davidson 2014).

In this context, it is important to question the fate of species that depend on wetlands, such as waterfowl. In the boreal region of North America, this group of species uses wetlands, particularly during the breeding season, to nest and raise young. Small ponds, such as beaver ponds, are particularly important for waterfowl reproduction because these habitats are devoid of thermal stratification and have a reduced exposure to wind and waves (Cowardin et al. 1979). Beaver ponds also tend to be rich in nutrients and resources, promoting their use for brood rearing (Nummi 1992, Nummi and Hahtola 2008, Nummi and Holopainen 2014).

In general, factors affecting the abundance of resources or access to these resources influence habitat selection by waterfowl. For example, shoreline characteristics such as depth (Pöysä 1983) or irregularity (Hudson 1983, Bélanger and Couture 1988) facilitate access to resources and favor the use of a given pond by waterfowl during the rearing period. Similarly, other factors that directly influence resource abundance also affect waterfowl. Aquatic invertebrates are essential for many waterfowl species that have high energetic requirements during the breeding season (Sugden 1973, Krapu 1974). These invertebrates are also consumed by fish, which are important competitors of waterfowl. For this reason, the presence of fish may negatively influence pond use by non-piscivorous species of waterfowl (Epners et al. 2010, Väänänen et al. 2012, Nummi et al. 2016). Similarly, low pH can negatively influence certain invertebrate taxa used by waterfowl (Desgranges and Gagnon 1994, McNicol et al. 1995).

The creation of alternative wetlands could compensate, at least partially, for recent wetland losses. For example, certain artificial water bodies such as sewage lagoons and stormwater ponds are rich in food resources and provide potential habitats for waterfowl (Swanson 1977, Piest and Sowls 1985, Duffield 1986, Carlisle et al. 1991). However, knowledge of waterfowl use of other artificially generated wetlands remains largely fragmentary. For instance, in areas where mining is important, tailing ponds could provide habitat for some waterfowl and other wetland-dependent species.

In Canada, management of tailings from mining operations is legislated and requires companies to provide their restoration plan before mining activities begin. The main purpose of restoration is to return the site to its original state and limit the adverse environmental effects associated with the formation of acid mine drainage that occurs from the oxidation of sulfide minerals (Asif and Chen 2016; Aubertin et al. 2015, *unpublished manuscript*, https://www.researchgate.net/publication/319914984). Various restoration approaches can be used such as a multilayer cover, an elevated water table, or the covering of the tailings with an aqueous layer, thus creating an open water pond (Aubertin et al. 2015, *unpublished manuscript*, https://www.researchgate.net/publication/319914984). This last method can restore the site by generating a wetland potentially used by several wildlife species (Vittet 2011). Some old mining sites located in the study area, i.e., western Quebec, are well known by amateur ornithologists and are considered hotspots of interest on platforms such as eBird, because they harbor a diversity of species, including some that are rare on a regional scale (Imbeau 2012, 2018). A few studies conducted in the United States show that some mining sites are used by different species of waterfowl (Uresk and Severson 1988, McKinstry and Anderson 1994, Horstman et al. 1998, McKinstry and Anderson 2002). These studies tried to identify the different parameters affecting wetland use by waterfowl, but they did not compare mining sites to natural wetlands.

The objective of this study was to quantify the value of the tailings management strategy of using a water-based layer to create an artificial wetland for waterfowl. We compared ponds created by flooding mine tailings (hereafter, mining ponds) to beaver ponds, which are recognized as a high-quality habitat for waterfowl. We quantified the use of these two pond types in relation to different wetland characteristics. We hypothesized that the two pond types are similar except for the presence of competing fish, which is lower in mining ponds because these sites are less connected to the hydrologic system than beaver ponds. Therefore, we expected that the probability of occupancy of mining ponds by different non-piscivorous species of waterfowl would be greater than that observed in beaver ponds because of the lower competitive pressure on invertebrate resources. Our main focus was to evaluate the use of mining sites by waterfowl during the breeding season.

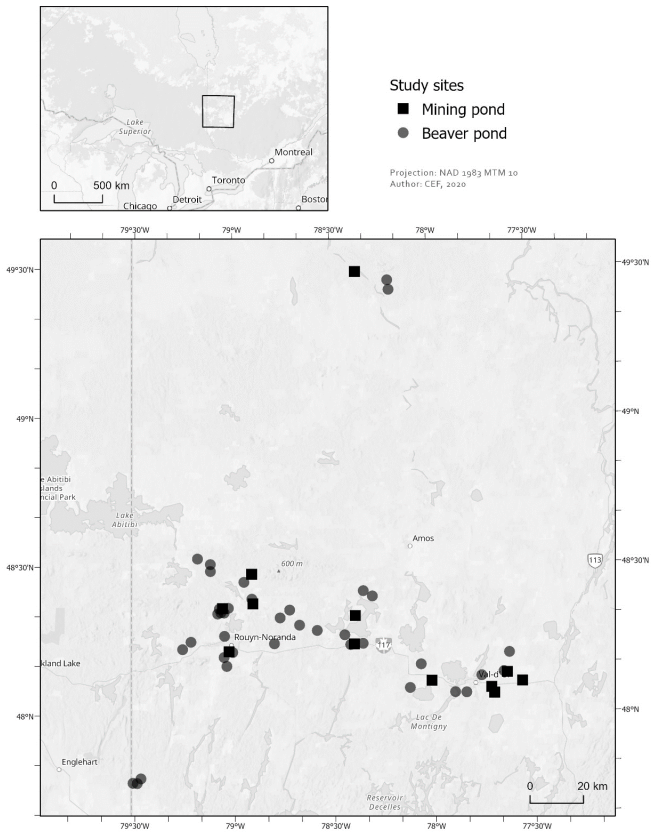
METHODS

Pond selection and waterfowl data

We identified the mining ponds in our study area using satellite imagery from Google Earth and data from the Quebec Department of Energy and Natural Resources (MERN 2020). We initially identified 26 mining sites, but after field validation only 12 ponds met our selection criteria. These criteria for mining ponds included size (0.3–20 ha), accessibility (authorization to visit sites), and origin (resulting from artificial flooding of tailings). To compare these mining ponds with natural wetlands, we also identified and visited approximately 80 beaver ponds. The first beaver ponds visited were located at a maximum of 15 km from selected mining ponds. To minimize the differences in surface area between the two types of ponds, we selected beaver ponds that were at least 0.30 ha. We would have included beaver ponds with an area up to 20 ha, but none were larger than 5 ha. However, given that there were not enough beaver ponds that met these criteria within 15 km from mining sites, we expanded our radius to identify additional beaver ponds, for a total of 38 beaver ponds ultimately retained (Fig. 1). All sampled ponds were at least 1 km apart in order to limit their use by the same individuals.

We sampled waterfowl at each pond by combining fixed point and perimeter searches. Two independent observers simultaneously visited the ponds on five occasions: two visits between 22 June and 11 August 2018, and three visits between 16 May and 25 July 2019. At each visit, two observers approached the pond making as little noise as possible and were each positioned at opposite ends of the pond. To allow the return of waterfowl individuals that had been flushed without being identified, they waited 5 minutes before starting a 20-minute observation period noting all adults and ducklings of waterfowl species detected from their position. All individuals were noted, but beside counts of ducklings during each visit, only binary detection data were used, i.e., detected or not. After the 20-minute observation period at a fixed point, each observer independently conducted a visual survey by walking along the entire pond perimeter (Rumble and Flake 1982).

Fig. 1. Location of the 12 mining ponds and 38 beaver ponds in western Quebec, Canada, sampled for waterfowl in 2018 and 2019.



Whenever possible, waterfowl surveys were conducted in the morning after sunrise (5:00–10:00) or in the evening in the hours before sunset (15:00–20:00), because these are the times when waterfowl are most active for feeding (Bennett 1967, Rumble and Flake 1982). For logistical reasons, a number of visits had to be made at less optimal times, up to 12:00 for morning surveys (5% of visits) and from 12:00 onward (20% of visits) for afternoon surveys. As much as possible, we rotated the sequence of visits to ponds during the different periods.

Pond characteristics and environmental covariates

During site visits, we recorded pond characteristics that could explain the use of the sites by waterfowl. These variables were separated into two groups: (1) characteristics related to habitat structure that influence access to resources and predator avoidance, and (2) characteristics related to the abundance of food resources (Nummi and Hahtola 2008, Holopainen et al. 2015).

We considered four different variables to reflect habitat structure. The first two consisted of pond area and shoreline development (Wetzel 2001). These variables were calculated from satellite images and GPS tracks that were created as we conducted waterfowl searches along the pond perimeter. Shoreline development is an indicator of shoreline irregularity in comparison with a water surface of the same area that would be perfectly circular. For the third habitat characteristic variable, we used the normalized difference vegetation index (NDVI) as an indicator of the vegetation in the ponds. Sentinel satellite imagery at 10 m resolution was used to obtain a vegetation index for each pixel in each pond. This index gives a value, ranging from -1 to +1, based on the absorbance and reflectance that would be expected from green vegetation. Higher values of NDVI indicate denser submerged and emergent vegetation, and lower values indicate less or no vegetation. From these indices, a mean NDVI value was then calculated for each pond. Sentinel images used were taken from July and August 2018, when vegetation was fully developed. The fourth variable, the average depth at 0.5 m from the shoreline, was calculated from 10 randomly selected points on each visit. Depth close to the shoreline was used because we were not able to access the center of ponds. Thus, our depth measurement is an indicator of the steepness of the shoreline.

We used fish presence and pH as proxies for characteristics related to food resources. Average pH was calculated from the same 10 randomly selected points used for depth measurement. Fish presence was assessed at each pond during a single visit between 26 July and 19 August 2019. To sample fish, we used four SilverCreek galvanized minnow traps. These traps had a 6.25 mm mesh size and openings enlarged up to 2.5 cm. Minnow traps were randomly positioned in the water close to pond shoreline (Mallory et al. 1994). Traps were removed after 24 hours and fish were identified directly at the site when possible. Specimens were brought to the laboratory for identification when necessary. Species were pooled and we used presence or absence of fish and number of fish captured in our analyses.

Waterfowl surveys were not conducted under heavy rain conditions. For each visit, we measured different parameters that could influence our ability to detect waterfowl species. Air temperature, wind intensity (on the Beaufort scale), Julian day, time of day (morning or evening), year and time spent sampling the pond were considered in our analyses. Although most inventories were carried out during optimal time periods, we compared species detection between the morning and evening to test whether detection probability varies between these two periods.

Statistical analysis

Site characteristics, with the exception of fish-related variables, were compared between beaver ponds and mining ponds using two sample t-tests. We used Fisher's exact test to test the association between fish presence and pond type. For the number of fish captured, a robust regression using the M-estimator (Tukey's biweight) was used to assess differences between pond types because there were extreme values observed at a few sites (Venables and Ripley 2002). The number of fish captured underwent a square root transformation to meet the assumption of homoscedasticity.

Table 1. List of candidate models for testing habitat use by waterfowl. The first group of models (a) was used to test if pond type (beaver pond or mining pond) had an effect on the probability of occupancy of six species and two guilds of waterfowl. The second group (b) was used to explain the effect of pond characteristics on the probability of occupancy of these species and guilds. For all groups of models, we tested the effect of the six different scenarios on detection probability (c).

Model names	Model structure
(a) Models assessing effect of pond type on occupancy	
Null model	ψ(Year)
Type	ψ(Year + Type)
(b) Models assessing effect of pond characteristics on occupancy	
Null model	ψ(Year)
Resources (additive)	ψ(Year + pH + Fish[†])
Habitat	ψ(Year + SD[‡] + Area + Depth + NDVI[§])
Habitat + Resources (additive)	ψ(Year + SD + Area + Depth + NDVI + pH + Fish)
Resources (interaction)	ψ(Year + pH + Fish + pH : Fish)
Habitat + Resources (interaction)	ψ(Year + SD + Area + Depth + NDVI + pH + Fish + pH : Fish)
(c) Models assessing effect of variables on detection probability	
Null	p(Intercept)
Weather conditions	p(Temperature + Wind)
Time	p(Sampling effort)
Day	p(Julian day)
Period	p(Sampling period)
Year	p(Year)
Type	p(Type)

[†] Presence/absence of fish
[‡] Shoreline development
[§] Normalized difference vegetation index

We used site occupancy models (MacKenzie et al. 2002) to test whether occupancy of adults and broods of different duck species are higher on mining ponds than beaver ponds. These models allowed us to estimate the probabilities of site occupancy (ψ) and detection (p) for Mallard (*Anas platyrhynchos*), Ring-necked Duck (*Aythya collaris*), Common Goldeneye (*Bucephala clangula*), American Wigeon (*Mareca americana*), Green-winged Teal (*Anas crecca*), Hooded Merganser (*Lophodytes cucullatus*), and two guilds of waterfowl (dabblers and divers). These six species were the most frequently observed on our sites with sufficient number of detections to use occupancy models. However, we excluded the first visit in 2019 for brood analysis because the first visit was conducted before most broods could be detected in 2019. Because species potentially breed in the wetlands and leave for the fall migration, we considered the data from each of the two years at a given site to be independent. However, we included a year effect on occupancy probability in all models to account for potential differences between years.

We tested two groups of models for occupancy using detection and non-detection data. The first model group assessed the effect of pond type (beaver pond or mining pond) on occupancy, whereas the second group quantified the effect of pond characteristics on occupancy (Table 1). This distinction was made because the characteristics used to explain waterfowl occupancy were strongly associated with the different pond types. Thus, we tested the effect of pond characteristics and the effect of pond type separately. For the first group of models testing pond type, we compared a model including the pond type (beaver pond or mining pond) to a null model considering only the year effect. For the second group of models testing pond characteristics, six candidate models were constructed by combining variables known to influence waterfowl habitat use: (1) habitat structure characteristics that affect access to resources and predator avoidance, and (2) abundance of food resources (Table 1). In all cases, we ensured that explanatory variables in a given model were not correlated ($|r| < 0.60$). For both groups of models, we tested the effect of different detection parameters.

The analyses were conducted in R 3.6.2 using the unmarked package (Fiske and Chandler 2011, R Core Team 2020). We estimated goodness of fit of the global model with the MacKenzie and Bailey test (MacKenzie and Bailey 2004). After correcting for overdispersion, we compared our models using the Akaike information criterion corrected for small samples ($QAIC_c$; Burnham and Anderson 2002). We performed model selection and multimodel inference using the AICcmodavg package (Mazerolle 2020). For these inferences, we used all our models to estimate the effect of our different variables using the shrinkage estimator (Burnham and Anderson 2002). For some of the species and guilds in the study, overdispersion was too high (> 4) in the case of certain analyses. We could not pursue these analyses further for these species.

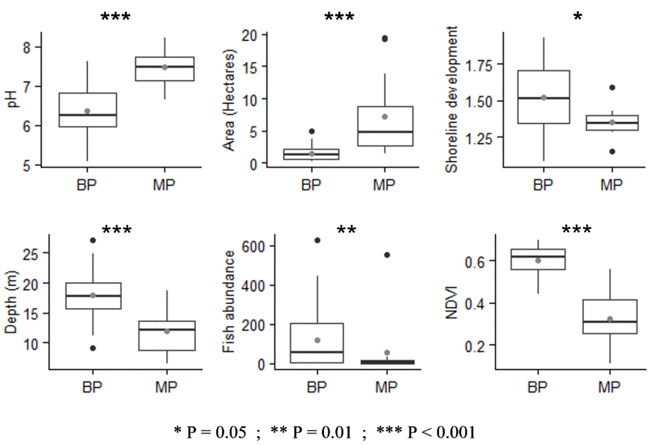
RESULTS

Comparisons of habitat parameters between site types

Mining ponds differed from beaver ponds for most variables characterizing the site (Fig. 2). On average, mining ponds were 4.8 times larger, were 18% less acidic, and had a littoral zone 33%

shallower than beaver ponds. The shoreline of the mining ponds was also more regular (11% less shoreline development) and these ponds were less vegetated (45% lower NDVI value) compared to beaver ponds. The most common fish species observed in our ponds were cyprinids from the *Chrosomus* genus (*Chrosomus* sp., 79% of our observations) and the pearl dace (*Margariscus margarita*, 11% of our observations). Fish were absent in 50% of mining ponds (6/12) and on 21% of beaver ponds (8/38), but this difference was only marginally significant (Fisher's exact test, p = 0.07). However, the number of fish captured was twice as high in beaver ponds compared to mining ponds. Despite high variance of the number of fish captured, the difference between the two pond types was statistically significant (Fig. 2).

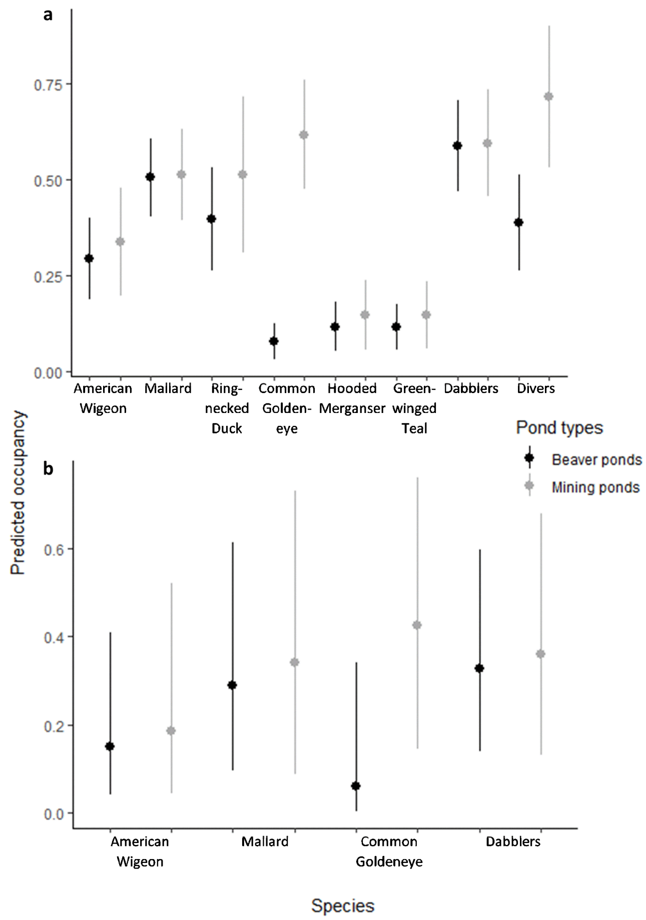
Fig. 2. Distribution of different habitat parameters for 38 beaver ponds (BP) and 12 mining ponds (MP) in western Quebec, Canada. "NDVI" is the normalized difference vegetation index and "Fish abundance" is the number of fish captured. The mean values of the parameters are represented by a gray dot on the boxplots. P-values are also presented; comparisons were conducted with two sample t-tests for all variables, except for the number of fish captured, which was analyzed with robust regression because of the presence of outliers.



Adult and brood occupancy

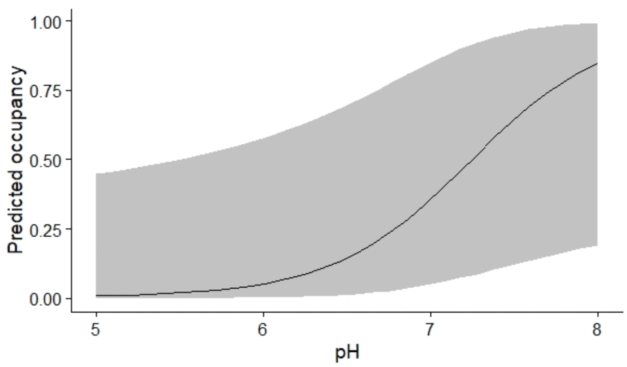
A total of 15 waterbird species were observed on both pond types. The most common species observed on our ponds were Mallard, Ring-necked Duck, American Wigeon, Common Goldeneye, Hooded Merganser, and Green-winged Teal (Tables A1.1, A1.2). For all species and models, results of model selection as well as c-hat values are presented in Tables A1.3, A1.4, A1.5, and A1.6. The first group of models compared mining ponds to beaver ponds, and results show that goldeneyes (adults and broods) used mining ponds more than beaver ponds (Fig. 3). Predicted occupancy of adult goldeneyes averaged 0.62 on mining sites compared to 0.07 on beaver ponds, whereas occupancy for broods averaged 0.42 compared to 0.03 on beaver ponds (Fig. 3). Despite differences in pond characteristics, breeding adults and broods of other species appeared to use both pond types at similar levels (Fig. 3). Detection probability did not vary with most variables tested for adults and broods (Tables A1.7 and A1.8). However, adult divers were more easily detected on mining ponds than on beaver ponds.

Fig. 3. Model-averaged predicted occupancy for breeding adults (a) and broods (b) of different waterfowl species and guilds. Data were collected from surveys of 38 beaver ponds (in black) and 12 mining ponds (in gray) in western Quebec, Canada in 2018 and 2019. Error bars denote 95% confidence intervals around estimates.



The second group of models focused on habitat parameters. We found no evidence of an effect of these parameters on occupancy of adult waterfowl (pH, area, shoreline development, depth, presence of fish, NDVI). This was observed for all six species (Mallard, Ring-necked Duck, Common Goldeneye, American Wigeon, Green-winged Teal, Hooded Merganser) and the two guilds (dabblers, divers) analyzed (Table A1.7). With respect to broods, only goldeneye occupancy increased with pond water pH (Fig. 4 and Table A1.8). Brood occupancy of the other species and the two guilds did not vary with any of the variables we considered (Table A1.8). Detection probability of adults and broods did not vary with any variables in the models (Tables A1.7 and A1.8). Average detection probability varied among different waterfowl species, although 95% confidence intervals overlapped substantially (Table A1.9).

Fig. 4. Model-averaged predicted occupancy for broods of Common Goldeneyes (*Bucephala clangula*) based on water pH of 38 beaver ponds and 12 mining ponds sampled for waterfowl in western Quebec, Canada, in 2018 and 2019.



DISCUSSION

We hypothesized that the different characteristics explaining waterfowl occupancy are similar between beaver ponds and mining ponds, with the exception of fish that would be less common in mining ponds on account of their low connectivity with the water system. We expected that waterfowl occupancy, adults and broods, in mining ponds would be higher than in beaver ponds because the species studied all depend on invertebrates during the breeding season and also because of higher competition from fish in beaver ponds. In contrast to our hypotheses, we observed that the occupancy of mining and beaver ponds by adults and broods was similar for most of the species and guilds studied. One species, Common Goldeneye (adults and broods), was more likely to use mining ponds than beaver ponds. These results suggest that a combination of mining pond characteristics make these sites more favorable to goldeneyes than beaver ponds. Although not originally intended for this purpose, mining ponds appear to be used as often as beaver ponds by waterfowl to breed. This result was unexpected, because beaver ponds are recognized as a high-quality habitat for the reproduction of waterfowl in the boreal environment (Nummi 1992, Nummi and Hahtola 2008, Nummi and Holopainen 2014). Comparable presence of broods on both types of sites also indicates that restored mining sites can support waterfowl reproduction.

Habitat parameters between pond types and waterfowl occupancy patterns

Contrary to what was initially hypothesized, several habitat characteristics differed between mining and beaver ponds. Although the two pond types differ in terms of their characteristics, they are apparently within ranges that are favorable for waterfowl establishment. As hypothesized, fish captures were lower at mining ponds, which supports the idea that mining ponds are probably less connected to the water system. Several studies reported a negative effect of the presence of fish on habitat use by waterfowl on account of competition for resources between the two groups (Eadie and Keast 1982, Elmberg et al. 2010, Väänänen et al. 2012, Nummi et al. 2016). However, we found no effect of the presence of fish on the probability of occupancy of the waterfowl species studied. For some of the six waterfowl species included in the analyses, we believe this lack of relationship could be explained by their feeding pattern and behavior in relation to fish. For example, the fish species present in our ponds were mainly small cyprinids. These fish species may have low impact on certain groups of aquatic invertebrates such as benthic species and, by extension, on certain waterfowl species that feed on these invertebrates (McAuley and Longcore 1988, McNicol and Wayland 1992). Other waterfowl species are also less affected by fish because they feed in less open areas or on invertebrates that are less visible to fish (Pöysä 1983, Väänänen et al. 2012, Nummi et al. 2013). As for goldeneyes, the species feeds on pelagic invertebrates. This feeding pattern did not induce an avoidance of ponds where fish were present, contrary to what we expected for the species. This result might be explained by the goldeneye's ability to dive to feed on benthos, which provides some versatility in its diet (McNicol and Wayland 1992, Nummi et al. 2012). An alternative explanation would be that most studies on the interactions between goldeneyes and fish have been done on boreal lakes that are rather oligotrophic. Indeed, Nummi and Hahtola (2008) showed that the abundance of invertebrates was much higher in beaver ponds than in other boreal lakes and ponds. A higher invertebrate abundance in beaver ponds could offset the higher abundance of fish competing with goldeneyes, potentially explaining the lack of direct effect of fish on goldeneye occupancy. For the Green-winged Teal, we expected to find an effect of fish on its occupancy (Väänänen et al. 2012), but a high invertebrate abundance in beaver ponds would also explain the lack of relationship with fish presence.

Mining ponds were less acidic than beaver ponds in general, probably on account of the current or past control of water pH in mining ponds by various means, such as liming. Of the species studied, only goldeneye broods were affected by pH, with a higher probability of occupancy at less acidic sites. In other studies, there is evidence of an indirect effect of pH in combination with the presence of fish. Below a certain pH, the number of invertebrate taxa decreases significantly, and competition from fish in these impoverished environments makes conditions less favorable for habitat use by waterfowl (McNicol and Wayland 1992, McNicol et al. 1995). In our case, pH values both at the beaver ponds and mining ponds always remained within ranges favorable for waterfowl settlement (> 5), which might explain the lack of relationship between pH and site occupancy found for most species.

The average depth near the shoreline in mining ponds was lower than in beaver ponds. Although shallow ponds were generally associated with increased accessibility to resources for dabblers, the depths observed near the shores of beaver ponds remained in ranges that should not limit access to these resources. Indeed, a study by Pöysä (1983) showed that some species of dabblers could reach resources up to a maximum depth of about 26–42 cm. However, at 50 cm from the shore, beaver ponds had an average depth of only 17.9 cm (with an observed maximum of 27.1 cm). Although this value represents the depth near the shoreline, it shows that depth did not increase quickly. This observation is consistent with studies conducted in Europe, confirming that beaver ponds are shallow and facilitate waterfowl establishment

(Nummi and Hahtola 2008). In beaver and mining ponds, the different species and broods were therefore able to feed at a sufficient distance away from the shoreline, allowing waterfowl to avoid land-based predators.

With respect to other elements of habitat structure, beaver ponds generally had more vegetation cover than mining ponds. Beaver ponds were also smaller and had a higher shoreline development index (irregularity) than mining ponds. As for pond area, we did not observe any effect of the variable on waterfowl occupancy. This lack of relationship could be because ponds in the study were relatively small, with only three ponds larger than 10 hectares and none larger than 20 hectares. Regarding vegetation cover, several waterfowl species are also associated with semi-open or open environments (Rempel et al. 1997, Lemelin et al. 2010). The Common Goldeneye, among others, prefers open environments for feeding because it dives to avoid predation and consumes pelagic invertebrates in the water column (Pöysä 1983, Nummi and Pöysä 1993, 1995, Nummi et al. 2013). However, our study did not show any effect of vegetation on the presence of broods. This could be explained because we did not consider duckling age, a factor that can influence feeding behavior (Nummi and Pöysä 1993, 1995).

Our models did not identify which site variables influence Common Goldeneye use of mining ponds. However, several studies focusing on habitat use by the species report effects of factors related to the characteristics of mining ponds. For example, goldeneyes generally use more open habitat, with clear water, simple shoreline configuration, and close to available tree cavities used for nesting (Eadie et al. 2020). Most of these characteristics seem to be representative of the conditions observed on our mining ponds. However, some of these variables were not considered in our study.

In our study, we included abandoned and active beaver ponds, as well as active and restored mining sites. However, pond age was not among the variables tested in our analyses because it was not possible to obtain an accurate measure of pond age for each pond studied. Conditions in beaver ponds, such as water level and vegetation cover fluctuate over time and depend on beaver activity (Renouf 1972, Naiman et al. 1986). Similarly, visits made on mining sites showed that conditions appeared to differ between sites still in operation and those restored for some time. In a management and restoration perspective, it would be important to describe the succession of ponds after their creation and quantify the resulting variations in the occupancy patterns of the various waterfowl species.

Waterfowl detectability and timing of surveys

Detection probability of the different species of waterfowl did not vary with the time of day (morning or evening), nor with most of the other variables considered including wind and temperature. The lack of effect of the different detection variables suggests that detection of this group of species is less sensitive to various sampling conditions than other groups, such as passerines (Drapeau et al. 1999). Nonetheless, we found an effect of the site type on the detection probability of adult divers. Detection probability for this group was higher on mining ponds, which indicates that other site characteristics such as lower vegetation density have probably affected detection by the observers around wetlands. Given that most environmental characteristics did not affect detection, our results indicate that there may be some flexibility in the conditions for conducting surveys in future waterfowl studies.

CONCLUSION

The main objective of the restoration of mining sites is to return the site to its original state, but restoration activities may result in the creation of new wetlands that benefit certain group of species, such as waterfowl. However, the restoration method using a water-based layer has been used less in recent years, because it is associated with an inherent risk to the physical and chemical stability of the water basins formed (Aubertin et al. 2015, *unpublished manuscript*, https://www.researchgate.net/publication/319914984). Therefore, this risk should be evaluated before making any decision. Nonetheless, for sites that are still being restored with this method, it seems that these new habitats have an interesting potential and could be developed for specific wetland-dependent fauna and flora. Our results are limited to short-term effects of mining ponds during the breeding season. Further studies are required to assess the impact of mining ponds on longer time scales. Given the potential of mining ponds during the breeding season, it would be interesting to consider restoring newly closed sites using flooding, but also documenting the long-term colonization of these sites and contaminant accumulation in the organisms frequenting these sites. Indeed, metals in tailing ponds can accumulate in water, sediments, plant shoots, and fish (Khozhina and Sheriff 2008). Metal recovery reagents employed in the treatment of gold mining sites as well as the production of acid effluents can also harm wildlife that use contaminated water (Asif and Chen 2016). This situation reinforces the idea that ecological consequences of tailings on bird mortality should be assessed by independent scientists using a standardized evaluation and statistical design (Timoney and Ronconi 2010). A formal investigation of the intake of heavy metals by ducks of different life stages at mining ponds relative to natural ponds would help quantify the risk of using these different wetland types in both the short and long terms. If mining ponds are found to not pose a risk to the species using them in the long term, these restored sites could then compensate, at least in part, for the loss of natural wetlands resulting from human activities.

Responses to this article can be read online at:
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Appendix 1.

Table A1.1: Detection of adults (a) and broods (b) of different waterbird species observed on 38 beaver ponds and 12 mining ponds sampled in western Québec, Canada in 2018 and 2019.

(a) Number of sites with adult detections

Species	2018		2019	
	Beaver ponds	Mining ponds	Beaver ponds	Mining ponds
Mallard (*Anas platyrhynchos*)	17	5	19	7
Ring-necked Duck (*Aythya collaris*)	12	7	20	10
Common Goldeneye (*Bucephala clangula*)	3	7	2	7
American Wigeon (*Mareca americana*)	9	4	10	5
Common Loon (*Gavia immer*)	1	3	3	5
Common Merganser (*Mergus merganser*)	2	2	0	2
Hooded Merganser (*Lophodytes cucullatus*)	9	0	12	3
Pied-billed Grebe (*Podilymbus podiceps*)	3	2	3	4
Red-necked Grebe (*Podiceps grisegena*)	1	1	0	1
Green-winged Teal (*Anas crecca*)	2	3	12	4
Blue-winged Teal (*Spatula discors*)	1	0	1	0
Wood Duck (*Aix sponsa*)	5	1	0	0
American Black Duck (*Anas rubripes*)	2	0	2	1
Bufflehead (*Bucephala albeola*)	0	1	0	1
Canada Goose (*Branta canadensis*)	0	1	5	1

Table A1.1 continuation:

(b) Number of sites with brood detections

Species	2018		2019	
	Beaver ponds	Mining ponds	Beaver ponds	Mining ponds
Mallard (*Anas platyrhynchos*)	9	4	4	3
Ring-necked Duck (*Aythya collaris*)	5	7	3	6
Common Goldeneye (*Bucephala clangula*)	1	5	1	4
American Wigeon (*Mareca americana*)	3	2	2	1
Common Loon (*Gavia immer*)	0	1	0	1
Common Merganser (*Mergus merganser*)	1	1	0	0
Hooded Merganser (*Lophodytes cucullatus*)	0	0	4	1
Pied-billed Grebe (*Podilymbus podiceps*)	3	2	1	1
Red-necked Grebe (*Podiceps grisegena*)	0	1	0	0
Green-winged Teal (*Anas crecca*)	0	1	2	0
Blue-winged Teal (*Spatula discors*)	0	0	0	0
Wood Duck (*Aix sponsa*)	0	0	0	0
American Black Duck (*Anas rubripes*)	0	0	0	0
Bufflehead (*Bucephala albeola*)	0	0	0	0
Canada Goose (*Branta canadensis*)	0	0	0	1

Table A1.2: Mean counts (by visit) of adults and ducklings of different waterbird species observed on 38 beaver ponds (BP) and 12 mining ponds (MP) sampled in western Québec, Canada in 2018 and 2019. For ducklings, mean number of broods observed by visit is also presented in parentheses.

Site	Site type	Adults	Ducklings	
1	BP	0.0	0.0	(0.0)
2	BP	2.6	3.2	(1.0)
3	MP	0.8	0.8	(0.5)
4	MP	4.2	6.0	(1.8)
5	MP	23.2	15.6	(3.8)
6	BP	0.8	0.0	(0.0)
7	BP	2.4	3.2	(0.8)
8	MP	1.4	0.4	(0.3)
9	BP	3.0	4.8	(1.0)
10	BP	0.8	2.2	(0.5)
11	BP	0.6	0.0	(0.0)
12	MP	3.6	1.8	(0.5)
13	BP	0.0	0.0	(0.0)
14	BP	1.4	0.0	(0.0)
15	BP	1.2	0.6	(0.3)
16	BP	2.2	0.0	(0.0)
17	BP	0.2	1.4	(0.3)
18	BP	1.0	1.2	(0.3)
19	MP	0.8	0.0	(0.0)
20	BP	5.2	0.8	(0.3)
21	BP	0.2	0.0	(0.0)
22	MP	18.8	9.8	(1.8)
23	BP	2.6	0.0	(0.0)
24	BP	5.6	2.2	(0.8)
25	MP	3.8	0.0	(0.0)

Site	Site type	Adults	Ducklings	
26	BP	0.4	1.6	(0.3)
27	BP	2.8	1.4	(0.3)
28	MP	23.0	10.6	(3.8)
29	BP	2.6	1.4	(0.5)
30	BP	4.0	3.8	(0.8)
31	MP	14.8	14.2	(3.3)
32	BP	0.4	0.0	(0.0)
33	BP	0.8	0.0	(0.0)
34	MP	7.8	10.4	(2.5)
35	BP	3.6	3.8	(2.5)
36	BP	2.0	1.6	(0.3)
37	MP	3.6	2.8	(0.8)
38	BP	0.2	0.0	(0.0)
39	BP	0.0	0.0	(0.0)
40	BP	6.0	4.4	(1.0)
41	BP	1.6	0.0	(0.0)
42	BP	1.2	0.8	(0.3)
43	BP	0.0	0.0	(0.0)
44	BP	0.4	0.0	(0.0)
45	BP	2.2	0.0	(0.0)
46	BP	1.4	2.6	(0.5)
47	BP	1.8	0.0	(0.0)
48	BP	0.4	0.0	(0.0)
49	BP	0.0	0.0	(0.0)
50	BP	1.6	2.2	(0.5)

Table A1.3: Model selection based on the Akaike Information Criteria corrected for small samples and overdispersion ($QAIC_c$) explaining the use of two pond types by adults of six species and two guilds of waterfowl in western Québec, Canada in 2018 and 2019. Only models with an $\Delta QAIC_c < 2$ are presented with their respective Akaike weights (ω_i), quasi log-likelihood (Q-LL), and number of estimated parameters (K).

Models	Q-LL	K	$QAIC_c$	$\Delta QAIC_c$	ω_i
Mallard ($\hat{c}$=1.43)					
ψ(Year)p(Year)	-159.97	5	330.57	0.00	0.22
ψ(Year)p(Intercept)	-161.15	4	330.73	0.16	0.20
ψ(Year)p(Sampling period)	-160.71	5	332.06	1.49	0.10
Ring-necked duck ($\hat{c}$=2.67)					
ψ(Year)p(Type)	-93.26	5	197.16	0.00	0.28
ψ(Year)p(Sampling effort)	-93.30	5	197.24	0.08	0.27
ψ(Year + Type)p(Sampling effort)	-92.37	6	197.65	0.49	0.22
Common goldeneye ($\hat{c}$=1.25)					
ψ(Year + Type)p(Type)	-75.19	6	163.28	0.00	0.35
ψ(Year + Type)p(Temperature + Wind)	-74.26	7	163.75	0.47	0.28
ψ(Year + Type)p(Julian day)	-76.17	6	165.25	1.97	0.13
American wigeon ($\hat{c}$=1.88)					
ψ(Year)p(Julian day)	-80.82	5	172.28	0.00	0.31
ψ(Year + Type)p(Julian day)	-80.43	6	173.76	1.48	0.15
ψ(Year)p(Intercept)	-82.91	4	174.23	1.95	0.12
Green-winged Teal ($\hat{c}$=1.24)					
ψ(Year)p(Year)	-95.57	5	201.78	0.00	0.19
ψ(Year)p(Intercept)	-97.02	4	202.46	0.68	0.14
ψ(Year + Type)p(Year)	-94.97	5	202.85	1.07	0.11
ψ(Year + Type)p(Intercept)	-96.47	5	203.59	1.81	0.08
ψ(Year)p(Type)	-96.48	5	203.60	1.83	0.08

Table A1.3 continuation:

Models	Q-LL	K	$QAIC_c$	$\Delta QAIC_c$	ω_i
Hooded Merganser ($\hat{c}$=1.48)					
ψ(Year)p(Year)	-80.07	5	170.78	0.00	0.18
ψ(Year)p(Intercept)	-81.29	4	170.99	0.21	0.16
ψ(Year + Type)p(Year)	-79.57	6	172.05	1.27	0.09
ψ(Year + Type)p(Intercept)	-80.83	5	172.30	1.51	0.08
ψ(Year)p(Sampling effort)	-80.84	5	172.31	1.53	0.08
ψ(Year)p(Sampling effort)	-81.02	5	172.68	1.89	0.07
ψ(Year)p(Type)	-81.05	5	172.73	1.95	0.07
Dabblers ($\hat{c}$ =2.44)					
ψ(Year)p(Year)	-117.99	5	246.61	0.00	0.28
ψ(Year)p(Intercept)	-119.70	4	247.82	1.21	0.15
Divers ($\hat{c}$ =2.21)					
ψ(Year + Type)p(Type)	-105.46	6	223.82	0.00	0.78

Table A1.4: Model selection based on the Akaike Information Criteria corrected for small samples and overdispersion ($QAIC_c$) explaining the use of two pond types by three species and one guild of waterfowl broods in small ponds in western Québec, Canada. Only models with an $\Delta QAIC_c < 2$ are presented with their respective Akaike weights (ωi), quasi log-likelihood (Q-LL) and number of estimated parameters (K).

Models	Q-LL	K	$QAIC_c$	$\Delta QAIC_c$	ω_i
Mallard ($\hat{c}$=3.43)					
ψ(Year)p(Intercept)	-29.74	4	67.89	0.00	0.20
ψ(Year)p(Sampling effort)	-28.93	5	68.50	0.61	0.15
ψ(Year)p(Year)	-29.28	5	69.21	1.32	0.10
ψ(Year + Type)p(Intercept)	-29.50	5	69.64	1.75	0.08
ψ(Year)p(Julian day)	-29.62	5	69.87	1.98	0.07
Common Goldeneye ($\hat{c}$=1.63)					
ψ(Year + Type)p(Temperature + Wind)	-30.17	7	75.56	0.00	0.36
ψ(Year + Type)p(Sampling period)	-31.85	6	76.60	1.04	0.22
American Wigeon ($\hat{c}$=1.11)					
ψ(Year)p(Intercept)	-41.24	4	90.89	0.00	0.21
ψ(Year)p(Temperature + Wind)	-39.66	6	92.22	1.33	0.11
ψ(Year + Type)p(Intercept)	-40.88	5	92.40	1.51	0.10
Dabblers ($\hat{c}$=2.67)					
ψ(Year)p(Sampling effort)	-46.12	5	102.89	0.00	0.21
ψ(Year)p(Intercept)	-47.39	4	103.21	0.32	0.18
ψ(Year)p(Year)	-46.64	5	103.92	1.03	0.12
ψ(Year + Type)p(Sampling effort)	-45.95	6	104.80	1.91	0.08

Table A1.5: Model selection based on the Akaike Information Criteria corrected for small samples and overdispersion ($QAIC_c$) explaining habitat use according to pond characteristics by adults of six species and two guilds of waterfowl in western Québec, Canada in 2018 and 2019. Only models with an $\Delta QAIC_c < 2$ are presented with their respective Akaike weights (ωi), quasi log-likelihood (Q-LL) and number of estimated parameters (K).

Models	Q-LL	K	$QAIC_c$	$\Delta QAIC_c$	ω_i
Mallard (ĉ=1.42)					
ψ(Year + SD[†]+ Area + Depth + NDVI[‡] + pH + Fish[§])p(Type)	-147.74	11	320.48	0.00	0.36
ψ(Year + SD+ Area + Depth + NDVI)p(Type)	-150.87	9	321.74	1.26	0.19
Ring-necked duck (ĉ=2.62)					
ψ(Year)p(Type)	-95.04	5	200.72	0.00	0.17
ψ(Year)p(Sampling effort)	-95.08	5	200.80	0.09	0.34
ψ(Year + pH + Fish)p(Sampling effort)	-93.08	7	201.38	0.66	0.47
ψ(Year + pH + Fish)p(Type)	-93.13	7	201.48	0.76	0.59
ψ(Year + pH + Fish + pH : Fish)p(Sampling effort)	-91.99	8	201.56	0.85	0.70
Common goldeneye (ĉ=1.26)					
ψ(Year + SD+ Area + Depth + NDVI)p(Type)	-70.78	9	161.56	0.00	0.18
ψ(Year + SD+ Area + Depth + NDVI)p(Temperature + Wind)	-69.86	10	162.19	0.63	0.13
ψ(Year + SD+ Area + Depth + NDVI + pH + Fish)p(Type)	-69.19	11	163.38	1.82	0.07
ψ(Year + SD+ Area + Depth + NDVI)p(Julian day)	-71.76	9	163.52	1.96	0.07
American wigeon (ĉ=1.87)					
ψ(Year + SD+ Area + Depth + NDVI)p(Julian day)	-78.19	7	171.59	0.00	0.25
ψ(Year)p(Julian day)	-81.25	5	173.14	1.55	0.11
ψ(Year + pH + Fish + pH : Fish)p(Julian day)	-77.96	8	173.50	1.90	0.10
ψ(Year + pH + Fish)p(Intercept)	-80.33	6	173.56	1.96	0.09

Table A1.5 continuation:

Models	Q-LL	K	$QAIC_c$	$\Delta QAIC_c$	ω_i
Green-winged Teal (ĉ=.1.26)					
ψ(Year)p(Year)	-94.05	5	198.74	0.00	0.23
ψ(Year)p(Intercept)	-95.48	4	199.38	0.64	0.16
ψ(Year)p(Type)	-94.95	5	200.54	1.80	0.09
Hooded Merganser (ĉ=1.41)					
ψ(Year)p(Temperature + Wind)	-95.74	6	204.38	0.00	0.24
ψ(Year + pH + Fish)p(Temperature + Wind)	-93.42	8	204.42	0.04	0.24
ψ(Year + pH + Fish + pH : Fish)p(Temperature + Wind)	-92.75	9	205.51	1.13	0.14
ψ(Year + pH + Fish + pH : Fish)p(Type)	-92.75	9	205.51	1.13	0.14
Dabblers (ĉ=2.43)					
ψ(Year)p(Year)	-118.47	5	247.58	0.00	0.18
ψ(Year)p(Intercept)	-120.19	4	248.81	1.22	0.10
ψ(Year + SD + Area + Depth + NDVI + pH + Fish)p(Year)	-112.28	11	249.57	1.98	0.07
Divers (ĉ=2.14)					
ψ(Year + SD + Area + Depth + NDVI)p(Type)	-104.42	9	228.85	0.00	0.69

† Shoreline development
‡ Normalized difference vegetation index
§ Presence/absence of fish

Table A1.6: Model selection based on the Akaike Information Criteria corrected for small samples and overdispersion ($QAIC_c$) explaining habitat use according to pond characteristics by two species and one guild of waterfowl broods in western Québec, Canada in 2018 and 2019. Only models with an $\Delta QAIC_c < 2$ are presented with their respective Akaike weights (ωi), quasi log-likelihood (Q-LL) and number of estimated parameters (K).

Models	Q-LL	K	$QAIC_c$	$\Delta QAIC_c$	ω_i
Mallard ($\hat{c}$=3.28)					
ψ(Year)p(Intercept)	-31.09	4	70.61	0.00	0.21
ψ(Year)p(Sampling effort)	-30.25	5	71.14	0.53	0.16
ψ(Year)p(Year)	-30.62	5	71.89	1.28	0.11
ψ(Year)p(Julian day)	-30.97	5	72.59	1.97	0.08
Common Goldeneye ($\hat{c}$=1.6)					
ψ(Year + pH + Fish†)p(Temperature + Wind)	-27.69	8	72.96	0.00	0.24
ψ(Year + pH + Fish)p(Sampling period)	-29.41	7	74.03	1.07	0.14
ψ(Year + pH + Fish + pH : Fish)p(Temperature + Wind)	-27.28	9	74.57	1.61	0.11
ψ(Year + pH + Fish + pH : Fish)p(Type)	-27.28	9	74.57	1.61	0.11
Dabblers ($\hat{c}$=2.68)					
ψ(Year)p(Sampling effort)	-45.95	5	102.54	0.00	0.21
ψ(Year)p(Intercept)	-47.22	4	102.85	0.31	0.18
ψ(Year)p(Year)	-46.47	5	103.57	1.03	0.13

† Presence/absence of fish

Table A1.7: Multimodel inference explaining habitat use according to pond characteristics by adults of six species and two guilds of waterfowl in small ponds in western Québec, Canada in 2018 and 2019. Estimates of the effect of explanatory variables on the probabilities of occupancy (ψ) and detection (p) are presented with their 95% confidence intervals. All candidate models were used for multimodel inference.

Parameters on ψ	Estimate	Lower limit	Upper limit	Parameters on p	Estimate	Lower limit	Upper limit
Mallard							
Fish[†]	1.93	-1.60	5.47	Temperature	0	-0.03	0.03
pH	-0.08	-1.76	1.6	Wind[#]	0	-0.03	0.03
pH:Fish[‡]	0.33	-1.44	2.09	Hour[††]	-0.01	-0.16	0.14
NDVI[§]	-3.43	-10.58	3.71	Time[‡‡]	0	-0.07	0.08
Depth[|]	-0.72	-2.40	0.95	Julian day	0	0	0
SD[¶]	-0.99	-2.46	0.49	Year	-0.05	-0.41	0.32
Area	5.39	-2.45	13.2	Type	-0.57	-1.51	0.36
Year	0.38	-1.5	2.26				
Ring-necked Duck							
Fish	0.42	-1.22	2.05	Temperature	0	-0.03	0.03
pH	0.57	-1.13	2.26	Wind	0	-0.03	0.03
pH:Fish	-0.28	-1.82	1.26	Hour	0	-0.07	0.07
NDVI	0.18	-0.88	1.24	Time	0.30	-0.39	0.98
Depth	0.10	-0.59	0.79	Julian day	0	0	0
SD	-0.14	-0.85	0.58	Year	-0.06	-0.58	0.46
Area	0.96	-3.65	5.57	Type	0.51	-0.84	1.85
Year	1.60	-0.20	3.40				
Common Goldeneye							
Fish	-0.76	-2.75	1.24	Temperature	0.16	-0.44	0.76
pH	0.49	-1.01	2.00	Wind	-0.11	-0.55	0.32
pH:Fish	-0.17	-1.29	0.95	Hour	0.01	-0.25	0.22
NDVI	-1.14	-2.55	0.26	Time	-0.02	-0.19	0.16
Depth	-0.15	-1.07	0.77	Julian day	0	-0.01	0.02
SD	0.11	-0.85	1.06	Year	0.02	-0.24	0.28
Area	0.20	-0.43	0.84	Type	0.44	-0.97	1.85
Year	-0.28	-1.78	1.23				

Table A1.7 continuation:

Paramet-ers on ψ	Estimate	Lower limit	Upper limit	Parameter on p	Estimate	Lower limit	Upper limit
American Wigeon							
Fish	0.32	-1.09	1.73	Temperature	-0.02	-0.22	0.18
pH	0.54	-0.49	1.57	Wind	0.01	-0.12	0.13
pH:Fish	0.10	-0.69	0.89	Hour	-0.05	-0.49	0.38
NDVI	0.02	-0.29	0.34	Time	0.01	-0.13	0.14
Depth	-0.02	-0.31	0.27	Julian day	-0.01	-0.03	0.01
SD	-0.01	-0.21	0.19	Year	0.01	-0.26	0.27
Area	0.01	-0.19	0.22	Type	0.03	-0.33	0.4
Year	0.02	-1.33	1.37				
Green-winged Teal							
Fish	-0.14	-0.96	0.68	Temperature	0.02	-0.15	0.19
pH	0.01	-0.31	0.33	Wind	-0.03	-0.27	0.21
pH:Fish	0.01	-0.26	0.27	Hour	0.03	-0.30	0.37
NDVI	0.00	-0.19	0.19	Time	0.03	-0.22	0.28
Depth	0.02	-0.23	0.27	Julian day	0.00	-0.01	0.01
SD	-0.01	-0.18	0.17	Year	-0.34	-1.57	0.89
Area	0.04	-0.32	0.39	Type	0.03	-0.34	0.41
Year	1.46	0.11	2.80				
Hooded Merganser							
Fish	1.16	-1.14	3.45	Temperature	-0.54	-1.26	0.19
pH	0.53	-0.93	2.00	Wind	-0.08	-0.53	0.38
pH:Fish	-0.33	-1.78	1.12	Hour	-0.02	-0.3	0.25
NDVI	-0.03	-0.51	0.46	Time	0.00	-0.07	0.07
Depth	0.01	-0.20	0.22	Julian day	0.00	0.00	0.00
SD	0.02	-0.23	0.27	Year	0.00	-0.18	0.18
Area	0.00	-0.22	0.23	Type	-0.04	-0.54	0.45
Year	0.72	-0.55	1.99				

Table A1.7 continuation:

Paramet-ers on ψ	Estimate	Lower limit	Upper limit	Parameters on p	Estimate	Lower limit	Upper limit
Dabblers							
Fish	0.72	-1.89	3.33	Temperature	-0.01	-0.12	0.1
pH	-0.14	-1.25	0.97	Wind	0	-0.1	0.09
pH:Fish	0.07	-0.81	0.95	Hour	-0.05	-0.39	0.29
NDVI	0.42	-1.05	1.90	Time	0.01	-0.09	0.10
Depth	-0.23	-1.26	0.81	Julian day	0	-0.01	0
SD	0.37	-1.52	0.77	Year	-0.24	-1.04	0.56
Area	2.42	-4.97	9.81	Type	0.03	-0.28	0.35
Year	0.95	-0.70	2.61				
Divers							
Fish	0.01	-0.88	0.90	Temperature	0	-0.01	0.01
pH	0.18	-0.79	1.15	Wind	0	-0.01	0.01
pH:Fish	-0.07	-0.89	0.75	Hour	0	-0.04	0.04
NDVI	-0.04	-1.25	1.17	Time	0	-0.03	0.03
Depth	0.18	-0.71	1.07	Julian day	0	0	0
SD	-0.45	-1.31	0.41	Year	0	-0.08	0.07
Area	4.17	-1.92	10.26	Type	1.39	0.47	2.31
Year	1.03	-0.53	2.60				

† Presence/absence of fish in the pond.
‡ Interaction between presence/absence of fish and pH.
§ Normalized difference vegetation index.
| Depth at 50 cm form the shoreline.
¶ Shoreline development.
# Force of wind on the Beaufort scale.
†† Period (morning or evening) when the inventory was done.
‡‡ Time spent around the pond to do the inventory.

Table A1.8: Multimodel inference explaining habitat use according to pond characteristics by two species and one guild of waterfowl broods in small ponds in western Québec, Canada in 2018 and 2019. Estimates of the effect of explanatory variables on the probabilities of occupancy (ψ) and detection (p) are presented with their 95% confidence intervals. All candidate models were used for multimodel inference.

Paramat-ers on ψ	Estimate	Lower limit	Upper lmit	Parameters on p	Estimate	Lower limit	Upper limit
Mallard							
Fish[†]	0.11	-1.09	1.31	Temperature	-0.02	-0.28	0.25
pH	0.06	-0.68	0.8	Wind[#]	0.04	-0.34	0.41
pH:Fish[‡]	0.06	-0.68	0.80	Hour[††]	0.02	-0.49	0.53
NDVI[§]	0	-0.25	0.25	Time[‡‡]	0.12	-0.49	0.72
Depth[ǀ]	0	-0.23	0.22	Julian day	0	-0.02	0.02
SD[¶]	-0.01	-0.24	0.23	Year	-0.16	-1.37	1.04
Area	0.02	-0.52	0.57	Type	-0.01	-0.59	0.57
Year	-0.73	-2.78	1.33				
Common Goldeneye							
Fish	-2.96	-9.40	3.47	Temperature	0.76	-1.15	2.67
pH	1.82	0.09	3.56	Wind	0.01	-0.62	0.64
pH:Fish	0.58	-4.52	5.67	Hour	0.32	-1.14	1.78
NDVI	-0.05	-3.61	3.50	Time	-0.02	-0.26	0.23
Depth	0	-0.51	0.51	Julian day	0	-0.01	0.01
SD	0.01	-1.76	1.78	Year	0.04	-0.47	0.55
Area	0	-0.83	0.84	Type	0.1	-0.95	1.14
Year	-0.38	-2.60	1.84				

Table A1.8 continuation:

Paramet-ers on ψ	Estimate	Lower limit	Upper limit	Parameters on p	Estimate	Lower limit	Upper limit
Dabblers							
Fish	0.07	-0.91	1.06	Temperature	-0.01	-0.16	0.15
pH	0.05	-0.62	0.71	Wind	0.01	-0.18	0.21
pH:Fish	0.08	-0.70	0.86	Hour	-0.01	-0.39	0.36
NDVI	0.02	-0.34	0.39	Time	0.16	-0.46	0.77
Depth	-0.02	-0.32	0.28	Julian day	0	-0.01	0.01
SD	-0.02	-0.31	0.27	Year	-0.18	-1.21	0.85
Area	0.06	-0.87	0.98	Type	0.02	-0.43	0.47
Year	-0.34	-1.99	1.31				

[†] Presence/absence of fish in the pond.
[‡] Interaction between presence/absence of fish and pH.
[§] Normalized difference vegetation index.
[|] Depth at 50 cm form the shoreline.
[¶] Shoreline development.
[#] Force of wind on the Beaufort scale.
[††] Period (morning or evening) when the inventory was done.
[‡‡] Time spent around the pond to do the inventory.

Table A1.9: Model-averaged predicted detection probability of breeding adults (a) and broods (b) of different waterfowl species and guilds presented with their 95% confidence intervals. Estimates were obtained after sampling 38 beaver ponds and 12 mining ponds in western Québec, Canada in 2018 and 2019.

(a) Adult detection

	Beaver ponds			Mining ponds		
Species	Prediction	Lower limit	Upper limit	Prediction	Lower limit	Upper limit
Mallard	0.41	0.29	0.55	0.41	0.28	0.55
Ring-Necked duck	0.44	0.27	0.62	0.57	0.30	0.80
Common Goldeneye	0.54	0.24	0.82	0.65	0.48	0.79
American Wigeon	0.46	0.32	0.62	0.48	0.32	0.63
Geen-winged Teal	0.37	0.15	0.64	0.38	0.16	0.65
Hooded Merganser	0.36	0.15	0.64	0.37	0.15	0.64
Dabbling ducks	0.55	0.38	0.71	0.56	0.39	0.72
Diving ducks	0.46	0.35	0.58	0.80	0.66	0.89

(b) Brood detection

	Beaver ponds			Mining ponds		
Species	Prediction	Lower limit	Upper limit	Prediction	Lower limit	Upper limit
Mallard	0.40	0.15	0.71	0.39	0.14	0.72
Common Goldeneye	0.47	0.07	0.89	0.53	0.25	0.79
American Wigeon	0.21	0.06	0.52	0.21	0.06	0.53
Dabbling ducks	0.43	0.22	0.66	0.43	0.22	0.68