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Policy analysis

Evaluating created wetlands for bird diversity and reproductive success

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ABSTRACT

Wetland creation is a common conservation practice to mitigate biodiversity loss, caused by global wetland destruction. Despite this, there is a lack of large-scale evaluations of how created wetland characteristics and landscape context relate to bird diversity and reproductive success. We inventoried 89 created wetlands (0.2–20 ha) in central Sweden to investigate which local and landscape components were associated with breeding wetland bird species richness, pair abundance and reproductive success. Wetland size was positively associated with species richness, pair abundance and chick abundance. However, several small (1 ha) wetlands taken together were similar to or exceeded individual large wetlands of similar total wetland area, in terms of species richness, pair abundance, and chicks produced. While species richness showed a clear negative relationship with the proportion of the adjacent 50 m buffer composed of forest, pair abundance was positively related to the proportion of flooded grassland area and negatively related to the proportion of emergent water vegetation. Reproductive success measures showed no clear relationships to local habitat characteristics but tended to increase with a decreasing forest at the landscape scale. Our results suggest that breeding wetland bird populations could benefit from creating wetlands with a high flooded area, continuous management to minimise both the area of emergent water vegetation and the establishment of shrubs and trees in the immediate surroundings. We also suggest a practice of creating mainly small wetlands with a few larger ones to facilitate breeding wetland bird communities at the regional scale (gamma diversity).

1. Introduction

Wetlands are important ecosystems providing multiple ecosystem services, such as nutrient retention, water quality improvement, carbon storage, protection from flooding, food provision and recreational values (Maltby and Acreman, 2011; Zedler and Kercher, 2005). However, since the beginning of the 20th century, as many as 60–70% of all wetlands worldwide have been lost due to agricultural drainage and urbanisation (Davidson, 2014), and of those remaining, many are degraded (Zedler and Kercher, 2005). Consequently, it is suggested that the decline of wetland biodiversity is greater than that in terrestrial systems (Dudgeon et al., 2006; Millennium Ecosystem Assessment, 2005). Among avian wetland species, about 55% are declining worldwide, although large herbivorous waterbirds are increasing (BirdLife International, 2017; Wilson et al., 2005; Montràs-Janer et al., 2019; Pöysä et al., 2019). Many conservation measures to abate wetland biodiversity declines have been implemented, including wetland protection (e.g. Ramsar convention), restorations and creations (e.g. agri-environmental schemes).

Created wetlands can be efficient in promoting diversity of water plants and insects similar to that in natural wetlands (Balcombe et al., 2005; Bantilan-Smith et al., 2009; Desrochers et al., 2008; Hartzell et al., 2007). They are relatively poor, however, in promoting breeding bird community diversity relative to natural wetlands (Desrochers et al., 2008; Sebastián-González and Green, 2016; Snell-Rood and Cristol, 2003). Thus, several questions can be raised when creating wetlands for bird conservation. How can we improve breeding bird diversity when constructing wetlands for biodiversity? Are the size (cf. Sebastián-González and Green, 2016), certain constructed habitat elements and the landscape context important for attracting wetland species? How do

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these characteristics relate to reproduction?

Several studies have evaluated the relationship between environmental variables and wetland birds within created wetlands in agricultural landscapes (Choi et al., 2015; Froneman et al., 2001; Sánchez-Zapata et al., 2005; Sebastián-González et al., 2010). However, in most studies wetlands were created for other purposes than biodiversity, including rice fields, irrigation or nutrient retention ponds, and abandoned quarries (McKinstry and Anderson, 2002; Sánchez-Zapata et al., 2005; Strand and Weisner, 2013; Tourenq et al., 2001). Large-scale studies on wetlands specifically created to facilitate wetland biodiversity are lacking. Furthermore, most studies on created wetlands investigate relationships between environmental variables and species richness and abundance. The effects on reproductive success are rarely evaluated (but see McKinstry and Anderson, 2002) and the chicks may have different needs than adult birds (Nummi and Pöysä, 1993). As with many other human-modified habitats (Battin, 2004), created wetlands may attract birds to breed but provide poor breeding conditions, due to increased predation, for example, thus functioning as ecological traps (cf. Desrochers et al., 2008). Furthermore, the landscape context may affect bird communities in created wetlands (Li et al., 2019; Pérez-García et al., 2014), but little is known about this, especially so in biodiversity wetlands. We do know that landscape composition can affect nutrient supply and predator communities, causing food availability and predation rates to vary among landscape types (Lehikoinen et al., 2016; Padyšáková et al., 2011; Pavón-Jordán et al., 2017). We need to consider the landscape in addition to local habitat attributes when evaluating the effects of created wetlands on wetland bird diversity and reproductive success.

Conservation strategies of creating new habitats should also consider whether it is more beneficial to create single large or several small (SLOSS) habitat patches of the same total area, as the creation of small wetlands may be cheaper and more practical to create but less beneficial for bird species preferring large wetlands. Historically, SLOSS comparison focused on what habitat size should be prioritised for biodiversity protection, often using species richness as the primary evaluation metric (Diamond, 1975; Simberloff and Abele, 1976). Recent evidence indicates that several small habitat patches together contribute similarly or more to species richness than a single large habitat patch of the same surface area (e.g. Deane et al., 2020; Fahrig, 2020). However, the SLOSS debate regarding habitat creation or involving other diversity measures, such as abundance, has not been thoroughly previously investigated. As any conservation strategy goals ultimately also involve an increase in biodiversity productivity, one should also consider the SLOSS creation strategy regarding reproductive success.

In Sweden, considerable funds have been invested in wetland creation and restoration to reach the national environmental goal of "Thriving wetlands" (Svensson, 2015). Since 1989 more than 1000 smaller wetlands (usually <5 ha in size) have been created, the majority to facilitate wetland biodiversity (SEPA, 2019, 2009). Our research aims to investigate the knowledge gaps concerning the successful creation of wetlands for higher diversity and reproductive success of wetland birds. First, we investigated how local habitat characteristics of the created wetlands relate to wetland bird diversity (species richness and pair abundance) as well as reproductive success. Second, we examined how landscape context affects these diversity measures. Last, we investigated whether single large or several small created wetlands support more wetland bird species, higher total pair abundance and, ultimately, greater reproductive output.

2. Materials and methods

2.1. Study area

In the province of Uppland (Fig. 1), Sweden, the majority of 170 known created wetlands have been constructed to improve wetland bird diversity (Dietrichson, 2017). Most of the created wetlands in this area consist of wetlands created in terrestrial sites. However, in some instances, wetlands were created at sites that had a wetland drained and converted into arable land or conventional forest at some point in history (>50 years before, wetland recreation). This region's landscape consists of a mosaic of managed boreal forest and agricultural land, with more forest in the northeast and more agricultural land in the southwest. During the last 150 years, the forests and arable land have been drained, reducing the amount and area of existing natural wetlands (Fredriksson and Tjernberg, 1996). Still, it is a region with many natural wetlands and lakes of which most are oligotrophic and situated in coniferous forest.

We performed a stratified random wetland selection in order to keep a similar variation of local habitat characteristics (size, number of

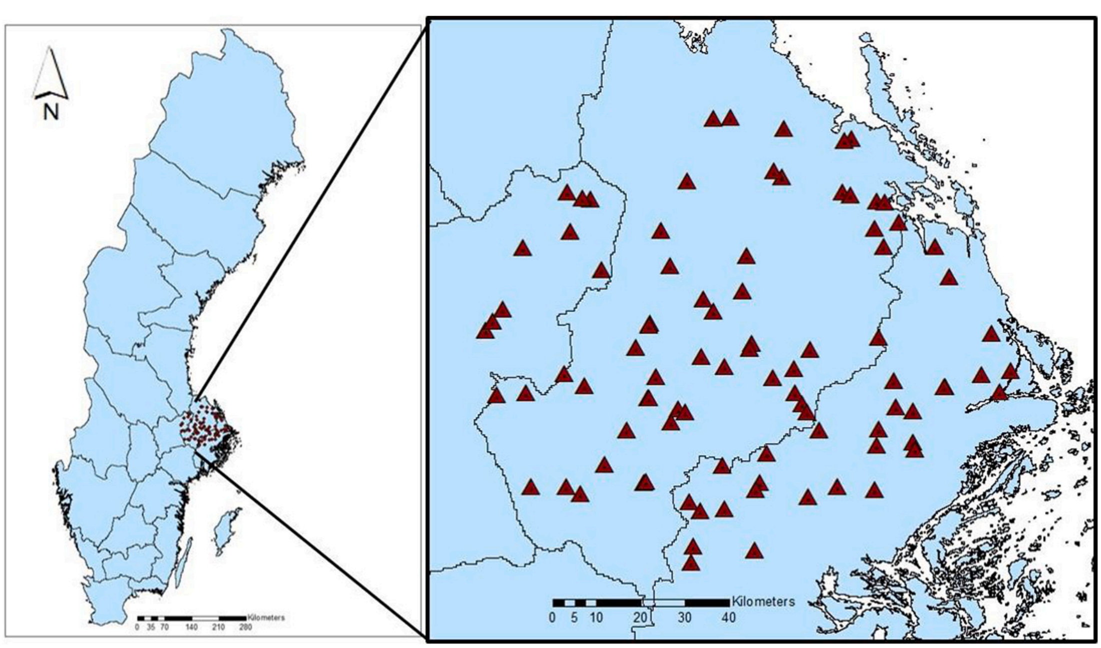

Fig. 1. The 89 surveyed created wetlands located in Uppland region (including Uppsala, and parts of Västmanland and Stockholm counties; 59°51′29″N 17°38′41″E).

separate open water bodies (ponds) within a wetland, the proximate area with forest, see Section 2.2 and Table 1) in different landscape types (forest- or agriculture-dominated: >50% and < 50% of forest respectively within 1 km buffer). Each habitat characteristic was thus equally distributed over environmental gradients. The 89 selected wetlands (Fig. 1) ranged in size between 0.14 and 20 ha; 70 wetlands were located in forest-dominated and 19 in agriculture- dominated landscapes. Most wetlands were created as single water bodies, but in 22 cases, multiple separate ponds (i.e. wetland complex) located next to each other were constructed. The wetlands also varied in depth, shape, shore steepness (though related to flooded area) and connectivity to watercourses, but these characteristics were not measured. Some wetlands have been managed by occasionally removing shrubs and aquatic plants (e.g. reed, cattail, floating vegetation), by grazing or mowing adjacent grassland, or by supplementary feeding of birds and introduced mallard chicks.

2.2. Habitat and landscape context

We collected data on local and landscape-scale characteristics known or hypothesised to affect bird diversity and reproductive success (see Appendix A1). We used ArcGIS software (v. 10.5), recent aerial photographs (2015/2017, Lantmäteriet), field notes, Swedish terrain and human population density maps (GSD Geografiska Sverigedata; Statistiska centralbyrån 2019) to estimate the area of: i) wetland surface, ii) water vegetation, iii) wooded and open islands, and within 50 m buffer from the wetland shore, iv) trees/bushes, and v) flooded grassland, as well as a count of vi) the number of ponds (see Table 1 for definitions). We also determined the presence of inflow (mainly preventing the wetland from drying out) and, within a 1 km buffer, the cover of urban area and forest (Table 1). We hypothesised that coniferous forest within the landscape could affect predator communities (Elmberg and Gunnarsson, 2007) and water quality, via acidity and lower nutrient levels than agriculture-dominated landscapes (Lehikoinen et al., 2016). The proportion of urban areas can be expected to positively and negatively affect bird communities in created wetlands. Humans may supply food and repel predators (for instance, settlements may repel mink predations, Brzeziński et al., 2012), but also increase disturbance and support a higher density of domestic predators. Last, we calculated the water area of neighbouring wetlands within a 3 km buffer because we expected bird communities in created wetlands to be influenced by dispersal and meta-community dynamics, affecting local species pool positively for some species but negatively for others (reviewed by Holopainen et al., 2015). We did not use spatial scales >3 km to avoid overlap between the sites at the landscape scale.

2.3. Bird surveys and response variables

Four standardised wetland bird inventories of the 89 created biodiversity wetlands took place during the breeding season in 2018: twice during the period when birds were settling or started breeding (14–29 May, "settlement stage"), and twice during the chick-rearing period (18 June–3 July, "reproductive stage"). The timing of the settlement stage was chosen to cover both early and late breeding species, and this is the same time period as used by the wetland bird national inventory of Sweden (Green et al., 2020). For detailed methods of the surveys, see Supporting information Appendix A2 and Table A1.

During the settlement stage, the two first visits were used to estimate species richness (hereafter ***richness***) and the number of pairs (***pair abundance***) of each breeding wetland bird species at each site. For each species, we used the maximum pair abundance (including zeroes; see Table A1 for more details of pair estimates) out of two inventories.

To determine wetland suitability for breeding wetland birds and whether created wetlands contribute to their community growth, we estimated reproductive success of a subset of 21 species for which chicks were relatively easy to detect (mainly ducks and grebes; Table A2). First, ***chick abundance*** was the highest number of chicks seen in a wetland for each species (including zeroes for species with no chicks observed). Second, ***breeding success*** was determined for each species that was observed in at least one of the first two visits, with success denoted for species that were also observed with at least one chick during the visits. This measurement was used to reflect the reproductive success of each species. Chick abundance was used to reflect wetland productivity.

2.4. Statistical analyses

2.4.1. Testing bird community associations with the environment at local and landscape scales

We used generalised linear models (GLM, GLMM when using mixed-

Table 1
Environmental variables considered having a potential influence on the wetland bird community. The variables were estimated by using the digitalised field and land use maps. Mean, standard deviations and range are presented for 89 wetlands. The *italic* variable names indicate landscape-scale variables.

Variable	Scale	Definitions	Mean ± SD (range)
Size	Local	Water surface, including emergent water vegetation (ha)	3.37 ± 3.60 (0.14–19.98)
Water vegetation	Local	Water surface covered by one or more species of emergent water vegetation (e.g. *Typha*, *Phragmites*, *Iris*, etc.) (%)	26.82 ± 23.47 (0–100)
Open islands	Local	Area of constructed islands covered by grass vegetation or bare soil (ha)	0.08 ± 0.18 (0.00–1.48)
Wooded islands	Local	Area of constructed islands that were covered with bushes and trees (ha)	0.06 ± 0.10 (0.00–0.55)
Number of ponds	Local	Number of separate created water bodies (pools) in a wetland complex	1.66 ± 1.57 (1–10)
Flooded area	Local	Adjacent grassland that can be flooded (%), defined by soil humidity and wet grassland vegetation (50 m buffer surrounding the water surface shore)	7.87 ± 10.90 (0.00–54.79)
Local forest	Local	Adjacent area with trees and bushes (%) (50 m buffer surrounding the water surface shore)	51.66 ± 29.96 (0.00–99.99)
Management	Local	Presence (yes/no) of management (grazing, mowing, shrub removal, feeding stations, water vegetation management, within wetland and 50 m buffer).	25 managed/ 74 non-managed
Year	–	Year wetland was created. When this was not known, the year interval (max five years) was assigned based on aerial photos, and the maximum year was used as an entry	2001 ± 6 (1985–2017)
Inflow	Local/ Landscape	Whether wetland is hydrologically connected (yes/no) providing water influx (ditches, streams, water pumps (latter just 2 cases)), so that water levels are less dependent on rain	38 with/ 51 without
Landscape forest	Landscape	Forest area within 1 km buffer (%) outside and extending from the 50 m buffer surrounding the shore (when the forest is <50%, the landscape is open)	63.97 ± 23.19 (0.96–100)
Urban area	Landscape	Area with at least one registered person living (100 m^2 resolution) within 1 km buffer extending from the 50 m buffer surrounding the shore (%)	4.76 ± 6.80 (0–50.94)
Neighbouring wetlands	Landscape	Area of water bodies within 3 km buffer extending from the 50 m buffer surrounding the shore (%)	4.13 ± 8.33 (0–65.43)

effects) to evaluate the relative importance of the environmental variables at local and landscape scales on two groups of response variables: two indices for bird diversity (***richness*** and ***pair abundance*** during the settlement stage), and two indices of reproductive success (***chick abundance*** and ***breeding success*** during the reproductive stage), resulting in four models in total. The models included 13 explanatory environmental variables listed in Table 1.

We modelled ***richness*** using GLM with a Poisson error distribution ($n = 89$). For ***pair abundance***, we used GLMM with negative binomial error distribution due to over-dispersion. This model contained species and wetland identities as random effects that account for different population sizes across wetlands and species. An alternative would have been to use total abundances summed over all species; however, this would result in estimates heavily driven by the most common species. Pair abundance of each species at each wetland was a single data record ($n = 3382$), including zeroes at each site where a species was not observed.

Chick abundance was modelled similarly to pair abundance using GLMM with negative binomial error distribution and species and wetland identity as random effects ($n = 462$). We included zeroes only at sites where we observed adults at the settlement stage for a species but not chicks in the reproductive stage. We included logged pair abundance from the settlement stage as an explanatory variable to account for the higher chick abundance at sites with more pairs. ***Breeding success*** was modelled using binomial GLMM, with species with chicks identified as successful and species observed as adults but without chicks as a failure ($n = 434$). The breeding success GLMM also used species and wetland identities as random effects and included logged pair abundance as an additional explanatory variable.

All explanatory variables were centred and scaled to make the coefficient estimates directly comparable. Due to data distribution heterogeneity, wetland size was logged, and both areas of wooded and open island variables were square-root transformed before scaling. We used a full model approach as we were interested in estimating and showing the effects of all variables expected to be biologically relevant (Table 1). We only removed variables due to multicollinearity. Multicollinearity among explanatory variables was evaluated using the variance inflation factor (vif), where variables with vif values >4 were removed. For a comparison to our full model approach, we also performed model averaging (MuMIn package, Bartoń, 2020) for all four responses to calculate the importance of each variable included (see Supporting Information Table A3). All analyses were done in R 3.6 (R Core Team, 2019), using package glmmTMB (Brooks et al., 2017) for all GLMMs.

2.4.2. SLOSS wetlands

We also investigated the effects of wetland size at the regional scale. First, we looked at whether cumulative species ***richness*** differed between the cumulative wetland area when combining sites in a different order: from large to small and from small to large (Quinn and Harrison, 1988). Then, to estimate the potential cumulative contribution of small wetlands to the regional wetland pair and chick abundance, we used predictions, with their uncertainties, of wetland size from GLMMs described above. We estimated the expected total ***pair abundance*** and ***chick abundance*** (but pair abundance was not included in the latter GLMM inference) for different wetland sizes (1, 5, 10, 15, 20 ha) by multiplying the predictions (and standard errors) of wetland size from GLMM models to a total of 20 ha (corresponding to the largest wetland in our sample). For instance, 1 ha pair estimate with its standard error was multiplied by 20, a 5 ha estimate by 4, etc. To represent the community level predictions, we set the random effects (species and site identity) to zero so that the predictions obtained were for an averaged species and wetlands. The rest of the environmental variables were set to their means to single-out size effects.

3. Results

In total, we observed 38 breeding wetland bird species, 1521 pairs and 2024 chicks at the surveyed 89 created wetlands. The most common species were mallard *Anas platyrhynchos* (218 pairs), common coot *Fulica atra* (197) and common goldeneye *Bucephala clangula* (94), see Table A2 for details.

3.1. Local habitat

Both species richness and pair abundance were much higher in large than small created wetlands (Figs. 2a, 3a–b, Table A3), and wetland size explained considerably more variation than other environmental variables. Variation in richness and pair abundance showed similar associations with local wetland characteristics (Fig. 2a, Fig. A1, Table A3). Pair abundance was associated with several local habitat characteristics: positively with proportion of flooded area (Fig. 3c-d, Table A3) and negatively with the proportion of water vegetation (Fig. 3g). Additionally, species richness showed a clear negative association with local forest (Figs. 2a, 3f, Table A3). Neither richness nor pair abundance showed clear relationships with other local characteristics such as islands, the number of ponds within the wetland, water inflow or absence of management (but see the negative tendency for local forest Fig. 3e; and management Fig. 3h).

Reproductive success measures showed no clear relationships with local habitat characteristics (Figs. 2b, A2, Table A3) except for wetland size which positively associated with chick abundance (Fig. 4c). Reproductive success measures were explained mainly by pair abundance (Figs. 2b, 4a–b).

3.2. Landscape context

Richness and pair abundance were not distinctly related to surrounding landscape variables (Figs. 2a, A1, Table A3). Reproductive success was not clearly related to landscape context, although breeding success tended to associate negatively with the landscape forest (Fig. 4d, Table A3). Overall, the results between our full model and the model averaging are relatively similar; see Table A3 in supporting information for details of model averaging results.

3.3. SLOSS wetlands

Locally, larger wetlands hold more species than small wetlands. However, at the regional scale, the cumulative species richness of several small wetlands (e.g. <1 ha) was similar to that of a single large when representing the same accumulated wetland area as species accumulation curves overlap (Fig. 5). Although several small wetlands together had seven species more than the largest wetland (i.e. 20 ha), overall, the cumulative species richness of the smallest wetlands were similar to the large ones. Predicted pair abundance for multiple sites making up a total of 20 ha was also similar in several small compared to a large wetland, though the difference was 0.5 pair higher in smaller wetlands (Fig. 6a, that is for an average species in an average wetland, see Section 2.4.2). In contrast, predicted total chick abundance was distinctly higher (~25 chicks) for several small compared to single large created wetlands when comparing the same created area (Fig. 6b, that is, for average species in an average wetland, see also Fig. A3c).

4. Discussion

Many countries are experiencing vast wetland destruction (Davidson, 2014) and new wetland creation to mitigate habitat loss is accelerating (Niu et al., 2012). Our results suggest how to improve wetland creation for wetland birds in the Northern hemisphere and highlight the importance of including measures of reproductive success and a landscape perspective in wetland creation evaluations. Richness and pair abundance were associated with several local characteristics (e.g. proportion of flooded area, local forest and water vegetation), whereas we found no distinct relationship with surrounding landscape characteristics. In contrast, variation in reproductive success showed fewer

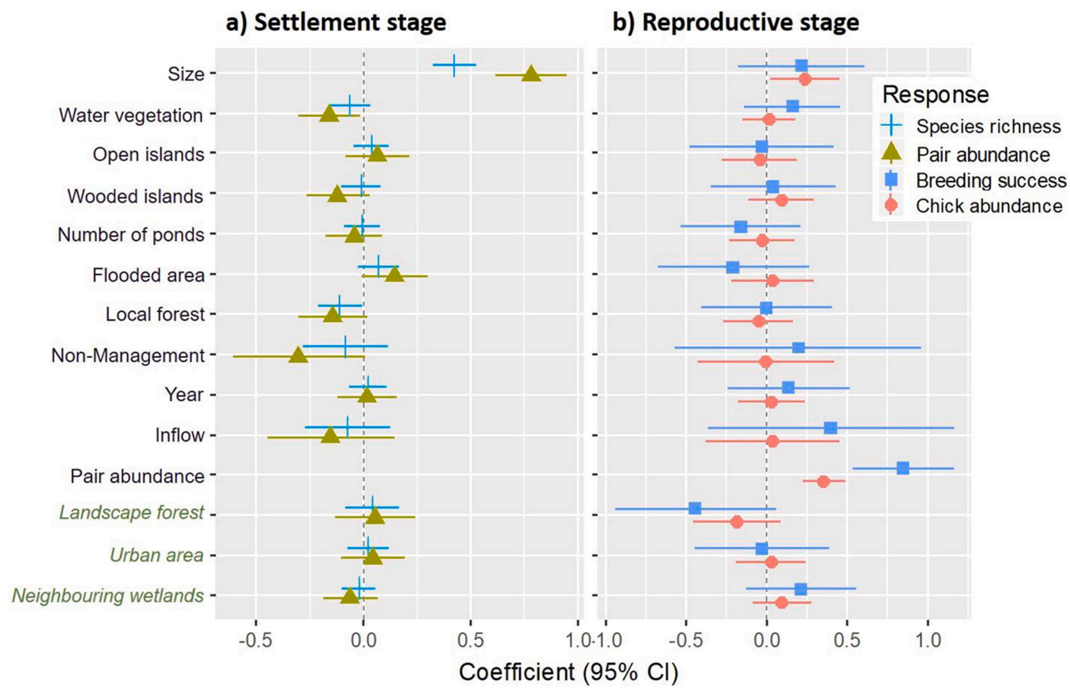

Fig. 2. Model coefficients and confidence intervals from models explaining variation in a) species richness and pair abundance, b) breeding success and chick abundance across 89 created wetlands of 38 species (21 for reproductive success). The coefficients are directly comparable (all predictors were centred and scaled; size and pair abundance were also log- and islands square-root-transformed). Predictors not considered have no estimates (see Table 1 for descriptions of environmental variables). Green italic variable names indicate landscape-scale variables. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

associations with local characteristics but tended to associate with the landscape context (e.g. forest at the landscape scale). We detected a strong positive effect of wetland size on local richness, pair and chick abundances, but no effect on breeding success measure. Still, several small wetlands can have similar breeding bird diversity and higher chick abundance as a single large wetland at a regional scale.

4.1. Local habitat

The positive relationships between richness and pair abundance with wetland area are in line with island biogeography theory and with previous findings on bird diversity in created wetlands (Froneman et al., 2001; Sánchez-Zapata et al., 2005; Sebastián-González et al., 2010; Sebastián-González and Green, 2014; Strand and Weisner, 2013). Wetland size was also related to chick abundance, but not with breeding success when pair abundance was included in the model. Very few studies have related wetland bird reproduction to the size of created wetlands (but see McKinstry and Anderson, 2002), but in natural systems, the size-reproductive success relationship is species-dependent (review by Holopainen et al., 2015). Any measure to improve wetland biodiversity should also aim to facilitate wetland bird reproductive success, but we often lack such information.

Our findings, as well as previous studies including natural wetlands, suggest flooded areas to be important when creating wetlands as they provide suitable foraging habitat, especially for waders and ducks (Milsom et al., 2002; Smart et al., 2006; Żmihorski et al., 2016). Flooded areas could also indicate the wetland's general shallowness, which benefits non-diving wetland species, but puts diving species at a possible disadvantage (reviewed by Ma et al., 2010). Additionally, high wetland bird abundance in flooded wetlands might be due to increased wetland productivity and habitat heterogeneity, which is especially important for wetlands within the boreal forest (where water conditions are usually oligotrophic, Nummi and Holopainen, 2014).

Prior research suggested that cover of emergent water vegetation benefits several breeding wetland bird species (Ma et al., 2010; McKinstry and Anderson, 2002; Sebastián-González et al., 2010), but our results contradict these findings (see Fig. 3g). The negative effects of water vegetation may reflect a decreased detection probability, as water vegetation may obscure visibility. It may also decrease the amount of foraging habitat for dabbling and diving birds (e.g. many duck species, grebes; reviewed by Ma et al., 2010). On the other hand, emergent water vegetation can offer good foraging and nesting opportunities as well as protection from predators for some species (Froneman et al., 2001; McKinstry and Anderson, 2002; Sebastián-González et al., 2010). The effects of water vegetation on the attraction of wetland birds are complex and likely differ between bird species and foraging guilds. Based on the knowledge from natural lakes in boreal forests, it seems to depend more on structural complexity than the coverage (Holopainen et al., 2015).

Additionally, species richness was also negatively related to the proportion of local forest. The negative relationship could be attributed to that trees and shrubs provide perching spots for avian predators, such as corvids (Holopainen et al., 2015), thus reducing the potential for high reproductive success and could therefore be avoided by some birds (Berg et al., 1992; Wallander et al., 2006). However, it could also be related to that bordering forest could reduce water nutrient levels (Licht, 1992), and thus the food availability.

It has been suggested that open islands may be important nesting habitats for several wetland bird species, including gulls, terns and ducks (Väänänen et al., 2016). Although some species were breeding on the islands, we found no distinct evidence for such effects of the whole wetland bird community on either settlement or reproductive stages. Reproductive success measures showed no simple relationships with local habitat characteristics except for chick abundance in relation to wetland size. The breeding pair density is one of the most important factors determining the higher chick abundance and breeding success of the wetland bird community in created wetlands.

The use of reproductive data is important when evaluating created

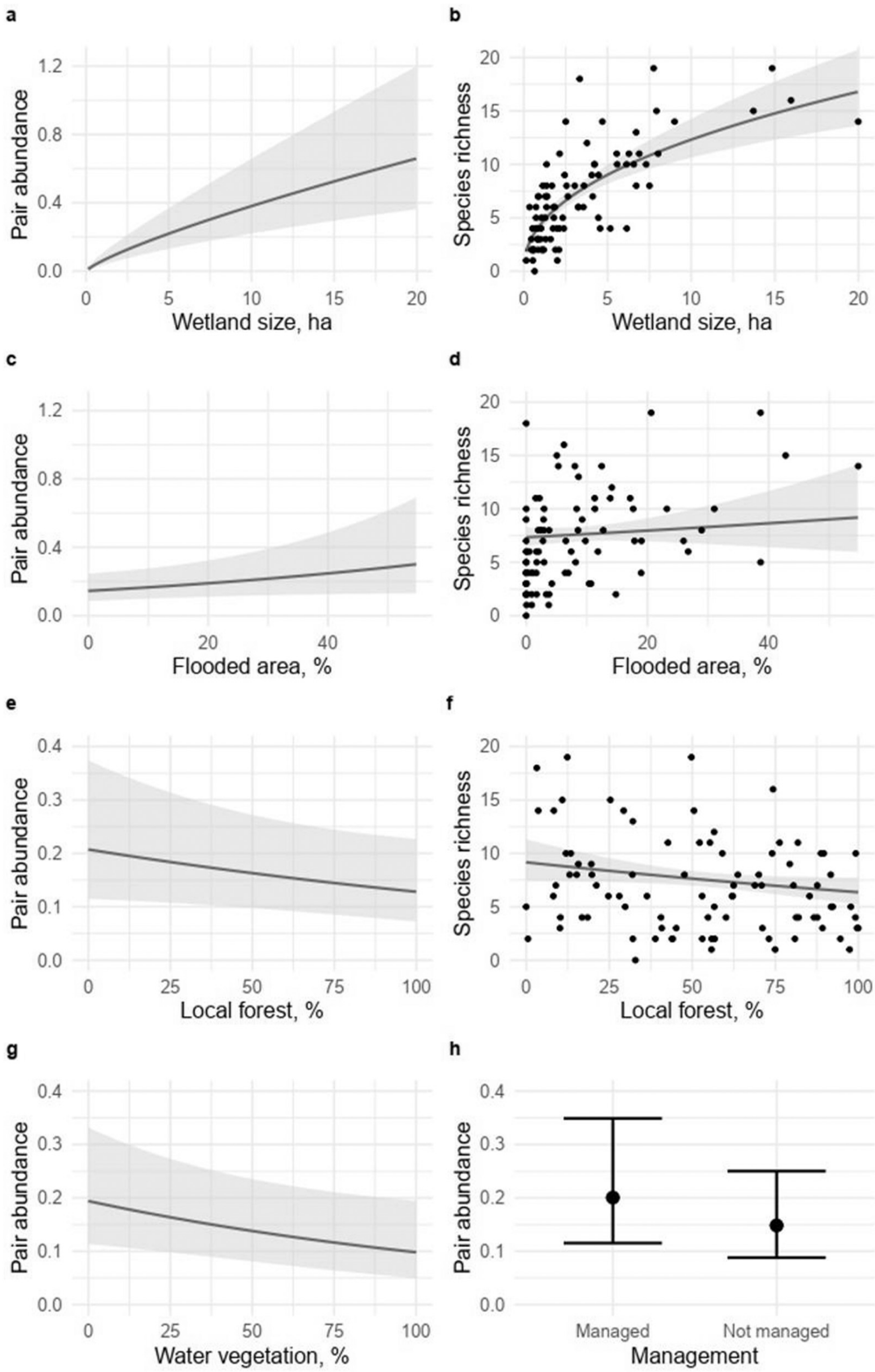

Fig. 3. Wetland bird species richness (right column, b, d, f) and pair abundance (a, c, e, g, h) in relation to selected characteristics of created wetlands as predicted by models summarised in Fig. 2a (shaded area shows 95% CIs). Black dots represent raw data points. The random effects (species and site identity) were set to zero, and the rest of the environmental variables were set to their means.

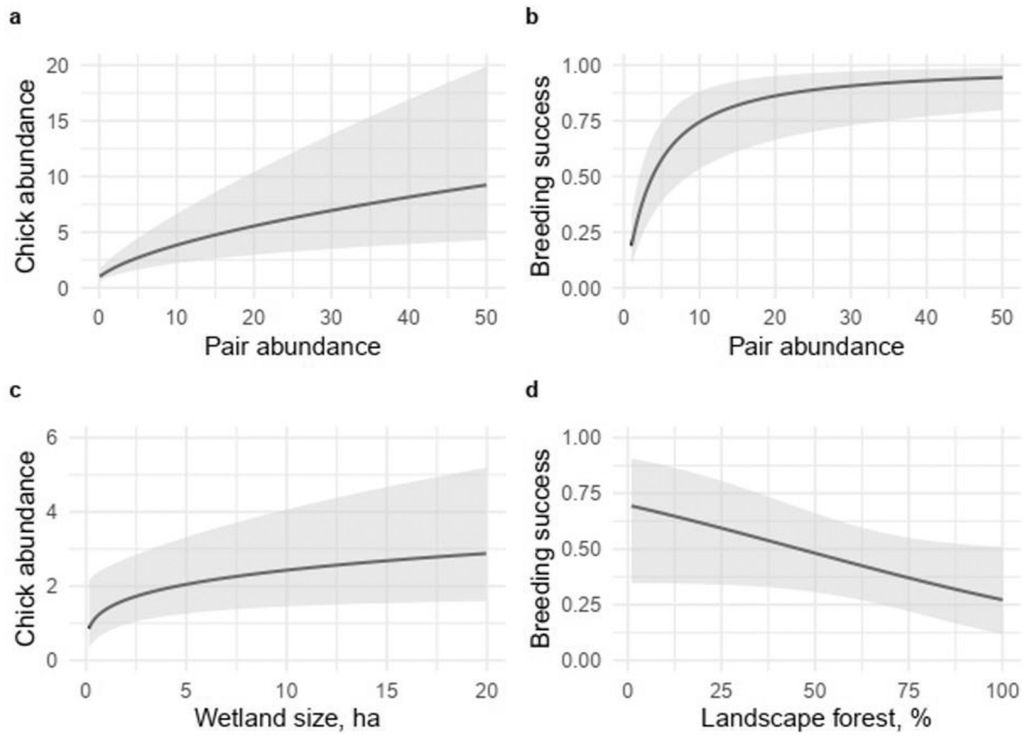

Fig. 4. Chick abundance (left column, a, c) and breeding success (right column, b, d) in relation to selected characteristics of created wetlands as predicted by models summarised in Fig. 2b (shaded area shows 95% CIs). The random effects (species and site identity) were set to zero, and the rest of the environmental variables were set to their means.

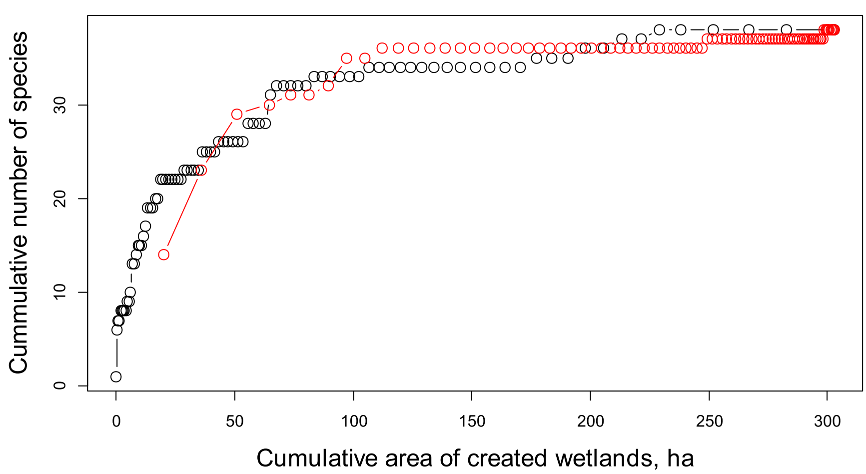

Fig. 5. Species accumulation plot (Quinn-Harrison curve) showing cumulative species richness as a function of cumulative area of created wetlands included. Black circles indicate accumulation direction from smallest to largest wetland, while red - from largest to smallest. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

wetlands, as high pair but low chick abundance could indicate an ecological trap mediated by human-modified habitats (Battin, 2004). Even though there were differences between the observed habitat-bird diversity relationships and habitat-reproductive success relationships, we did not find an indication that created wetlands might act as ecological traps. On the other hand, some species may move their chicks from the wetland of nesting to a wetland where the chicks are reared (e.g. goldeneyes, Paasivaara and Pöysä, 2008; even grebes Kloskowski and Frączek, 2017), thus adding some uncertainty to our estimates of local wetland bird diversity and reproductive success. However, wetlands with many broods and chicks should still represent high-quality wetlands for chick-rearing irrespective of the chick origin. Thus, chick movements do not change our general interpretations of what constitutes a good or bad wetland for reproductive success.

4.2. Landscape context

We found no distinct relationships between surrounding landscape characteristics and species richness or pair abundance at the settlement stage. This is surprising, as landscape context has been shown to relate with wetland birds in natural systems (Holopainen et al., 2015; Pavón-Jordán et al., 2017). Although the relationship between bird diversity and landscape context may vary between the spatial scales used, our general result of no clear relationship likely applies also at different

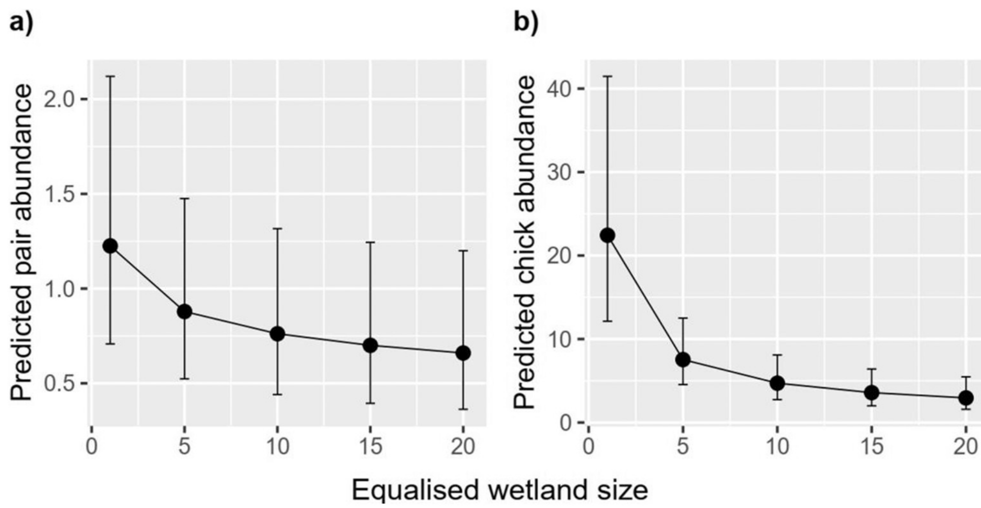

Fig. 6. Comparison of estimated effects of single large or several small wetlands on the abundance of pairs and chicks for multiple wetlands of different sizes, making up a total of 20 ha. The predicted pair (a) and (b) chick abundance when controlling for species and site identity and environmental variables (but not controlling for pair abundance in the analyses of chick abundance). Error bars refer to 95% confidence intervals.

spatial scales, as these are highly correlated ($r > 0.73$ for the three landscape types between one and three-kilometre buffers). However, landscape composition might be important for explaining reproductive success estimates. Though highly uncertain in our full models, and not statistically clear, the proportion of forest within the landscape showed the strongest support among the environmental variables, suggesting a possibly negative effect on reproductive success (see Fig. 2b). Predation pressure is unlikely to be higher in forest dominated landscapes (Holopainen et al., 2020). The most likely explanation, however, could be the lower food availability in oligotrophic wetlands (which are usually found in coniferous forest-dominated landscapes) than in eutrophic wetlands, which are generally located in agricultural landscapes (Holopainen et al., 2015; Pöysä et al., 2001). However, with this paper's analysis, we intended to explore what variables might affect breeding bird community and infer productivity in created wetlands. To establish more definitive evidence of ecological effects on such communities, further studies, preferably experiments, are required.

4.3. SLOSS wetlands

A recent review including 157 studies focusing on SLOSS comparisons showed that most studies suggest several small habitat patches support greater total species richness than single large patches (Fahrig, 2020; see also Deane et al., 2020). One reason for this pattern could be biased sampling, where a higher sampling effort per unit area is exerted in small than large habitat patches (Gavish et al., 2012). Nevertheless, the results of studies with unbiased sampling effort (75 studies) still showed more species in several small than a single large habitat patch (52% of studies) while the other studies were inconclusive (37%) or supported single large over several small (11% of studies, Fahrig, 2020). Our SLOSS comparisons were also based on unbiased sampling (i.e. with a similar sampling effort/ha; see Section 2.3 and Supporting information A2). Our species accumulation curves crossed each other (Fig. 5) thus suggesting inconclusive results concerning SLOSS comparison on species richness (sensu Fahrig, 2020). Thus, scenarios of single large or several small created wetlands of the same total area would likely produce similar gamma diversity between both scenarios.

In addition to species richness, we also compared abundance measures between SLOSS wetlands, a biodiversity indicator usually not tackled in previous SLOSS research. We estimated pair and chick abundances based on model predictions that were adjusted to match the same total created wetland area (20 ha). While there was no apparent difference concerning pair abundance, results on chick abundance suggested that the creation of several small wetlands (1 ha) would be better than a single large equalling the same total wetland area (Fig. 6). One potential reason for this pattern could be that small wetlands have a higher shore/area-ratio with relatively more shore habitats in small compared to large wetlands. This habitat structure benefits many dabbling ducks and waders (Eriksson, 1983; Nilsson, 1986). Though a single large wetland has higher wetland bird diversity, a strategy of creating several small wetlands instead of a single large one is supported for reproductive success (at the community level) at the regional scale. Here a practical issue also comes into play concerning the uptake of landowners. As small wetlands are cheaper, easier to create, and do not require as much land as large ones (e.g. 20 ha), the uptake of creating small wetlands is higher among most landowners (as seen in the sizes of created wetlands in our study area). Furthermore, several species are known to be more common in small as compared to natural large inland wetlands (e.g. little grebe *Tachybaptus ruficollis*, moorhen *Gallinula chloropus*, Ottosson et al., 2012), although other species show preferences for larger wetlands (Black-throated loon *Gavia arctica* or Great crested grebe *Podiceps cristatus,* e.g. piscivores Nilsson, 1986). Thus, to benefit the wetland bird community at a regional scale, creating a mixture between many small and few large wetlands would be a good solution.

4.4. Conclusions

As small as they are, most of the created wetlands contribute to the regional species pool, i.e. gamma diversity, and are valuable for wetland bird conservation. In this region, 87% of the 45 regularly breeding inland wetland species (excluding passerines; Ottosson et al., 2012) were observed at our sites and many bred successfully. Out of these, four species are in the European red list (Slavonian grebe *Podiceps auritus*, Pochard *Aythya ferina*, Northern lapwing *Vanellus vanellus,* and coot) and 14 are in decline (Table A2). Overall, our results are in line with the general recommendations (see Appendix A1) for wetland creation for birds, for instance, by constructing low shoreline (to increase the area flooded), managing water vegetation so that wetlands do not become fully covered and reducing the cover of adjacent shrubs/trees. The use of reproductive success measures enabled us to detect the potential importance of the landscape context (i.e. coniferous forest within the landscape tended to reduce reproductive success). Although further research on landscape context is needed for clear conclusions, we suggest that future wetland creations should consider avoiding the surrounding coniferous forest within the landscape as a precautionary strategy. Lastly, our SLOSS comparison showed that while a single large wetland exhibited similar species richness and pair abundance levels compared with several smaller, the total production of young remained higher in multiple smaller wetlands at the regional scale. When resources for creating wetlands are limited, we therefore recommend creating several predominantly small wetlands over fewer and larger ones, especially in landscapes where large natural wetlands are already available.

CRediT authorship contribution statement

Ineta Kačergytė: Conceptualization, Methodology, Software, Data curation, Formal analysis, Writing- Original draft preparation, Visualization, Investigation, Writing- Reviewing and Editing.
Tomas Pärt:. Conceptualization, Methodology, Investigation, Funding acquisition, Writing- Original draft preparation, Writing- Reviewing and Editing.
Debora Arlt: Conceptualization, Methodology, Writing- Reviewing and Editing.
Åke Berg: Conceptualization, Methodology, Investigation, Writing- Reviewing and Editing.
Michał Żmihorski: Conceptualization, Methodology, Software, Writing- Reviewing and Editing.
Jonas Knape: Methodology, Software, Writing- Reviewing and Editing, Writing- Reviewing and Editing.
Zuzanna M. Rosin: Investigation, Writing- Reviewing and Editing.

Data availability

The data used in our analysis are available in an online repository https://snd.gu.se/en/catalogue/study/2021-90.

Declaration of competing interest

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

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Appendix A. Supplementary data

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