



Quantifying effects of wetland restorations on bird communities in agricultural landscapes

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ABSTRACT

Restoring wetlands to improve habitats for birds has become an important conservation tool as many wetlands have deteriorated and wetland bird populations declined. To what extent such restorations are effective is not well known because surveys usually either lack data before the restoration or means of correcting for background population trends. We identified wetland restorations made in agricultural landscapes in Sweden and retrieved all available Before-After survey data of breeding birds. From the resulting heterogeneous surveys, we quantified the effectiveness of restorations for eight bird groups comprising 72 bird species from 30 wetlands. We used national survey data to correct for background population trends. We estimated that island breeder populations have increased by between 62 % and 315 % (95 % confidence intervals) following restorations. Deep water foragers, shallow water foragers and short meadow breeders also mainly increased following restoration. The direction of effect was uncertain for tall meadow breeders, reed breeders and predators. Shrubland breeder populations declined between –55 % and –4 % following restorations. While restoration measures seemed to generally benefit about half of the breeding wetland bird community, estimated species- and site-specific responses varied greatly and were associated with large uncertainty. Such heterogeneity in responses can arise due to biotic and abiotic interactions, varying management actions and survey methods between wetlands. Thus, to improve the effectiveness of future wetland restorations, funding bodies and environmental agencies should require standardised Before-After bird surveys at both restored and non-restored reference sites. Such improved survey designs would facilitate the development of more efficient restoration efforts.

1. Introduction

Ongoing land-use changes and water management have led to the loss of more than half of wetlands worldwide (Davidson, 2014; Smart et al., 2006; Zedler and Kercher, 2005). Many remaining natural wetlands, including protected ones, are deteriorating (Davidson, 2014) or modified for human needs (Zhang et al., 2021), possibly making most of the wetland ecosystems degraded to some degree (Zedler and Kercher, 2005). Wetland destruction and degradation are directly linked to overall wetland biodiversity loss, with wetland bird decline as perhaps the best documented (IUCN, 2022; Wang et al., 2021). Hence, conservation measures are often targeted directly at supporting bird diversity via wetland protection and restoration of habitats (BirdLife International, 2017; Ma et al., 2010; Pöysä et al., 2019a). Consequently, a

considerable investment is being put into restoring wetlands to halt biodiversity loss (BirdLife International, 2017; Fan et al., 2021; Svensson, 2015). The restoration efforts seem to be particularly important for shallow eutrophic lakes situated in agricultural landscapes (henceforth referred to as agricultural wetlands). The excess of nutrients and lack of management speeds up the succession and overgrowth of emergent water plants, such as reeds *Phragmites*, and the establishment of shrubs, such as *Salix* spp., and trees, such as alder *Alnus* spp., all of which affect a large part of the wetland bird community (e.g. Lehikoinen et al., 2017). Although significant funds are placed in wetland restoration programs for birds, the effects of these interventions are understudied (Lehikoinen et al., 2017).

Evaluating the effectiveness of wetland restorations is challenging as experimental studies are often impractical, and observational

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approaches may need to be employed. Evaluations comparing restored and non-degraded wetlands (Control-Impact studies) have shown that restored wetlands can have levels of bird diversity similar to those of non-degraded wetlands (Fan et al., 2021; Sebastián-González and Green, 2016; Sievers et al., 2018). However, conclusions drawn from such evaluations may be biased due to inherent differences between reference sites and restored sites, unrelated to the restoration itself (Josefsson et al., 2020; Sievers et al., 2018). For instance, wetlands prioritised for restoration might have a high potential for rich biodiversity and might have had higher biodiversity than reference wetlands before the restoration was initiated. Before and After restoration biodiversity surveys could help alleviate these issues, but such studies are few, and most lack control sites (Bregnballe et al., 2014; Hellström and Berg, 2001; Hickman, 1994; Lehtikoinen et al., 2017). Without appropriate controls, Before-After studies are vulnerable to background trends and other variations in biodiversity that are unrelated to restoration effects (Chevalier et al., 2019; Underwood, 1992). Only a handful of studies have combined Before-After and Control-Impact data to disentangle restoration effects from other variation, and these usually compare only one control with one impact site (Raposa, 2008; Rochlin et al., 2012; see also Fox et al., 2020; Mazerolle et al., 2006).

To improve our understanding of the effectiveness of wetland restoration for bird communities, we gathered available Before-After survey data from 30 wetland restorations across Swedish agricultural landscapes between years 1969–2016. We estimated the population change for 72 bird species of eight distinct groups, in which the species were expected to respond similarly to restoration measures. The species groups broadly link species habitat requirements to various restoration measures applied (Tables 1, S1): island breeders, deep water foragers, shallow water foragers, short meadow breeders, tall meadow breeders, reed breeders, shrubland breeders and predators. Both the restoration measures and the methods and effort of the surveys varied considerably between species and wetlands. This created multiple data handling challenges that were partially solved with meta-analyses tools. We investigated how effective wetland restoration measures have been by estimating the percentage change in abundance from before to after restoration and used national bird monitoring data to adjust for background trends, which have been substantial for some wetland species in Sweden (Lindström et al., 2020).

2. Methods

2.1. Data collection

Sweden has no database containing information about wetland restorations for biodiversity. Therefore, we focused on finding restored agricultural wetlands (i.e. shallow eutrophic lakes in agricultural landscapes) as these species-rich eutrophic wetlands have been the focus of most wetland restorations actions in Sweden. Thus, we did not consider mires, peat bogs and oligotrophic forest wetlands. To aid the identification and listing of all wetland restorations performed from the 1970s and onwards, we compiled a list of >300 agricultural wetlands with >1000 bird observations made between 2005 and 2015 according to the Swedish Species Observation System (Artportalen, 2016). During 2015–2017, we contacted all Swedish county boards, municipalities (when county boards suggested so), local birding clubs and some well-known bird experts to determine whether and how these agricultural wetlands had been restored for birds. Additionally, we inquired whether bird surveys had been performed Before and After the restoration(s). The collected information included: when and where restoration actions had been done, type of restoration and management, and when bird inventories had been performed concerning restoration (see Appendix S1). Using all these sources of information, we are confident to have acquired data from almost all agricultural wetland restorations made between the late 1970s and 2015 in Sweden (those covered mainly southern Sweden, see Fig. S1).

2.2. Wetland restorations

We found 123 restored agricultural wetlands, out of which 91 had bird surveys following the restoration (Figs. 1, S1). Out of these, only about every third (35 wetlands) had Before-After restoration surveys. Four of these wetlands had bird surveys at different spatially separated sites within the same large wetland or wetland system. These were treated as separate sites as restoration years or restoration measures differed, making observations rather independent. This resulted in 40 sites, but two were excluded because there were long gaps between surveys Before and After the restoration (>12 years apart between the last survey before and the first survey after restorations, where the average was 3.94 ± 0.94 (95 % confidence interval) years). Two additional sites were excluded due to spatial overlap, and at two more sites where surveys included migratory birds in their estimates. Hence, we used 34 sites (Fig. S1, Table S1) for further analyses to estimate the effects of wetland restorations.

Of the restorations aimed at improving bird diversity in our sample of wetlands, the earliest took place in the early 1980s (e.g. wetlands Angarnsjöängen, Kvismaren, Hornborgarjön), and their numbers accelerated in the 1990s. In terms of bird habitat, the reasons behind wetland degradation were related to increased vegetation growth due to vegetation succession, increased input of agricultural nutrients, and reduced or abandoned management of wet meadows. Therefore, restorations usually involve several major measures (Table S1):

- i Hydrological modifications, which included increased or regulated water levels to restore spring/autumn flooding regimes ('Hydrology', applied at 15 sites out of 34);
- ii Cutting or complete removal of emergent water vegetation, mainly reed *Phragmites australis*, cattail *Typha latifolia* and sedge *Cyperaceae*, which increased the amount of open water surface and open shorelines ('Reed removal', 21 sites);
- iii Clearing, cutting and managing open wet meadows surrounding the wetland, where tussocks, tall grasses ('Tussock removal', 23 sites), shrubs and trees ('Shrub removal', 29 sites) were removed. Most of those wet meadows received long-term grassland management involving 'Grazing' (28 sites), 'Mowing' (10 sites) or prescribed 'Burning' (4 sites; all specific measures summarised as 'Grassland management', total 33 sites).

The spatial extent of restorations varied between wetlands (especially concerning grassland and reed treatments). In most cases, the spatial extent of restoration measures was the same as for the area of breeding bird inventories (Table S2). However, at 11 sites, it was not possible to estimate the proportion of the area that had been restored because of ambiguities of what should be classified as a restored area (e.g. creating/restoring islets for breeding terns) or because the precise descriptions of restoration areas were lacking (e.g. concerning which parts of the wetland were cleared of reeds or shrubs). Similarly, restorations varied in time; some were finished in one year while others continued for years. When restoration took several years to finish, we defined all bird surveys as "Before" when performed before the first year of restoration and "After" when performed after the last year of restoration (excluding the surveys in intermediate years).

2.3. Bird surveys

All wetland inventory data were based on standard survey protocols (e.g. point counts, line transects, territory mapping), and all surveys were done between April and early July. However, the standard bird survey methods varied among the wetland sites considered, while the survey method was kept constant for both 'Before' and 'After' periods within each wetland. Most common methods included repeated territory mapping and nest counts across the whole wetland and adjacent wet meadows, while in some wetlands, transects and point counts were used

Table 1

The columns of the table show species groups, lists of species within each group, explanations of expected responses to restorations, red-list status and species population trends in Europe (IUCN, 2022). Additionally, we present the number of times species were observed only After Restoration (Species gains) or Before Restoration (Species losses, excluded from the magnitude of population change analyses). No number indicates any such case.

Group	Species	Explanation	Status ^a	Trend ^b	Gains	Losses		
Island breeders	Black-headed gull	Bird species that use open water to forage, some also use the surrounding grasslands/arable land to forage and some breed on islands. Expected to benefit from restoration of the whole wetland and surrounding grasslands and island creation.	LC	-	3	1		
	<i>Chroicocephalus ridibundus</i>		LC	?	2			
	Little gull <i>Hydrocoloeus minutus</i>		LC	?	2	1		
	Common gull <i>Larus canus</i>		LC	-				
	European herring gull <i>Larus argentatus</i>		LC	?	6	1		
	Common tern <i>Sterna hirundo</i>		LC	?	4	1		
	Black tern <i>Chlidonias niger</i>		LC	0	3	2		
	Deep water foragers		Little grebe <i>Tachybaptus ruficollis</i>	Bird species that dive when foraging. Expected to benefit from removal of emergent water vegetation and modifications of hydrological conditions.	LC	0	3	2
	Black-necked grebe <i>Podiceps nigricollis</i>		VU		-	1	1	
	Slavonian grebe <i>Podiceps auritus</i>		NT		-	2	1	
Red-necked grebe <i>Podiceps grisegena</i>	VU	-	2					
Great crested grebe <i>Podiceps cristatus</i>	LC	0	2					
Great cormorant	LC	+	1					
<i>Phalacrocorax carbo</i>								
Common pochard <i>Aythya ferina</i>	VU	-	1					
Tufted duck <i>Aythya fuligula</i>	NT	-	2		1			
Common goldeneye	LC	-	1					
<i>Bucephala clangula</i>								
Red-breasted merganser	NT	-						
<i>Mergus serrator</i>								
Common merganser <i>Mergus merganser</i>	LC	+	1					
Osprey <i>Pandion haliaetus</i>	LC	+						
Eurasian coot <i>Fulica atra</i>	NT	-	3					
Shallow water foragers	Grey heron <i>Ardea cinerea</i>	Bird species that forage in shallow open waters, though some tolerate floating water vegetation. Expected to benefit from removal of shrubs and emergent water vegetation.	LC	-	1			
	Mute swan <i>Cygnus olor</i>		LC	+	1	1		
	Whooper swan <i>Cygnus cygnus</i>		LC	+	1	1		
	Common shelduck <i>Tadorna tadorna</i>		LC	0	1			
	Eurasian wigeon <i>Mareca penelope</i>		LC	-	1	1		
	Gadwall <i>Mareca strepera</i>		LC	+	3			
	Eurasian teal <i>Anas crecca</i>		LC	+	2	4		
	Mallard <i>Anas platyrhynchos</i>		LC	-				
	Northern pintail <i>Anas acuta</i>		VU	-	1	1		
	Garganey <i>Spatula querquedula</i>		LC	-	3	1		
Northern shoveler <i>Spatula clypeata</i>	LC	-	3	1				
Short meadow breeders	Greylag goose <i>Anser anser</i>	Bird species that need intensively managed grasslands, flooded areas, and moist soil. Expected to benefit from more intensive grassland management, shrub/tree removal, emergent water vegetation removal, and restored wetland hydrology.	LC	+	3			
	Canada goose <i>Branta canadensis</i>		LC	+	3			
	Eurasian oystercatcher		VU	-		1		
	<i>Haematopus ostralegus</i>							
	Pied avocet <i>Recurvirostra avosetta</i>		LC	-				
	Little ringed plover		LC	-	5			
	<i>Charadrius dubius</i>							
	Common ringed plover		LC	+	1	2		
	<i>Charadrius hiaticula</i>							
	Northern lapwing <i>Vanellus vanellus</i>		VU	-	3			
Dunlin <i>Calidris alpina</i>	LC	?						
Common redshank <i>Tringa totanus</i>	VU	-	4					
Common sandpiper <i>Actitis hypoleucos</i>	LC	-	2					
Meadow pipit <i>Anthus pratensis</i>	LC	-						
Yellow Wagtail <i>Motacilla flava</i>	LC	-		1				
Tall meadow breeders	Corn crane <i>Crex crex</i>	Bird species that prefer unmanaged or less intensively managed grasslands. Expected to benefit from shrub/tree removal and less intensive grassland management.	LC	0	1	1		
	Ruff <i>Calidris pugnax</i>		NT	-		3		
			VU	-				

(continued on next page)

Table 1 (continued)

Group	Species	Explanation	Status ^a	Trend ^a	Gains	Losses		
Reed breeders	Common snipe <i>Gallinago gallinago</i>	Bird species that breed/forage mainly within emergent water vegetation. Expected not to benefit from wetland restorations, especially when including emergent water vegetation removal.						
	Black-tailed godwit <i>Limosa limosa</i>		NT	0	1	1		
	Eurasian curlew <i>Numenius arquata</i>		NT	–	1	3		
	Whinchat <i>Saxicola rubetra</i>		LC	–				
	Eurasian bittern <i>Botaurus stellaris</i>		LC	0	1	2		
	Common moorhen <i>Gallinula chloropus</i>		LC	-	2			
	Water rail <i>Rallus aquaticus</i>		LC	?	3			
	Spotted crane <i>Porzana porzana</i>		LC	-	3			
	Common crane <i>Grus grus</i>		LC	+	4			
	Savi's warbler <i>Locustella luscinioides</i>		LC	?	1	2		
	Eurasian reed warbler <i>Acrocephalus scirpaceus</i>		LC	0				
	Great reed warbler <i>Acrocephalus arundinaceus</i>		LC	0	1	1		
	Bearded reedling <i>Panurus biarmicus</i>		LC	+				
	Predators		Marsh harrier <i>Circus aeruginosus</i>	Birds of prey and owls that may benefit from clearing of shrubs/trees and introduced grassland management, as these species hunt in the vicinity of wetlands.	LC	0		
			Hen harrier <i>Circus cyaneus</i>		LC	–		1
Montagu's harrier <i>Circus pygargus</i>		LC	-			1		
Eurasian hobby <i>Falco subbuteo</i>		LC	0					
Common kestrel <i>Falco tinnunculus</i>		LC	–		1			
Long-eared owl <i>Asio otus</i>		LC	?		2			
Short-eared owl <i>Asio flammeus</i>		LC	0					
Shrubland breeders		Thrush nightingale <i>Luscinia luscinia</i>	A mixed group of species, but all of them need bushes/trees for nesting or foraging. Expected not to benefit from wetland restorations, especially when including shrub/tree removal.		LC	+		
		Common grasshopper warbler <i>Locustella naevia</i>			LC	-		1
		River warbler <i>Locustella fluviatilis</i>			LC	-	1	
	Sedge warbler <i>Acrocephalus schoenobaenus</i>	LC		0		2		
	Marsh warbler <i>Acrocephalus palustris</i>	LC		?	1			
	Eurasian penduline tit <i>Remiz pendulinus</i>	LC		+	1			
	Common rosefinch <i>Carpodacus erythrinus</i>	LC		–		1		
	Common reed bunting <i>Emberiza schoeniclus</i>	LC		–				

^a Status and trends information obtained from IUCN Red List (IUCN, 2022) of threatened species for European level status: LC – Least Concern, NT – Near Threatened, VU – Vulnerable; trends: “-” – decreasing; “+” – increasing, “0” – stable and “?” – unknown population trends.

(e.g. along shores and within the surrounding wet meadows; Table S2). In general, most surveys estimated the number of breeding pairs, but in two sites, number of broods (only for geese) was counted. Additionally, the area and time spent surveying varied among sites but not between single survey events within the same year and wetland. However, number of inventories per year varied for a few sites, but there was no obvious bias in relation to Before or After restoration. Thus, such variation should not have systematically affected variability in Before-After estimates, but rather the variance around the estimates. In general, at least two and a maximum of 12 inventories were made to estimate the abundances within a year (henceforth surveys; Table S2).

The 34 wetland sites had a varying number of Before-After restoration surveys. The number of years surveyed varied from two (one Before and one After restoration) to 47 survey years in a time series. On average, wetlands had three Before and five After restoration surveys. Such surveys were often not conducted in consecutive years, and a time gap between surveys was frequent.

Most surveys did not include the whole wetland bird community, and

the species selected for inventories differed between sites. Therefore, the number of sites varied greatly for each species analysed. We separated the wetland bird community into eight distinct groups (Table 1) based on their major habitat preferences for foraging and breeding because we expected those species to respond similarly to restoration measures. The groups largely represented taxonomy and guilds and were island breeders (gulls, terns), deep water foragers (diving ducks, grebes), shallow water foragers (dabbling ducks), short meadow breeders (small waders), tall meadow breeders (larger waders), reed breeders (warblers, rails), shrubland breeders (songbirds) and predators (owls, raptors).

2.4. Restoration effects on bird abundances

We analysed changes in species abundances of the eight species groups linked to the timing of the restoration. We performed two sets of analyses. First, we made an overview of the direction of population change. In this comparison, we included all available Before-After data, including species absent in all Before or After restoration inventories, i.e.

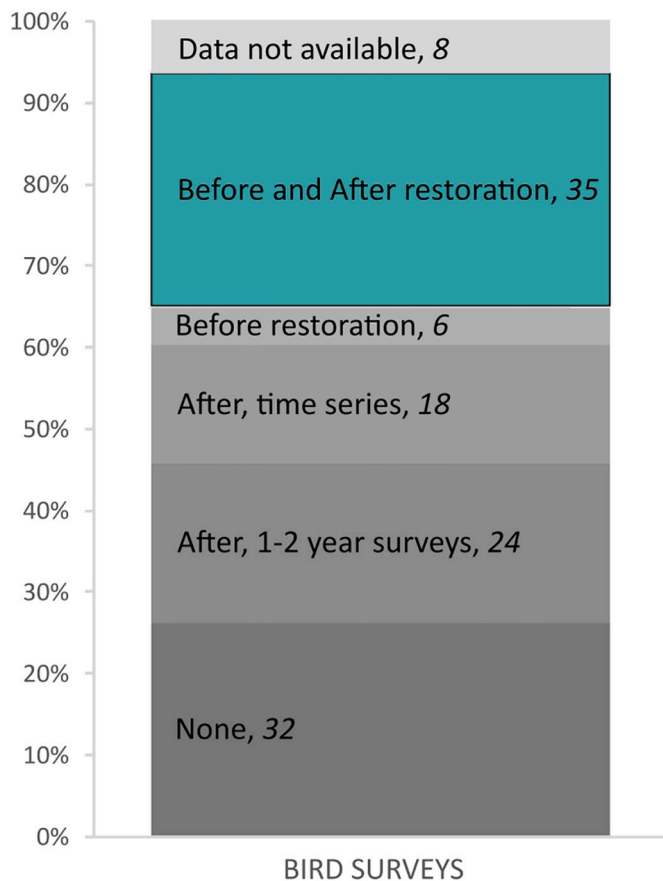


Fig. 1. The types of data available for the identified 123 restored wetlands. No bird surveys were conducted at about every 4th restored wetland ('None'). Wetland data with less than three years of bird surveys following the restoration are denoted as 'After, 1–2 year,' with at least three years as 'After, time series'. 'Before restoration' for wetlands where bird surveys were conducted only Before restoration. If at least one Before and After restoration survey was done, the type of data is denoted as 'Before and After'. 'Data not available' for wetlands where bird inventories were not publically available.

species that had not been observed during surveys either Before or After the restoration. Second, we quantified the magnitude of change (%) which could, however, only be done for species that were present both Before and After the restorations, i.e. we excluded species with mean zero abundance Before or After the restorations (see below), as we wanted to quantify the proportional change in abundance.

2.4.1. Direction of population change

To get an overview of the direction of change in bird abundance despite the variation in the number of years surveyed and in survey methodology, we simply compared average bird abundances Before and After restoration. This allowed us to use all available Before-After data for 72 species and 34 sites (30 wetlands), 675 site-species combinations in total. We determined whether average abundance increased, decreased, or did not change (abundance Before = After) from Before to After restoration for each species and wetland restoration. Note that this overview only compares abundances between Before and After restoration and does not correct for general large-scale population changes. It is well known that some wetland species, particularly large grazing birds, have increased strongly in the last few decades, while others have decreased. Hence, the directional changes do not necessarily indicate a response to restoration for all species or wetlands but could instead reflect trends due to other factors. This will be considered in [Section 2.4.3.](#)

2.4.2. Magnitude of relative population change

To handle the highly heterogeneous inventories across sites, due to varying methods, effort, timing and set of species, we used a two-step approach to quantify the magnitude of change in abundance from Before to After restorations. We first analysed abundance for each site and species separately to extract coherent and comparable estimates of the response to restoration. We then analysed the resulting estimates using a meta-analysis model to get the groups' mean estimates. To estimate species- and site-specific changes in abundance (effect sizes) in the first step, we used the number of pairs, individuals or broods as a response in a generalised linear model (GLM) using a single factor with two levels representing the period Before or After restoration. Since the data were composed of counts, we used a negative binomial response distribution with a log-link when possible and Poisson when the negative binomial gave boundary estimates for the overdispersion parameter (theta values exceeding 1000, Table S3). As two data points are insufficient to estimate dispersion, we only included 507 site-species combinations with at least three surveys (one Before and two After or two Before and one After). Next, we extracted a log response ratio and its uncertainty from the negative binomial or Poisson model fit. The log response ratio was computed from the contrast between the Before and After levels at the log scale and represents the logarithmic change in the mean of the abundance between the two periods from Before to After restoration. It estimates relative population change from Before to After a restoration. Because we used the logarithmic change, we had to exclude surveys for sites and species combinations with no species observations (i.e. only zeroes) Before or After the restoration. This meant that we had to additionally exclude 140 species-site combinations, which were 98 apparent species gains (species not observed Before restoration, 15 % of species-site combinations) and 42 losses (species not observed After restoration, 6 %), for which the calculation of logarithmic relative change was not possible, but see the end of this section for a sensitivity check of this exclusion. After omitting sites with too few surveys and remaining species gains and losses, this resulted in 25 sites and 66 species (367 unique species-sites combinations and hence models) left for the following analyses of relative change in abundance.

We pooled the 367 restoration effect sizes obtained from the GLMs above in a second analysis step to estimate the mean effect sizes of wetland restorations for bird groups sharing similar habitat preferences for foraging and breeding ([Table 1](#)). We used the random-effects meta-analyses model from the Metafor package ([Viechtbauer, 2010](#)) with site, species, and site by species as random effects and with group as a fixed factor with eight levels ([Table 1](#)):

$$BA_{ij} = b_{g(j)} + v_i + v_j + v_{ij} + SE_{ij} \varepsilon_{ij} \quad (1)$$

here, BA_{ij} is the estimated effect size of a change between bird numbers from Before to After restoration (log response ratio) at site i and for species j , $b_{g(j)}$ is a fixed effect for the group g that species j belongs to, i.e. the joint effect sizes of the groups, v_i is a random site effect, v_j is a random species effect, v_{ij} is a random species by site effect. SE_{ij} is the estimated standard error of the effect size BA_{ij} retrieved from the negative binomial (or Poisson) model, and ε_{ij} is a random residual error term with a standard deviation equal to one.

Exclusion of apparent species gains and losses could potentially lead to a biased view of the effects of restoration. To investigate if it had consequences for the estimates, we additionally analysed the data using a $\log(x + 1)$ transformation, which enabled the inclusion of species gains and losses ([Appendix S2](#)). However, the effect sizes from $\log(x + 1)$ transformed data do not have a straightforward interpretation regarding the magnitude of change. Thus this analysis is presented only as a check of sensitivity. The results are qualitatively similar and follow the generally observed pattern (see below and [Appendix S2](#)).

2.4.3. Controlling for background trends

The above analysis estimates the magnitude of change from Before to

After restoration without controlling for background trends in abundance. To take background trends into account, we used the Swedish Bird Survey (SBS, Lindström et al., 2020; see Jellesmark et al., 2021 for a similar approach). For each wetland and species, we extracted count data from all SBS routes for the same years covered by the bird surveys of restored wetlands (see Appendix S3 for details). However, several species did not have enough data (Table S3). Additionally, we wanted to reduce the possibility that our national estimates were influenced by wetland restorations, thus, we removed SBS routes that were in the proximity of the restored wetland used for the analyses (overlapping defined SBS grid cells). This caused the final sample size to decrease to 328 species-site combinations (62 species).

We used a similar two-step approach and first estimated the background change in abundance corresponding to each restored site and species separately and then combined the estimates in meta-analysis models. To estimate species- and site-specific background changes, we, for each of the 328 species-site combinations, fitted a negative binomial or Poisson GLM to all extracted route counts for that combination to obtain estimates of background change from the survey data. In these models, we included a factor with a level for each of the Before-After periods of the restored wetland. The survey route identity was included as a fixed effect to account for variation in abundance among routes. We then estimated the log change in abundance from the Before to After restoration period in the national bird survey data and its standard error. In this way, for each restored site and species, we obtained a corresponding estimate of background change from the SBS data covering the same time period. The background change represents a national scale change and does not reflect potential regional differences in population changes as the number of routes generally was too small for a more refined analysis.

We contrasted the estimated background changes to the changes estimated in the restored wetlands. Formally, we did this in two ways. First, we simply compared the group effect sizes estimated from the restored wetlands to those from the national survey, as derived from the model in Eq. (1). Second, we fitted the model in Eq. (1) to the differences between restored wetlands and the national survey in their species-site-specific effect sizes $Diff_{ij}$, hence replacing BA_{ij} by $Diff_{ij}$. In this case, we used the square root of the sum of the squared standard errors for the restored wetland effects and the national survey effects as the estimate of uncertainty, SE_{ij} , of the difference in effect size (this is the standard error of the difference in effect size under the assumption that effect sizes of the national survey and the restorations are independent). The results from the model fitted to the difference in effect size can be viewed as a contrast providing an estimate of the restoration effect adjusted for the background trend.

2.4.4. Species-specific effects

We looked at the species-specific effects in more detail. For that, we have analysed each species group with the meta-analyses method separately, but keeping sites and species nested in sites as random effects and with species identity as a fixed factor.

2.4.5. Effectiveness of specific restoration measures

We also tried to compare the specific restoration measures' effectiveness. Here we were interested in separating which of the restoration measures were more effective for which species groups. For this, we only used contrasted effect sizes and compared the species group abundance change following the restoration across wetlands with and without a specific restoration measure (Appendix S4). We investigated this for only four specific measures (which do not coincide with the major measures, see Section 2.2) for which it was possible to compare wetland with and without the application of the measure.

2.4.6. Effects of the area restored

We investigated the approximated restored area effects on mean species group abundance change. However, only 16 out of the 25 sites

were used to estimate the restoration extent effectiveness as the area restored was not known for all the sites (Table S2, Appendix S5).

All analyses were done in R 4.1.2 (R Core Team, 2021).

3. Results

3.1. Direction of change

After wetland restorations, the direction of change of wetland bird abundances was positive in 382 cases out of the 675 unique species-site combinations, negative in 236 cases, and there was no change in 57 cases (Fig. 2). There was a high proportion of increases for island breeders, shallow water foragers, short meadow breeders and reed breeders (at least 60 %, Table 2). For deep water foragers, tall meadow breeders and predators, there were more variable patterns, although half of the species showed slightly more increases than decreases (Fig. 2). The shrubland breeders mainly decreased (Fig. 2, Table 2).

3.2. Magnitude of change

Without adjusting for national bird population trends, four species groups showed increases in abundances of an average between 43 % and 95 %, including island breeders, deep water foragers, shallow water foragers, and short meadow breeders (Fig. 3, Table 2). However, the confidence intervals slightly overlapped zero for short meadow breeders. For tall meadow breeders, reed breeders and predators, the restoration effect was not clearly positive or negative, while shrubland breeders showed a clear decrease in abundance following the restoration (Fig. 3; Table 2). After accounting for the national bird population trends, the estimates were overall similar (but not identical) to the unadjusted estimates (Fig. 3). Notably, for island breeders, deep water foragers and short meadow breeders, population increases following the restoration appeared stronger when accounting for the national background trends, while for shallow water foragers, the increase appeared smaller (Fig. 3, Table 2).

The effect sizes for species varied greatly between sites, making the overall predictions of the response magnitude for species or species groups rather wide. Overall, the individual species and site estimates were heterogeneous (Table S4). This was manifested in that the site by species random effects explained 59 % of the variation (heterogeneity statistic I^2) with a standard deviation in the log response ratio of 0.7. The random site effects explained 18 % of the variation with a standard deviation of 0.38. The species random effects accounted for only 4 %, with a standard deviation of 0.17. Despite the heterogeneity and uncertainty in species and site-specific responses, some species still showed clear changes in abundances following the restoration (e.g. red-necked grebe *Podiceps grisegena*, common redshank *Tringa totanus*; Fig. S2).

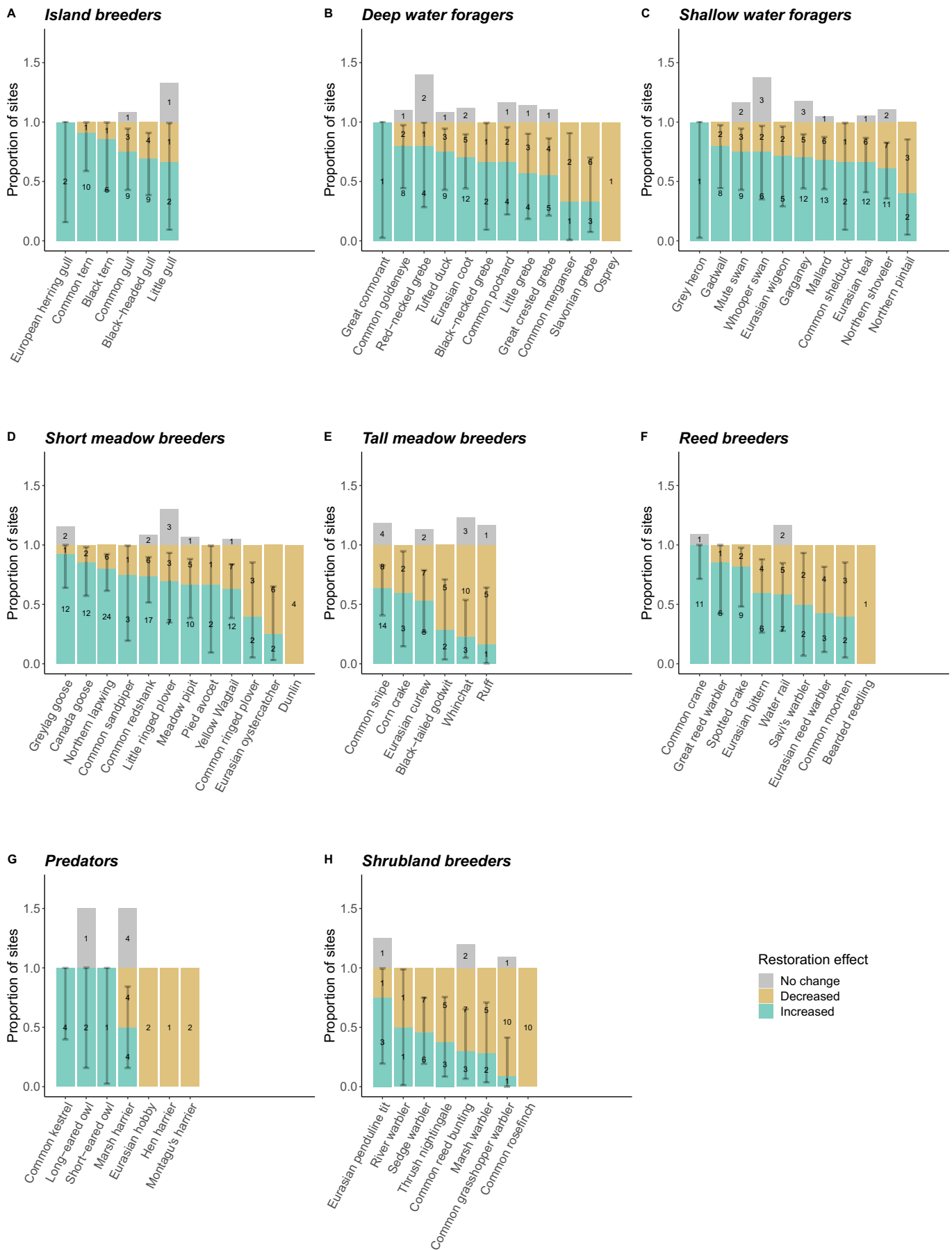
3.3. Effectiveness of specific restoration measures and area restored

Finally, we investigated the effectiveness of several applied restoration measures. We did not find much apparent difference in species population changes following restoration between wetlands with or without specific restoration measures (Appendix S4). The only clear effects were that short meadow breeder populations decreased at sites at which tussocks were managed (Appendix S4, Fig. S4), while deep water forager populations increased after wetland hydrology was restored. We did not detect clear effect of the area restored on the relative change in bird numbers, except for positive relationships with the deep water forager group (Appendix S5, Fig. S5).

4. Discussion

4.1. Quantified bird population responses to wetland restorations

Bird species of conservation concern can be sustained mainly in



(caption on next page)

Fig. 2. The proportion of Increases (electric blue bars) and Decreases (orange bars) among sites that changed in their observed mean from Before to After restoration for each species. On top of these proportions, grey bars indicate sites with no observed change in abundance (Before = After). All observed species and site combinations are shown ($n = 675$ combinations) except for one case of Red-breasted merganser, whose population did not change. Numbers indicate the number of sites with changes in the direction corresponding to the bar's colour. The Exact Binomial Test was used to calculate confidence intervals for the proportions of Increases. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2

Restoration success in percentages for each species group. The second column shows the estimated directional change as a percentage of sites with positive population change following the restoration, in parentheses giving the number of sites with positive change out of the total number of all sites. The third column shows the magnitude of change, estimated from changes in species abundance from Before to After restoration (pooled from meta-analysis model BAIj coefficient and confidence intervals transformed to %). The fourth column shows the estimated magnitude of change when controlling for background changes in abundance using SBS dataset.

Group	Direction of change	Magnitude of change	
	% of species-site combinations with positive change in mean abundance (x out of y)	% increase from Before to After restoration (lower, upper CI)	% increase from Before to After Restoration (CI) after accounting for SBS
Island breeders	76 (38 out of 50)	95 (8; 249)	159 (62; 315)
Deep water foragers	56 (53 out of 95)	59 (4; 143)	108 (46; 196)
Shallow water foragers	62 (81 out of 130)	66 (9; 151)	42 (0; 100)
Short meadow breeders	66 (103 out of 157)	43 (−1; 106)	52 (15; 101)
Tall meadow breeders	40 (31 out of 78)	−16 (−50; 40)	−4 (−34; 38)
Reed breeders	65 (46 out of 71)	−7 (−43; 52)	−2 (−39; 57)
Predators	44 (11 out of 25)	6 (−50; 123)	−3 (−48; 81)
Shrubland breeders	28 (19 out of 69)	−38 (−61; 0)	−34 (−55; −4)
Total	57 (382 out of 675)	24 (−1; 55)	32 (5; 67)

natural wetlands (Wang et al., 2021), with natural flooding regimes and high wetness limiting vegetation succession toward shrubs and forests. However, habitat degradation occurs in almost all wetlands (Zedler and Kercher, 2005), making wetland restorations one of the most important conservation tools to halt wetland biodiversity loss. Evaluating and quantifying restoration effects are crucial for improving restoration measures for species, such as birds in our study. The majority (95 %) of studies focusing on the effects of wetland modifications on biodiversity use Control-Impact designs (Sievers et al., 2018) which, in an unknown number of cases, may be biased due to inherent differences between reference sites and restored sites. Here, the use of Before-After surveys and accounting for the national population trends provides an unbiased evaluation of whether wetland restorations fulfil our desired biodiversity goals.

According to our results, half of the bird species groups showed a clear positive response to wetland restorations. The strongest restoration effects manifested among island breeders, short meadow breeders and deep water foragers. Shallow water foragers also showed a mainly positive response. This increase in bird abundance supports wetland restorations as an important conservation tool for wetland birds. The exception from this was shrubland breeders, which declined 4–55 % following wetland restoration. Clearly, as for all conservation measures changing breeding habitats, some species benefit at the cost of other species.

Several species among the island breeders (gulls and terns) are in decline (Table 1). The strong estimated increase in this group suggests

that restorations are generally effective (95 % confidence interval of estimated increase ranged from 62 % to 315 %). Other wetland species may also benefit from an increase in island breeders because some colonial species have mobbing behaviour guarding against predators (Pöysä et al., 2019b). The increase for deep water foragers (mainly diving ducks, grebes) was estimated to be between 46 % and 196 %, and the effect on shallow water foragers (mainly dabbling ducks, swans) was between 0 % and 100 %. This is generally in line with previous research that also suggests that diving and dabbling ducks benefit from wetland restorations (Bregnballe et al., 2014; Lehikoinen et al., 2017), although several piscivorous species have been reported to suffer from some restoration measures, such as removal of water vegetation (Lehikoinen et al., 2017). Because high eutrophication levels can increase the successional overgrowth of agricultural wetlands, which might cause waterfowl population declines (Lehikoinen et al., 2016), restoring open water surfaces by removing emergent wetland vegetation to create open water surfaces and open shores for foraging could improve breeding waterfowl populations as suggested by our data.

Short meadow breeder (geese, waders, ground foraging passerines) abundances were estimated to have increased by between 15 % and 101 %, a possible outcome from continuous grazing to restore wet grassland, which was part of the schemes for most sites. These species have previously been reported to respond well to wetland restorations, where restored seasonal flooding and introduced grazing create a mosaic of short grass and open mud patches suitable for nesting and foraging (Eglington et al., 2008; Lehikoinen et al., 2017; Žmihorski et al., 2016; but see Breeuwer et al., 2009). Another group of meadow breeders that are among the focus species of wetland restoration are tall meadow breeders, including red-listed Eurasian curlew *Numenius arquata* and Black-tailed godwit *Limosa limosa*, but this group showed an unclear direction of population change following wetland restorations (95 % CI ranging from −34 % to 38 % change). A similar lack of evidence for restoration success of Black-tailed godwit and Ruff *Calidris pugnax* has been reported elsewhere (Breeuwer et al., 2009; Bregnballe et al., 2014; but see Hellström and Berg, 2001). However, it is possible that due to restoration efforts, the otherwise negative population declines of such species were not as severe as they would have been otherwise (Jellessmark et al., 2021). Considering that some of the tall meadow breeders showed 34 % population declines, restoration measures and/or alternative conservation measures to benefit these species need to be further evaluated and improved. However, these estimates should be taken with care, as the sample size was small due to the rarity of these species.

Like the tall meadow breeders, reed breeders (rallids, warblers) and predators (raptors, owls) showed no clear response direction, with the mean reed breeder effect size ranging between 39 % decline to 57 % increase. Such inconclusive effects of restoration have been drawn in previous research, although restorations often reduce their habitat (Lehikoinen et al., 2017). Predators are not restricted to wetlands, need large areas for foraging and breeding, and may be more limited by other actors. Consequently, predators might show unclear responses to wetland restorations.

While overgrowth is detrimental to many wetland species, it increases the amount of habitat suitable for the shrubland breeding birds (songbirds, finches, Hellström and Berg, 2001; Žmihorski et al., 2016). In line with some studies (Hellström and Berg, 2001) and the fact that many wetland restorations included removing trees and shrubs, shrubland breeders showed a 4–55 % decline following the implementation of restoration measures. In contrast, a study in Finland with similar restoration measures showed no clear response of passerines to wetland

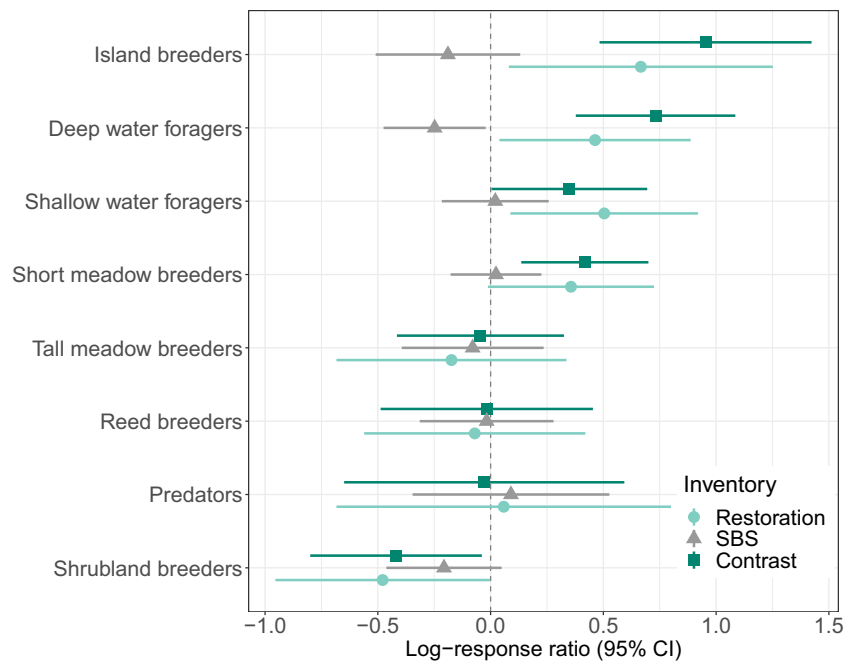


Fig. 3. Mean species group (see Tables 1–2) abundance change (log response ratio) from three analyses: based on Before-After inventories in restored wetlands, for national background data from the Swedish Bird Survey (summer point count data; SBS), and analysing the contrast effect when the bird population trends from the national survey were subtracted from the restored wetland data (based on Eq. (1)).

restoration (Lehikoinen et al., 2017). As the passerines in that study included species from both our reed breeder and our shrubland breeder groups, the difference is possibly due to the different groupings of species. The negative restoration effects on shrubland breeders at the restored wetlands might, however, not affect the general population trends of those species as long as there are other suitable habitats for parts of their populations in restored wetlands and the surrounding landscape.

4.2. Variation in effect sizes

Despite gathering all available Before-After data from the restored wetlands in agricultural landscapes, our estimates of restoration effectiveness are associated with considerable uncertainty. The magnitude of the restoration effect varied greatly from site to site within species, with two-thirds of the effect size heterogeneity attributable to the random interaction between species and site. Therefore, the effectiveness of any particular restoration made in wetlands is hard to predict from our results. Possible general reasons for this heterogeneity are attributable to the variation in type and extent of restoration measures, pre-restoration conditions, species interactions, and sampling and survey designs.

Variation in sampling and survey designs could lead to heterogeneity in effect sizes, for instance, due to variation in the effort, detection probabilities, area covered (e.g. Ruete et al., 2020), timing of surveys relative to restoration, and due to small sample sizes (Lajeunesse, 2015). Any such variation not fully captured by our model for effect size estimation would inflate the heterogeneity component. Further, the lack of control sites for investigating the effectiveness of wetland restorations meant that we had to use national bird survey data to derive background trends. If such national trend estimates do not properly capture background trends relevant for the restoration sites, the estimated effect sizes will be confounded with incorrect trends.

Heterogeneity could also arise due to variation in the restoration measures taken, the scale at which they are applied at a given wetland, the environmental conditions of the wetland, and the responses by specific species associated with these factors. To better understand such mechanisms that can explain when, why and for which species a certain

restoration action is effective is of primary interest from a conservation perspective. However, the issues with variation in sampling and study design severely complicate attempts to identify these mechanisms, as we had almost no variation to investigate the independent effects of different restoration measures. The potential for wetland restoration is still high even in countries with a high restoration uptake, such as Sweden (Graversgaard et al., 2021), and worldwide restoration actions are likely to increase in the future. Thus, these identified limitations beg the question of how studies of the effectiveness of restoration may be improved in the future for cost-effective conservation. We suggest that major improvements could be made if funding bodies allocate money for and condition restoration funding on Before-After surveys in the restored wetland and similar control sites (a Before-After-Control-Impact design). Such designs will be most effective when several control sites are used (Underwood, 1992), but still, even a single control site per restored wetland will help contrast changes after restoration against background variation. In particular for future meta-analyses of effects of wetland restorations. Furthermore, standardised protocols for documenting restoration efforts together with improved survey guidelines, including spatially-explicit inventories such as territory mapping and point counts to estimate the effectiveness of specific restoration measures on bird populations (e.g. Žmihorski et al., 2016), would contribute to more efficient learning about the effectiveness of wetland restorations.

4.3. Conclusions and policy implications

Our results suggest that restorations of wetlands in agricultural landscapes have, in general, improved conditions for birds at risk from wetland habitat degradation, thus, conservation actions seemed to have been successful, at least locally. Therefore, the current restoration measures and management strategies, including restoration of water, marsh and the surrounding wet meadows, are suitable for the majority of wetland birds. However, ongoing declines in some wetland species suggest that improvements in restoration strategies may be necessary to avoid further reductions in wetland bird diversity. We argue that an essential tool for this would be to monitor the outcomes of restoration

efforts more efficiently. As only detailed knowledge can help tune future restoration actions, we emphasise the need for environmental agencies and other funding bodies to, in addition to supporting the management actions themselves, provide support, clear guidelines and requirements for monitoring the outcomes of wetland restoration actions. Such monitoring should include Before-After surveys at restored sites and at reference sites.

Data availability statement

Data available from the SND Repository <https://doi.org/10.5878/7nx7-ds35>. The SBS (Lindström et al., 2020) dataset is available at GBIF doi:10.15468/2aajk9.

CRedit authorship contribution statement

IK: Conceptualization, Methodology, Formal analysis, Writing - Original Draft, Writing - Review & Editing, Visualization. **TP:** Conceptualization, Methodology, Investigation, Data Curation, Writing - Review & Editing, Project administration, Funding acquisition. **ÅB:** Methodology, Data Curation, Writing - Review & Editing. **DA:** Methodology, Writing - Review & Editing. **MŽ:** Writing - Review & Editing. **JK:** Conceptualization, Methodology, Formal analysis, Writing - Review & Editing.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.biocon.2022.109676>.

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