Can water table restoration in drained peatlands contribute to improving the population status of Eurasian teal *Anas crecca*?

Anthony David Fox[1], Philippe Frankard[2], Andreas Lindén[3],
Tuomas Seimola[3], Robert Hughes[4,5], Meelis Leivits[6]

[1] Department of Ecoscience, Aarhus Universitet, Aarhus, Denmark
[2] Service Public de Wallonie, Direction de la Nature et de l'Eau, Robertville, Belgium
[3] Natural Resources Institute Finland (Luke), Helsinki, Finland
[4] Environmental Research Institute, University of the Highlands and Islands, Thurso, UK
[5] Centre for Conservation Science, Royal Society for the Protection of Birds (RSPB) Scotland, Inverness, UK
[6] Estonian Environment Agency, Nigula Nature Centre, Reinu village, Estonia

SUMMARY

The Eurasian teal (*Anas crecca*, hereafter "teal"), a small dabbling duck that breeds across temperate Eurasia and winters farther south, numbers about 670,000 wintering birds in northwest Europe and is an important huntable species. Despite regionally increasing numbers of wintering birds, the European Commission is working to identify key actions to address threats to this species because of its recent classification as "Decreasing" in the EU due to breeding declines in parts of Europe. Teal population dynamics are largely driven by reproductive output rather than by small changes in annual survival. Hence, key actions to increase the extent of highly productive breeding habitats can potentially make a vital contribution to restoring teal to a more favourable population status. Nesting teal thrive on peatlands and acidic wetlands, so peatland restoration can potentially contribute to increased breeding abundance. Results from a literature review and key case studies showed that rewetting and ditch blocking to restore cut-over and drained peatlands for other purposes also attracts nesting teal or significantly increases their local breeding abundance, likely by creating suitable brood rearing habitats that provide abundant invertebrate prey. Results suggest that ditch blocking and associated high shoreline-to-open-water ratios may support higher breeding densities than large blocks of open water. Given the alignment of peatland restoration with EU environmental policies to reduce greenhouse gas emissions, such projects, supported by funding programmes, create favourable conditions for breeding teal by expanding shallow water areas and invertebrate populations. Despite abundant evidence for such effects, further research and especially monitoring are needed to optimise peatland restoration practices for the benefit of teal and other species.

KEY WORDS: breeding ducks, brood rearing, ditch blockage, invertebrate abundance, mire rewetting

INTRODUCTION

The Eurasian green-winged teal (hereafter "teal") *Anas crecca crecca* is among the smallest of northern hemisphere dabbling ducks, breeding throughout temperate Eurasia at the latitudinal range 38–71 °N from 23 °W in Iceland to 169 °W in Chukotka Far East Russia, and wintering further south (Johnson *et al.* 2020). The global population of *Anas crecca* is thought to number about 7.3 million individuals, some 4.3 million of which occur in Eurasia (Johnson *et al.* 2020). Around 670,000 of these overwinter in northwest Europe where numbers have apparently been increasing over the shorter (2009–2018) and longer (1967–2018) periods of monitoring (Nagy & Langendoen 2020) and where the species is an important huntable quarry species, especially on the wintering grounds (Guillemain & Elmberg 2014). The teal is listed in Annex II of the European Union (EU) Birds Directive (European Union 2009), permitting its hunting under national legislation but requiring Member States to ensure that the hunting of these species does not jeopardise conservation efforts in their distribution area. The teal was also one of 42 non-secure Annex II taxa in the 27 EU states whose long- and/or short-term population trend status was classified as "Decreasing" based on a review of available information from the 2013–2018 Article 12 reporting round under the Birds Directive (European Commission 2020a). This is partly due to declines in the numbers of extralimital breeding records in lowland south and west Europe between the 1980s and 2013–2017 (EBBA 2024). Within Britain and especially in Ireland, the species has also shown contractions in geographical breeding range since the 1970s (especially in lowland *versus* more upland areas where occupancy has stayed constant; BTO 2024). In Finland the abundance of breeding teal has declined in the long (-26 % over 39 years) and short term (-24 % over ten years; Piha *et al.* 2024). Because of such signs of falling breeding numbers and contraction of range in a huntable species, the European Commission initiated a process to identify key actions to address habitat and non-habitat related pressures and threats to Annex II of the EU Birds Directive (i.e. huntable) migratory bird species which were judged to have non-secure status, a process that included the teal (Musil *et al.* 2024). Part of this process is to identify potential habitat-related actions that can contribute to restoration of the species to more favourable conservation status.

Recent analysis has shown that reproductive output rather than survival drives teal population dynamics, because the species has low annual survival rate (0.53), short generation time (3.88 years) and relatively large mean clutch size (9.5; Stroud 2023). Hence, teal live a life almost as short as many passerines, compared to swans and geese that have annual survival rates of up to 0.90 and average life spans of 10 years, up to 30 years or more in the longest-lived individuals (Koons *et al*. 2014). For this reason, while placing restrictions on hunting teal could be an effective but relatively blunt conservation management instrument for rapid restoration of falling population levels, boosting the size of the breeding population is likely to have a more major effect on autumn population abundance and ultimate recovery. For this reason, it is important to assess the effectiveness of conservation actions that can establish breeding teal and enhance reproductive success in areas where the species was formerly absent or has been lost through habitat modification/loss.

In northern Europe, and to some extent in North America, breeding teal are often associated with more acid, less base-enriched peatland habitats (often small bog and fen pools), in particular compared to other breeding duck species that prefer larger, more base-enriched waters (Fox *et al.* 1989, Décarie *et al.* 1995, Nummi & Pöysä 1995, Desrochers & van Duinen 2006). In the Boreal region, teal is a classic and common breeding species on the pool systems of ombrogenous mires, where they can attain high nesting densities when the extent of open water permits (e.g. Häyrinen *et al*. 1986). However, it is also a characteristic breeding species of lowland raised mires further south and west in Europe (e.g. in Logné, western France, Barbier & Visset 1997 and Corsydd Fochno a Caron, West Wales, United Kingdom, Roderick & Davis 2010). In the British Isles, the species favours moorland pools, bogs and patterned mires, particularly acidic base-poor upland waters (e.g. dubh lochans in the Flow Country of Caithness and Sutherland; Fox *et al.* 1989). Hence, the majority nest in the north and west of Britain, although substantial numbers also breed in lowland Britain in a variety of well-vegetated wetlands (Balmer *et al.* 2013). Interestingly, the species has shown the greatest contraction in breeding distribution in the lowland parts of the United Kingdom between 1968–1972 and 2007–2011, whereas it has increased its range in the north and west (Sharrock 1976, Balmer *et al*. 2013). Whether this makes teal a true "peatland" specialist is open to question, because it also exploits more base-rich lakes for breeding habitat (e.g. Danell & Sjöberg 1982). However, there is no doubt that teal is one of the very few duck species that breeds - often at high densities - and raises ducklings on very base-poor, highly acidic, often *Sphagnum* dominated wetlands, where it could benefit from restoration of open water habitats (e.g. Fox 1986a).

In a recent Finnish study of new, artificially created wetlands, the densities of spring settling pairs and subsequent broods of teal, which also respond rapidly to flooding, were several times higher compared with those on natural Finnish boreal lakes (Čehovská *et al.* 2022). Teal have long been known to rapidly colonise and breed on newly flooded Eurasian beaver *Castor fiber* ponds in southern Finland, where observed teal pair and brood densities were higher than on non-beaver ponds (Nummi & Pöysä 1997, Nummi & Hahtola 2008), confirming the *r*-selected strategy of the teal, responding rapidly to occupy newly created habitats (Nummi *et al.* 2015). Wetlands created by beaver flooding were characterised by exceptionally high Cladoceran densities in the first year after flooding (known to be important in the teal diet, with ducklings taking most food from the water column and surface; Nummi 1993), with high chironomid and *Asellus* abundance from the second year onwards, peaking after four to eight years (Nummi 1989, Nummi *et al.* 1999, Mustonen & Kontkanen 2019). High invertebrate densities were positively correlated with teal pair density, brood density and duckling density, but not with vegetation cover, which is often thought to be a critical factor for the species (Čehovská *et al.* 2022). Numbers of breeding teal also increased rapidly during the first three years after creation of a studied man-made lake on flooded sedge meadows, before declining as vegetation and food supply changed in the fourth and fifth years (Danell & Sjöberg 1982). Taken together, these findings imply that the early stages of succession in created waterbodies and small acidic base-poor wetlands (including those on peatlands) are likely to be highly productive in generating high invertebrate densities and, consequently, increasing the number of teal broods raised to maturity.

The rewetting of peatlands is seen as a critical mechanism for meeting the current objectives of EU environmental policy. More than half of the peatlands in the EU area (about 350,000 km^2) have been degraded by drainage and agricultural/silvicultural use (Littlewood *et al*. 2010), and are estimated to contribute 7 % of total EU-27 annual greenhouse gas emissions (EEA 2024). Therefore, restoring peatland that is currently used as cropland, grassland and for non-sustainable forestry to natural vegetation, as well as ceasing exploitation of cut-over peatlands mined for fuel, horticultural and other peat products and instead restoring them to functional carbon-capturing wetlands, has become a key mitigation measure to reduce greenhouse gas production globally (IPCC 2019). The EU 2030 Biodiversity Strategy (European Union 2020) calls for the restoration of peatlands and, by 2020, funding under the LIFE grants programme had already supported 363 projects to conserve and restore peatlands, mainly through rewetting by blocking outflows via drainage ditches (European Commission 2020b). Several European countries already have mechanisms to fund restoration of peatlands. For example, in Belgian Wallonia and Germany, climate related funding has been used successfully to restore peatlands and their functions (MFA 2021, WASPW 2021). Results-based funding is also available under the Agri-Environment Climate Measures scheme in Ireland, promoting agricultural management that raises water tables in drained peatland to reduce greenhouse gas emissions (DAFM 2021).

Backed by current public and political goodwill, potential funding sources to promote peatland restoration and the relatively large areas of peatland damaged by drainage, it seems there has never been a better time to contribute to the creation of teal breeding habitat through the rewetting of peatlands by blocking ditches and raising water tables. However, despite the circumstantial evidence outlined above, how much real evidence do we have that shows numbers of breeding teal pairs are greater following such hydrological management on peatlands, from both the flooding of shallow cut-over peatland and the blocking of linear ditches? How much do we know about what drives these changes (in terms of nesting habitats and suitable food resources) to inform best practice? Here, we present the results of a literature survey and enquiries to professional peatland conservation experts and site managers associated with such programmes to test the prediction that their activities have resulted in increases in number of successfully nesting teal and as far as possible to investigate what practices have been most successful in maximising the numbers present. We also present novel national analyses, providing quantitative estimates and comparisons of breeding pair and brood densities, from 36 rewetted mire habitat sites in Finland and eleven in Estonia.

METHODS

Literature review

We undertook a literature survey, searching in Google Scholar (Google 2024) using "crecca and rewetting and peatlands" (31 results) and "crecca and ditch blocking and peatlands" (167 results), the majority of results being largely uninformative in both cases. We also contacted researchers and managers known to us in Czech Republic, Estonia, Finland, Germany, Latvia, Norway, Sweden and United Kingdom who have experience of breeding teal, restoring peatlands, blocking ditches on mires or are otherwise likely to have knowledge about these issues. Because nests are extremely difficult to find and the presence of teal pairs in spring can be a weak indication of the true numbers of nesting birds, most of the literature reports of breeding teal pairs refer to observation of brood rearing females with non-fledged ducklings as their currency of measurement of successful breeding of the species. This clearly underestimates potential true numbers of breeding pairs present at a site by omitting those which were either not detected or lost due to abandoned or predated eggs and ducklings at earlier stages.

Estonian analysis of peatland breeding teal pre- and post-restoration

We analysed data from before-after bird surveys of eleven restored peatland sites in Estonia, undertaken as part of the national monitoring programme of mire breeding bird species whereby monitoring at a given peatland site occurs approximately every ten years (Keskkonnaagentuur 2023). Single breeding season bird census visits mapped all territories of breeding birds along parallel fixed census routes 150–200 m apart (Svensson 1978, Boström & Nilsson 1983). Data were extracted from the Estonian national environmental monitoring information portal (http://kese.envir.ee) for sites where restoration (primarily ditch blocking and rewetting) was known to have occurred between two consecutive visits. Observations were filtered according to their intersection with restoration areas. In seven cases, restoration had finished just before the survey took place (see Table A1 in the Appendix for full details).

Breeding teal on restored Finnish mires

The "SOTKA" project is a large-scale habitat restoration initiative by the Finnish Ministry of Agriculture and Forestry (https://mmm.fi/en/sotka-project) which involves constructing new wetlands and restoring mires and cut-over catchments to create staging and breeding habitats for waterbirds. A sample of these sites, other constructed wetlands from previous projects and various other locations were monitored by the Natural Resources Institute Finland (Luke) during 2020–2023. Of these constructed or rewetted wetland sites, 36 were on peatlands and considered suitable for this study. The sites were distributed over a large area within Finland, from 61° 46′ N, 21° 52′ E in the southwest to 66° 01′ N, 31° 49′ E in the northeast; and were classified into: i) former active peat extraction sites which have been reflooded by damming (n = 20 sites, none of which would have supported breeding teal previously), and ii) drained peatlands rewetted by damming of ditches or excavation (n = 16 sites, some of which may have supported breeding teal but for which there are no prior data). According to all metrics, the old peat extraction areas were considerably larger than the rewetted natural wetlands. Hence, when studying differences in density between the two types of sites, it is impossible to distinguish between effects of habitat quality and effects of size, such as preference for small waterbodies or biases related to detection.

Data on teal were collected following the guidelines set in the instructions for national waterfowl counts (Kauppinen *et al.* 1988, Koskimies *et al.* 1988). The survey method applied was consistent between years for each site, consisting of: 1) fixed point surveys (Koskimies *et al.* 1988; n = 5), 2) circling the wetland along the shores (Kauppinen *et al.* 1988; n = 14), or 3) a combination of 1) and 2) - in practice, several point surveys along the wetland shore to cover it thoroughly (n = 17). The method was dictated by the surrounding vegetation and water levels, i.e., the practicality of circumnavigating the wetland by following its shores or the possibility of observing anything by doing so. Pair counts were conducted during one or two visits in May. If two pair counts were done, the higher number of teal pairs was selected to represent the wetland in question. Brood surveys took place during July, in most cases during the first half of the month. Although the elevated vegetation cover at this time of year might significantly reduce the detectability of broods, the probability of detecting most broods and pairs was maximised by conducting counts mainly by methods 2) and 3) at potentially affected sites. We acknowledge that there is a greater risk of reduced detection probability - and hence under-estimation of the numbers of both pairs and broods - at larger sites such as old peat extraction areas. The data set is unbalanced in that not all sites were surveyed every year, but in all except one case there are data from at least two years (20 sites with 2 years, 9 sites with 3 years and 6 sites with 4 years of data).

Pair and brood densities were estimated in relation to open water area (pairs or broods ha^{-1}) and shoreline length (pairs or broods km^{-1}). The analyses were done using generalised linear mixed models (GLMM), with either the interpreted number of pairs or the number of broods as the response variable. Among the explanatory variables, type of mire was included as a categorical fixed effects variable and site ID as a random effect on the intercept, to control for multiple inclusion of the same site (repeated measures) and for unbalanced monitoring efforts at different sites. We applied a log link function. The natural logarithms of open water area (ha) or shoreline length (km) were included in the model as offset variables, to relate the number of pairs and broods to measures of available habitat and hence provide direct estimates of density in the fixed effects investigated. For the model on number of pairs we applied a negative binomial error distribution to account for overdispersion, and for broods we used a COM Poisson error distribution with capability to model both over- and underdispersion. We fitted the model using package "glmmTMB" (Brooks *et al.* 2017) in the R programming environment (R Core Team 2023). To test for differences in significance between habitats, likelihood ratio tests were applied.

Changes in breeding teal abundance before and after ditch blocking on Cors Fochno, Wales

In a previously reported study, ADF regularly counted teal broods post-hatching along linear drainage ditches on the Cors Fochno National Nature Reserve in mid Wales (52° 30′ N, 04° 01′ W) during 1980 to 1983 inclusive (Fox 1986a). One section out of six of these drainage ditch complexes was blocked in winter 1981/82, while those elsewhere were not, providing a quasi-BACI arrangement to compare the resulting before/after control/impact frequency of broods. Because teal are single brooded and attendant females and broods were relatively site faithful during brood rearing, it was possible to relate broods to ditch length and estimate changes in brood size with age. See Fox (1986a) for full details of methods and Fox (1986b) for locations of blocked ditches.

RESULTS

Ditch blocking / peatland rewetting attracts breeding teal

Based on the literature review and responses from correspondents, there are several reports of blocking ditches to create long linear waterbodies (cases 1, 7, 8, 9, 10, 12, 15 and 16 in Table 1) or raising water tables above ground level on peatlands to create large areas of shallow water (cases 2, 3, 4, 5, 10, 11, 12, 13 and 14 in Table 1) which have resulted in attracting nesting teal that were (seemingly) not previously present. The results from the Somerset Moors and Levels in Britain (cases 6 and 7 in Table 1) suggest that ditch blocking on formerly drained wet flooded grassland on marine clay substrates did not result in habitat suitable for breeding teal, while in adjacent areas similar restoration measures on peat substrates resulted in breeding teal in areas where they were formerly absent. In one case (2), gradual colonisation of peat cuttings by natural bog vegetation led to impediments to drainage, elevated water tables and the creation of open water that led to colonisation of the site by breeding teal. Frustratingly, it was not always clear from other such reported studies whether teal had been genuinely absent prior to the hydrological management, but this was generally the implication because of the nature of the habitat before restoration, which lacked even small bodies of open water prior to implementation of sympathetic management. None of the literature accounts provide census data upon which to judge pre- and post-management breeding densities, but they do support the hypothesis that blocked ditches and the creation of shallow water above cut-over peat surfaces results in the attraction, or enhancement in abundance, of nesting teal. It was not possible from any of these reports to assess what features of the management activity and consequent habitat features favoured their successful use by colonising teal.

Estonian analysis of peatland breeding teal pre- and post-restoration

At the eleven Estonian mires for which there were data pre- and post-restoration, numbers of registered pairs of teal increased significantly from 3 to 35, an increase of more than 10-fold over the baseline. (Figure 1, Table A1).

Breeding teal on restored Finnish mires

The average densities of prospecting teal pairs early in the season were always higher on rewetted drained peatlands compared to restored and reflooded peat extraction areas (Figure 2, Table A2). However, the difference in densities was clearly larger for pairs ha^{-1} open water (219 % higher), compared to pairs km^{-1} shoreline (78 % higher). Also, the average density of broods ha^{-1} open water was higher (+157 %) on rewetted drained peatlands, compared to old peat extraction areas. However, for broods km^{-1} shoreline the difference (37 % higher in rewetted peatlands) was not statistically significant (Figure 2, Table A2).

Changes in breeding teal abundance before and after ditch blocking on Cors Fochno, Wales

As reported by Fox (1986a), 13–18 pairs of teal bred successfully annually on the ditches of Cors Fochno. Blocking of ditches on the site gave rise to deep linear pools with abundant emergent vegetation and was followed by a statistically significant three- to four-fold increase in the frequency of successfully breeding teal ($\chi^2_{(1)} = 8.3$, $P < 0.01$) compared to no change on the five other ditch areas not subject to ditch blocking ($\chi^2_{(1)} = 5.3$, $P > 0.05$), monitored at the same time (Figure 3). A partial site visit in June 2024 confirmed teal broods were still present in the same stretches of blocked ditches at similar densities, suggesting the restored habitat remains suitable for the species over a span of 40 years.

DISCUSSION

Based on the literature and the more detailed studies presented here, there seems little doubt that rewetting of peatland - through either ditch blocking or damming to create larger areas of relatively acidic shallow water - attracts teal to sites that have not previously supported them as a breeding species. In the case of Linnunsuo, the creation of large areas of shallow water over bare peat established a mean density of 0.302 broods ha^{-1} within two years of restoration works and maintained this density over four years of monitoring. This result was very similar to the mean (0.35 brood ha^{-1}) of brood densities observed at 20 rewetted peat extraction sites in Finland during post-restoration years of monitoring (Table A2), suggesting that such habitat restoration sites can contribute effectively to breeding teal conservation. The extensive reinstatement of 350 ha of drained, degraded and cut-over mire on the Hautes-Fagnes plateau by ditch blocking or removal of vegetation initially attracted 0.057–0.087 pairs of teal ha^{-1}. Dedicated surveys of the species throughout the Hautes-Fagnes plateau are unfortunately no longer possible owing to the treacherous nature of the terrain restricting human access, but the species continues to colonise recently rewetted areas while continuing to reproduce in numbers on older flooded areas. The Hautes-Fagnes teal population today

Table 1. List of examples from the literature or from correspondents describing the appearance of successfully breeding Eurasian teal *Anas crecca* following management to restore or rewet peatlands (through ditch blocking or other methods) where the species was considered absent prior to such management. RSPB = Royal Society for the Protection of Birds.

Site	Region	Habitat	Management and results	References
1. Oweninny Bogs	County Mayo, Ireland 54° 06′ N 09° 34′ W	6,500 ha harvested for milled peat until 2003	Rehabilitation to stabilise bare peat surface, blocking of ditches. Limited rewetted areas surveyed in 2009 finding 12 breeding pairs and 8 more potential breeding pairs in areas previously unsuitable for the species.	Copland *et al.* 2011
2. Un-named peat cuttings	Islay, Argyll, Scotland 55° 46′ N 06° 12′ W	Small lochan, formerly (1970s) an area of domestic peat cuttings	Natural occlusion of drains has resulted in reflooding of peat cutting area, with fluctuating water tables, creating ideal teal conditions without active management, while other areas continue to erode and not revegetate. Three adult teal with 8 ducklings seen May 2023.	A. Ward *in litt.*
3. Airds Moss	East Ayrshire, Scotland 55° 30′ N 04° 10′ W	Lowland blanket mire, drained	Widespread blockage of ditches to restore high water tables. Proven video recording of successful breeding in August 2024 (likely relaying female).	T. Lill *in litt.* per C. McKay
4. Scottish Flows and Highlands	Caithness and Sutherland, northern Scotland 58° 22′ N 03° 53′ W	Lowland/upland patterned blanket mire, drained and planted with non-native forestry	Numerous forest-to-bog restoration projects undertaken by RSPB (e.g. Forsinard National Nature Reserve) and Forestry and Land Scotland (Dalchork and Benmore Forests), involving tree-felling, ditch blocking and dam construction, raising water levels and creating small pools. Teal have bred on newly created pools in previously unsuitable forestry, with numbers of teal breeding in Forsinard increasing by 59 % between 2011 and 2021 from such habitat creation.	Hughes *et al.* 2024
5. Blaen-y-Coed, Migneint SAC	Conwy, North Wales 52° 59′ N 03° 47′ W	Upland drained blanket peatland subject to peat cutting	Restoration efforts starting 2017 rewetted the area by blocking old drainage ditches, raising water tables and promoting natural water retention. Previously absent, two teal pairs both raised six young in 2024, but difficult to monitor total numbers present.	M. Clift *in litt.*
6. Greylake Moor	Somerset, England 51° 06′ N 02° 52′ W	10 ha drained peatland claimed for arable, restored in 2003	Water levels raised to restore to wet grassland and fen. Supported between zero and 7 (mean 2.0 ± 0.45 SE) pairs of breeding teal 2003–2023 where none previously. Interestingly, there was no such colonisation of similar habitats on other locally restored moors on formerly marine substrates.	D. Bridge *in litt.*; RSPB unpublished data
7. Avalon Marshes	Somerset, England 51° 09′ N 02° 47′ W	1,200 ha extracted for milled peat until the 1990s	Mostly bare peat workings now transformed to open water and reedbeds, providing limited breeding habitat for teal that would not have been present before. 6 pairs found 2008 but repeat surveys of same area found none in 2020.	D. Bridge *in litt.*; RSPB unpublished data
8. Hatfield Moors	Humberside, England 53° 33′ N 00° 55′ W	1,400 ha harvested for milled peat until 1990s	95+% bare peat, but even in 2008 mostly unsuitable. LIFE projects cleared scrub, elevated water tables, at least 3 pairs of teal bred 2018, 18 in 2019, 14 in 2021 and 11 in 2022. Very difficult to monitor effectively.	B. Wainwright, Natural England, *in litt.*

Site	Region	Habitat	Management and results	References
9. Thorne Moors	Humberside, England 53° 38′ N 00° 53′ W	1,900 ha harvested for milled peat until 1990s	Almost all originally bare peat, but with some encroaching open water, 2–25 pairs reported in 1990s, but only up to 6 pairs since, although 14 in 2017. Very difficult to monitor effectively.	B. Wainwright, Natural England, *in litt.*
10. Hautes-Fagnes	Province of Liège, Wallonia, Belgium 50° 32′ N 06° 07′ E	9,400 ha peatland dug for fuel (15th century to early 20th century), drained for forestry in mid-19th century	Rewetting of 350 ha of cut-over or drained bog, blocking of 178 km of ditches, creation of pools (100 ha), restoration of 250 ha of wet heath by scraping *Molinia caerulea* vegetation, sod-cutting and deforestation of spruce plantations on peaty soils. Restoration began early 1990s, with major activity since 2007 under an EU Life project, continued to present with other funding. One to three teal nests found 2012–2014, then 20–25 pairs 2015–2017 (Alain De Broyer *pers. comm*., Jacob *et al*. 2015, 2016; Paquet *et al*. 2017). Since then, 20–30 pairs (0.057–0.087 pairs ha^{-1}). Formerly absent as a breeding species, now the most important site for breeding teal in Wallonia.	Frankard *et al.* 1998, Frankard 2001, Frankard & Janssens 2008, Frankard *et al.* 2017, Frankard 2022
11. Großes Torfmoor	Nord-Rhine Westphalia, Germany 52° 19′ N 08° 41′ E	Severely damaged peripheral areas of raised mire system progressively drying the central dome	LIFE project blocked many drainage ditches in the most badly damaged areas. Site has become the most important site for breeding teal in Nord-Rhine Westphalia (although no prior surveys for comparison).	Belting 2007
12. Dosenmoor	Schleswig-Holstein, Germany 54° 08′ N 10° 10′ E	Heavily drained cut-over raised mire, damaged 1900–1970	Since rewetting, open water has had a positive effect on numbers of breeding teal.	Irmler 1998, Zerbe 2023
13. Chiemsee	Southern Bavaria, Germany 47° 52′ N 12° 27′ E	Raised mires cut over for peat, covered in *Molinia* and birch scrub	LIFE project blocking “hundreds” of ditches resulted in increasing numbers of breeding teal.	Silva *et al*. 2007, EULPD 2023
14. Western Finland	South Ostrobothnia and Central Finland Regions 62° 46′ N 24° 26′ E	Peatlands drained for forestry, ditches blocked and trees removed	On 11 study sites, based on 10 pre-restoration and 38 post-restoration visits, teal “territories” increased from zero to 22. Forty-eight visits to pristine parts of the mire found one teal.	Alsila *et al.* 2021
15. Linnunsuo	Joensuu, North Karelia, Finland 62° 37′ N 32° 02′ E	100 ha cutover mire causing acid pollution to rivers downstream	Peat extraction caused sloping area of long parallel cuttings, thought to be devoid of breeding teal pre-restoration. Community restoration project aimed to stabilise bare peat and reduce pollution. Contour dams created extensive shallow pools covering most of the site, which were recolonised by peatland vegetation. Annual bird surveys revealed 16 pairs of breeding teal in 2013 (the year after reflooding), 30 in 2014, then 35, 26 and 30 pairs in subsequent years until 2017.	Laventure & Scherer 2017
16. Orshinsky Moss	Tver Oblast, Russia 56° 57′ N 36° 20′ E	28 million tonnes of peat extracted over 35 km^2	Rewetting, including creation of pools (60 × 200 m, 2–6 m deep) reported to be successful in attracting breeding teal which were absent previously.	Mikhailov *et al.* 2017

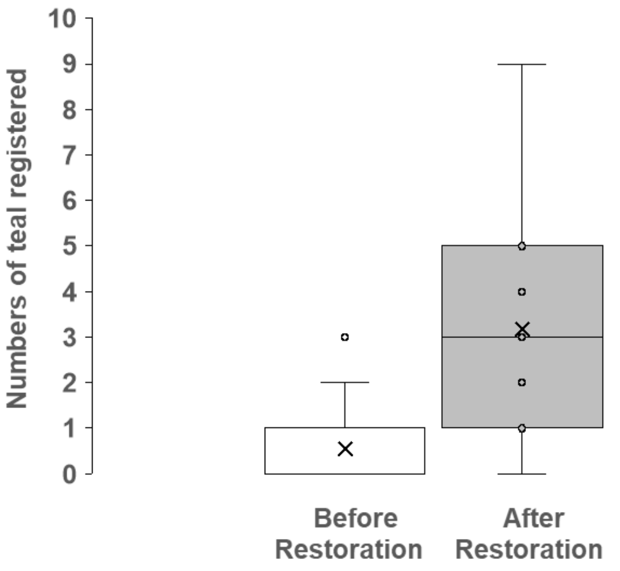

Figure 1. Box and whisker plots of numbers of breeding teal pairs registered on eleven Estonian mire sites in years before and after restoration (rewetting and blocking of ditches, see Table A1 for details). Before–after differences were significant based on a Wilcoxon signed-rank test for paired samples (W = 2.6, P = 0.004).

constitutes the main breeding population in Wallonia (Kever *et al*. 2018) in an area where the species was formerly totally absent as a breeding bird. Re-establishment of mire vegetation following elevation of water tables over bare peat can be rapid, but the time needed for the vegetation to recover varies with peat type, climate and other factors (e.g. Tuitilla *et al*. 2000). Consequently, the attractiveness of a rewetted peatland to nesting teal can be expected to vary depending on the development of suitable invertebrate food resources and plant recolonisation in relation to suitable nesting sites.

In the case of Cors Fochno, the blocking of ditches originally some 2–3 metres wide and up to 1 metre deep created linear ponds up to 3 metres deep and 8 metres wide to elevate and maintain stable water tables in the surrounding peat (with the aim of maintaining water levels within 5–10 cm of the surface to restore active *Sphagnum* growth; Horton 2008). This transformation supported a three- to four-fold increase in the number of teal broods immediately following restoration, which was associated with increases in Odonata abundance (Fox 1986b) - not only as a potential source of food but also indicative of enhanced invertebrate prey available as a feeding resource for teal broods that

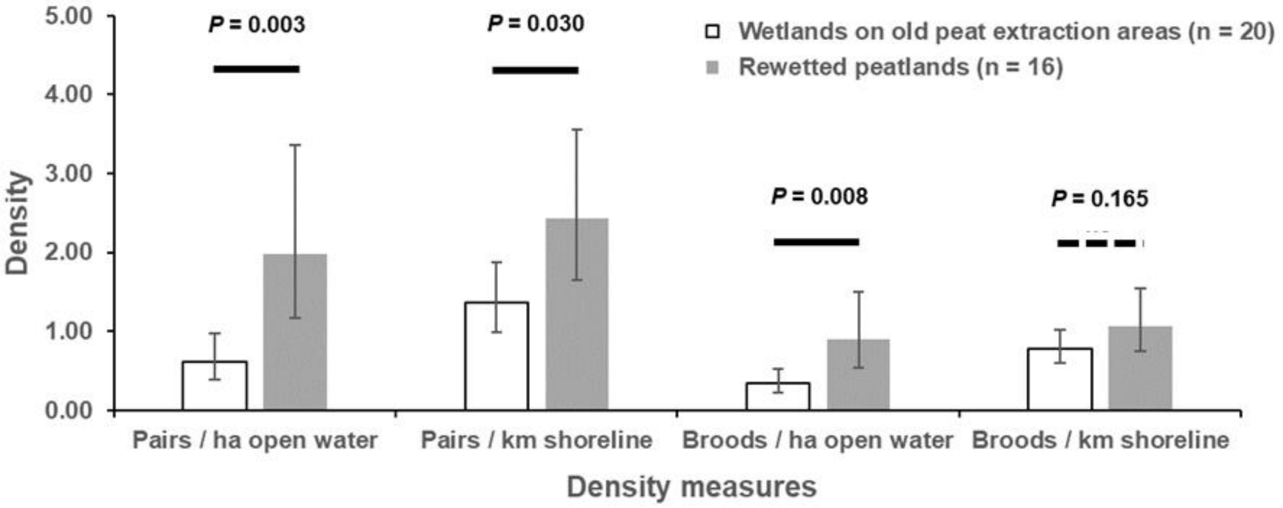

Figure 2. Estimated average densities of teal pairs and broods at wetlands with restoration of old peat extraction areas (white) and rewetted natural peatland habitats (grey) in Finland. All cases describe the situation post-restoration. Prior to restoration, possible breeding habitats available for teal were absent or negligible. The analyses are based on log-linear GLMMs with negative binomial (pairs) or COM Poisson (broods) error distributions. The whiskers show 95 % confidence intervals. Differences between habitats were assessed using likelihood ratio tests.

resulted from the restoration actions. Such brood densities were still evident along the same ditch lines in 2024, suggesting little diminution in prey densities and other breeding conditions over 40 years (J. Lyons *in litt*. and ADF pers. obs.). Although of course not directly comparable, the densities observed on this site were high (4.5 broods km^{-1} of ditch line) compared to densities in relation to lake shores in oligotrophic boreal wetlands (e.g. mean 0.23 broods km^{-1} shoreline ± 0.07 s.d.; Nummi & Pöysä 1995), suggesting that blocked peatland ditches can potentially support high levels of brood production (since mean brood size at age about 10 days was only slightly lower than at fledging; Fox 1986a).

The data presented here from monitoring of teal densities at restored peatlands in Finland also showed that settling teal pair densities were generally 78–219 % higher on rewetted drained peatlands (typically with blocked ditches) compared to reflooded old extraction areas, although the differences for broods were smaller (37–157 % higher) and the differences in relation to shoreline length failed to reach statistical significance (see Table A2). Previous studies showed that densities of teal pairs settling in spring and subsequent broods were highest on small boreal ponds (< 0.5 ha) and lowest on large lakes (> 10 ha) (Nummi & Pöysä 1995). Hence, the combination of wet heath and mire vegetation suitable for nesting adjacent to small ponds created by ditch blocking and suitable as brood rearing habitat creates ideal conditions to support high densities of breeding teal (average for all sites from Table A2: 0.86 broods km^{-1} shoreline) on restored peatlands compared to other nesting habitat (e.g. mean 0.23 broods km^{-1} in Nummi & Pöysä 1995). This means that, to attract maximum numbers of breeding teal, it may be optimal to favour (i) the creation of many small pools, (ii) the construction of islands, or (iii) in general, geometries with longer shorelines where possible, over extensive flooding of cutover peatlands resulting in large uniform open water areas. We fully acknowledge that we should be prudent in claiming that there are considerable differences in habitat quality between the two site types compared here, as the old peat extraction sites were generally so much larger (on average, 6-fold area and 3-fold length of shoreline). Indeed, there are many excellent examples of sites on old peat extraction areas which provide good breeding opportunities for teal, perhaps emphasising the need to plan restoration carefully to make the most of the physical properties restored in terms of encouraging the species post-restoration; e.g., by providing ample adjacent suitable nesting habitat, maximising islands and length of shoreline, and forming complex waterbody shapes with sheltered shallow waters.

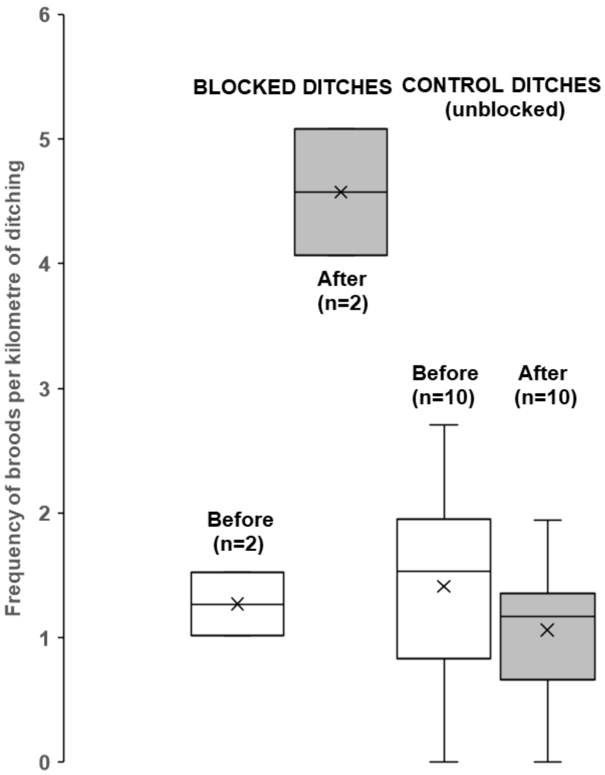

Figure 3. Box and whisker plots of encounter frequency of teal broods per kilometre of surveyed ditch line on Cors Fochno, Wales in 1980 and 1981 (pre ditch blockage) in the impact areas (n = 2) and control ditches (n = 10, all of which remained unblocked subsequently) and in 1982 and 1983 (post ditch blockage) in the impact and control areas. See Methods text for methods and explanation, and Results for statistical results.

The lack of pre- and post- survey data on nesting waterbirds generally, and on teal in particular, from existing peatland restoration schemes makes it very difficult to conclude very much about how best to manage other sites to maximise their attractiveness to nesting teal and other species. Compilation of more monitoring data from a variety of peatland restoration projects in a central database should be a major priority to better inform best practice for maximising biodiversity gain in future restoration programmes. We emphasise the high priority for explicit surveys before any restoration actions, even for cases where it can be assumed that there is hardly anything important to survey, to establish a baseline for subsequent comparisons.

The majority of 80 analysed EU Life Programme peatland restoration schemes involved ditch/drain blocking, creation of dams/embankments to retain water, and/or creation of open water or other elevation of water tables (Andersen *et al*. 2016), so the re-engineering of small pools during restoration of damaged peatlands is entirely compatible with normal practice in projects aiming to restore more normal hydrological regimes to damaged peatlands. The biomass and diversity of invertebrates associated with open water bog pools is generally greater than with *Sphagnum* covered or peaty/muddy pools (e.g. Paasivirta *et al*. 1988) and waterbird breeding densities on northern peatland generally correlate positively with area of open water (Kolmodin & Nilsson 1982, Boström & Nilsson 1983). Studies of invertebrate faunas associated with natural bog pools in Caithness found no relationships between species richness or taxa densities and pool size along a gradient from 8 to 281 m^2, except for beetles (Towers 2004), although some species showed optima for certain pool sizes. Potential prey for teal ducklings to eat within and around pools are therefore likely to increase with the volume of suitable habitat, but deeper peatland pools tend to support far greater species richness and biomass than do shallower ones (e.g. Downie *et al*. 1998). Water retained in blocked ditches tends to be deeper than in natural pools and can, therefore, potentially support elevated invertebrate densities compared to the previous state with unblocked ditches (e.g. Vaikre *et al*. 2024) - initially Chironomids in relative diversity and large numbers, later typically with increasing numbers of Odonata and Coleoptera (e.g. Fox 1986b, Krieger *et al*. 2019, Beadle *et al*. 2023). Blocked ditches also contain very deep water compared to flooded bare peat surfaces, which thus tend to colonise more rapidly with mire species including *Sphagnum* and common cotton grass *Eriophorum angustifolium* (Sliva & Pfadenhauer 1999). This may explain why the ditches on the west side of Cors Fochno still retain open water as well as high teal brood densities 40 years after the ditches were blocked. Studies from Europe and North America generally suggest that restoring peatland pools (e.g. by blocking ditches or excavating pools) delivers significant benefits for aquatic fauna by providing extensive new habitat that did not exist previously, but is largely equivalent to natural pools in terms of the diversity and biomass of invertebrate fauna they support as they develop (Brown *et al*. 2016). Therefore, although literature on the subject is relatively sparse, evidence seems to be gathering that newly created pools on peatlands with low macrophyte cover can sustain substantial populations of larger invertebrate fauna based on algal primary production, consumption of peat detritus, and microbial processing of humic substances and methane (Beadle *et al*. 2015). In summary, experience suggests that blocking ditches not only raises water tables to rewet peatlands badly damaged by the drainage (although this may not always be the case; see Sliva & Pfadenhauer 1999) but also recreates freshwater habitat for an invertebrate fauna that closely resembles the fauna of natural pools, as favoured by teal ducklings. Seen as a component of more strategic hydrological restoration management of drained peatlands, ditch blocking seems to be contributing positively to the freshwater diversity as well as providing teal brood rearing areas at no extra cost. We might also conclude that shallow rewetting of cut-over peatlands has a similar effect, albeit less long lasting because of their propensity to overgrow with mire vegetation (Allan *et al*. 2024).

While we have found evidence for benefits of peatland restoration for teal, we still lack evidence to support best practice guidelines on active peatland restoration interventions for a range of taxa including breeding teal. It is frequently the case that restoration actions motivated by a particular environmental goal can fail to deliver maximum biodiversity benefits due to the lack of knowledge, or the lack of involvement, of relevant experts (e.g., successful floodplain reinstatement to reduce agricultural sediment and fertiliser runoff could have been better designed for breeding wading bird species; Bregnballe *et al*. 2014). There is an increasing need to inform management actions with scientific evidence in support of their efficacy, with regard to both habitats and taxa. Given a chronic lack of resources, conservationists tend to be satisfied with the results of nature conservation management that are known to deliver benefits, without concern for effective monitoring to determine whether management interventions could be made even more effective. However, in a world where natural resources and ecosystems are coming under increasing pressure, we need to be better at monitoring and properly estimating the effects of different restoration actions to inform and thus improve the efficiency of such programmes in the future. It is a distressing fact that a recent RSPB survey of the extent of biodiversity monitoring of any taxa in association with peatland restoration projects revealed eleven such programmes, representing a very small fraction (maximum 6 %) of the 200+ restored peatlands in the UK (Douglas *et al*. 2019). We therefore need to be far more effective at understanding best practice in peatland restoration (and indeed all forms of habitat restoration) to create a better environment post-restoration for teal and all of the very many other taxa that benefit from these actions.

CONCLUSIONS

Despite the remaining gaps in our knowledge, these results show that blocking of ditches on drained peatlands and shallow flooding of cut-over mires create considerably better conditions for breeding teal than in their former degraded state. While we have failed in our attempt to find good evidence for specific management interventions to maximise attractiveness to nesting and brood rearing teal, we propose it is useful - so far - to show that simple blocking of ditches on drained peatlands to raise mire water tables can increase teal densities three- to four-fold over their previous state, and also that shallow flooding over bare cutover peatlands can support high densities of breeding teal. Given this evidence, we urge continued restoration of peatlands by ditching blocking and shallow flooding of cutover mires in pursuit of other objectives as a simultaneous means of enhancing the current breeding population of teal in western Europe. Since we are unable to provide evidence (in terms of the precise changes in abundance of specific prey items exploited by teal ducklings) to explain these increases, nor to come with specific management recommendations to maximise the benefits of peatland restoration to local nesting teal densities, we recommend enhanced levels of monitoring and research to provide such information. In the meantime, it is evident that many of the current programmes in place in the region to restore damaged and degraded peatlands will simultaneously generate new opportunities for breeding teal that will benefit this species at a time when there are questions about its unfavourable conservation status in Europe as a huntable species.

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AUTHOR CONTRIBUTIONS

Conceptualisation: ADF; methodology: all; software: all; data curation: all; writing - original draft: ADF; writing - review and editing: all; visualisation: all; formal analysis: all; investigation: all; resources: all; funding acquisition: all ; project administration: all; methodology: all; validation: all.

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Author for correspondence: Professor Anthony Fox, Department of Ecoscience, Aarhus Universitet, C.F. Møllers Allé 8, DK-8000 Aarhus C, Denmark. Tel: 0045-20675711; e-mail tfo@ecos.au.dk

Appendix

Survey of changes in breeding numbers of teal on selected Estonian mires before and after restoration activities

Methods

Restoration sites

Data on restoration sites were obtained from the Estonian State Forestry Center (RMK). For each site, the year of completion of restoration works was used to filter out the most recent census results from the last pre-restoration year ("Before" in Table A1) and from the first census year ("After") after completion of restoration activities ("Restoration"). Mire and lake systems were considered as one complex in the analysis and bird numbers from both areas were summed for each site. The areas of open water were estimated using a combination of the Estonian Land Board vector data (accessible at https://geoportaal.maaamet.ee/est/ruumiandmed/eesti-topograafia-andmekogu/laadi-etak-andmed-alla-p609.html) and most recent aerial photographs. Numbers of breeding teal pairs within the entirety of each monitoring site were registered before and after restoration activities, except in cases where the monitoring site was significantly larger than the area subject to restoration. In the latter cases, changes in numbers of breeding pairs were re-analysed using the raw data relating to the areas of restored habitat only, to capture this effect.

Table A1. Spring bird census of 11 Estonian peatlands carried out before and after restoration, showing the year of completion of restoration works, sites with changes in area of open water and associated numbers of teal.

Site name	Monitoring site code	Latitude and longitude	"Before" survey year	Area of open water	Number of teal recorded	Restoration year	Site characteristics and restoration	"After" survey year	Area of open water	Number of teal recorded
Kaasikjärve	SJA5097000	58° 51′ N 26° 14′ E	2004	~4 ha	0	2016	Small bog with a drained lake ("Sinilaugas") and pool system. Outflow ditch dammed during restoration, resulting water level stabilisation.	2018	~5 ha	4
Laukasoo	SJB2729000	59° 29′ N 25° 54′ E	2017	14 ha	2	2020	Bog with a huge drained lake-pool system in the middle. The lake-pool system formed a lake after damming of the outflow ditch.	2020	~30 ha	3
Maarjapeakse	SJB2715000	58° 12′ N 24° 37′ E	2002	0 ha	0	2020	Drained bog without waterbodies. Ditches filled and dammed to create waterbodies behind them.	2020	~1.6 ha	0
Meelva	SJA0486000	58° 09′ N 27° 18′ E	2012	~1.5 ha	0	2019	Bog with a drained pool system. The pool system was rewetted after damming outflow ditch.	2022	~4.8 ha	1

Site name	Monitoring site code	Latitude and longitude	"Before" survey year	Area of open water	Number of teal recorded	Restoration year	Site characteristics and restoration	"After" survey year	Area of open water	Number of teal recorded
Nigula	SJA9172000	58° 00′ N 24° 41′ E	2020	~1 ha	0	2022	Bog with drainage ditches. Ditches filled and dammed to create waterbodies behind them.	2022	~7 ha	2
Ohepalu raba	SJB2719000, SJB2720000	59° 20′ N 25° 54′ E	2009	~70 ha	0	2020	Bog-system with a drained lake. Lake drains were filled and dammed, raising the water level of lake.	2020	~84 ha	1
Rongu	SJA6458000	58° 00′ N 24° 55′ E	2014	30 ha	1	2022	Bog with a huge drained pool-system and intensive edge drainage. All ditches were filled and dammed.	2022	38 ha	5
Suursoo	SS2017	59° 09′ N 23° 59′ E	2018	<10 ha	0	2021	Mostly fen and wooded transitional mire. Ditches were filled and dammed.	2021	~70 ha	2
Tolkuse	SJA9003000	58° 08′ N 24° 32′ E	2008	<1 ha	0	2021	Bog with huge drained lake-system in the middle.	2022	~15 ha	5
Udriku	SJB2722000, SJB2723000, SJB2724000	59° 20′ N 25° 56′ E	2009	49 ha	0	2020	Bog with drained lakes. Ditches were filled and dammed, increasing the area of shallow water	2020	50 ha	9
Viru	SJB1448000	59° 28′ N 25° 39′ E	2015	<1 ha	3	2018	Abandoned peat mining area. Several unsuccessful restoration attempts. Final attempt filled and dammed the main outflow, stabilising water tables.	2024	~14 ha	3

At seven of the restoration sites (Laukasoo, Maarjapeakse, Nigula, Ohepalu, Rongu, Suursoo, Udriku), restoration was completed in the same year before the breeding season took place, so surveys were made immediately after restoration.

Bird data

Breeding mire birds in Estonia are routinely monitored under the national avian monitoring scheme (Keskkonnaagentuur 2023) which is part of the Estonian environmental monitoring programme. The interval between monitoring at any one individual site is usually 10 years. A single visit bird census is used to map all territories of breeding birds at a monitoring site. Fixed census routes are used, defined in parallel at intervals of 150–200 m, based on the original methodology developed by Svensson (1978) and Boström & Nilsson (1983).

Bird data were extracted from the mire breeding bird monitoring scheme within the environmental monitoring information system (http://kese.envir.ee). Registrations are assigned to numbers of breeding pairs on the whole monitoring site.

Table A2. Generalised mixed model estimates of Eurasian teal *Anas crecca* pair and brood densities from annual surveys in Finland, at 20 reflooded former peat extraction areas and 16 rewetted drained peatlands following ditch blockage. At the cut-over peatlands, there were considered to be no breeding teal prior to reflooding, whereas there may have been breeding teal prior to ditch blocking at the drained peatlands subject to restoration.

Density measure	Reflooded old peat Extraction areas (n = 20)	Rewetted drained Peatlands (n = 16)	Whole data (n = 36)	Full model statistics				
	Average (95 % CI)	Average (95 % CI)	Average (95 % CI)	Random effect SD	Dispersion	LRT (χ^2)	df	*P*-value
Pairs ha^{-1} open water	0.62 (0.39–0.97)	1.98 (1.17–3.36)	0.99 (0.66–1.49)	0.95	13.6	8.92	1	0.003
Pairs km^{-1} shoreline	1.36 (0.99–1.87)	2.42 (1.65–3.55)	1.69 (1.29–2.23)	0.62	12.8	4.74	1	0.030
Broods ha^{-1} open water	0.35 (0.23–0.52)	0.90 (0.54–1.50)	0.49 (0.34–0.71)	0.82	0.98	7.01	1	0.008
Broods km^{-1} shoreline	0.78 (0.59–1.01)	1.07 (0.74–1.54)	0.86 (0.69–1.07)	0.44	0.98	1.93	1	0.165