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Just Add Water and Stir: An Artificial Suburban Lake Develops Into an Important Moulting Site for Large-Bodied Herbivorous Wildfowl

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ABSTRACT

Egø Engsø is an artificial Danish suburban lake created in 2006, primarily for nutrient retention and flood control. Expanding submerged macrophyte cover (dominated by Stoneworts *Chara* spp. and Pondweeds *Potamogeton* spp.) attracted moulting concentrations of 600 mute swans *Cygnus olor*, 1100 greylag geese *Anser anser* and 280 Canada geese *Branta canadensis*. These unexpected additions to the avifauna benefit from reliable food supplies and effective protection from recreational disturbance on and near the water surface. Egø Engsø is a model of enabling intense human activity at a waterbird moulting site, and confirming appropriate planning can accommodate multiple functional objectives following wetland creation.

1 | Introduction

The motivations behind establishing new or restoring former wetland areas are often complex and multifaceted. Consequently, in the planning and execution of such projects, managers consider a plethora of sometimes conflicting objectives, embracing the needs of nature conservation, species protection, nutrient retention, human recreation and flood control (Moreno-Mateos and Comin 2010; Worley et al. 2023). Some benefits may be unplanned and/or complimentary; for instance, creating functional wetlands to reduce catchment nitrogen runoff from agricultural fertiliser may benefit local plant, invertebrate and avian diversity (dependent on wetland conditions and maintaining nutrient loadings below critical levels; Verhoeven et al. 2006; Hefting, van den Heuvel, and Verhoeven 2013). Equally, some objectives may conflict, for example, when wetland (re-)creation incorporates ambitions for human recreational use with attracting wildlife. Although public access is often essential to the success of many urban restoration projects, mere human presence inevitably disturbs wildlife species, potentially reducing the effective carrying capacity of a site (Platteeuw and Henkens 1997; Lewis et al. 2021). Reconciling societal and ecological needs are therefore not straightforward, especially when public support is a prerequisite to enable project advancement. Concerning lake (re-)creation, waterbirds (especially wildfowl: the Anatidae, ducks, geese and swans) are often critical, because they benefit more than most bird species from the safety of open water associated with the cover of emergent macrophytes and increased food availability, so new created habitat constitutes real contributions to offset massive wetland loss and degradation in recent decades. Wildfowl make their own unique local contributions to ecosystem services, for example, provisioning services (consumptive use through hunting), cultural services (e.g., their recreational value, because of their often spectacular aggregations and attraction to birdwatchers and

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photographers) and supporting services (such as dispersal of plant disseminules and nutrient cycling functions). Wildfowl seek food in undisturbed habitats year-round but are especially vulnerable during the simultaneous shedding and regrowth of wing feathers, rendering them flightless for several weeks (Mccleery et al. 2007; Fox et al. 2014). During this phase, birds are forced to commit to a single site (i.e., a discrete waterbody) for an extended period, aggregating in areas safe from predators in open water with ample food (Loonen, Zijlstra, and van Eerden 1991; Fox et al. 2014). For large-bodied herbivorous wildfowl such as geese and swans, this means areas of open water, undisturbed surroundings and abundant edible plants (either submerged macrophytes and/or in adjoining meadows or pastures). For many species, the importance of high-quality moulting habitats has led to the evolution of often prolonged moult migrations to reach such distant, remote suitable areas (Salomonsen 1968; Nilsson, Kahlert, and Persson 2001).

Here, we demonstrate how a newly established and artificially created urban lake has developed as a moulting site for mute swans *Cygnus olor*, greylag geese *Anser anser* and Canada geese *Branta canadensis*. Specifically, we (1) describe the development in numbers of moulting mute swans, greylag geese and Canada geese from establishment of the lake up until 2022; (2) investigate the hypothesis that annual changes in moulting wildfowl numbers were related to the coverage of submerged vegetation available in the lake and (3) contrast the development in bird numbers at our study site with numbers at a nearby natural lake, to assess whether changes at our focal site merely reflected regional development in bird numbers. In addition, we discuss how the birds' need for undisturbed areas during the critical time of remigial moult might be accommodated despite intensive human activities in close proximity.

2 | Methods

2.1 | Study Sites

Egå Engsø is a shallow, eutrophic artificial lake established in October 2006 on the northern edge of the city of Aarhus in Eastern Jutland, Denmark (56.217° N, 10.224° E) to reduce agricultural runoff nutrient loads into Aarhus Bay under the Danish 1998 Action Plan on the Aquatic Environment II (APAE II; Ærtebjerg, Andersen, and Hansen 2003). The area was historically wetland, but in the 1950s, drains were dug and a pumping station was established to claim the land, which was then used for intensive agricultural practices for the next 50 years. The artificial lake was created by the local authority stopping the artificial drainage of the area and damming part of the river Egå, flooding the former agricultural fields. Although mainly created to reduce nutrient flux into Aarhus Bay, it was also planned to accommodate surface water in periods of heavy precipitation to prevent flooding of adjacent urban areas, to provide opportunities for human recreational activities and create habitat for organisms associated with wetland habitats (Ærtebjerg, Andersen, and Hansen 2003; Climate Change Adaptation 2012; Schwinn et al. 2019). The lake has an area of 90–115 ha (depending on recent precipitation and stream recharge), with two predesigned artificially created islands for nesting birds, currently surrounded by approximately 0.3 km^2 of grazed meadows and 0.05 km^2 of reed beds. The average water depth is approximately 0.6 m, and the maximum depth is 1.5 m (Grøn 2021). Under the current management, much of the periphery of the lake is grazed, so there has been little development of dense emergent vegetation, much of which is muddy or short-grazed vegetation. The river Egå flows into the lake from the western end and out via a single outlet in the south-eastern corner (Figure 1). To the north and east, the lake is bordered by busy roads and to the west by a railway, with urban areas to the north and south, and a recreational path encircling the lake created to support human recreational traffic (extremely popular for dog-walking, hiking, jogging, cycling, etc.; Figure 1). No boats are normally allowed on the surface of the water, opportunities for swimming and bathing are zoned to limited areas, and the majority of the less accessible water edges are fenced off for grazing and therefore excluded from pedestrian access. Despite such intense recreational activity, the public shows great respect for the local regulations, so disturbance rates are low.

For a similar and neighbouring contrasting control site, we used the 153-ha shallow-water natural lake, Brabrand Sø, situated 9.5 km away from Egå Engsø (56.142° N, 10.132° E). This lake was created at the end of the last ice age (> 10,000 years ago) and has an average water depth of 1.1 m and a maximum depth of 2.7 m (Jørgensen 2000). Like Egå Engsø, the water surface is surrounded by reed beds and grazed wet meadows, and public paths encircle the entire area.

2.2 | Bird Counts

Although the dataset we use is dominated by systematic counts carried out by the author HLL, all observations of mute swans, greylag geese and Canada geese from Egå Engsø were extracted from the online citizen science database DOFbasen (www.dofbasen.dk), the largest online portal for reporting of bird observations in Denmark. The data series covered the years 2007 (the first summer after the creation of the lake) to 2022. Both systematic counts and volunteer reportings were available for all years for all species (see Table S1 for sample sizes). In addition, organised counts of the three species were undertaken in 2020 to depict phenology at the lake, including 109 observation days evenly distributed across the year (see Figure S1 and Grøn 2021 for details). Assuming the moult phenology of the three species is similar to well-studied sites in northern Europe, we defined the moulting period as July–August for mute swan (Clausen et al. 1996) and June–July for greylag geese (Fox et al. 1995) and Canada geese (Brides et al. 2023). The presence of moulting birds was confirmed by direct observations of birds clearly lacking fully developed flight feathers at the lake. From the portal, we extracted the annual maxima for each species within these periods as an index of relative annual abundance. Care was taken to ensure that the annual maxima were not obvious outliers compared with other records for the same combination of species and year. Both mute swans and greylag geese breed at Egå Engsø, but the number of breeding pairs is much too small to account for changes in summer abundance of these species (six pairs and 38 pairs respectively in 2020; Grøn 2021). For all three species, numbers in Egå Engsø peaked in the moulting period, but they were also present in lower numbers at other times of the year (Grøn 2021 and Figure S1). To compare and contrast changes in bird abundance at Egå Engsø with the nearby control site of

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FIGURE 1 | Map of Egå Engsø and surrounding area. Note that the waterside of the path around the lake is fenced away from the water's edge on the northern and western sides of the lake (i.e., top and left sides respectively on the picture) to keep the public off the meadows used by birds. Urban areas are visible to the northeast and south of the lake.

Brabrand Sø, a data set identical to that from Egå was extracted for Brabrand Sø from the same citizen science database.

2.3 | Macrophyte Coverage

Because all three moulting swan and goose species are herbivores and because Mute Swans in particular specialise in feeding on submerged macrophytes, we wished to track changes in the abundance of these plants at the site in relation to bird numbers. Summer prevalence of macrophytes in Egå Engsø was monitored in July–August in the years 2007, 2008, 2009, 2010, 2012, 2015, 2018 and 2020. In all years, macrophyte cover was assessed along 10 transects traversing the lake at 150 points using a bathyscope, and the total cover of each macrophyte species was expressed as % of total lake area (Grøn 2021). The monitoring followed the standard protocol for water plants in lakes from the Danish National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environments (NOVANA). Registered macrophytes included 32 taxa, the most prevalent of which were Canadian Waterweed *Elodea canadensis*, Small Pondweed *Potamogeton berchtoldii*, Sago Pondweed *Stuckenia pectinata*, Eurasian Watermilfoil *Myriophyllum spicatum*, Fragile Stonewort *Chara globularis* and Common Stonewort *Chara vulgaris* (Grøn 2021; Figure S2). Among these, previous studies have found both Pondweeds and Stoneworts to be preferred foods among herbivorous wildfowl species (Sparck 1958; Coleman and Boag 1987; Holm 2002; Bailey, Petrie, and Badzinski 2008; Fox and Stipniece 2023; Morkūnė, Bučas, and Morkūnas 2023), and we defined all species in these two groups as preferred available macrophyte food. Although *Elodea* is occasionally taken by mute swans (Bailey, Petrie, and Badzinski 2008), it is not favoured, and because of rapid changes in its availability elsewhere (as well as at Egå Engsø), it is rarely a long-term reliable resource for the birds (e.g., Jernelöv 2017).

2.4 | Statistical Analysis

Trends in numbers of geese and swans were investigated using linear models, and the association between moulting bird numbers and macrophyte cover was tested with Spearman's ρ (Spearman 1904). To test whether the attraction to Egå Engsø was significantly higher than the regional trend in bird numbers, a model with bird numbers as response variable and lake (Egå Engsø or control site) and year as explanatory variables were specified for all three species. The interaction between lake and year was included to test for differences in the development of bird numbers between sites. Analyses were conducted in R 4.2.2 (R Core Team 2022), and graphs were plotted using the package 'ggplot2' (Wickham 2016).

3 | Results

Following the establishment of Egå Engsø, in October 2006, the number of records per year within the moulting season contributing to the analysis varied between 17 and 57 for mute swans, 9–59 for greylag geese and 8–99 for Canada geese (see Table S1). The data demonstrated an increase in the numbers of moulting mute swans ($F_{1,14}=132.3$, $p<0.0001$), greylag geese ($F_{1,14}=363.3$, $p<0.0001$) and Canada geese ($F_{1,14}=26.5$,

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$p = 0.0001$) in the period 2007–2022 (Figure 2). The increase seemed to be more rapid from *c*. 2010 onwards, coinciding with the combined cover of the palatable submerged macrophytes exceeding 25% (Figure 3), most notably associated with the increase in *C. globularis* cover (Figure S2). There was a very highly significant positive association between total preferred macrophyte cover in the lake and total number of moulting individuals among the three focal species (Spearman's $\rho = 0.93$, $p = 0.0009$; Figure 3). In recent years, the increase in numbers of moulting birds levelled off slightly for all three species and numbers of geese have declined slightly in the last 2 years, especially so in the case of Canada Geese.

For all three species, the positive development in bird numbers at Egå Engsø greatly exceeded the development in numbers at the nearby control site Brabrand Sø (all interaction terms with *p*-values of < 0.0001, see Figures S3–S5). Although the numbers of mute swans, greylag geese and Canada geese were similar at the two lakes in the beginning of the time series, numbers at Egå Engsø were manifold higher by the end of the study period (Figures S3–S5).

4 | Discussion

The restoration of Egå Engsø demonstrates that even artificially created lakes in urban environments subject to high levels of zoned human activity can, under appropriate conditions, support moulting wildfowl, despite their habitual avoidance of human disturbance. The success of this area in accommodating geese and swans during the critical time of remigial moult most likely relates to food availability combined with its size and lack of human access to both peripheral meadows and the water surface of the lake. No boats are allowed on the water body, except briefly for the annual monitoring of the ecological interest of the site. All the critical meadow areas used by flightless grazing geese are fenced from the public on the path around the lake and frequent interpretative signs with maps stress the importance of humans remaining away from these areas to maintain the site's ecological integrity. Most importantly, the natural development of a rich submerged macrophyte community and the natural maintenance of a clear shallow water column have ensured ample and stable food resources for feeding flightless wildfowl on the lake. After an initial massive bloom (and subsequent die-off) of *Elodea* during summer in the first few years, the combined cover of palatable submerged macrophytes has stabilised and increased modestly in cover from around 2010 onwards, providing a reliable food resource for vulnerable large-bodied waterbirds committed to flightlessness for several weeks in summer. According to Grøn (2009), the massive breakdown of *Elodea* litter that occurred in winter 2008/2009 following its dramatic and rapid colonisation and disappearance, triggered a collapse of the underwater vegetation at the time, which may have deterred the use of the lake as a moulting site in the subsequent early years. The populations of mute swan, greylag geese and Canada geese may also have taken time to gradually discover the newly established site and assess its suitability as a moulting site, which may have contributed to the lag in the development of moulting numbers immediately after creation of the lake. It is important to note that nationally, autumn numbers of Greylag Geese have been increasing, whereas moulting Canada Geese remain very rare in Denmark and the population of Mute Swans has fluctuated without major change for the last 40 years (Nielsen et al. 2023). The comparison with the nearby control site Brabrand Sø revealed that the increase in numbers of all three species was much higher than what could be attributed to mere regional change, and the restored Egå Engsø can therefore be considered a preferred moulting site for these large-bodied wildfowl species.

Although mute swans and Canada geese rely primarily on macrophytes for foraging, the grazed meadows surrounding the lake are likely most important to greylag geese (Strong et al. 2021). The suitability of the lake as a moulting site for this species therefore relies on continued grazing of the vegetation near the water's edge. Although the area around Egå Engsø is very heavily used for human recreation, all activity is strictly limited to the established path around the lake, which is also fenced to retain grazing animals water-side, and is therefore both constrained at a distance and is very predictable to the birds. Crucially, all water activities (including swimming and sailing) are prohibited in the lake. Moulting wildfowl are known to be highly vulnerable to disturbance, responding severely to human disturbance during the flightless period (Kahlert 2006; Clausen et al. 2020;

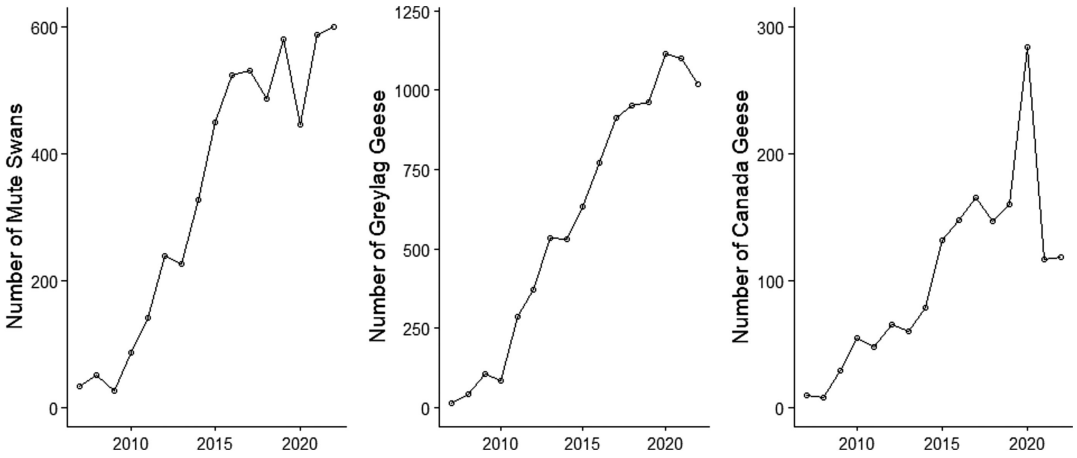


FIGURE 2 | Annual peak numbers of moulting Mute Swans *Cygnus olor*, Greylag Geese *Anser anser* and Canada geese *Branta canadensis* in Egå Engsø, during the period 2007–2022.

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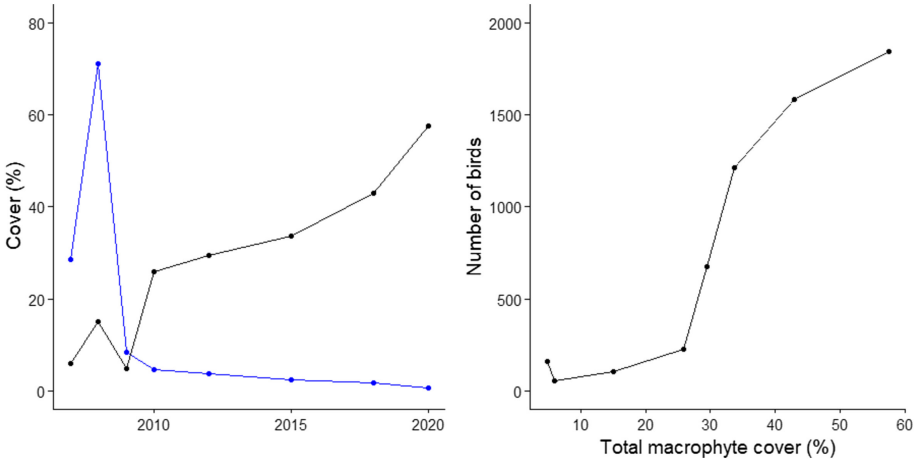


FIGURE 3 | Left: Development in the cover of Canadian Waterweed *Elodea canadensis* (blue) and preferred macrophytes (Pondweeds *Potamogeton* spp. and Stoneworts *Chara* spp., black) in Egå Engsø, during the years 2007–2020. Right: Relationship between total cover of preferred macrophytes and combined annual numbers of moulting mute swans *Cygnus olor*, greylag geese *Anser anser* and Canada geese *Branta canadensis* in Egå Engsø.

Morkūnė, Bučas, and Morkūnas 2023). Part of the success of Egå Engsø in accommodating moulting wildfowl is therefore highly likely to be because of the total lack of disturbance on the water surface and about the majority of its periphery.

Nilsson and Hermansson (2019) described how restoration of the lake Hornborgasjön in Sweden established a new moulting site for up to 28,000 greylag geese, and Egø Engsø supports similar numbers for its open water area (Hornborgasjön is > 23 times larger in a completely agricultural setting) demonstrating that moulting sites can be as effective in a suburban setting given appropriate management. Egå Engsø is currently one of only two sites in Denmark with numbers of Canada geese exceeding 100 individuals during the moulting period (www.dofbasen.dk), and for both greylag geese and mute swans, the number of moulting birds constitute around 1% of national moult totals (Holm et al. 2021). The case proves that, with the correct planning, wetland restoration projects can accommodate multiple (and sometimes seemingly conflicting) societal and nature conservation objectives. Because of the relatively small size of the lake, numbers of moulting wildfowl cannot be expected to continue to grow; hence, the levelling-off in numbers of all three species in recent years may indicate that the carrying capacity is being approached. The site provides an excellent example of how an artificial lake, created for the management of agricultural runoff and flood control, can, with sympathetic grazing and minimal control of heavy recreational use, support highly vulnerable moulting large-bodied waterbirds in an urban setting, with potential application of best practice throughout Europe.

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Ethics Statement

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data on bird numbers and macrophyte cover used for this study are available at the Harvard Dataverse repository on the following link: https://doi.org/10.7910/DVN/9HMUCZ.

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