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RESEARCH

Grazing effects of greylag goose *Anser anser* – a short-term exclosure experiment in beds of common Reed *Phragmites australis* in lake Tåkern, Sweden

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Abstract
Natural wetlands, including reedbed ecosystems, are globally declining in area and quality at an alarming rate. Given their importance for biodiversity and provision of ecosystem services, understanding the causes of reedbed decline is essential for conservation. Previous research shows that grazing by geese can have a strong impact on emergent vegetation in both Arctic and temperate wetlands. In this study, we used exclosures to examine the direct impact of grazing by greylag goose *Anser anser* on common reed *Phragmites australis*, as well as indirect effects on macroinvertebrates, during one season (April–August, 2023) in Lake Tåkern, Sweden. In this eutrophic lake, the number of geese has increased during the last decades, simultaneously with a decline in reedbed area. The experiment revealed significant impacts on reed growth variables already in early June. In open (control) plots, reed shoots were shorter than in the exclosures. This difference remained throughout the season. Moreover, at the end of the experiment, reed biomass was lower and horizontal expansion smaller in the control plots. However, no significant effects were observed for reed stem density, or aquatic invertebrates (number of taxa and total abundance). As the exclosures led to expansion of new reed shoots and higher biomass, we suggest that temporal fencing could contribute to protection and reestablishment of reedbeds in this lake. We also suggest that further studies should explore whether grazing impacts can propagate through the rhizome-connected clonal network, potentially inhibiting neighbouring shoot growth and weakening reed's resistance to herbivory.

Keywords Aquatic macroinvertebrates · Herbivory · Macrophytes · Vegetation · Waterfowl · Wetland

Introduction

Natural wetlands are in long-term decline globally, both in terms of habitat quality and area, with an estimated loss of 411 million hectare (about 22%) since 1970 (Convention on Wetlands 2025). This is concerning given their typically high biodiversity and productivity (Gardner and Finlayson 2018). A common and often dominant species in many wetlands is common reed *Phragmites australis* (hereafter "reed"), a clonal, rhizomatous perennial grass that forms dense stands and can cover large wetland areas (Haslam 1972; Ostendorp 1993). These reedbeds are of special interest as they create a distinct environment at the interface between aquatic and terrestrial ecosystems. Reedbeds do not only provide habitat for a diverse range of species, including birds, fish, mammals, and invertebrates (Valkama et al. 2008; Sarneel et al. 2014; Andersen et al. 2021), but also important ecosystem services, such as carbon fixation, soil formation and stabilization, nutrient cycling, and water filtration (Haslam 1972; Ostendorp 1993; Bakker et al. 2018). Although common and characteristic of many wetlands in the northern hemisphere, there is a growing concern about the degradation of reedbeds, which has been reported in many sites since the late 20th century, including

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in Europe. There is no consensus on the explanations to the phenomenon, which is called “reed die-back” (van der Putten 1997), but suggestions include eutrophication, climate change, shoreline changes, wave erosion, and insect and fungal pests (Ostendorp 1999; Armstrong and Armstrong 2001; Vermaat et al. 2016; Packer et al. 2017; Dosdall et al. 2018; Gaberščik et al. 2020; Ojdanič et al. 2023). Among other potential causes of reed degradation, increasing populations of grazing mammals (e.g. muskrat *Ondatra zibethicus*) and waterfowl (e.g. greylag goose *Anser anser*) have received growing attention in recent years (Vermaat et al. 2016; Bakker et al. 2018).

In general, species diversity contributes to maintaining ecosystem functioning and structure (Naeem et al. 2009; Şekercioğlu et al. 2016). However, when one species becomes overabundant, it can lead to adverse ecological and socioeconomic impacts, exemplified by growing populations of geese in Northern Europe and North America (Ankney 1996; Nilsson 2002; Fox et al. 2017). The increase in goose numbers likely has multiple causes, but is believed to be mainly attributed to a shift in foraging habits, from the utilization of natural habitats in the vicinity of wetlands, to pasture and crop lands in agricultural landscapes (Jefferies et al. 2003; Buij et al. 2017; Fox and Madsen 2017). In addition, greater protection of species (e.g. through hunting restrictions) and their habitats (e.g. establishment of protected areas) have likely contributed to population increases (Fox and Madsen 2017). In combination with climate change effects, this has resulted in larger summer populations and being more sedentary at sites that were previously used only for wintering (Feige et al. 2008; Klok et al. 2010; Dessborn et al. 2016; Buij et al. 2017).

Previous studies on goose grazing have documented strong impacts on wetland vegetation in some Arctic tundra regions (Abraham and Jefferies 1997; Jefferies et al. 2003). In temperate wetlands, several studies suggest that waterfowl generally have a negligible effect on vegetation, except when vegetation is sparse or where herbivore densities are high (Marklund et al. 2002; Chaichana et al. 2011). In such cases, grazing, grubbing, and trampling by geese can significantly alter vegetation structure, reduce plant biomass, and affect species diversity (Gauthier et al. 2004; Chaichana et al. 2011; Fox et al. 2017; Bakker et al. 2018; Tombre et al. 2019). Moreover, impact may also include indirect cascading effects on invertebrates (e.g. Sherfy and Kirkpatrick 2003; Flemming et al. 2022). Some aquatic ecosystems, such as smaller shallow lakes and surrounding wetlands, seem to be particularly susceptible (Dessborn et al. 2016; see also review by Bakker et al. 2016). However, the findings are not consistent across regions, and differences between Arctic and temperate systems may partly reflect uneven research efforts, with more studies from temperate areas. In fact, according to a systematic review by Wood et al. (2017), there is no general effect of latitude on the magnitude of herbivore impacts (including geese) on macrophyte biomass in aquatic ecosystems.

In wetlands, alterations in vegetation structure directly affect the feeding and nesting habitats of waterbirds (Smart et al. 2006; Beemster et al. 2010), while also indirectly influencing nutrient cycling and overall ecosystem functioning (Nishizawa et al. 2021). Waterfowl can additionally impact water quality by redistributing nutrients through guano deposition (Kitchell et al. 1999; Green and Elmberg 2014; Fox and Madsen 2017; Adhurya et al. 2020). In nutrient-rich wetlands, high densities of geese can thus lead to further increase in nutrient levels, algal blooms and oxygen depletion, which in turn may result in adverse effects for macroinvertebrates and other aquatic organism groups (Dessborn et al. 2016; Buij et al. 2017; Wang et al. 2021). However, some research suggests a positive correlation between geese abundance and macroinvertebrate richness and abundance, which may reflect shared habitat preferences rather than enhanced environmental conditions for invertebrates (Jensen et al. 2019; Gunnarsson et al. 2024). Macroinvertebrates are integral components in reedbed ecosystems (Kornijów et al. 2021), influencing decomposition and thus nutrient cycling within reedbeds and serving as prey for both waterfowl and reed dwelling birds (e.g. Cooper and Anderson 1996; Covich et al. 1999; Silver et al. 2012). The taxonomic and functional composition of macroinvertebrates may differ within reedbeds, depending on e.g. reed stem density, water depth, oxygen concentration, nutrient levels, and proximity to the shoreline or open water (Kornijów et al. 2021). It is therefore likely that grazing may indirectly affect ecosystem processes and biodiversity through habitat alteration.

Lake Tåkern, located in south-central Sweden is recognized for its high biological diversity and importance as a staging and breeding site for birds, with 270 bird species recorded and about 100 confirmed nesting (Ramsar 2017b). Among these is the greylag goose, which occurs at the lake in high numbers during most parts of the year. For example, 29,000 individuals were counted at the lake in early September 2021, which is the highest number so far recorded at a single location in Sweden (Bergner and Gezelius 2022). Due to its ecological importance, the lake is protected as both a Ramsar site and part of the Natura 2000 network (European Commission 2007; Ramsar 2017b). A large part of the lake is covered by reedbeds, but have been reported to decline markedly in recent decades. Spatial and temporal overlap with growing numbers of greylag goose has led to the hypothesis that their grazing may be a major driver of reedbed decline (Bergner and Gezelius 2022), although direct experimental evidence is lacking.

The aim of this study is therefore to experimentally examine short-term effects (one breeding season) of greylag goose grazing on common reed, a key structural species in the reedbeds of Lake Tåkern. In addition to reed-specific responses, the study also examines impacts on aquatic macroinvertebrates. We hypothesize that goose grazing negatively affects reed shoot growth and indirectly reduces macroinvertebrate abundance and richness.

Methods

The study site

Lake Tåkern is a 44 km^2 shallow, moderately eutrophic lake in the county of Östergötland, south-central Sweden (58° 21’ N, 14° 48’ E; Fig. 1; Ramsar 2017b). Although several goose species are regularly observed at the lake, greylag goose is the most numerous one, also in terms of breeding number (Gezelius et al. 2022). The lake and its surroundings provide high quality feeding habitats sustaining substantial numbers of greylag geese during a large part of the annual cycle. In line with a general trend in Northern Europe (Fox and Madsen 2017), numbers of greylag goose in Lake Tåkern have increased during the last decades. This is evident when analysing annual monitoring data from Tåkern Field Station, collected consistently since 1998 in standardized point counts around the lake, recording morning flights from the lake roost to surrounding farmland (Fig. 2). In autumn and mild winters the geese mostly forage in adjacent fields, whereas they use meadows close to the lake during the breeding period in spring and summer. Here, the number of greylag goose often exceed ten thousand (including moulting birds; Gezelius et al. 2022).

Reedbeds are characteristic of Lake Tåkern, covering more than 30% of the lakes surface. Its degradation in cover in recent decades, as suggested by Bergner and Gezelius (2022), also appears by analysing (Image J, v. 1.8.0, 2023) georeferenced high-resolution satellite TIFF images of four larger reedbeds around the lake during 2004–2022 (Fig. 2, Appendix 1).

No mammalian herbivores are known to utilize the reedbeds in Lake Tåkern as a food resource. Wild boar (*Sus scrofa*) frequently occurs in the reedbeds, but do not graze on it. Based on recent data collected in a standardized gill net survey (EN 14757), the fish community is dominated by perch (*Perca fluviatilis*) with a relative abundance of 54% (Skog 2020). Among other species, none are strict herbivores, although omnivorous cyprinids such as roach (*Rutilus rutilus*, 16%) and rudd (*Scardinius erythrophthalmus*,

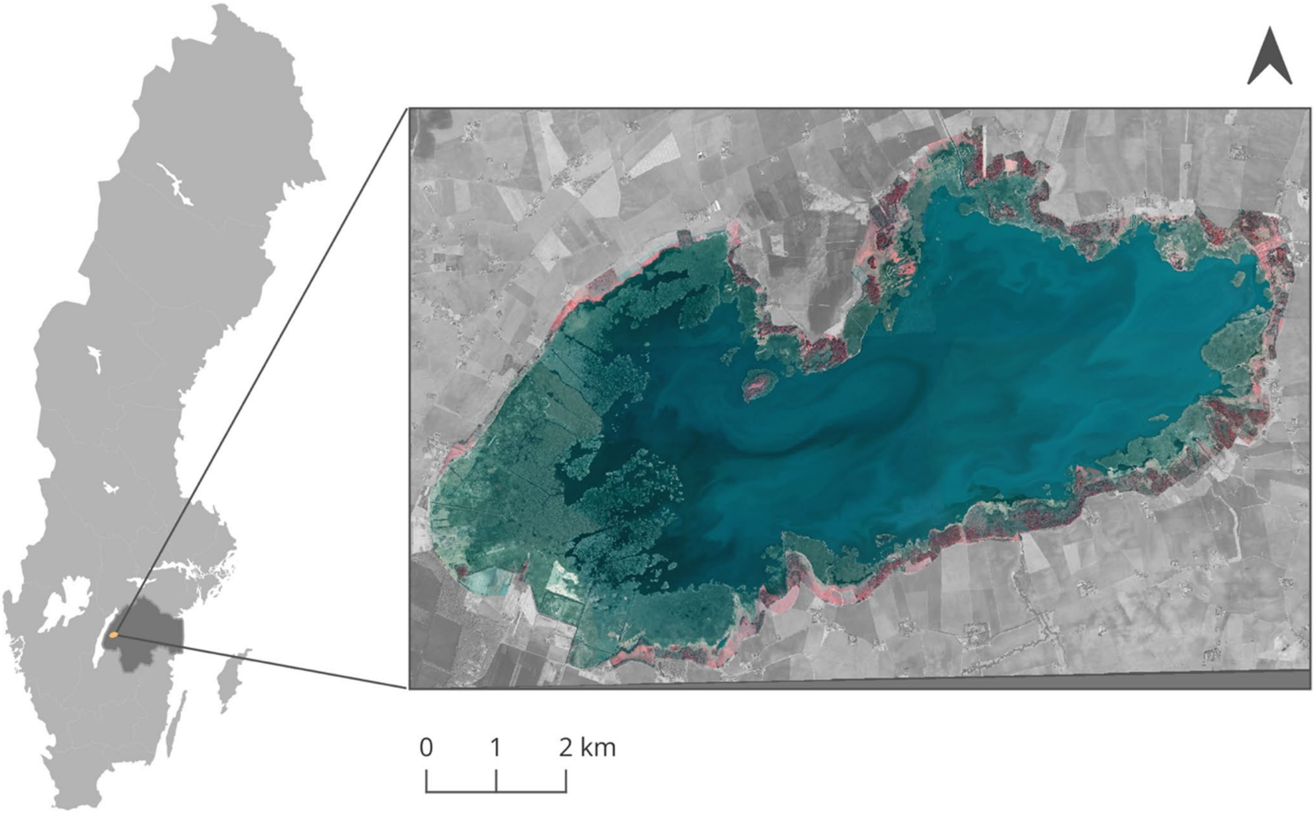


Fig. 1 Location of Lake Tåkern in south-central Sweden. The study area was in the southern part of the lake (see also Fig. 3). ©Lantmäteriet, SWEREF 99 TM, 2025

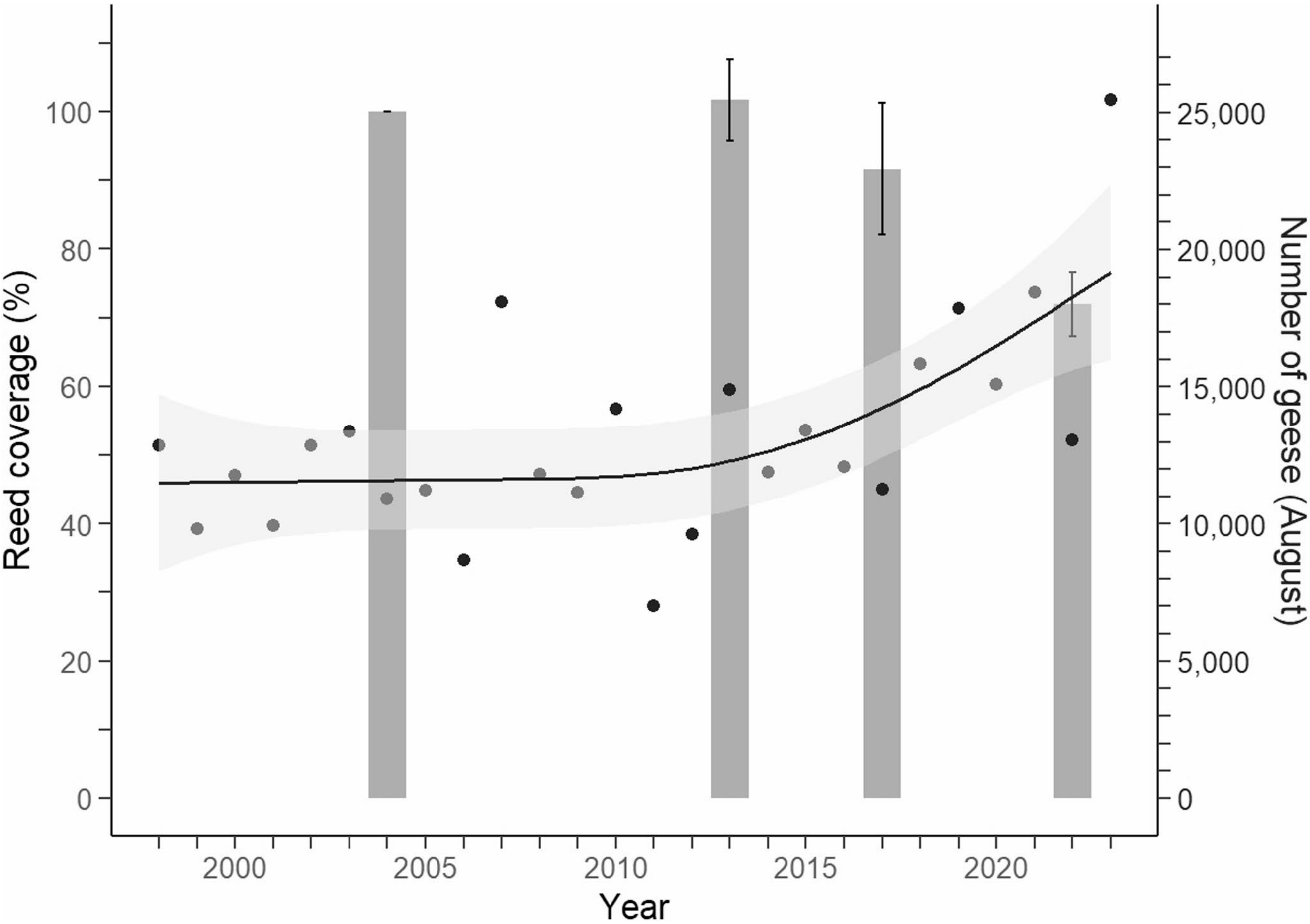


Fig. 2 Goose numbers (dots) and reed cover (bars) at Lake Tåkern during the last decades. Annual goose data were collected in August, and Kendall's rank correlation confirms a significant increase over the years ($\tau=0.38$, $n=26$, $p=0.005$) (trend line is generated as a generalized additive model). Reed cover values are means (with SEM), based on four larger reedbeds around the lake (Appendix 1) assessed in four years, and expressed as percentages relative to 2004 set as 100%. See main text for details

9%) occasionally consume macrophytes (Brabrand 1985; Johansson 1987). As our experimental design (see below) allowed fish access, any potential effects of fish grazing are assumed to be similar between treatments.

Field exclosure experiment

Experimental design

Eight exclosures were established between April 21 and 28 in 2023 to exclude waterfowl, each paired with a corresponding open (control) plot that allowed full access to waterfowl. The exclosures were placed within the experimental area, along a 1.5 km reedbed stretch near the bird-watching tower at Glänås, in the southern part of the lake (Fig. 3). Selection of sites for excloures and controls was based on accessibility from a boat and the presence of a relatively straight, homogenous reedbed edge, enabling accurate estimates of reed horizontal expansion distance by the end of the experiment (see below). Common reed dominance was consistent across all sites, with presence of sparsely occurring reed sweet-grass *Glyceramaxima*, lesser bulrush *Typha angustifolia* and branched bur-reed *Sparganium erectum*.

The exclosures measured 3 × 2 m and extended at least 1 m above the water surface to prevent waterfowl access (Fig. 4). They reached downward to approximately 10 cm above the sediment, allowing fish to pass below, but excluding e.g. diving ducks and rails, which were never observed inside, confirming effective exclusion. The exclosures were constructed from plastic netting (mesh size: 19 × 19 mm) attached to four wooden poles (45 × 45 mm), one at each corner. Each exclosure was set out across the reedbed edge, resulting in one half of the cage enclosing reedbed and the other half open water. To deter birds from landing within the exclosures, two red-and-white plate bands were suspended diagonally across their top (Fig. 4).

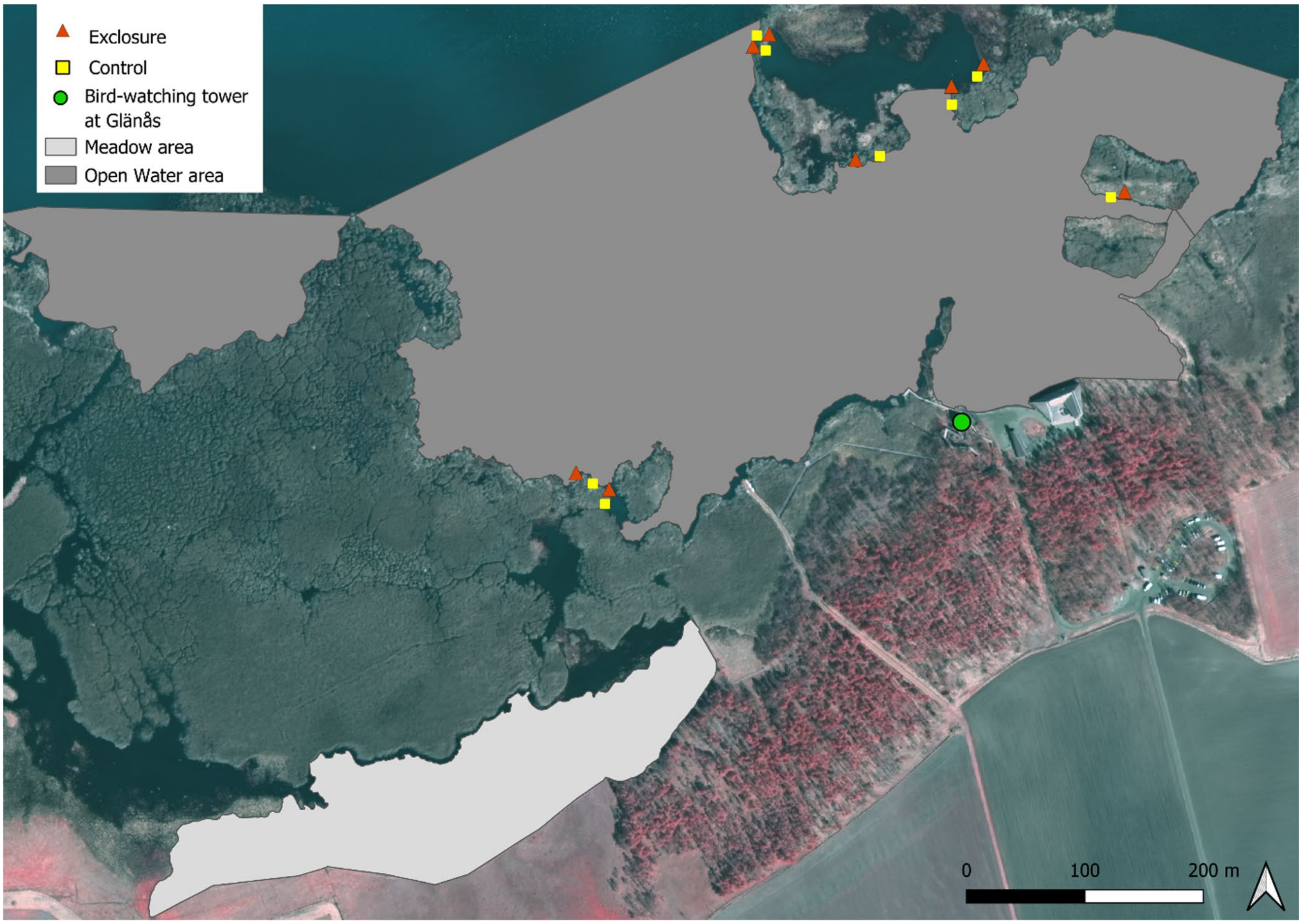


Fig. 3 Bird counting areas and exclosure locations in the southern part of Lake Tåkern. Two areas were selected for bird counting, an open water area and a meadow area. The former also includes the positions of the eight exclosure and control pair plots used for reed and macroinvertebrate sampling. Digitala Kartor och Geodata, slu.se, 2025

Control plots were positioned 5–20 m from the exclosures and marked with two poles spaced 2 m apart at the reedbed edge, thus corresponding to the midpoint of an exclosure, but without any fencing, leaving the area fully accessible to birds.

Sampling, as described below, was done on June 1, July 26, and August 27–28 in 2023, and thus covered the breeding, moulting, and post-moulting periods of geese.

Reed sampling

Reed stem density (i.e., number of current-year shoots) was estimated using five quadrats (0.5 × 0.5 m) placed within the sampling area at each exclosure and control plot, considering potential edge effects (Fig. 4). Quadrats were placed arbitrarily within the designated area, covering open water and occasionally capturing the transition zone from dense reed to open water, but not extending more than 0.5 m into the reed edge. In each exclosure and control plot, ten standing shoots (i.e., excluding long fallen shoots) were measured to the nearest millimetre from the sediment surface to the tip to estimate average height. Mean values of stem density and height were used in subsequent analyses.

In addition to reed height and density, the assessment included measurements of horizontal shoot expansion over the course of the experiment. At each exclosure and control plot, the distance from the reedbed edge to the most distant new shoot was measured on June 1 and again at the final sampling on August 27. Horizontal expansion was calculated as the difference between these two measurements. Only shoots established within the plot boundaries were considered, limiting the maximum measurable expansion to 150 cm.

To document standing biomass of annual reed shoots at the end of the experiment, all such stems within two diagonally positioned 0.5 m^2 quadrats, one located in the reedbed part and the other in the open water part of each exclosure and control plot (Fig. 4c), were harvested on August 28. All stems within each quadrat were cut at the sediment surface using secateurs and then dried at 70 °C for 48 h (Termaks

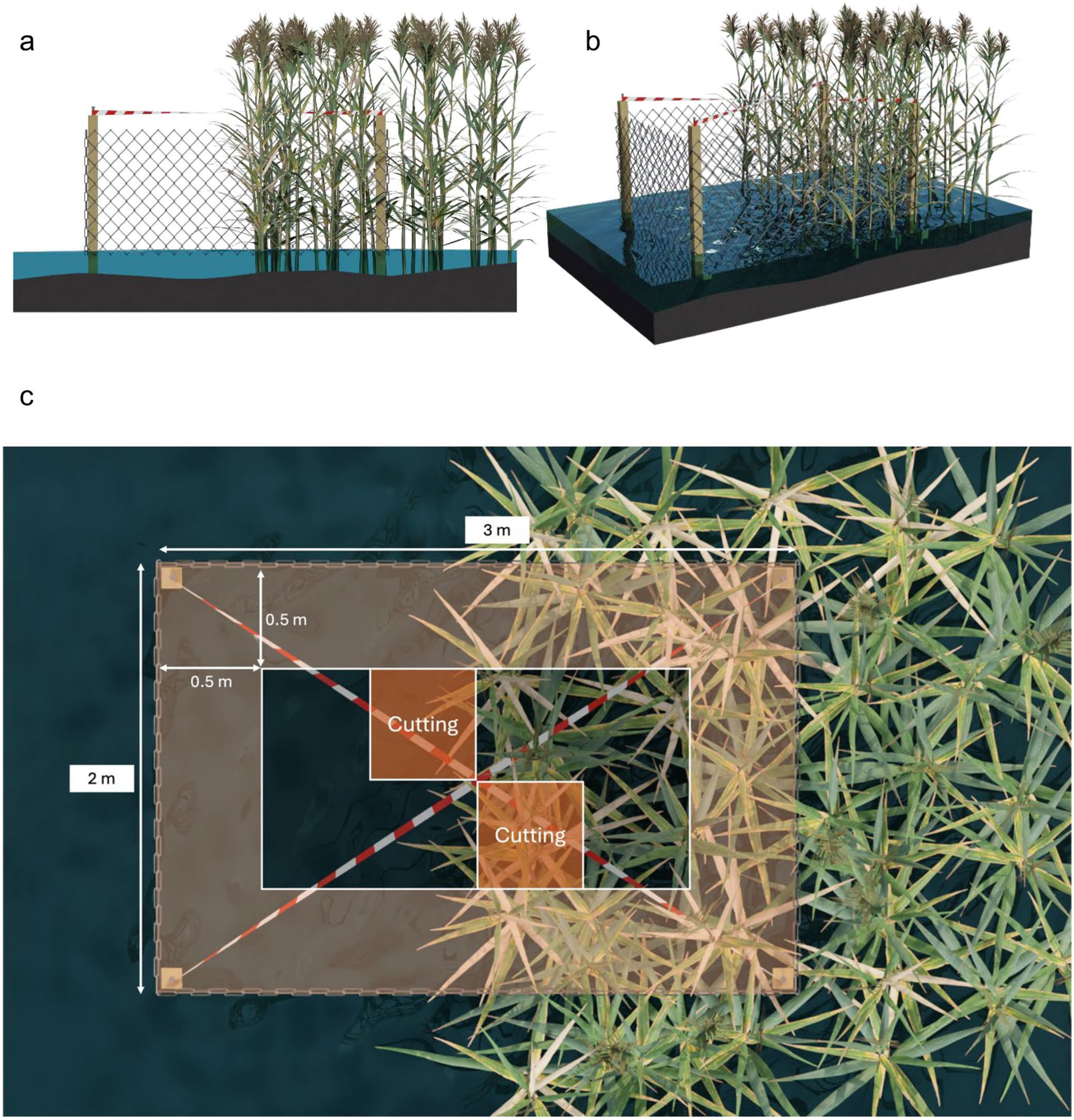


Fig. 4 Design of the exclosures used in the study. (**a**) Side view; (**b**) Three-dimensional view; (**c**) Top view; sampling area is the inner darker area (2 × 1 m), excluding a 0.5 m strip from the net to mitigate edge effects, and with sampling quadrats for biomass measurements ("Cutting") outlined

drying oven, model TS 8136) or until mass was constant (Sartorius scale, model BP 3100 S).

Aquatic macroinvertebrate sampling

Sampling of aquatic macroinvertebrates followed the method proposed by Murkin et al. (1983) and modified by Elmberg et al. (1992), in which activity traps are used to collect nektonic invertebrates. The trap consisted of a one-litre glass jar fitted with a plastic funnel measuring 100 mm at the large opening and 20 mm at the narrow end. To match the peak of waterfowl using invertebrates as prey, and to be comparable to similar studies (e.g. Elmberg et al. 1992), data collection was carried out on June 1, when two traps were placed within the sampling area of each exclosure and control plot, at a median depth of 27 cm. All traps were oriented with the funnel opening parallel to the reed edge, facing the same direction across all plots. After 48 h, traps were retrieved and the invertebrates preserved in 70% ethanol before transport to the laboratory for classification and counting. Mean values from the two traps in each exclosure and control plot were used in subsequent statistical analyses.

A previous study (Kornijów et al. 2021) has shown that even when analyzed at low taxonomic resolution, macroinvertebrates in reedbeds can be used to examine local differences in diversity, relative abundance of individual taxa and total density. The collected invertebrates were thus identified to the family level for insects, crustaceans, leeches and snails, class for ostracods (Ostracoda), and subclass for mites (Acari) and worms (Oligochaeta) (see complete list of protocol taxa in Appendix 2, modified from Nudds and Bowlby 1984).

Waterfowl counts

To gather descriptive information about the waterfowl community at the study site (i.e., not to be analyzed statistically), monthly counts were done from April to August 2023 in two distinct areas in the southern part of the lake: a 3.9 ha meadow in the blue border, and a 15.3 ha open water area; with observations made from a trail and bird tower, respectively (Fig. 3). The point count method followed the protocol described by Koskimies and Väisänen (1991). The surveys revealed that greylag goose was the most abundant waterbird, with maximum numbers observed in June. Other observed waterbirds, in descending order of abundance, included gadwall *Mareca strepera*, Eurasian coot *Fulica atra*, common pochard *Aythya ferina*, mute swan *Cygnus olor*, tufted duck *Aythya fuligula*, and mallard *Anas platyrhynchos* (Appendix 3).

Statistics

All statistical analyses and visualizations were conducted using R software (version 4.5.0). Paired analyses (t-test or Wilcoxon) were used to assess differences between exclosures and their matching control plots, with separate tests conducted for each sampling period. The variables assessed included reed height, reed density, reed biomass, number of macroinvertebrate taxa, and macroinvertebrate abundance (for all taxa pooled, as well as for the most common taxa, defined as those occurring in at least half of exclosure/control pairs). The assumption of normality of differences was met in all cases, as evaluated by Shapiro-Wilk test, except for abundance of invertebrates, for which Wilcoxon paired test was applied.

Results

Reed height, density, expansion and biomass

Reed stems were significantly taller in the exclosures than in the control plots (Fig. 5). Already in June, reed in exclosures had a greater height and this difference remained significant in the two subsequent months. In late July, the differences in reed height became more pronounced. By August, however, the median reed height had decreased slightly in both control and exclosure plots, with increased variability, particularly in the exclosures, as indicated by lower medians and larger interquartile range compared to the previous sampling occasions.

The medians of reed stem density were higher in exclosures than in the control plots throughout the season. However, these differences were not statistically significant (Fig. 6).

The comparison of reed horizontal expansion distance showed that excluding waterfowl had a significant positive effect (t = −2.31, $n=8$, $p=0.036$), being greater in exclosures (median = 98 cm, IQR = 74) than in control plots (median = 50 cm, IQR = 120). The horizontal expansion of the reed in the exclosures could have been wider, if not restricted by the maximum reach of the cages at 150 cm from the reedbed edge, and the effect of grazing is thus likely underestimated.

At the end of the experiment, significantly higher reed dry weight biomass was noted in the open water part of the exclosures, being almost seven times greater than in the control plots. In contrast, biomass in the reedbed part was not significantly different between exclosures and control plots (Fig. 7).

Number of taxa and abundance of aquatic macroinvertebrates

The number of macroinvertebrate taxa did not differ between exclosures (median = 7.5, IQR = 4.0) and control plots (median = 7.5, IQR = 3.0; t = 0.25, $n=8$, $p=0.811$). The same holds for the total abundance of invertebrates, with equal numbers for exclosures (median = 40.5, IQR = 36.8) and control plots (median = 36.8, IQR = 29.5; Z = −1.26, $n=8$, $p=0.208$). Separate analyses of the most commonly occurring taxa did not reveal in significant differences either (Appendix 4).

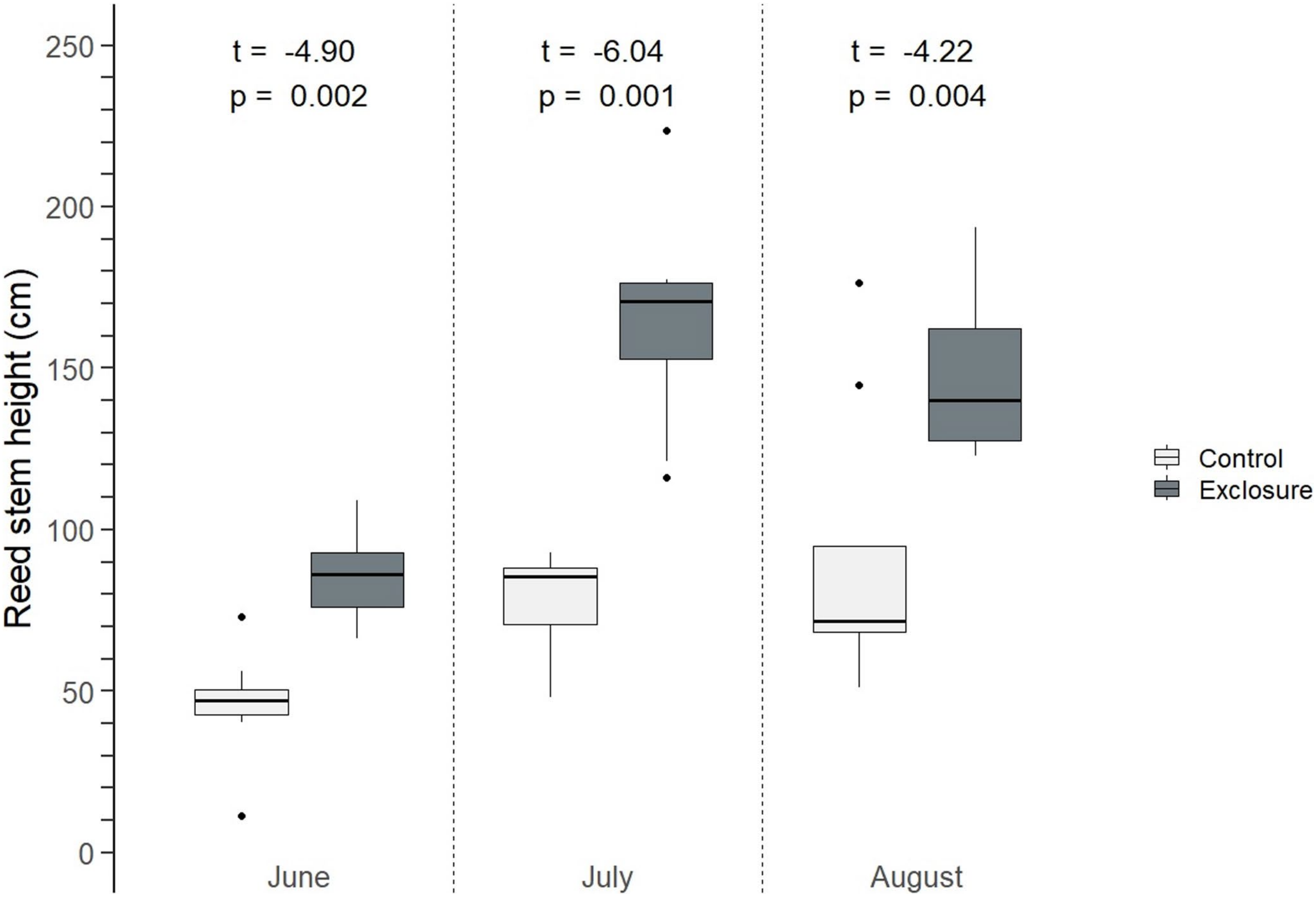


Fig. 5 Reed stem height (cm) on three sampling occasions (June 1; July 26; August 27) in exclosures and control plots. Pairwise t-test results are presented atop the graphs; *n* = 8

Discussion

The experiment revealed significant effects of geese grazing on reed stem height, horizontal expansion, and standing biomass at the end of the study. Although we did not study reedbed area per se, these findings align with similar previous studies (van den Wyngaert et al. 2003; Bakker et al. 2018; Reijers et al. 2019), supporting the suggestion that increasing goose populations have played a role in the reduction of reedbeds in Lake Tåkern in recent decades (Bergner and Gezelius 2022).

Grazing effects were noted already at the first sampling in early June and appeared even stronger in July, after which they stagnated. The latter may partly be explained by the fact that long fallen stems, observed to be more common in August, were left out. Yet, lower grazing effects during the season is consistent with observations of decreasing goose numbers towards the end of the summer and with previous research (Haslam 1969; Hudec 1973). Such early-season grazing is largely driven by the high nutritional value and accessibility of young reed shoots, which are green, soft, and nutrient-rich (Bakker et al. 1999; Reijers et al. 2019). As the season progresses, the shoots become taller, denser, and accumulate silica, a known herbivore deterrent, reducing their palatability (Hwang and Metcalfe 2021).

Interestingly, grazing by geese has been shown by van den Wyngaert et al. (2003) to result in increased net productivity of reed shoots. In their study, grazing led to less bottom substrate in terms of organic debris, in contrast to ungrazed areas where dead leaves and culms of reed accumulated, lowering the oxygen level in the water and sunlight availability. Similar results are reported from a study on effects of winter harvest of reed in Lake Tåkern (Hansson and Granéli 1984), in which the removal of culms and leaves from the previous season reduced the amount of decomposing debris and resulted in increased shoot density and higher biomass the following year.

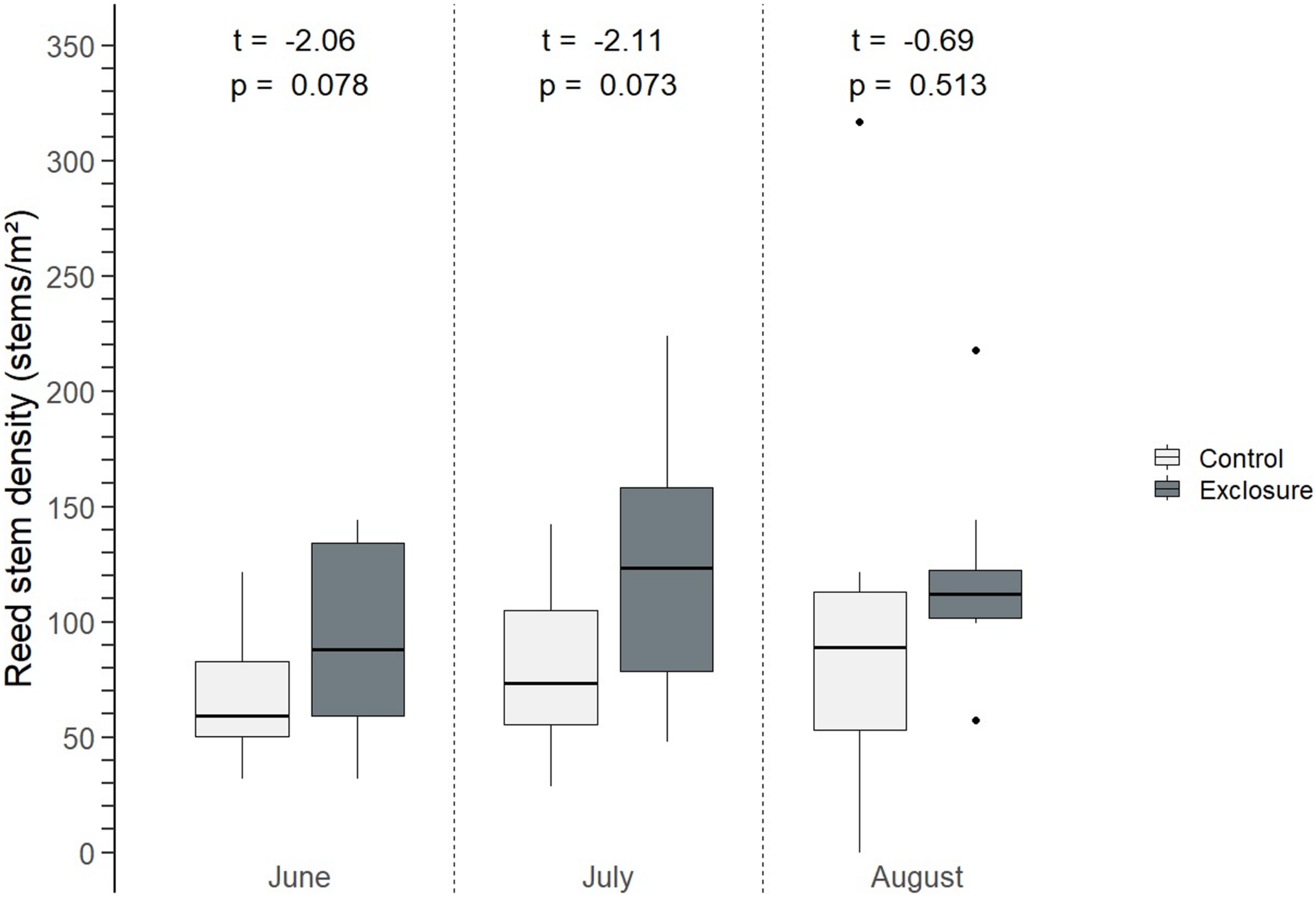


Fig. 6 Reed density (stems/m²) on three sampling occasions (June 1; July 26; August 27) in exclosures and control plots. Pairwise t-test results are presented atop the graphs; $n = 8$

However, in the present study, there were no indications of compensatory growth in the grazed plots, as indicated by similar densities between treatments and lower values for height and standing biomass in the control plots than in the exclosures. Concerning reed height, we noted *a posteriori* that even ungrazed shoots, i.e., when analyzed separately from grazed shoots, were lower in the control plots than in the exclosures throughout the season ($n = 8$, $p \leq 0.029$). This is intriguing, and we suggest such reduced growth could be a result of declined energetic status. We base this suggestion on previous results from experimental cutting of growing reed, indicating that effects of grazing are likely to depend on its timing, frequency, whether stems are grazed below or above the water surface, and the physiochemical characteristics of the sediment in which the reed is growing (Weisner and Granéli 1989; Hayball and Pearce 2004). Cutting stems below the water surface blocks oxygen translocation from stem and leaves to the belowground rhizome. Cutting above the surface, which is relevant for simulation of grazing by geese, has less impact on oxygen translocation, but the outcome depends on sediment characteristics. In reed growing in sediment with low redox potential (i.e., organic and nutrient rich), translocation of oxygen is blocked and growth therefore reduced (Weisner and Granéli 1989). Hypothetically, in the present experiment, reduced growth of ungrazed stems in the control plots could thus have resulted from low oxygen in adjacent, physiologically connected, rhizome. Low oxygen stress is likely to be more pronounced early in the growing season, when growth rate is at its maximum and stored energy is at its minimum (Weisner and Granéli 1989; Granéli et al. 1992). However, without data on redox potential in the sediment in the present study, the causal relationship behind oxygen stress and the indirect effects on growth of ungrazed shoots become speculative. Yet, the study lake in Weisner and Granéli (1989), the eutrophic Lake Krankesjön in southern Sweden (Ramsar 2017a), showing low

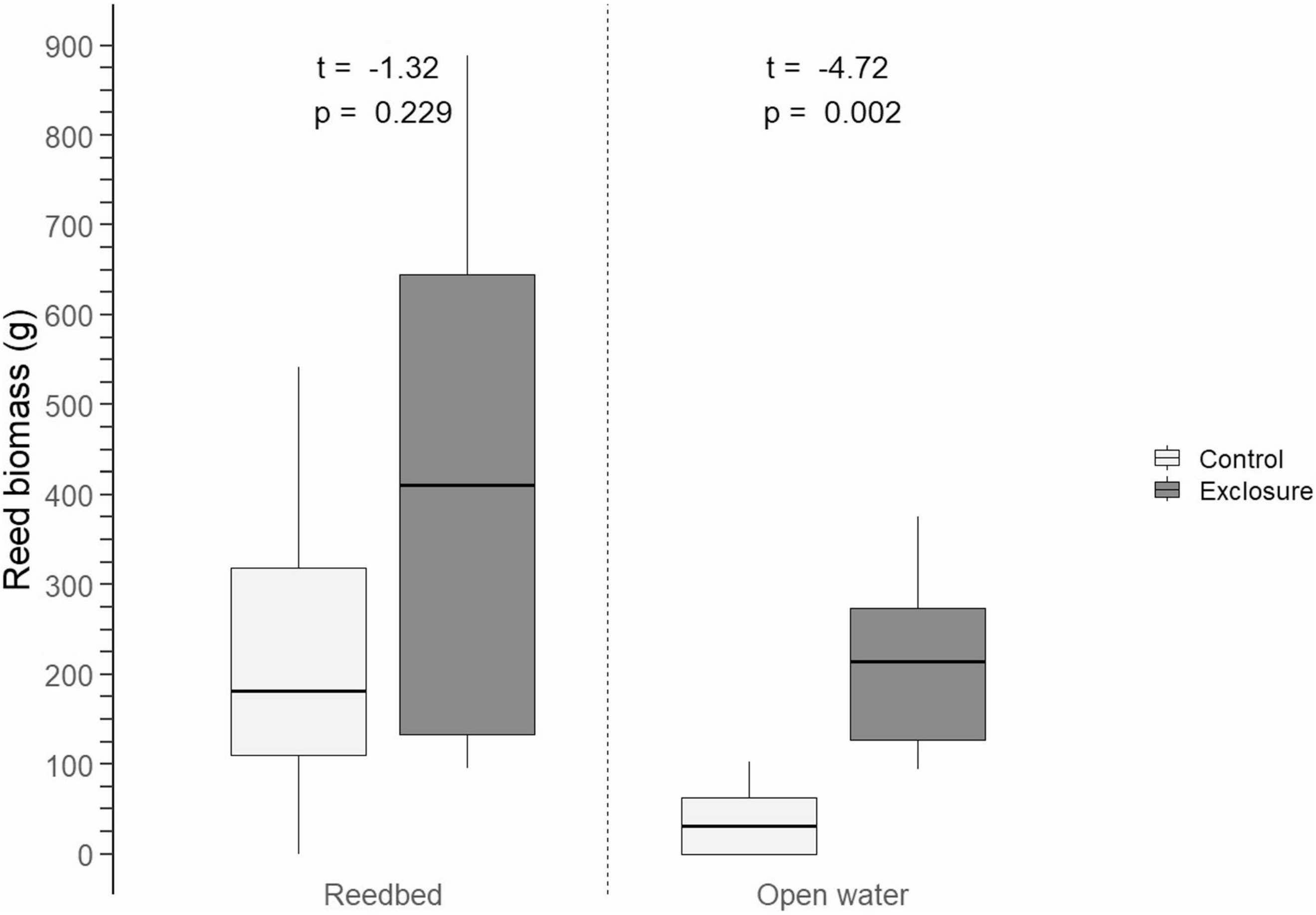


Fig. 7 Dry weight biomass of reed biomass at the end of the experiment on August 28, in two parts of the exclosure and control plots, i.e., reedbed half and open water half. Pairwise t-test results are presented atop the graphs; $n = 8$

redox potential of its sediment, is similar to Lake Tåkern regarding water chemistry and plant species composition (Blindow et al. 1993). Furthermore, a study on effects of winter harvest on subsequent reed growth was conducted by Hansson and Granéli (1984) in Lake Tåkern at a site close to the present study location. During summer, their results showed diurnal fluctuations in oxygen and redox potential in the water within the control area, and usually negative redox potential in the sediment, indicating a chemically reducing environment. If such reducing conditions for reed roots and rhizome also prevail at the study area in the present study, this could hence explain the lack of compensatory growth in terms of shoot density, stem height and final standing biomass.

That significant grazing effects were not detected for all variables may be linked to the fact that our study was short-term, and the lack of a significant effect on reed density thus suggests that such rhizomatous plants may require longer periods to show measurable changes in this variable. This aligns with findings by Bakker et al. (2018), who reported that it took two years of goose exclusion before reed density differences became apparent. Likewise, early summer cutting of new reed stems was shown to reduce growth in the following year for reed growing in the organic sediment of Lake Krankesjön (Weisner and Granéli 1989). This implies that in a eutrophic wetland like Lake Tåkern, evaluation of management should proceed over several years, even if actions intended to protect reed are implemented only for a shorter period.

While no signs of compensatory growth were detected in the present study, it remains possible that such responses occur under different conditions. For instance, previous studies have found that reed harvest can stimulate the development of secondary shoots (Björndahl 1985; Engloner 2009). Other potential long-term consequences include reduced reproductive success. In fact, repeated cutting, like frequent grazing, can prevent inflorescence development (Kulik et al. 2023), thereby reducing seed production and limiting the capacity for sexual reproduction. Although reed primarily reproduces vegetatively, sexual reproduction remains important for dispersal and maintaining genetic diversity (Engloner 2009). In this context, stem height, being affected by grazing in our study, may be of significance too, as taller stems have been documented to have greater potential for seed germination, competitive success, and biomass (McKee and Richards 1996; Gaberščik et al. 2020).

There are likely several causes behind the profound reduction in reed biomass outside the established reedbed as revealed by our results. Besides what has been suggested above regarding translocation of oxygen, another obvious reason is that grazed stems in the open areas outside the reedbed edge did not appear to increase in height after the grazing event, as judged by similar values recorded from June to August (Appendix 5). In other words, when the geese graze the most edible top, they also remove the growth zone of the straw, thus affecting biomass.

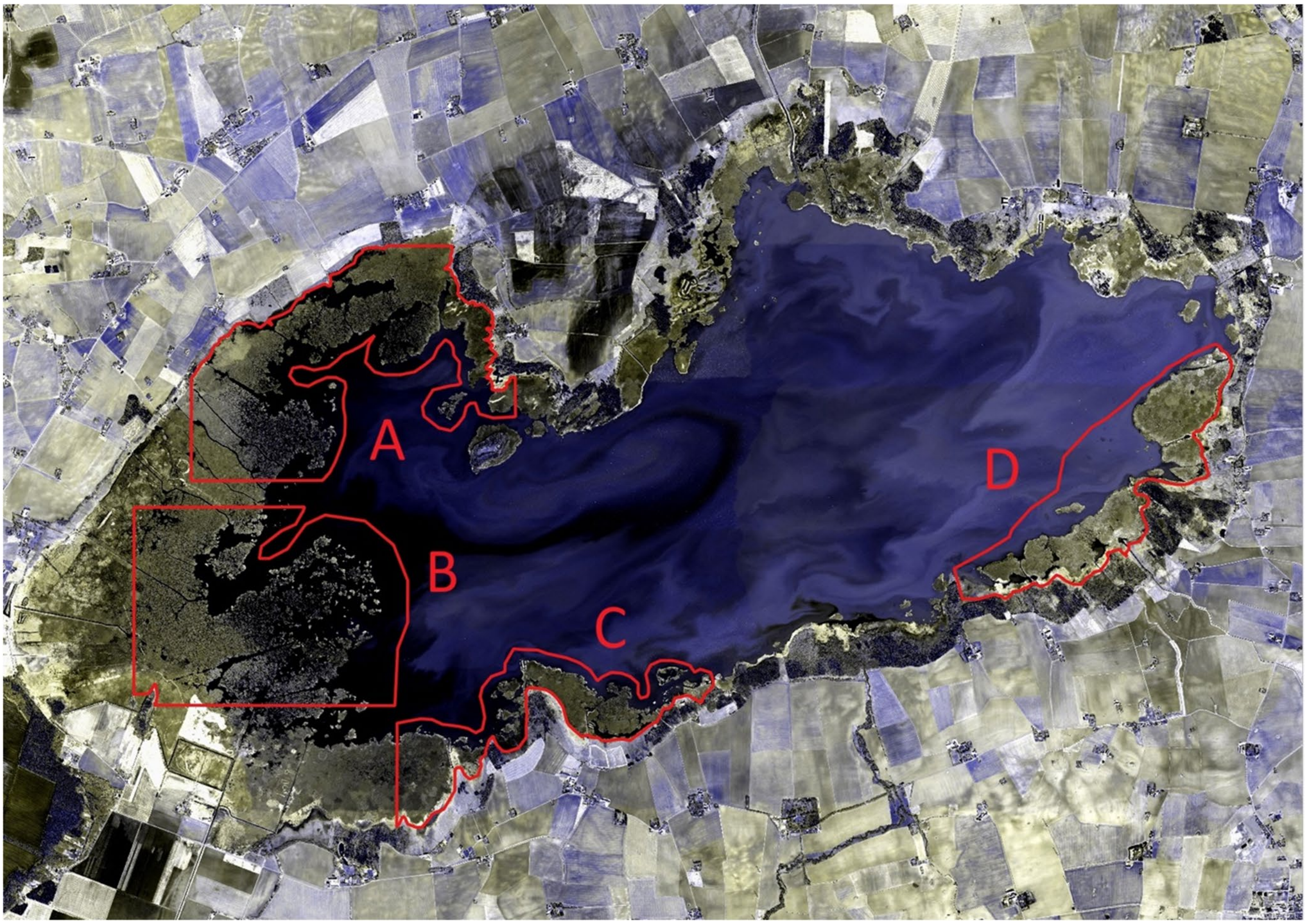
In contrast to the effects on reed growth and biomass, the exclusion of geese did not significantly affect the number of taxa or the abundance of aquatic macroinvertebrates. This result appears to contradict previous findings by Gunnarsson et al. (2024), which showed a positive correlation between the presence of geese and invertebrate richness and abundance, suggestively by indirectly altering habitat structure and nutrient dynamics. Differences in study design, environmental context, or timescale could explain these discrepancies. Still, there is previous research suggesting a minor impact of waterfowl on macroinvertebrates (Marklund et al. 2002). On the other hand, the timescale may indeed be an important factor in this case, as grazing has been suggested to initially alter habitat structure and nutrient dynamics, which may subsequently contribute to eutrophication and affect invertebrates (Vickery 1999; Wang et al. 2021). Macroinvertebrates are indeed an integrated organism group in reedbeds (Kornijów et al. 2021). We therefore call for further research specifically focusing on long-term studies of indirect effects associated with reedbeds and their macroinvertebrate communities.

A long-term decline in reedbeds will likely result in altered composition of organism groups that are fundamental to the goals of preserving many wetlands (Graveland 1998; Beemster et al. 2010; Voslamber and Vulink 2010). Based on the results of the present study, not least the ability of reed to occupy new areas when grazing is removed, temporal fencing of selected reedbed areas may be useful to counteract such trends. In particular, it may be of interest to examine whether a relatively short period of protection from grazing in early summer, when grazing pressure is highest, would be sufficient for reed shoots to reach a height and accumulate enough silica to become less vulnerable to grazing. In this context, it is also important to consider aspects linked to other birds and local conditions. For example, in the present study area, high grazing pressure observed in early summer was likely due in large part to moulting non-breeding birds, which may have been displaced from adjacent meadows by breeding geese, as noted in other studies (Fox et al. 2014; see also Brides et al. 2019).

The decline of reedbeds often refers to a shoreward regression of the outer bed edge, bordering open water (Engloner 2009; Oteman et al. 2021). Aerial photos of the reedbeds of Lake Tåkern covering the last decades, however, also show a long-term process, including degradation of the bed structure, going from apparently homogenous to increasingly fragmented mosaic structures and, finally, a complete loss of reed vegetation in some areas (Bergner and Gezelius 2022; cf. also Fig. 2). The significant impact of goose grazing on reed in our study highlights the capacity of reed to thrive in the absence of grazing pressure. This finding has important implications for reedbed management, as it suggests that protecting certain areas from grazing could enhance reedbed recovery and help reinstate their ecological functioning and provision of essential ecosystem services (Haslam 1972; Ostendorp 1993; Bakker et al. 2018). In this context, it is important to mention that, although reedbeds provide important values, these must be balanced against the needs of other species that depend on open water habitats. For example, although reed expansion may benefit species like the bearded reedling (*Panurus biarmicus*; Beemster et al. 2010), it could negatively impact shorebird populations that rely on open water areas for nesting and foraging (Smart et al. 2006; Buij et al. 2017).

In conclusion, this study highlights the significant impact of greylag goose on reedbeds in Lake Tåkern, emphasizing the need for integrated conservation strategies to address both grazing pressure and environmental stressors. While short-term effects on reed height, expansion and biomass were evident, the potential for systemic impacts via the rhizome-connected clonal network, suggested by reduced growth even in ungrazed shoots, as well as cascading effects on fauna, warrants further investigation. Such mechanisms may reduce reed's resilience and long-term ecological functioning, underscoring the value of targeted protection measures during key growth periods.

Appendix



Four reedbed areas (A–D) in Lake Tåkern selected for analyses of development 2004–2022 (results presented in Fig. 2). In processing, images were converted to 8-bit and adjusted in Lightroom Classic (v12.5.0.1, 2023) to enhance contrast and mask misclassified areas (e.g., waves, non-reed vegetation). Manual thresholding in ImageJ reduced noise and delineated reed areas. Exclosure and control plots were located in area C. Digitala Kartor och Geodata, slu.se, 2024

Protocol of macroinvertebrate taxa (and fish) used for classifying activity trap catches, adapted from Nudds and Bowlby (1984)

Taxon
Gastropoda-Valvatidae
Gastropoda-others
Bivalvia
Annelida-Oligochaeta
Annelida-Hirudinea
Arachnida-Araneida
Arachnida-Acari
Anostraca
Phyllopoda/Cladocera
Ostracoda
Copepoda
Isopoda
Amphipoda
Crustacea-others
Ephemeroptera
Plecoptera
Odonata-Anisoptera
Odonata-Zygoptera
Heteroptera-Corixidae
Notonectidae
Heteroptera-Ilyocorinae
Heteroptera-others
Coleoptera-Dytiscidae
Coleoptera-others
Neuroptera
Trichoptera
Diptera
(Pisces)

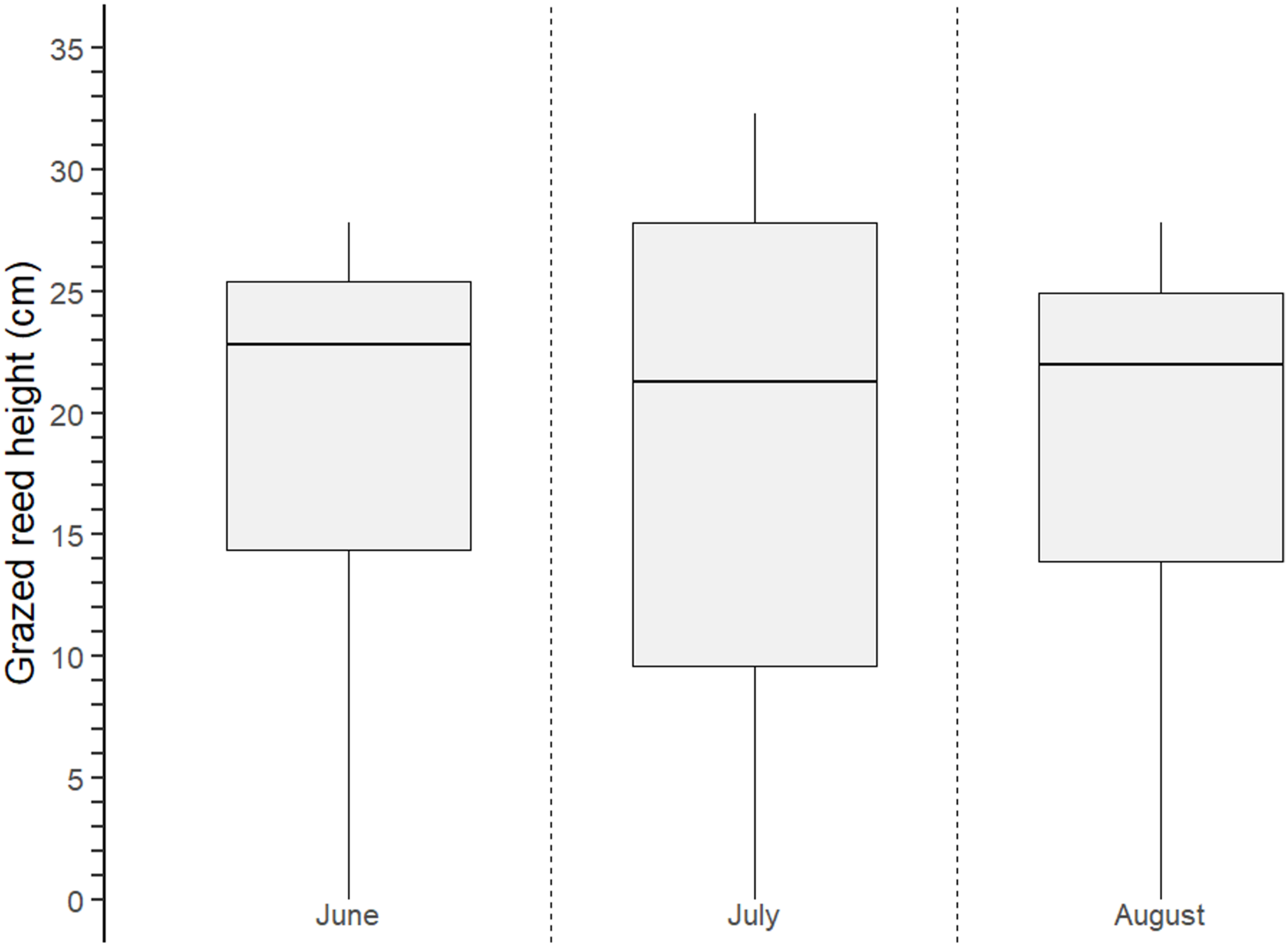
Number and density (number per km-2) of waterbird species (breeding individuals and their young) observed at two areas (one meadow and one open water area) in the southern part of Lake Tåkern (Fig. 3). Values are based on the maximum counts recorded across monthly surveys (April–August, 2023)

	Meadow		Open water	
Waterbird species	Number	Density	Number	Density
Mute swan *Cygnus olor*	2	33	103	343
Greylag goose* *Anser anser*	71	1183	255	850
Mallard *Anas platyrhynchos*	0	0	12	40
Gadwall *Mareca strepera*	2	33	198	660
Common pochard *Aythya ferina*	6	100	102	340
Tufted duck *Aythya fuligula*	0	0	29	97
Eurasian coot *Fulica atra*	2	33	119	397

*Maximum greylag goose numbers were recorded in June and July, for the meadow and open water areas, respectively

Statistical results (Wilcoxon) of the most commonly occurring macroinvertebrate taxa, contrasting exclosure and control plots (n = 8 in all cases)

Taxon	Z	*p*
Gastropoda-Valvatidae	-0.272	0.785
Gastropoda-others	-0.378	0.705
Annelida-Hirudinea	-0.842	0.400
Arachnida-Acari	-0.840	0.401
Ostracoda	-1.690	0.091
Isopoda	-0.704	0.482
Amphipoda	-0.272	0.785
Ephemeroptera	-0.368	0.713
Odonata-Anisoptera	-0.680	0.496
Odonota-Zygoptera	-1.289	0.197
Heteroptera-Corixidae	-0.405	0.686
Notonectidae	-0.921	0.357
Coleoptera-Dytiscidae	-0.420	0.674
Coleoptera-others	-0.378	0.705
Trichoptera	-0.763	0.445
Diptera	-0.211	0.833



Height (cm) of grazed shoots on three sampling occasions (June 1; July 26; August 27) in control plots

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Data availability The datasets produced and/or analysed in this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval This study involved non-invasive observations of wild animals in their natural habitat. According to national regulations and institutional guidelines, no ethical approval was required.

Consent to participate and publish Not applicable.

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Competing interests The authors declare no competing interests.

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