Site Selection by Geese in a Suburban Landscape

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ABSTRACT

Background

In ~~northern~~ European and North American cities geese are among~~one of~~ the most common and most visible large herbivores. As such, their presence and behaviour often conflict with the desires of the human residents. Fouling, noise, aggression and health concerns are all cited as reasons that there are "*too many*". Lethal control is often used for population management~~control~~, however, this raises questions about whether this is a sustainable strategy to resolve the conflict between humans and geese, when paradoxically, it is humans that are responsible for creating the habitat and often providing the food and protection of geese at other times. We hypothesise~~hypothesis~~ that the landscaping of suburban parks can be improved to decrease its attractiveness to geese and to reduce the opportunity for conflict between geese and humans.

Methods

Using observations collected over five years from a botanic garden situated in suburban Belgium and data from the whole of Flanders in Belgium, we examined~~examine~~ landscape features that attract geese. These included~~, including~~ the presence of islands in lakes, the distance from water, barriers to level flight and the size of exploited~~grazing~~ areas. The birds studied were the tadornine goose *Alopochen aegyptiaca* (L. 1766) (Egyptian goose~~geese~~) and the anserine geese, *Branta canadensis* (L. 1758) (Canada goose~~geese~~), *Anser anser* (L. 1758) (greylag goose~~geese~~) and *Branta leucopsis* (Bechstein, 1803) (barnacle goose~~geese~~). Landscape modification is a known method for altering goose~~modifying geese~~ behaviour, but there is little information on the power of such methods with which to inform managers and planners.

Results

Our results demonstrate that lakes with islands attract more than twice as many anserine geese~~,~~ than lakes without islands~~island~~, but make little difference to Egyptian geese. Furthermore, flight barriers between grazing areas and lakes are an effective deterrent to geese using an area for feeding. Keeping grazing areas small and surrounded by trees reduces their attractiveness to geese.

Conclusion

The results suggest that landscape design can be used successfully to reduce the number of geese and their conflict with humans. However, this approach has its limitations and would require humans to compromise on what they expect from their landscaped parks, such as open vistas, lakes, islands and closely cropped lawns.

Keywords

Egyptian geese, Alopochen aegyptiaca, Canada geese, Branta canadensis, greylag geese, Anser

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anser, barnacle geese, Branta leucopsis, feral, invasive, Flanders, Belgium, behaviour, habitat, suburban

Introduction

In Europe and North America wild and feral geese frequently inhabit artificial lakes and their surrounding parks in urban and suburban areas. These parks are appreciated by people for their recreational and aesthetic value. However, this often brings geese in conflict with people (Conover & Chasko, 1985; Hughes et al., 1999; Smith, Craven & Curtis, 1999; Fox, 2019). While people often enjoy seeing small numbers of geese, when there are large flocks the soil becomes fouled and people are intimidated by the geese's threatening behaviour (Miller et al., 2001). Geese are also known to exert pressure on small water bodies such as ponds, reducing water quality through eutrophication (Allan et al., 1995; Gosser et al., 1997; Smith et al., 2000; Kumschick & Nentwig 2010). They have also been suggested to be a disease risk, though the evidence is circumstantial and other domestic and wild animals pose a greater known risk (Fleming & Fraser, 2001; Clark, 2003; Bönner et al. 2004). ~~It also seems likely that such a large and dominant group of species would also have impacts on other species of animal and on the plants that occur where they graze. However, there is little specific research on this in an urban context.~~ Throughout Europe and the western Palearctic, native as well as non-native geese are increasing in numbers and distribution (Allan, Kirby & Feare, 1995; Fox et al. 2010). Several populations have developed a resident component and~~. This will undoubtedly increase~~ their year-round presence increases human-wildlife conflicts~~overall impact on people~~ and impacts on biodiversity (Buij et al. 2017). A~~and a~~ variety of strategies are needed to reduce these impacts

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(Austin et al., 2007; Gyimesi & Lensink, 2012).

In Europe, from the 18th century onwards~~onward~~, it has been traditional to create landscaped parks reflecting an idealised vision of the countryside. Lakes with islands, open vistas, lawns and patches of woodland are typical (Turner, 1985). Lake-side vegetation and lawns are cut regularly ~~to ensure unimpeded views~~ and the canopies of trees are kept high to ensure unimpeded views.~~.~~ For those goose~~geese~~ species that are habituated to the presence of people, such landscapes are very suitable~~:,~~ they have abundant grazing and~~,~~ proximity to water and islands for undisturbed nesting sites. In addition, people often provide supplementary feeding.

In north-western Europe four species of "geese" are the main inhabitants of urban and suburban parks: the~~,~~ non-native Egyptian geese (*Alopochen aegyptiaca*)~~,~~) ~~and~~ the Canada geese (*Branta canadensis*), ~~and~~ mixed populations of wild and feral greylag geese (*Anser anser*) and the barnacle geese (*Branta leucopsis*). All are members of the family Anatidae, but Egyptian geese are members of the subfamily Tadorninae, which are referred to as tadornine geese, whereas the others are members of subfamily Anserinae, which are referred to as anserine geese. Egyptian geese are similar in several aspects to anserine geese, such as their large size, long neck~~necks~~ and feeding behaviour, but they do differ in other important aspects. Anserine geese, such as Canada geese, barnacle geese, greylag geese and their hybrids, usually nest on the ground close to bodies of water and~~. They moult during the summer; at which time they lose the ability to fly for a short period. They~~ are also likely to form large flocks (Adriaens et al. 2020).~~.~~ Egyptian geese are also water birds, but their biology shows many characteristics of a

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duck, including larger clutch sizes. Although they ~~although they can~~ nest on the ground, their nest site selection is highly variable and they also~~they prefer to~~ nest in large tree holes, on buildings, on top of willow trees or in nest boxes (Gyimesi & Lensink 2012; Huysentruyt et al. 2020). ~~They moult over a longer period and do not have such a clear flightless period during their moult.~~ They also differ in their social behaviour. Paired Egyptian geese defend territories near their nest site before and during nesting. Large flocks of Egyptian geese only occur after breeding, during moulting (Gyimesi & Lensink 2010). ~~and before establishment of territories. During the spring only non-breeding birds will create flocks.~~

The site selection criteria of geese are important, because their ~~Islands provide undisturbed nest~~ sites can bring them into conflict with people. ~~and protected roosting areas. In Belgium the vast majority of lakes are artificial, some were created for mineral extraction; some are ornamental; some recreational; while other are impounded meanders to make a river more navigable. Being such common features of lakes, we wanted to know if the presence of islands within lakes attracts geese to use those lakes, rather than lakes without islands.~~

The proximity of water, food and breeding sites are ~~obviously~~ relevant to goose site~~habitat~~ selection, but there are likely to be additional influences. ~~features that influence site selection.~~ These features may be related to predator avoidance (Conover & Kania, 1991), ~~,~~ accessibility of feeding grounds for adults and families with chicks, nutritional quality of feed (Owen, Nugent & Davies, 1977; Fox & Kahlert, 2005), ~~,~~ sward length (Hassall, Riddington & Helden, 2001; Feige et al., 2008; Conover, 1991; Van Gils et al., 2009; Huysentruyt & Casaer, 2010) and competition

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with other grazers such as other geese, livestock and rabbits (Van der Wal, Kunst & Drent, 1998~~Owen, Nugent & Davies, 1977; Conover & Kania, 1991; Hassall, Riddington & Helden, 2001; Feige et al., 2008~~). Given this, it may be possible to identify management strategies and landscape features that alter the site selection of geese and these might be used to control the geese in such a way to reduce conflict between geese and people (Conover, 1992; Owen, 1975).~~human interests (Conover, 1992; Owen, 1975). These site preferences may vary between species and season. For example, moulting adults and their young are often flightless, which restricts their movements. Understanding these habitat preferences provides better scope for improvement in habitat management of geese.~~

Culling is often used to reduce the impact of geese (Reyns et al. 2018),~~;~~ but several other strategies have been used to discourage and redistribute geese, including birds scarers and chemical antifeedants (Conover, 1985), fencing of feeding grounds or landscape modification including altered mowing regimes or landscaping solutions (Cooper 1998; Van Daele et al. 2012). ~~). Geese can also be managed through fertility reduction by pricking, shaking, coating eggs with liquid paraffin or by destruction of the nest. Although less effective at the population level this strategy has proven useful to level off geese numbers in specific areas with good knowledge on and access to breeding sites (Klok et al., 2010). In Flanders, several management strategies are integrated. Culling is performed by shooting during the open season for game species (greylag and Canada goose) and can be practiced year-round for non-native species like Egyptian geese although in practice, numbers reported shots are rather low (Van Daele et al., 2012). Egyptian geese are also captured at breeding grounds using multicapture Larsen traps~~

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~~with live decoy birds. Alternatively, culling is performed by capturing flocks of geese during~~
~~moult (June-July) when birds are flightless (Allan et al., 1995). In Flanders, this practice is~~
~~applied at the level of the two westernmost provinces since 2010, mainly targeting flocks of~~
~~Canada and greylag geese (Van Daele et al., 2012). Since 2014 moult captures have been~~
~~upscaled to the whole region (Reyns et al., 2018).~~

~~Although this integrated strategy, mainly involving culling, has appeared to bring down Canada~~
~~goose numbers (Van Daele et al., 2012), the effect on other species is mixed. Moreover, culling,~~
~~which involves humanely killing large numbers of birds with their offspring using carbon dioxide~~
~~or chemical euthanasia by injection, faces opposition from the public and from animal welfare~~
~~groups.~~ In the context of a landscaped park with large numbers of visitors, culling risks~~visitor~~
~~such action would face a high risk of~~ losing public support for a ~~public~~ garden and bird scaring
might disturb people too. At the same time, the context of a botanic garden urges careful
consideration of grazing and fouling impacts of geese on plantings, lawns and vegetations
without losing the recreational opportunities for wildlife watching provided by the presence of
these attractive birds. ~~–~~Therefore, habitat modification is considered as~~to find~~ a cost effective,
sustainable solution to reduce numbers of geese on sites~~site~~ and to mitigate the impact~~ of~~
~~geese present on site. Geese generally have a preference for young nutrient rich grass of a~~
~~certain length (Conover, 1991; Van Gils et al., 2009; Huysentruyt & Casaer, 2010). During moult,~~
~~they often switch to more protein-rich food types (Fox & Kahlert, 2005). They prefer easy~~
~~access to water, either for roosting or predator avoidance. They avoid woodland and need open~~
~~areas for taking off and landing, though they will walk to forage for food. These preferences are~~
~~likely to vary between species and season.~~

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~~Known examples of habitat modification for geese include the removal of islands for breeding, steepening of the shores, making breeding grounds accessible to predators, adjusted mowing regimes resulting in higher vegetation types that are less suitable for geese to forage and roost. At the landscape scale, the density of the landscape matrix can be increased with planting of hedges, high crops or trees, in order to make it less attractive to geese. Making feeding grasslands inaccessible to chicks using some form of fencing is another method but is controversial as chicks then starve.~~

~~Understanding the habitat preferences of different species of geese provides better scope for improvement in habitat management of geese. However, to find cost effective, sustainable solutions we need to consider habitat modifications.~~ Previous studies on site occupancy of geese have concentrated on wild geese in more or less rural~~natural~~ settings. These studies have concentrated on ways to discourage geese from feeding on crop plants (e.g. Olsson et al., 2017; Si et al., 2011). In the case of Canada geese most studies have occurred in North America (e.g. Conover, 1992).

The aim of this study is to quantify the site selection of the different species of geese within the Meise Botanic Garden (Belgium) and create models to predict their behaviour based upon the landscape ~~and management features~~ of the park. These models can then be used to suggest strategies to reduce~~avoid~~ conflict between the geese and the visitors ~~to the park. Within the park~~ without losing the opportunities~~geese do little harm though~~ they represent for wildlife watching. ~~are a nuisance due to the fouling of paths and they may be complicit in the~~

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~~eutrophication of the lakes (Fleming & Fraser, 2001; Ayers et al., 2010).~~

Materials & Methods

Most of the research was conducted at ~~The survey area~~ the Meise Botanic Garden (Flanders, Belgium), ~~is~~ situated just north of Brussels, Belgium (50°55'42.4"N 4°19'37.6"E). The exception was the study on the effect of islands and those data are described below. The 92 ha g~~G~~arden is a landscaped park ~~is~~ like many such parks in northern and western Europe. It~~, it~~ has extensive lawns, woodlands, ~~and~~ two large lakes and ~~one~~ a small one (Fig. 1)~~.~~, The Garden is subdivided into different numbered areas, divided by paths, which join various historic buildings and greenhouses with formal gardens, with approximately half the area covered by woodland. Most of the grassland is mown between two and four times a month during the growing season, though~~. Though~~ small areas are maintained as ~~"~~wildflower~~"~~ meadows and are cut once or twice a year.

All geese in the Garden are considered either non-native or feral. All species breed in the park, though the breeding of Canada geese is, in part, controlled by egg-shaking.

The birds using the park are part of a larger population of geese that inhabit the greater Brussels area, and birds move in and out of the park to the many other lakes and waterways in the neighbourhood. None of these populations are truly migratory, except for local movements (Anselin & Cooleman, 2007). Canada goose is under management in the region and flocks of geese are regularly ~~moult~~ captured on water bodies in neighbouring municipalities since 2010 (Reyns et al. 2018). The park is in almost constant use by geese, except for on the rare

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occasions when the lakes freeze ~~over~~ for long periods in the winter.

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Geese feed on all the lawns and grasslands within the park, but the extent to which these areas are used varies considerably from area to area and from species to species.

~~Summer goose count data to investigate the influence of islands~~

~~To investigate the preference of geese towards islands we used the summer goose counts in Flanders downloaded from the Global Biodiversity Information Facility (Devisscher et al., 2016). These are annual counts of geese collected by volunteers at set sites across Flanders, Belgium. They are conducted over one week in mid-July when anserine geese are moulting. These data are provided with the geographic centroid of the lake. The area of the lake was calculated by tracing it on a GIS system and the area of the lake included the area of any island in the lake. The presence of an island in the lake was determined from visual inspection of aerial photographs from Google Maps.~~

~~Edge effects between grassland and woodland~~

~~Where geese grazing lawns are bordered by woodland it is reasonable to expect edge effects. These might be the result of decreased grazing quality in the partial shade of trees, or perhaps the avoidance of areas that give cover to potential predators. The use by geese of different areas of lawn was estimated by the amount of droppings on the lawn. Geese defecate frequently and seemingly indiscriminately. Counting dropping is a well-known method for estimating geese density on areas of land (Owen, 1971). However, we found it difficult to distinguish individual defecation events, because the droppings tend to break apart as they are released. Therefore, we preferred to measure the total length of droppings in a unit area. We~~

~~consider this measure more reliable than trying to count of the number of defecation events. The presence of edge effects was investigated with 10 m wide rectangular plots laid out on the lawns perpendicular to the woodland – lawn boundary on sections of the Garden frequently used by geese. The first set of four of plots were 12m long and were surveyed in July 2014 the second set were 15m long and surveyed in March and April 2015. These plots are detailed in table S1. The sites for these plots were chosen because they were well separated from each other; were away from other trees and faced different directions. The plots were marked out using bamboo canes and a tape measure. Then either 20 or 30 randomly chosen 1 m^2 square quadrats were surveyed within the rectangular plot. The cumulative length of dropping in a quadrat were measured to the nearest centimetre with a ruler.~~

~~Analysis of these data was conducted using non-linear mixed-effects models using the plot number as a random factor (Crawley, 2012). Calculations were performed using the 'nlme' package in R (Pinheiro, 2016). Two possible models were compared, a 3-parameter asymptotic exponential model and a 3-parameter logistic sigmoidal function, both with a positive intercept. Model comparisons were made using the Akaike information criterion. Models were conducted using distances perpendicular to the woodland – lawn boundary and for a control modelling was repeated with distances parallel to the woodland – lawn boundary.~~

The preference for grazing areas

The usage by geese of the different areas of the Botanic Garden was assessed by fixed transect counts (Groom, 2019a; Groom, 2019b). ~~walking fixed routes and by counting the number of geese in each area while walking these routes.~~ A total of four routes around the garden were

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used, each route took approximately 40 minutes to walk and was always walked in a clockwise direction. Almost all of the grassland areas of the garden were counted on at least two of these routes, woodland sectors were only counted when they were on the route between grassland areas. ~~Maps of the routes and sectors have been deposited openly (Groom, 2019a; Groom, 2019b).~~

Transect~~The survey~~ counts were conducted between 12pm~~12am~~ and 2pm Central European Time. Geese were counted on an average of 2.7 days per week spread throughout the survey period that lasted nearly 6 years, between 11 Oct 2011 and 10 July 2017. Counts were conducted only from ~~on~~ Monday to Friday at the convenience of the surveyors, but irrespective of weather conditions. The only consistent period of the year when surveying was not conducted was between 25th December and 1st January. On a few occasions, two routes were walked simultaneously to give an approximate number for the total number of geese in the park for that day. Routes 1 and 2 gave the best coverage for all the main areas used by geese in the park. On other days routes 1 to 4 were chosen at random (Haahr 2019). All the observation data are available on the Global Biodiversity Information Facility (Groom, 2019c).

It has been well argued, with good justification, that detectability is an important consideration in site occupancy modelling of animals (Kéry & Schmidt, 2008). Nevertheless, geese are large, noisy and bold and easy to recognize apart from the occasional hybrids. The areas where they feed in the Garden are small and open. Therefore, counts of the geese are expected to be reliable. We~~Therefore, we~~ have not considered detectability in our analysis as~~and~~ we have no reason to think that this would make a difference to the results ~~in this rather exceptional situation~~.

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In one year, four hybrids were~~Some hybridization was~~ observed, two ~~in geese flocks including~~ between greylag and Canada geese and two between barnacle and Canada geese. Furthermore, many of the greylag geese were either escapes from captivity or hybrids with farmed birds. ~~As such they some appeared to be hybrids with swan geese (*Anser cygnoides* (L., 1758)).~~ Nevertheless, such distinctions were not made during counting and hybrids were counted along with the species they consorted with. ~~For example, Canada-greylag hybrids were found in flocks of Canada geese and so were counted with them.~~

Three landscape parameters were examined for their importance for geese in ~~feeding~~ site selection. The size~~area~~ of the survey area, the distance from the site to the nearest lake and the presence of physical barriers preventing direct flight to the nearest lake. Details of each survey sector are available in Groom (2019b). For the physical barriers, each area was evaluated as to whether it was surrounded by barriers, such as tall trees and buildings that prevented easy flight access either to or from the lakes to the sector (Fig. 1).

These data have several issues which need to be addressed in statistical models, these~~there~~ are seasonal variations in behaviour, temporal autocorrelation and potentially spatial autocorrelation. Various statistical modelling approaches were considered including generalized linear models, mixed effects models and time series models. However, although these techniques might be useful to extract other valuable~~useful~~ information from these data, we determined that, for the questions~~question~~ we wanted~~want answers~~ to answer, we would fit linear models to the mean individual count per sector. By averaging site occupancy across time, we eliminate the issue of temporal autocorrelation. ~~which was a serious problem when we examined the data with other methods.~~

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Model selection was achieved by stepwise simplification of the model as described in Crawley (2012)~~,~~ using the step and lm functions of R (Venables & Ripley, 2002)~~.~~ Independent variables were the area of the sector; the closest distance from the sector to the nearest lake; whether the sector was woodland (1) or grassland (0) and the presence or absence of flight barriers out of the sector towards the lakes. The log of the mean individual count per sector was our dependent variable. Evaluation of our initial models using residuals versus leverage plots showed that the sectors containing lakes (13, 18 & 21) had a~~where having~~ disproportionate influence on the models as judged by the Cook's Distance. This is not surprising as the behaviour of geese and their relation to these areas is very different to grassland areas they visit to graze. For this reason, the lake sectors of the garden were excluded from our models. This reduced the number of sectors used for the model to 29, but no~~then not one~~ sector had a disproportionate influence on the models. R version 3.4.1 was used in all modelling~~, and~~ data analysis and visualization. manipulations.

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~~***Results***~~

~~**Do islands in lakes attract geese?**~~

Edge effects between grassland and woodland

Where goose grazing lawns are bordered by woodland it is reasonable to expect an edge effect, whereby the difference in usage by geese at a woodland-lawn boundary is gradual rather than abrupt. These might be the result of decreased forage quality in the partial shade of trees, or perhaps the avoidance of areas that give cover to potential predators. The use by geese of

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different areas of lawn was estimated by the amount of droppings on the lawn. Geese defecate frequently and seemingly indiscriminately. Counting droppings is a well-known method for estimating relative intensity of goose grazing on areas of land (Owen, 1971; Van Gils et al. 2010). However, we found it difficult to distinguish individual defecation events, because the droppings tend to break apart as they are released. Therefore, we preferred to measure the total length of droppings in a unit area. We considered this measure more reliable than trying to count the number of defecation events.

The presence of edge effects was investigated with 10 m wide rectangular plots laid out on the lawns perpendicular to the woodland-lawn boundary. The first set of four plots were 12m long and were surveyed in July 2014. The second set were 15m long and surveyed in March and April 2015. These plots are detailed in table S1. The sites for these plots were chosen because they were on sections of the Garden frequently used by all goose species; well separated from each other; were away from other trees and faced different directions. The plots were marked out using bamboo canes and a tape measure. Then either 20 or 30 randomly chosen 1 m^2 square quadrats were surveyed within the rectangular plot. The cumulative length of droppings in a quadrat was measured to the nearest centimetre with a ruler.

Analysis of these data was conducted using non-linear mixed effects models using the plot number as a random factor (Crawley, 2012). Calculations were performed using the 'nlme' package in R (Pinheiro et al., 2016). Two possible models were compared, a 3-parameter asymptotic exponential model and a 3-parameter logistic sigmoidal function, both with a positive intercept. Model comparisons were made using the Akaike information criterion. Models were conducted using distances perpendicular to the woodland - lawn boundary and

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for a control, modelling was repeated with distances parallel to the woodland - lawn boundary.

Summer goose count data to investigate the influence of islands

Only one of the three lakes in the Botanic Garden has an island and this is the primary nesting site of greylag, Canada and barnacle geese. Nevertheless, with only one island it is impossible to draw conclusions about the importance of islands on habitat choice. ~~Therefore, a dataset of summer goose counts from Flanders, that includes the Botanic Garden, was used. Lakes with islands house more Canada, greylag and barnacle geese in the summer (Fig.~~ Therefore, we used a dataset of summering goose counts from Flanders, that includes the Botanic Garden (Devisscher et al., 2016). These annual counts of geese are collected by volunteers from bird working groups at set sites across Flanders, Belgium. They are conducted simultaneously over one weekend in mid-July, to avoid double counts and when most species have completed their moult but are still found aggregated in larger groups on water bodies (Adriaens et al. 2010, 2011).~~2). These results indicate that a lake without an island has 35%–60% fewer anserine geese than a lake of an equivalent size with an island. However, islands make no difference to the number of Egyptian geese. All geese numbers show a positive relationship with lake size, although this is not significant in the case of barnacle geese.~~ These data are provided with the geographic centroid of the lake. The area of the lake was calculated by tracing it on a GIS system and the area of the lake included the area of any island in the lake. The presence of an island in the lake was determined from visual inspection of aerial photographs from Google Maps.

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Results

Do geese avoid proximity to trees?

During the study geese were rarely ~~ever~~ observed in woodland. Egyptian geese ~~are~~ were occasionally found perched in trees where they nest, but rarely on the ground in woodland. ~~Four camera traps permanently positioned in one woodland of the Garden have never photographed a goose during the survey period. The absence of geese from woodland may be due to the lack of suitable food, or may be a result of their fear of being in a habitat where predators may hide and are difficult to escape from.~~ It was hypothesised that this negative association with woodland would extend beyond the boundary between the woodland, and lawns and be the cause of an edge effects on grazing.

Quantification of the length of geese droppings showed a clear edge effect at the border to woodland (Fig. 2~~3~~). A shorter length of droppings was found close to the woodland, but this effect only extended 5-10 m from the boundary. Modelling was also performed in parallel to the woodland boundary as a control, but models either failed to converge or showed no directional trend. ~~Two plots were also surveyed next to non-woodland boundaries but showed no edge effect (data not shown).~~

Which habitat features attract geese?

Here we model the site selection of geese, based upon habitat features we suspect might be important to geese. The area of the sector, barriers to flight, presence of woodland and proximity to lakes all appear relevant from observations of geese and the literature cited in the introduction. The mean individual counts of geese in the different sectors of the Garden are

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mapped in figure 34. From these maps it is clear that all species had a high affinity to the sectors containing lakes, though there are clear differences between species. The greylag geese in particular are far more wide-ranging than other species notably in the large western sectors. The models of sector usage were evaluated with various means. The Cook's distance was used to evaluate if particular sectors had an exaggerated influence on the model outcomes, but this does not appear to be the case (Fig. S1). Variograms of the residuals didde not show evidence for spatial autocorrelation that wasis not accounted for in the model parameters (Figs S2-S5). A plot of residuals versus fitted values indicates that there may bemaybe some non-linearity between the predictors and the abundance of geese, but this wasis not clear (Fig. S6). The Q-Q plot shows that the residuals wereare quite normally distributed for all models (Fig. S7). The Scale-Location plot was used to test for homoscedasticity. Some amount of heteroscedasticity was evident in all models,models; however, we consider that only the model for *Branta leucopsis* wasis so heteroscedastic that it might impact our interpretation of the results. Given that no real-world model will perfectly match our assumptions, and some of the reasons for deviation from these assumptions are suggested in the discussion.

A summary of the minimum adequate models is given in table 1. The simplest minimum adequate model selected was for *Anser anser*. Only the area of the sector and the presence of woodland were significantly correlatedsignificant correlates to their distribution in the Garden, when away from the sectors containing a lake. For *B. canadensis* the area was also positively correlated with the number of geese, but not significantly in the model. However, in contrast to *Anser anser*, distance from a lake was a significant factor for *B. canadensis*, but also barriers to direct flight and their interacting term. For *Alopochen aegyptiaca*, area and barriers are

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significant as single factors, and~~but~~ they reoccur in interacting terms. Distance from the lake was not a significant term, but it did~~does~~ occur in an interaction term with area. In the case of *B. leucopsis*, area was~~is~~ a significant correlate, the other terms are more difficult to interpret, but both distance from a lake and the presence of barriers remained in the model due to their interactions and their interaction with area.

Goose abundance was negatively correlated with woodland for all except *B. leucopsis*, but this variable is not ideal as all those areas of woodland are also surrounded by trees as barriers to flight, So, there are no areas of woodland without barriers. Therefore, some of the variance stemming from the presence of woodland may be being accounted for in the barrier variable.

Therefore, for all species the area of the sector was~~is~~ positively correlated with goose abundance and the area was part of the significant interactions included in the models for *Alopochen aegyptiaca* and *Branta leucopsis*. The distance from the lake remained in models~~was a significant factor~~ for all species, except *Anser anser*. This is also evident in figure 3, where4~~,~~ ~~were~~ *A. anser* can be seen to have a wider range ~~to range more widely~~ than other geese. All other predicted habitat determinants were included in one or more of the models.

For Canada and greylag geese there was a negative influence of barriers on site usage, particularly for Canada geese. In the case of Egyptian and barnacle geese, barriers were not a clear determinant of site selection, but did remain in minimum adequate models as interactions with distance and area.

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~~Discussion~~

Do islands in lakes attract geese?

Lakes with islands attract ~~house~~ more Canada, greylag and barnacle geese in the summer (Fig. 4). These results indicate that a lake without an island had 35%–60% fewer anserine geese than a lake of an equivalent size with an island. However, islands made no difference to the number of Egyptian geese. All goose numbers showed a positive relationship with lake size, although this is not significant in the case of the barnacle geese.

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Discussion

The results demonstrated ~~demonstrate~~ the complicated relationship between habitat choice and ~~the~~ landscape, for ~~of~~ suburban geese. A casual observer could assume that there is a rather passive relationship between geese and their landscape, but as with any other animal, ~~urban~~ geese are clearly actively selecting ~~and using~~ particular landscapes and landscape features suited to their preferences.

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~~Islands are used by geese year-round, they provide protection from disturbance where geese can rest and nest. The results show a strong preference of anserine geese for lakes with islands (Fig. 2). The lack of a similar preference for Egyptian geese is consistent with the territorial breeding behaviour of Egyptian geese and their use of nest holes in trees.~~

~~Although anserine geese prefer lakes with islands in the summer, the reasons are probably various and this preference may not be true in winter. Island breeders are presumably more protected from predators, particularly foxes. However, when breeding success on islands has~~

~~been examined it is not necessarily better than on the mainland (Gosser & Conover, 1999). In the Botanic Garden the vast majority of nests of anserine geese are on the only island, but due to control measures on breeding, casual observations suggest that the few mainland breeders in the Botanic Garden are more successful. Breeding on islands may be somewhat innate for these geese and if so, provides a useful landscape modification to redirect geese, if human landscapers can avoid the cliché island in a lake.~~

~~It might be argued that native birds would also suffer from the lack of island breeding sites, however, islands in urban parks are probably unsuitable for other prominently island nesters, such as terns (Sternidae).~~ ~~Islands could perhaps be made less attractive if they were connected to the mainland by constructing bridges or an isthmus. They can also be modified with banks that deter access from the water, rather than from the air.~~

Edge effects are relevant to the usage of geese on lawns~~lawn~~ because they reduce the active area of use~~preferred grazing~~ for the geese. Our methodology did~~From our observations it is~~ not ~~possible to~~ distinguish whether there are species differences ~~in these edge effects~~, however, the effect was~~is~~ so distinct~~clear~~ that we speculate~~it seems likely~~ that all species are influenced. While there may be many potential causes of an~~the~~ edge effect, an area of lawn less than 20 m in diameter is likely to be ~~almost entirely influenced by this effect and be~~ undesirable to geese. ~~However, with increasing size the relevance of this effect will diminish. In ornamental parks individual specimen trees might extend the influence of this edge effect~~However, with increasing size the relevance of this effect will diminish. In ornamental parks individual specimen trees might extend the influence of this edge effect. ~~, however, this is not necessarily~~

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~~true where pruning has been used to raise the canopy. On hot summer days geese were observed to rest in the shade of specimen trees in lawns with a high canopy, apparently in conflict to our results from the proximity of trees.~~

Sector area~~Area~~ was ~~also~~ the most consistent predictor of goose abundance (Table 1).~~in a sector.~~ This was anticipated, ~~is not surprising~~ as more space can contain more geese. Yet in addition to the edge effects there are reasons to expect a more sophisticated ~~influence of area. Firstly, anserine geese are social species forming large flocks and they may only select areas with sufficient capacity to hold the whole flock.~~ relationship between goose number and area. Firstly, anserine geese are social species forming large flocks and they may only select areas with sufficient capacity to hold the whole flock. Secondly, if an area is surrounded by tall trees, the landing and take-off angle ~~the flight angle needed to enter and leave it from the air~~ becomes progressively steeper the smaller the area~~it~~ becomes. Mature trees stand 15–20m tall, but average vertical and horizontal airspeeds of geese are approximately 0.5 m s^{-1} and 16 m s^{-1} respectively (Hedenström & Alerstam, 1992). Therefore, to enter and escape a small area surrounded by trees they must either considerably steepen their descent or climb rate, or circle while gaining or losing height. Both of these strategies would be more energetically expensive (Norberg 1996). For these reasons, it is not ~~it is not~~ surprising that the area of the sector also appears in interacting terms in the models with ~~.~~ ~~The distance from the lake is most significant for *B. canadensis* and is an important distinction between the *Anser anser* and *B. canadensis*. Absence of~~ barriers ~~to flight are also a clear predictor of *B. canadensis* abundance.~~

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~~Goose abundance was negatively correlated with woodland for all except *B. leucopsis*, but this variable is not ideal as all those areas of woodland are also surrounded by trees as barriers to flight, So, there are no areas of woodland without barriers. Therefore, some of the variance stemming from the presence of woodland may be being accounted for in the~~. Barriers particularly restrict movement of geese~~barriers variable.~~

~~Habitat models showed the importance of flight barriers for the habitat choices of geese. Canada geese particularly are inhibited by flight barriers. Such barriers probably inhibit site usage in two ways. Geese wash, roost and breed on or near water, barriers prevent convenient access to grazing, particularly~~ when flight is not an option, such as, when raising young or moulting. However, the~~Trees act as barriers to level flight and geese normally take off with a running start and a shallow assent. To leave an area by flying a goose needs to have sufficient room to clear the surrounding barriers and whether this is achieved by circling or climbing more steeply it will be more energetically expensive. The~~ negative influence of barriers was hardly ~~barely~~ significant~~not seen~~ for *Alopochen aegyptiaca*. This~~, which~~ may be a result of their behaviour of nesting in tree holes. Though they do not inhabit densely forested areas, their preferred habitat is open grassland with some trees in proximity to freshwater (Cramp et al., 1984; Carboneras, 1992; Gyimesi and Lensink, 2012). They~~woodland they~~ defend territories around nest sites and therefore must be in proximity to trees (Sutherland & Allport, 1991). ~~.~~

Distance from lakes was not as important to site selection as had been assumed~~, before the study~~ and the interactions with area and the presence of barriers suggests that the ease of

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access to grazing is more important to site selection than the linear distance. This perhaps indicates~~suggests~~ that careful usage of landscape features could guide geese to use particular feeding sites, irrespective of their distance from the lake. ~~Nevertheless, in such an observational study there may be other correlated variables that we have not modelled which may influence our interpretation of the results. For example, in the Botanic Garden human usage of the park is not uniform and is probably more concentrated closer to the lakes. On the one hand this might mean the geese are more often disturbed by people near the lakes, but on the other hand they might be attracted by supplementary feeding from visitors to the garden, even though this is prohibited. Another variable varying with distance from the lake is sward height of the lawn. It tends to increase with distance from the lake, both due to the intense grazing of the geese close to the lake, but also the distribution of mowing regimes in the park.~~

The results show a strong preference of anserine geese for lakes with islands during the summer (Fig. 4). Islands are used by geese year-round, as they provide protection from disturbance, where geese can rest and nest. The lack of a similar preference for Egyptian geese is consistent with the territorial breeding behaviour of Egyptian geese and their use of nest holes in trees. Although anserine geese prefer lakes with islands in the summer, the reasons are probably many and this preference may not be true in winter. Island breeders are presumably more protected from predators, particularly foxes (Wright & Giles, 1988), stone marten (*Martes foina*), brown rat (*Rattus norvegicus*) and carrion crow (*Corvus corone*) (Huysentruyt et al. 2020). However, when breeding success on islands has been examined it is not always better than on the mainland (Gosser & Conover, 1999; Petersen, 1990). Other studies on the influence

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of islands on goose nest site selection vary. Fox et al. (1989) showed no influence for greylag goose, whereas others report an effect for Canada Goose (Lokemoen & Woodward, 1992; Bromley & Hood, 2013). Huysentruyt et al. (2020), in their study of 200 breeding pairs of barnacle goose in Flanders, also note that barnacle goose mainly breeds on small islands in lakes and ponds in the region.

Based on the results of this study we suggest that landscape adaptations could indeed~~can~~ reduce the number of geese in suburban~~urban~~ parks, which could be an alternative to lethal control and prevent~~their~~ conflict with people. Unfortunately~~human usage. Removing islands from lakes, either entirely or by creating bridges to the mainland will make sites less attractive to geese. This is likely to be a result of the increased disturbance of geese when selecting a nest site. Reducing the areas of lawns, planting trees to break up large lawns and not raising the canopy of trees are all likely to increase the proportion of lawn influenced by the woodland edge effect and will reduce the attractiveness to geese.~~

~~Nevertheless~~, many of the~~these~~ landscape adaptations that would reduce the presence of geese are in opposition to popular ~~will conflict with~~ landscape design features, such as ponds and lakes ~~that have been popular with urban landscapers in the past. Water features~~, islands, open vistas~~visas~~ and extensive lawns. Other ~~are common features of suburban parks. However,~~ ~~other~~ sorts of landscape and garden design with more enclosed and higher vegetation are more suitable where geese are a problem. Woodlands, shrubberies, coppice, hedges, tall grass meadows, prairie planting, hard landscaping features, shallow water and moving-water

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features would all deter geese from using an area (Allan, Kirby & Feare, 1995; Gosser, Conover & Messmer, 1997; Allan, 1999; Baxter, Hart & Hutton, 2010). ~~. Furthermore, if lawns are to be used for field sports it makes sense to partition them from area of water with trees and likewise if areas of water are to be used for recreation then these too should be surrounded by trees to reduce the usage by geese.~~

If artificial islands were eliminated from suburban lakes it might be argued that native birds would also suffer from the lack of island breeding sites. ~~,~~ H~~h~~owever, islands in suburban parks are mostly unsuitable for island nesters of conservation concern, such as common terns (*Sterna hirundo*) which ~~do~~ breed successfully ~~well~~ on artificial rafts in bigger lakes and lagoons (Coccon et al., 2018; Dunlop et al., 1991). ~~Ultimately, landscape modifications cannot completely remove geese from a suburban landscape, particularly where open water and grazing are found in close proximity. However, the results presented in this paper show that landscape features do make a difference to the use of geese of an area and that this could be considered when designing or modifying parks where geese are considered a problem. Finally, grazing geese should not only be considered as a problem.~~ Islands could perhaps be made less attractive if they were connected to the mainland by constructing bridges or an isthmus. They can also be modified with banks that deter access from the water, rather than from the air. However, making feeding areas inaccessible is controversial as chicks can then starve (Allan 1999). Modifications or removal of islands should however consider the trade-off with ongoing management. For example, when practicing egg shaking or egg oiling for fertility reduction, the success of this measure depends on sustained effort and a high percentage of treated nests (Klok et al., 2010;

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Beston et al., 2016). Hence, having all geese nest on the same island is practical to perform this management.

There is also a need to educate the public to the benefits of geese. In the Botanic Garden their selective grazing of grasses has created an exceptional species rich grassland that is unlikely to be maintained with mowing alone, yet can only be maintained under current grazing intensity (Ronse 2011). An adaptive management approach, whereby vegetation~~s~~ as well as goose numbers in the Garden are thoroughly monitored and objectives are clearly stipulated, could be a good way to learn more about the behaviour and impacts of geese~~. Urban grasslands have lost all other large grazing animals and to an extent geese occupy this vacant niche~~.

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Conclusions

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Landscape features have a powerful influence on the distribution of geese, though these influences differ between species. Landscape modifications cannot completely remove geese from a suburban landscape and an integrated management strategy may be necessary (Allan, Kirby & Feare, 1995). Retroactively modifying landscapes to reduce their attractiveness to geese is difficult, so designing landscapes for wildlife usage should be among the primary design criteria.

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improvement of the paper.

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