# Site Selection by Geese in a Suburban Landscape

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**ABSTRACT**

Background

In northern European and North American cities geese are one of the commonest and most visible large herbivores that inhabit the suburban environment . As such, their presence and behavior often conflicts 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 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 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 examine landscape features that attract geese, including the presence of islands in lakes, the distance from water, barriers to level flight and the size of grazing areas. The birds studied were the tadornine goose *Alopochen aegyptiaca* (L. 1766) (Egyptian geese) and the anserine geese, *Branta canadensis* (L. 1758) (Canada geese), *Anser anser* (L. 1758) (greylag geese) and *Branta leucopsis* (Bechstein, 1803) (barnacle geese). Landscape modification is a known method for modifying geese behavior, 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 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.

### *Keywords*

Egyptian geese, Alopochen aegyptiaca, Canada geese, Branta canadensis, greylag geese, Anser anser, barnacle geese, Branta leucopsis, feral, invasive, Flanders, Belgium, behavior, 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). 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 behavior. 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 non-native geese are increasing in numbers and distribution. This will undoubtedly increase their overall impact on people and biodiversity and a variety of strategies are needed to reduce these impacts (Austin et al., 2007; Gyimesi & Lensink, 2012).

In Europe, from the 18th century 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. For those geese species that are habituated to the presence of people, such landscapes are very suitable, they have abundant grazing; 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, non-native Egyptian geese (*Alopochen aegyptiaca*) and Canada geese (*Branta canadensis*), and  mixed populations of wild and feral greylag geese (*Anser anser*) and 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 necks and feeding behaviour, but they do differ in other important aspects. Anserine geese usually nest close to bodies of water. 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. Egyptian geese are also water

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birds, but although they do nest on the ground, they prefer to nest in large tree holes. 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 and before establishment of territories. During the spring only non-breeding birds will create flocks.

Islands provide undisturbed nest sites 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 habitat selection, but there are likely to be additional features that influence site selection. These features may be related to predator avoidance, accessibility of feeding grounds, nutritional quality of feed, sward length and competition with other grazers such as other geese, livestock and rabbits (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 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.

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Understanding these habitat preferences provides better scope for improvement in habitat management of geese.

Culling is often used to reduce the impact of geese, but several other strategies have been used to discourage and redistribute geese, including birds scarers and chemical antifeedants (Conover, 1985). 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 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

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groups. In the context of a landscaped park with large numbers of visitor such action would face a high risk of losing public support for the Botanic Garden. Therefore, habitat modification is considered to find a cost effective, sustainable solution to reduce numbers of geese on 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. Moulting adults and their young are often flightless, which restricts their movements.

Known examples of habitat modification for geese include the removal of islands for breeding, steepening of the shores, to make 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 crop types or trees, in order to make it less attractive to geese. Making feeding grasslands unaccessible to chicks using some form of fencing is another method but is often considered controversial as chicks then starve on the nest.

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 natural settings. These studies have concentrated on ways to discourage geese from feeding on crop plants (Olsson et al., 2017). 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 Botanic Garden and create models to predict their behaviour based upon landscape and management features of the park. These models can then be used to suggest strategies to avoid conflict between the geese and the visitors to the park. Within the park geese do little harm though they are a nuisance due to the fouling of paths and they may be complicit in the eutrophication of the lakes (Fleming & Fraser, 2001; Ayers et al., 2010).

## *Materials & Methods*

### The survey area

Meise Botanic Garden is situated just north of Brussels, Belgium (50°55'42.4"N 4°19'37.6"E). The 92 ha landscaped park is like many such parks in northern Europe, it has extensive lawns, woodlands and two large lakes and one 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 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.

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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). The park is in almost constant use by geese except for on the rare occasions when the lakes freeze over for long periods in the winter.

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

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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 dropping tend to break apart as they are released. Therefore, we preferred to measure the total length of droppings in an unit area. We consider a this measure more reliable than trying to count of the number of defecation events.

The presence of edge effects were 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 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 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).

The survey counts were conducted between 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 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. The areas where they feed in the Garden are small and open. Therefore, counts of the geese are expected to be reliable. Therefore, we have not considered detectability in our analysis and we have no reason to think that this would make a difference to the results in this rather exceptional situation.

Some hybridization was observed in geese flocks including between greylag and Canada geese and 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 area of the survey area, the distance 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, there are seasonal variations in behavior, temporal autocorrelation and potentially spatial autocorrelation. Various statistical modeling approaches were considered including generalized linear models, mixed effects models and time series models. However, although these techniques might be useful to extract other useful information from these data we determined that for the question we want answers to 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. Model selection was achieved by stepwise simplification of the model as described in Crawley (2012) using the step and lm functions of R. 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) 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 then not one sector had disproportionate influence on the models. R version 3.4.1 was used in all modelling and data manipulations.

## *Results*

## Do islands in lakes attract geese?

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. 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.

## Do geese avoid proximity to trees?

During the study geese were rarely ever observed in woodland. Egyptian geese are 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. 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

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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 mapped in figure 4. 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 do not show evidence for spatial autocorrelation that is not accounted for in the model parameters (Figs S2-S5). A plot of residuals versus fitted values indicates that there maybe some non-linearity between the predictors and the abundance of geese, but this is not clear (Fig. S6). The Q-Q plot shows that the residuals are quite normally distributed for all models (Fig. S7). The Scale-Location plot was used to test for homoscedasticity. Some amount heteroscedasticity was evident in all models, however we consider that only the model for *Branta leucopsis* is 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 significant correlates to their distribution in the Garden, when away from the sectors containing a lake. For *B. canadensis* 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 the significant as single factors, but they reoccur in interacting terms. Distance from the lake was not a significant term, but it does occur in an interaction term with area. In the case of *B. leucopsis*, area 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.

Therefore, for all species the area of the sector 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 was a significant factor for all species, except *Anser anser*. This is also evident in figure 4, were *A. anser* can be seen 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.

## *Discussion*

The results demonstrate the complicated relationship between habitat choice and the landscape 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 actively selecting and using particular landscapes suited to their preferences. 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 behavior 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 lawn because they reduce the area of

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prefered grazing for the geese. From our observations it is not possible to distinguish whether there are species differences in these edge effects, however, the effect is so clear that it seem likely that all species are influenced.  While there may be many causes of 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 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 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.

Area was also the most consistent predictor of goose abundance in a sector. This 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. Secondly, if an area is surrounded by tall trees the flight angle needed to leave it becomes progressively steeper the smaller it becomes. Therefore, it is not surprising that the area of the sector also appears in interacting terms in the models.

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.

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 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. 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 not seen for *Alopochen aegyptiaca*, which may be a result of their behavior of nesting in tree holes. Though they do not inhabit woodland they defend territories around nest sites and therefore must be in proximity to trees.

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 access to grazing is more important to site selection than the linear distance. This 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.

Based on the results of this study we suggest that landscape adaptations can reduce the number of geese in urban parks and their conflict with 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 these landscape adaptations will conflict with landscape design features that have been popular with urban landscapers in the past. Water features, islands, open visas and extensive lawns are common features of suburban parks. However, other sorts of landscape and garden design 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 features would all deter geese from using an area. 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.

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. 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. Urban grasslands have lost all other large grazing animals and to an extent geese occupy this vacant niche.

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## *Literature Cited*

Anselin A & Cooleman S. 2007. Wintertelling van de Canadese Gans, Branta canadensis in Vlaanderen (2007). Rapport van het Instituut voor Natuur-en Bosonderzoek. INBO.R.2007.9. 16 pp. Part of: Rapport van het Instituut voor Natuur- en Bosonderzoek. Instituut voor Natuur- en Bosonderzoek: Brussel. ISSN 1782-9054. http://www.vliz.be/en/imis?refid=133881

Austin GE, Rehfisch MM, Allan JR & Holloway SJ. 2007. Population size and differential population growth of introduced Greater Canada Geese *Branta canadensis* and re-established

Greylag Geese *Anser anser* across habitats in Great Britain in the year 2000. *Bird Study* 54:343-352 DOI: 10.1080/00063650709461494

Ayers CR, DePerno CS & Moorman CE. 2010. Canada goose wind dispersal and nutrient loading in turfgrass systems. *Applied Turfgrass Science* 7: DOI: 10.1094/ATS-2010-0212-02-RS

Bönner BM, Lutz W, Jäger S, Redmann T, Reinhardt B, Reichel U, Krajewski V. Weiss R, Wissing J, Knickmeier W, Gerlich WH, Wend UC & Kaleta EF. 2004. Do Canada geese (*Branta canadensis* Linnaeus, 1758) carry infectious agents for birds and man? *European Journal of Wildlife Research* 50:78-84 DOI: 10.1007/s10344-004-0044-1

Clark L. 2003. A review of pathogens of agricultural and human health interest found in Canada Geese. USDA National Wildlife Research Center-Staff Publications, 205.

Conover MR. 1985. Alleviating nuisance Canada goose problems through methiocarb-induced aversive conditioning. *The Journal of Wildlife Management* 49:631-636

Conover MR 1991. Herbivory by Canada geese: diet selection and effect on lawns. *Ecological Applications* 1:231-236. DOI: 10.2307/1941816

Conover MR, Chasko GG. 1985. Nuisance Canada goose problems in the eastern United States. *Wildlife Society Bulletin* 13:228-233.

Conover MR, Kania GS. 1991. Characteristics of feeding sites used by urban-suburban flocks of Canada geese in Connecticut. *Wildlife Society Bulletin* 19:36-38

Conover MR. 1992. Ecological Approach to managing problems caused problems caused by urban Canada geese. *Proceedings of the Fifteenth Vertebrate Pest Conference 1992*. Paper 19. http://digitalcommons.unl.edu/vpc15/19

Crawley MJ. 2012. The R book. John Wiley & Sons. Chichester, UK.

Devisscher S, Adriaens T, Brosens D, Huysentruyt F, Driessens G, Desmet P. 2016. Zomerganzen - Summering geese management and population counts in Flanders, Belgium. v1.1. Research Institute for Nature and Forest (INBO). Dataset/Samplingevent. DOI: 10.15468/a5ubtp

Feige N, van der Jeugd HP, van der Graaf AJ, Larsson K, Leito A, Stahl J. 2008. Newly established breeding sites of the Barnacle Goose *Branta leucopsis* in North-western Europe – an overview of breeding habitats and colony development. *Vogelwelt* 129:244–252.

Fleming R, Fraser H. 2001. The impact of waterfowl on water quality – literature review. University of Guelph, Ridgetown, Ontario, Canada.

Fox AD, Kahlert J. 2005. Changes in body mass and organ size during wing moult in non breeding greylag geese *Anser anser*. *Journal of Avian Biology* 36:538-548 DOI 10.1111/j.0908-8857.2005.03301.x

Gosser A, Conover M. 1999. Will the Availability of Insular Nesting Sites Limit Reproduction in Urban Canada Goose Populations? *The Journal of Wildlife Management* 63: 369-373.

Groom Q. 2019a. A map describing routes used in goose monitoring at Meise Botanic Garden. Zenodo. DOI: 10.5281/zenodo.2529725

Groom Q. 2019b. Goose monitoring data from the Meise Botanic Garden, Belgium [Data set].

*Zenodo*. DOI: 10.5281/zenodo.2529723

Groom Q. 2019c. Waterbirds of the Botanic Garden Meise. Version 3.6. Botanic Garden Meise. Occurrence dataset DOI: 10.15468/cgffyq accessed via GBIF.org on 2019-01-05.

Gyimesi A, Lensink R. 2012. Egyptian Goose *Alopochen aegyptiaca*: an introduced species spreading in and from the Netherlands. *Wildfowl* 62:128-145.

Haahr M. 2019. RANDOM.ORG: True Random Number Service. Retrieved from https://www.random.org

Hassall M, Riddington R, Helden A. 2001. Foraging behaviour of brent geese, *Branta b. bernicla*, on grasslands: effects of sward length and nitrogen content. *Oecologia* 127:97-104. DOI: 10.1007/s004420000563

Hughes B, Kirby J, Rowcliffe JM. 1999. Waterbird conflicts in Britain and Ireland: ruddy ducks *Oxyura jamaicensis*, Canada geese *Branta canadensis*, and cormorants *Phalacrocorax carbo*. *Wildfowl* 50:77-99.

Huysentruyt F, Casaer J. 2010. Het bepalen van mogelijke herkomstgebieden bij landbouwschade door overzomerende ganzen : Een eerste aanzet voor een modelmatige benadering. Rapporten van het Instituut voor Natuur- en Bosonderzoek INBO.R.2010.9. Instituut voor Natuur- en Bosonderzoek, Brussel.

Kéry M, Schmidt B. 2008. Imperfect detection and its consequences for monitoring for conservation. *Community Ecology* 9:207-216 DOI: 10.1556/ComEc.9.2008.2.10

Klok C, Van Turnhout C, Willems F, Voslamber B, Ebbinge B, Schekkerman H. 2010. Analysis of population development and effectiveness of management in resident greylag geese *Anser anser* in the Netherlands. *Animal Biology* 60:373-393 DOI: 10.1163/157075610X523260

Olsson C, Gunnarsson G, Elmberg. 2017. Field preference of Greylag geese *Anser anser* during the breeding season. *European Journal of Wildlife Research* 63:28 DOI: 10.1007/s10344-017-1086-5

Owen M. 1971. The Selection of Feeding Site by White-Fronted Geese in Winter. *Journal of Applied Ecology* 8:905–917 DOI: 10.2307/2402690

Owen M. 1975. Cutting and fertilizing grass land for winter goose management. *The Journal of Wildlife Management* 39:163-167.

Owen M, Nugent M, Davies N. 1977. Discrimination between grass species and nitrogen-fertilized vegetation by young barnacle geese. *Wildfowl* 28:21-26

Pinheiro J, Bates D, DebRoy S, Sarkar D, R Core Team. 2016. nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-124, http://CRAN.R-project.org/package=nlme.

Reyns N, Casaer J, De Smet L, Devos K, Huysentruyt F, Robertson PA, Verbeke T, Adriaens T. 2018. Cost-benefit analysis for invasive species control: the case of greater Canada goose *Branta canadensis* in Flanders (northern Belgium). *PeerJ*, 6:e4283 DOI: 10.7717/peerj.4283

Smith AE, Craven SR, Curtis PD. 1999. Managing Canada geese in urban environments. Jack Berryman Institute and Cornell University Cooperative Extension Publication 16, Ithaca, New York, USA.

Turner R. 1985. Capability Brown and the eighteenth century English landscape. Rizzoli.

Van Daele P, Adriaens T, Devisscher S, Huysentruyt F, Voslamber B, De Boer V, Devos K, Casaer J. 2012. Beheer van Zomerganzen in Vlaanderen en Zeeuws-Vlaanderen. Rapporten van het Instituut voor Natuur- en Bosonderzoek 2012 (INBO.R.2012.58). Instituut voor Natuur- en Bosonderzoek, Brussel.

Van Gils B, Huysentruyt F, Casaer J, Devos K, De Vliegher A, Carlier L. 2009. Project Winterganzen 2008-2009: onderzoek naar objectieve schadebepaling. Rapport van het Instituut voor Natuur- en Bosonderzoek INBO.R.2009.56. Instituut voor Natuur- en Bosonderzoek, Brussel.

## ***Tables and Figures***

Table 1. A summary of the minimum adequate models results. Blue cells indicate a positive association of geese numbers with the independent variables and red cells a negative association. The independent variables are the area of that sector of the garden, the distance from a lake, the presence of woodland on the garden sector and barriers to direct flight out of a sector. The number of asterisks indicate the degree of significance. Details of the models are presented in tables S2, S3, S4 and S5.

| | *Alopochen aegyptiaca* | *Anser anser* | *Branta canadensis* | *Branta leucopsis* |
|---|---|---|---|---|
| area | +* | +*** | + | +** |
| distance from a lake | + | | -*** | + |
| Woodland | - | -** | - | |
| Barriers to direct flight | -* | | -*** | + |
| area:distance | -* | | | -* |
| area:barriers | +* | | | - |
| distance:barriers | | | +*** | - |
| area:distance:barriers | | | | +* |

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Table S1. Details of the plots used to study edge effects of grazing at the boundary of lawns with woodland. Plots were extended and quadrat numbers increased in the second year to improve the detection of the effects. Plots were chosen with a variety of aspects as noted to avoid any systematic bias related to the direction of the plot with respect to the sun or landscape features.

| Plot number | Sector | Latitude | Longitude | Observer | Date | Dimensions (m) | quadrats | Aspect |
|---|---|---|---|---|---|---|---|---|
| P1 | 67 | 50.927168 | 4.329814 | Colsoulle | 2014-07-07 | 10 x 12 | 20 | S |
| P2 | 67 | 50.926701 | 4.32993 | Colsoulle | 2014-07-09 | 10 x 12 | 20 | N |
| P3 | 67 | 50.92684 | 4.331549 | Colsoulle | 2014-07-10 | 10 x 12 | 20 | S |
| P4 | 67 | 50.926743 | 4.331992 | Colsoulle | 2014-07-11 | 10 x 12 | 20 | S |
| P7 | 14 | 50.92902 | 4.32868 | Delhez | 2015-03-25 | 10 x 15 | 30 | SW |
| P8 | 14 | 50.9294 | 4.32865 | Delhez | 2015-03-30 | 10 x 15 | 30 | SW |
| P9 | 34 | 50.92922 | 4.32663 | Delhez | 2015-03-30 | 10 x 15 | 30 | SE |
| P10 | 34 | 50.92886 | 4.32614 | Delhez | 2015-04-07 | 10 x 15 | 30 | SE |
| P11 | 67 | 50.92644 | 4.33056 | Delhez | 2015-04-08 | 10 x 15 | 30 | SE |
| P12 | 67 | 50.92638 | 4.33093 | Delhez | 2015-04- | 10 x 15 | 30 | NW |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 09 | | | |

Table S2. Minimum adequate model for *Alopochen aegyptiaca*.

```
Call:
lm(formula = log(aegyptiaca + 1) ~ area + distance + woodland +
    barriers + area:distance + area:barriers, data = data2019)
Residuals:
     Min       1Q   Median       3Q      Max
-0.69472 -0.20809  0.01262  0.15653  0.91915


Residual standard error: 0.3966 on 22 degrees of freedom
Multiple R-squared:  0.6628,  Adjusted R-squared:  0.5708
F-statistic: 7.207 on 6 and 22 DF,  p-value: 0.0002389
```

| | ±S.E. | t | p |
|---|---|---|---|
| (Intercept) | 0.578(±0.286) | 2.02 | 0.0556 |
| area | $3.69\times10^{-5}(\pm1.46\times10^{-5})$ | 2.51 | **0.020 *** |
| Minimum distance from a lake | $4.12\times10^{-4}(\pm1.06\times10^{-3})$ | 0.39 | 0.700 |
| woodland | -0.267(±2.02) | -1.32 | 0.200 |
| barriers to direct flight | -0.613(±0.292) | -2.10 | **0.047 *** |
| area:distance | $-2.67\times10^{-7}(\pm1.18\times10^{-7})$ | -2.27 | **0.034 *** |
| area:barriers | $5.56\times10^{-5}(\pm2.55\times10^{-5})$ | 2.18 | **0.040 *** |

Table S3. Minimum adequate model for *Anser anser*

```
Call:
lm(formula = log(anser + 1) ~ area + woodland, data = data2019)
```

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Residuals:

Min 1Q Median 3Q Max

-0.73629 -0.38745 -0.06434 0.35822 1.06562

Residual standard error: 0.51 on 26 degrees of freedom

Multiple R-squared: 0.6983, Adjusted R-squared: 0.6751

F-statistic: 30.09 on 2 and 26 DF, p-value: 1.714e-07

| | ±S.E. | t | p |
|---|---|---|---|
| (Intercept) | 0.307(±0.171) | 1.79 | 0.085 |
| area | $5.99\times10^{-5}$(±$9.73\times10^{-6}$) | 6.16 | **$1.65\times10^{-6}$***** |
| woodland | -0.786(±0.240) | -3.28 | **0.003**** |

Table S4. Minimum adequate model for *Branta canadensis*

Call:

lm(formula = log(canadensis + 1) ~ area + distance + woodland +

barriers + distance:barriers, data = data2019)

Residuals:

| Min | 1Q | Median | 3Q | Max |
|---|---|---|---|---|
| -1.34943 | -0.18677 | 0.02133 | 0.19197 | 0.65493 |

Residual standard error: 0.4227 on 23 degrees of freedom

Multiple R-squared: 0.8498, Adjusted R-squared: 0.8171

F-statistic: 26.02 on 5 and 23 DF, p-value: 9.323e-09

| | ±S.E. | t | p |
|---|---|---|---|
| (Intercept) | 2.13(±0.273) | 7.82 | **$6.40\times10^{-8}$***** |
| area | $1.63\times10^{-5}$(±$9.46\times10^{-6}$) | 1.72 | **0.099** |
| distance | $-5.75\times10^{-3}$(±$1.09\times10^{-3}$) | -5.29 | **$2.29\times10^{-5}$***** |
| woodland | -0.338(±0.211) | -1.60 | **0.123** |
| barriers | -1.87(±0.312) | -5.98 | **$4.23\times10^{-6}$***** |
| distance:barriers | $5.64\times10^{-3}$(±$1.41\times10^{-3}$) | 4.00 | **$5.68\times10^{-4}$***** |

Table S5. Minimum adequate model for *Branta leucopsis*

Call:

lm(formula = log(leucopsis + 1) ~ area + distance + barriers +

area:distance + area:barriers + distance:barriers + area:distance:barriers,

data = data2019)

Residuals:

Min 1Q Median 3Q Max

-0.47063 -0.10868 -0.04301 0.08108 0.83859

Residual standard error: 0.2706 on 21 degrees of freedom

Multiple R-squared: 0.6551, Adjusted R-squared: 0.5402

F-statistic: 5.699 on 7 and 21 DF, p-value: 0.0008578

| | ±S.E. | t | p |
|---|---|---|---|
| (Intercept) | $6.24\times10^{-3}(\pm0.287)$ | 0.02 | 0.983 |
| area | $4.37\times10^{-5}(\pm1.46\times10^{-5})$ | 2.99 | 0.007** |
| distance | $1.81\times10^{-3}(\pm1.49\times10^{-3})$ | 1.21 | 0.239 |
| barriers | $7.52\times10^{-2}(\pm0.342)$ | 0.22 | 0.828 |
| area:distance | $-3.18\times10^{-7}(\pm1.29\times10^{-7})$ | -2.47 | 0.022* |
| area:barriers | $-5.98\times10^{-5}(\pm3.38\times10^{-5})$ | -1.77 | 0.091 |
| distance:barriers | $-1.95\times10^{-3}(\pm1.70\times10^{-3})$ | -1.15 | 0.264 |
| area:distance:barriers | $4.01\times10^{-7}(\pm1.74\times10^{-7})$ | 2.30 | 0.032* |

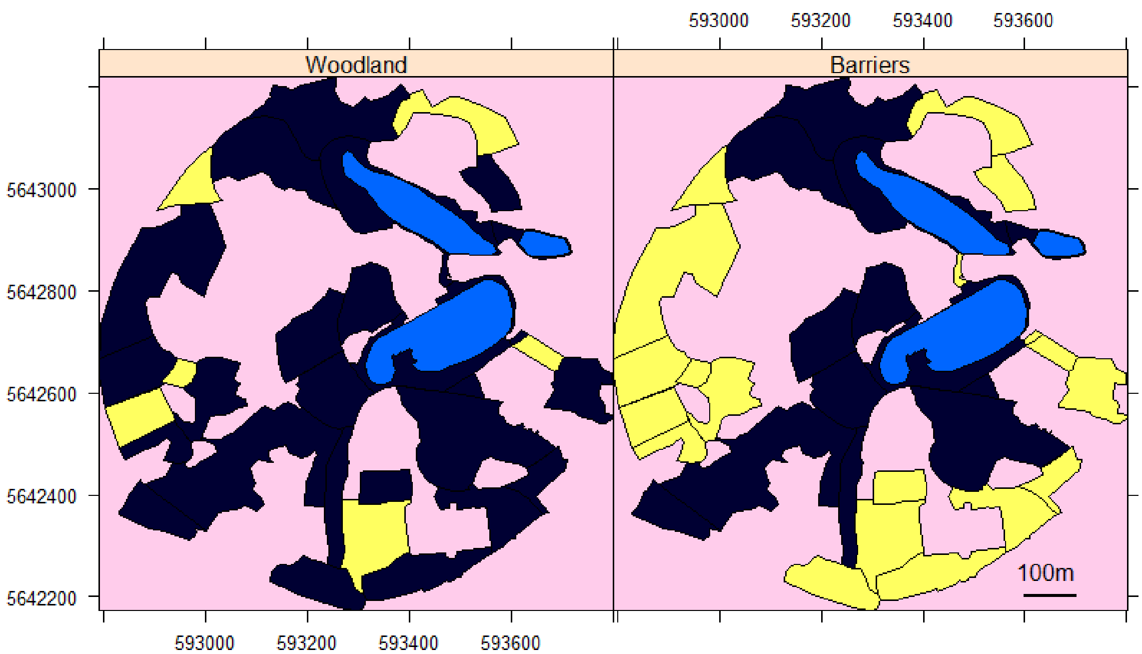



Figure 1. Maps of the surveyed areas of the Garden showing the areas of woodland and those areas largely surrounded by tall trees that act as barriers to direct flight of the geese out of that area (yellow). Blue area are lakes and pink areas were not surveyed. The unsurveyed area are either covered by woodland, building or greenhouses.

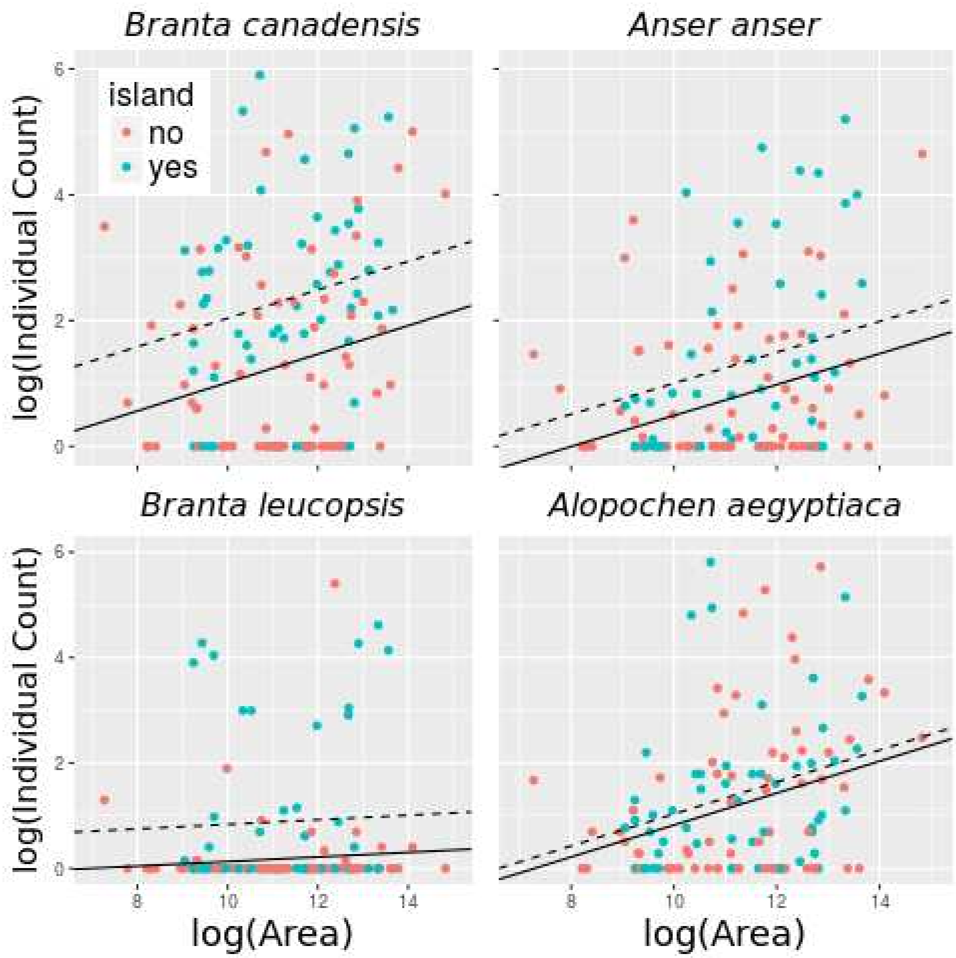
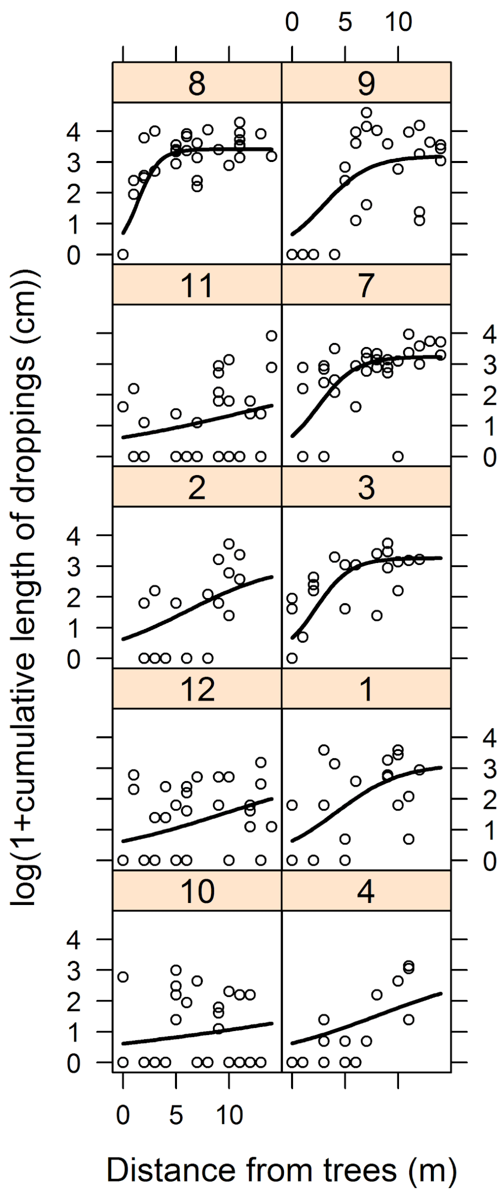



Figure 2. A comparison of summer goose counts for lakes in Flanders compared to the lake area, either with islands (dashed line) or without islands (solid line). The lines are the results of linear models of the log of the average individual count on a lake and the log of the area of the lake. The models assume a constant relationship between average individual count of geese and the lake's area. There is a significantly larger number of Canada, greylag and barnacle geese on lakes with islands ($p > 0.05$). There is a significant positive relationship between the lake area and counts of Canada, greylag and Egyptian geese.




615

Figure 3. The total length of geese droppings deposited at varying distances from the boundary between woodland and lawn. Geese dropping were the sum length of all dropping from all

618 species of geese. The numbers on each graph refer to the original plot number.

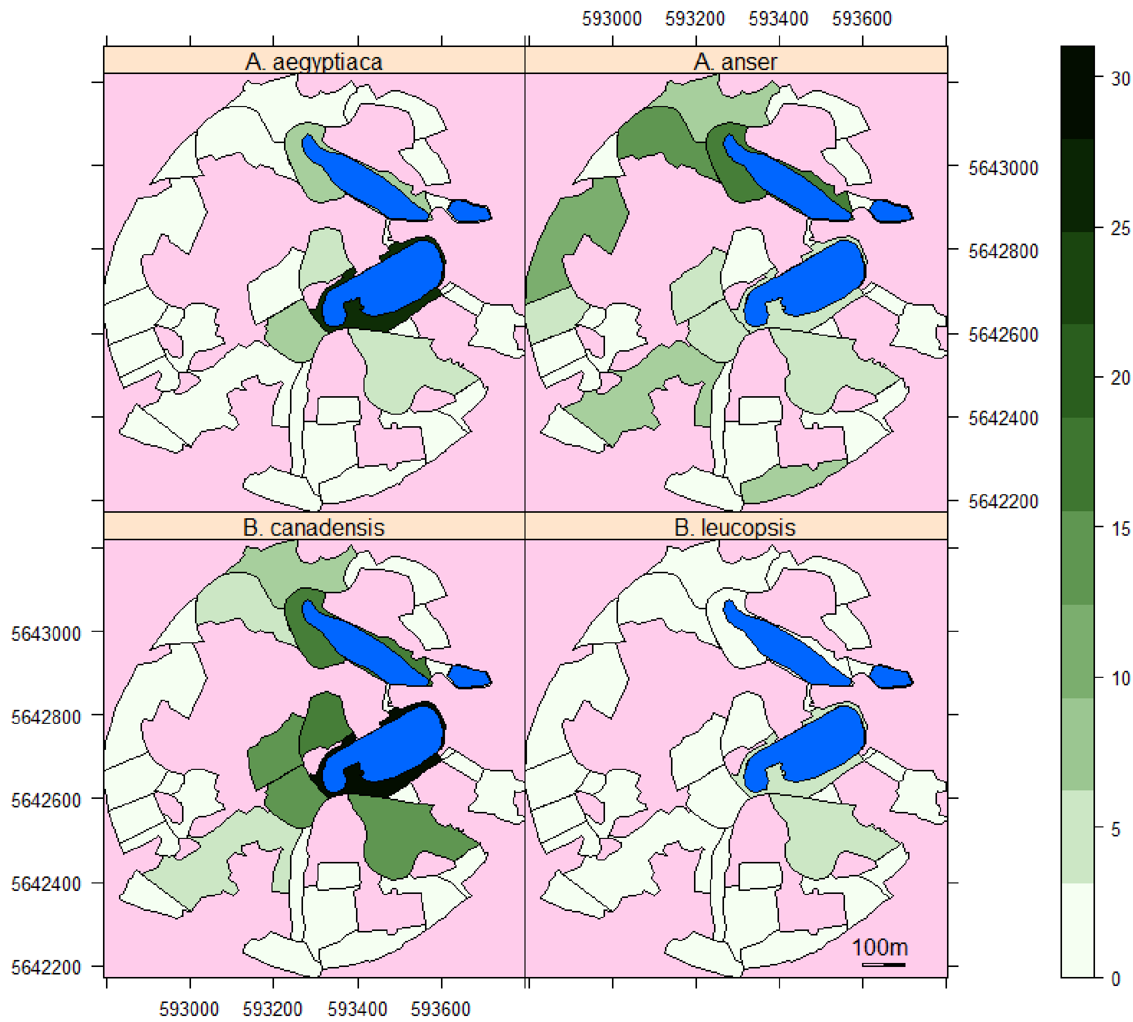



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Figure 4. Maps of the mean number of individuals of each species in the surveyed areas of the

621 Botanic Garden. Lakes are in blue, unsurveyed areas and in pink.

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# Supplementary figures

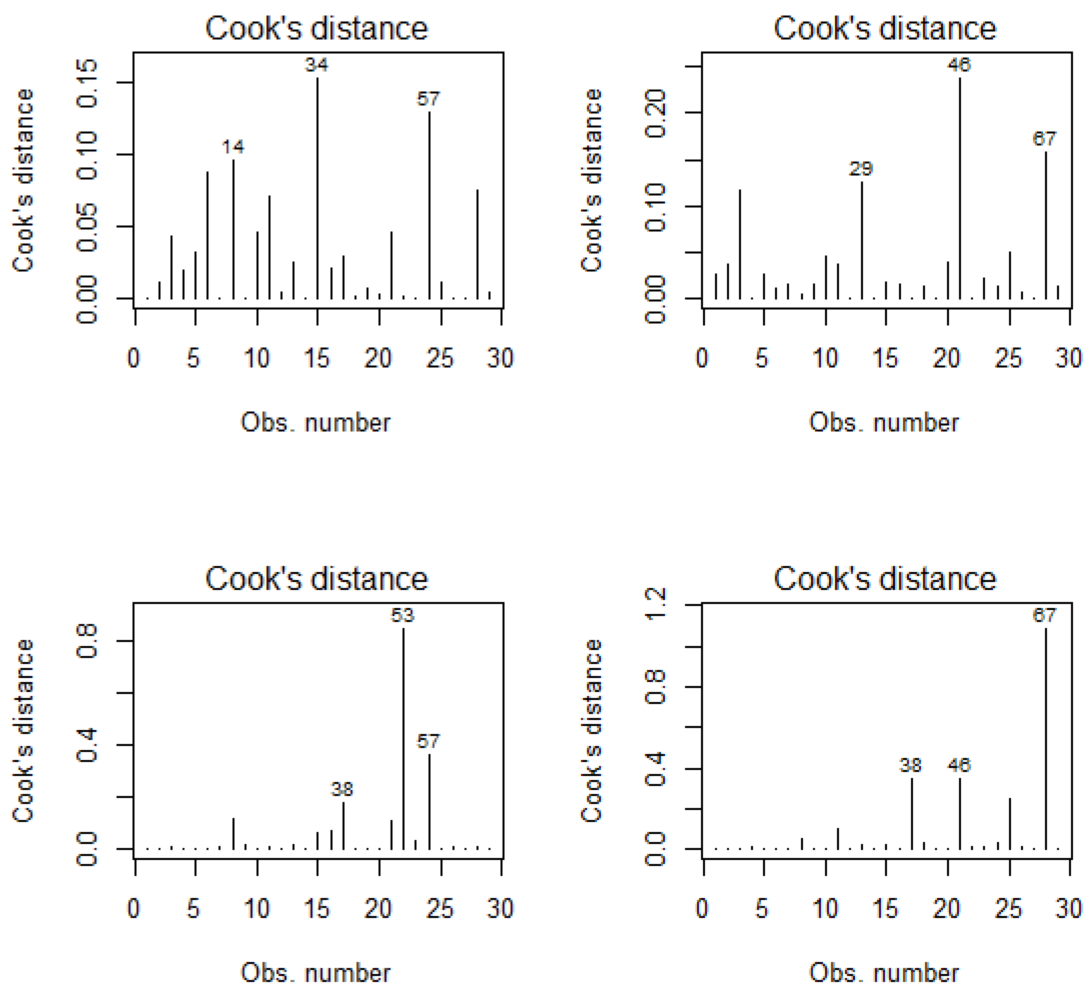


Figure S1. Cook's distances from minimum adequate models of geese grazing. From right to left and top to bottom. *Alopochen aegyptiaca, Anser anser, B. canadensis* & *B. leucopsis*

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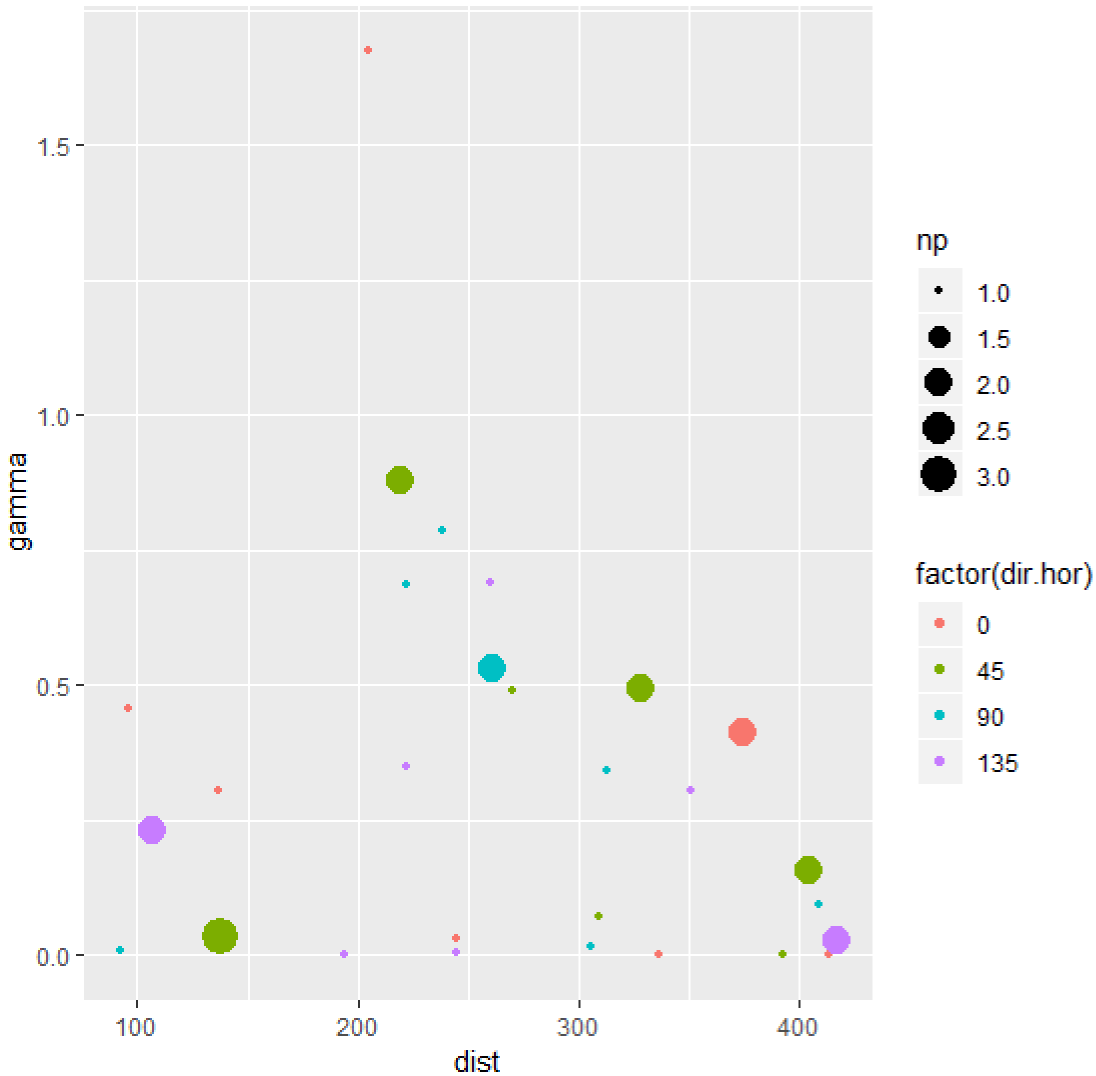


Figure S2. Variogram of model residuals from the minimum adequate model for *Alopochen aegyptiaca*. The variogram was produced in four directions, np =the number of point pairs for this estimate.

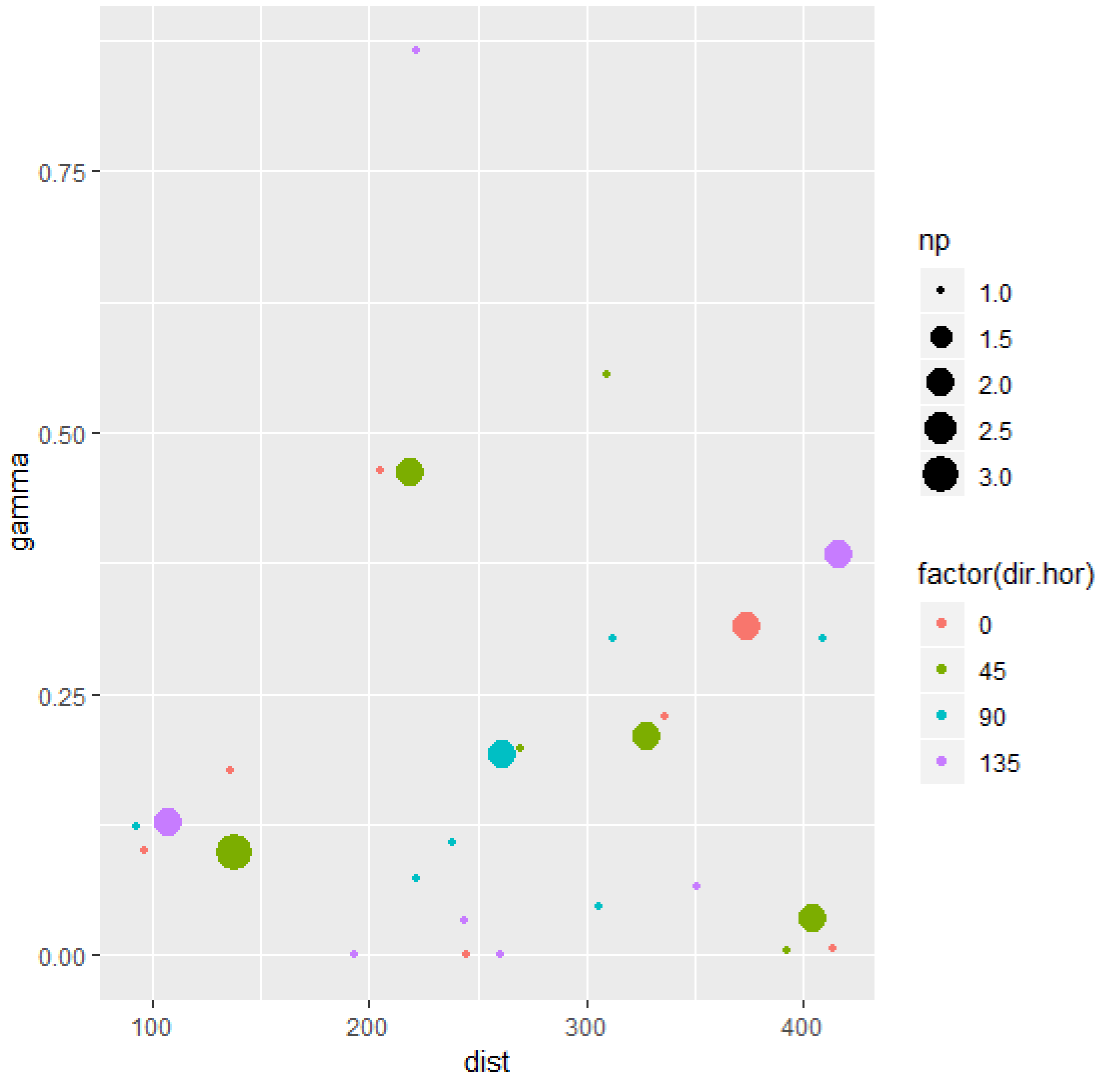


Figure S3. Variogram of model residuals from the minimum adequate model for *Anser anser*.

633 The variogram was produced in four directions, np =the number of point pairs for this estimate.

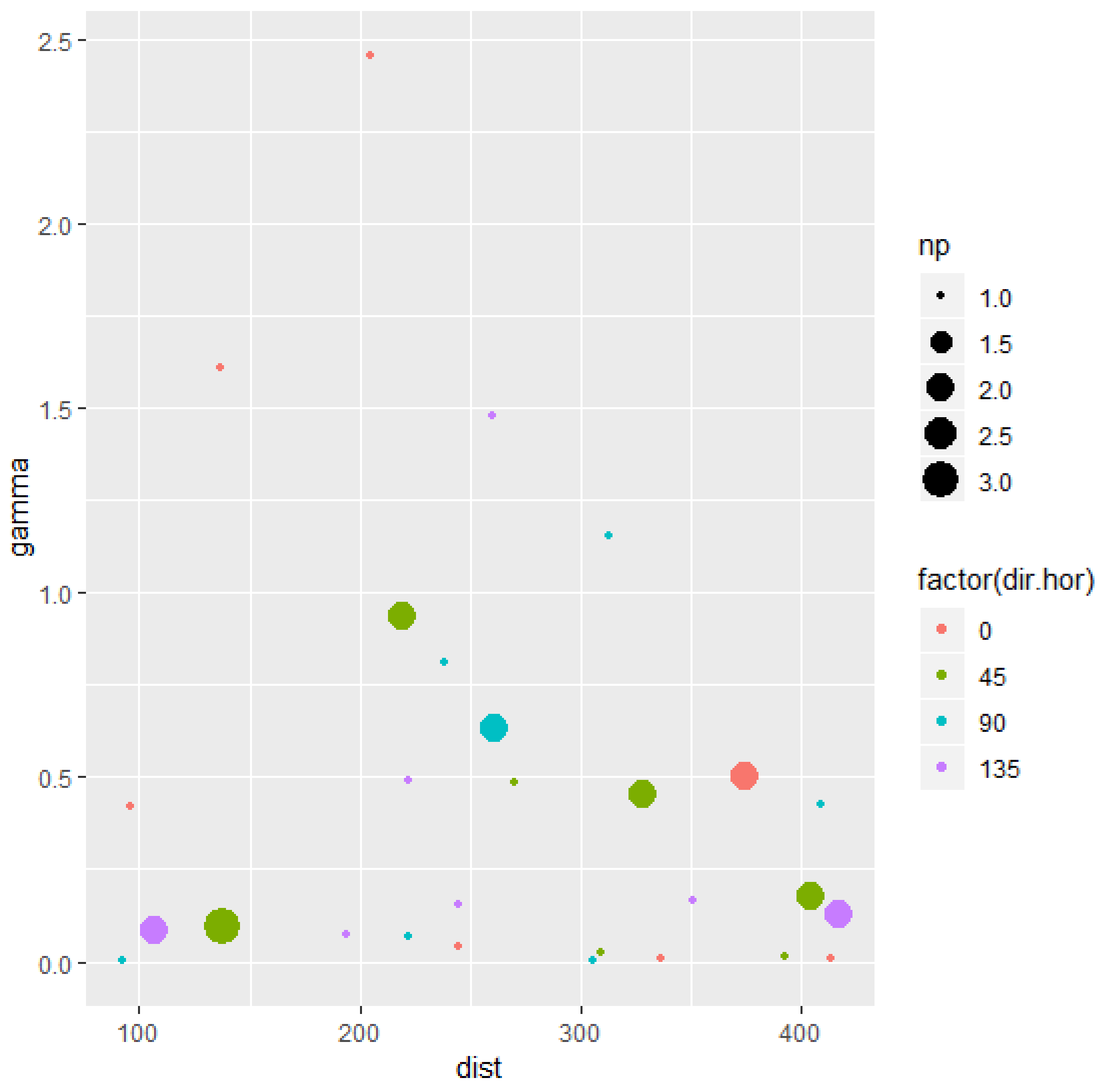


Figure S4. Variogram of model residuals from the minimum adequate model for *B. canadensis*. The variogram was produced in four directions, np =the number of point pairs for this estimate.

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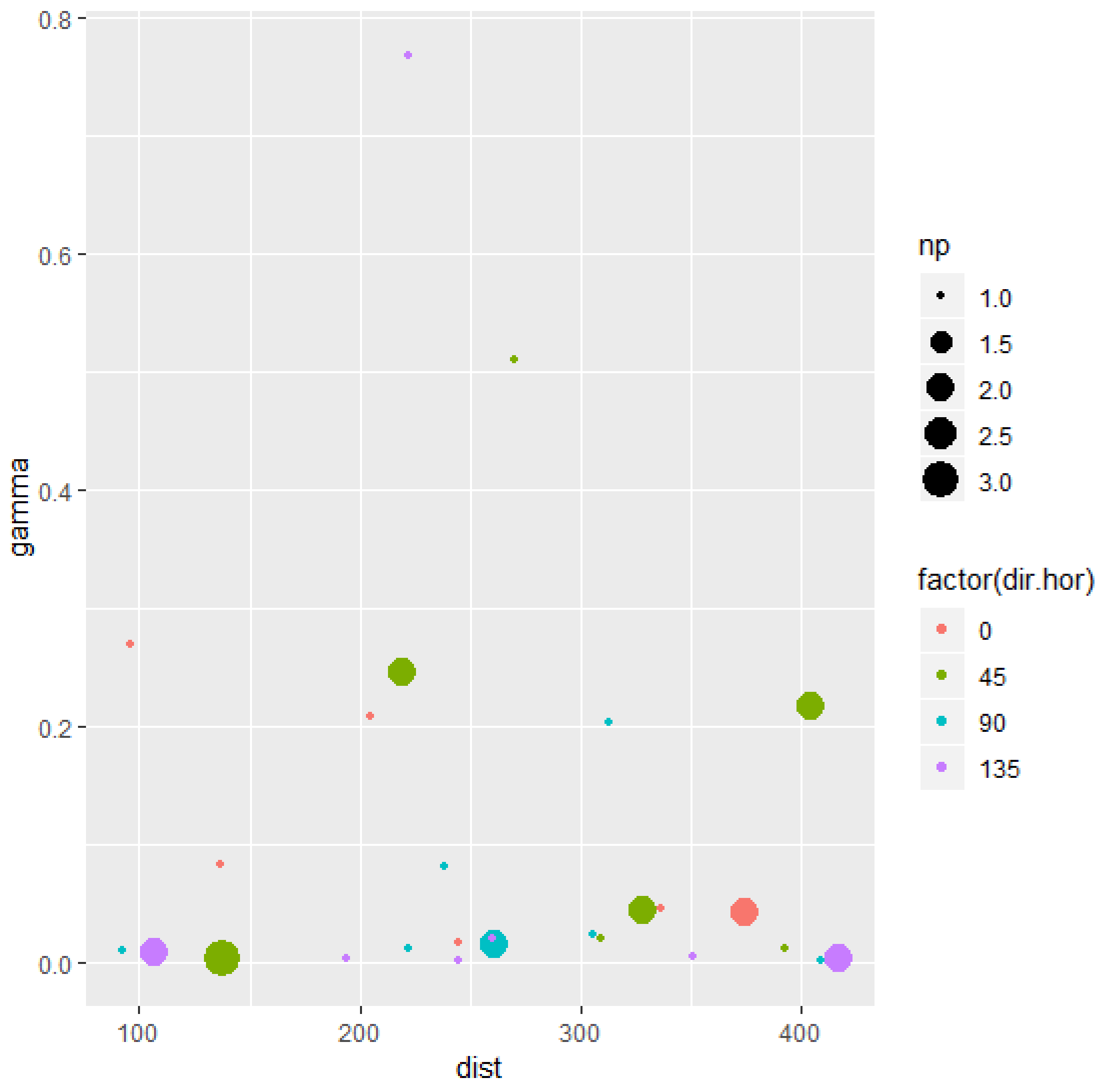


Figure S5. Variogram of model residuals from the minimum adequate model for *B. leucopsis*.

639 The variogram was produced in four directions, np =the number of point pairs for this estimate.

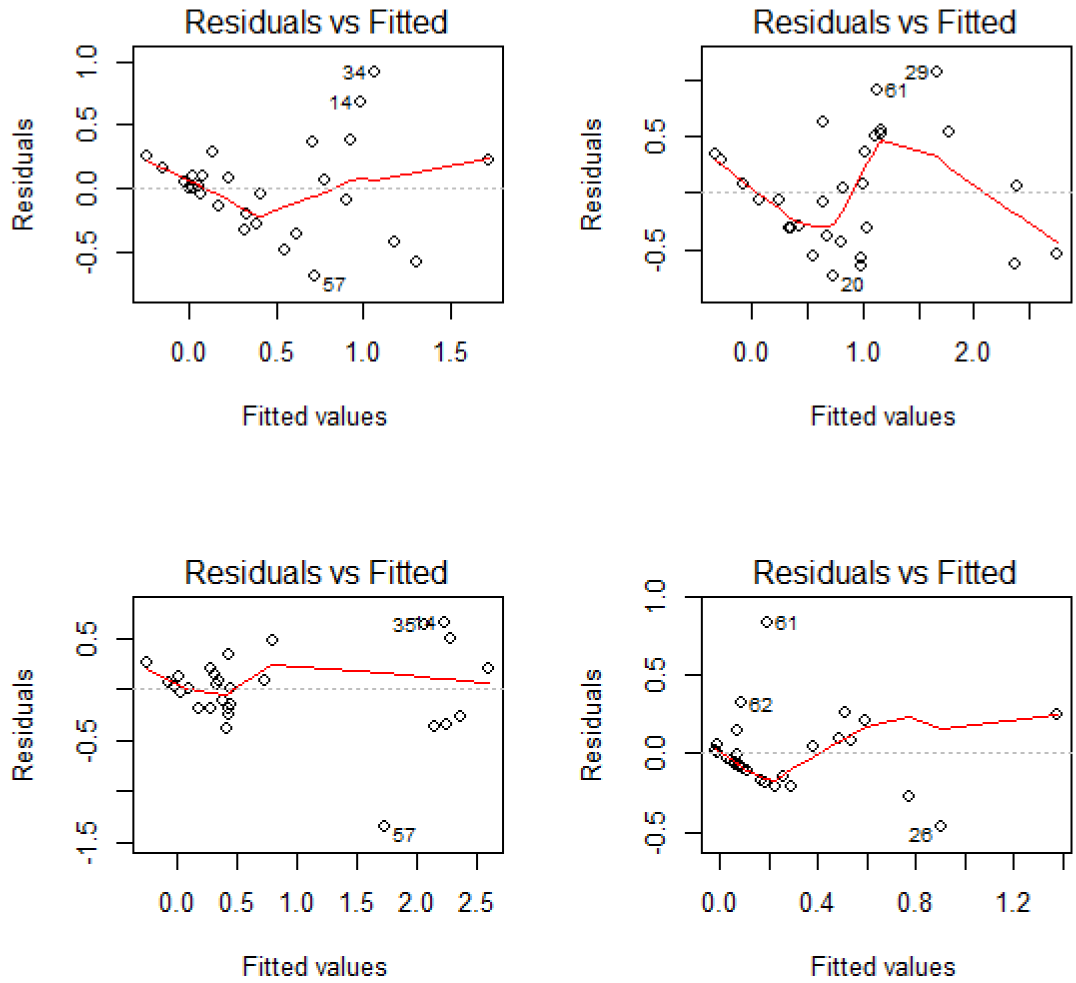


Figure S6. Plots of the model residuals versus the fitted values from minimum adequate models of geese grazing. From right to left and top to bottom. *Alopochen aegyptiaca*, *Anser anser*, *B. canadensis* & *B. leucopsis*.

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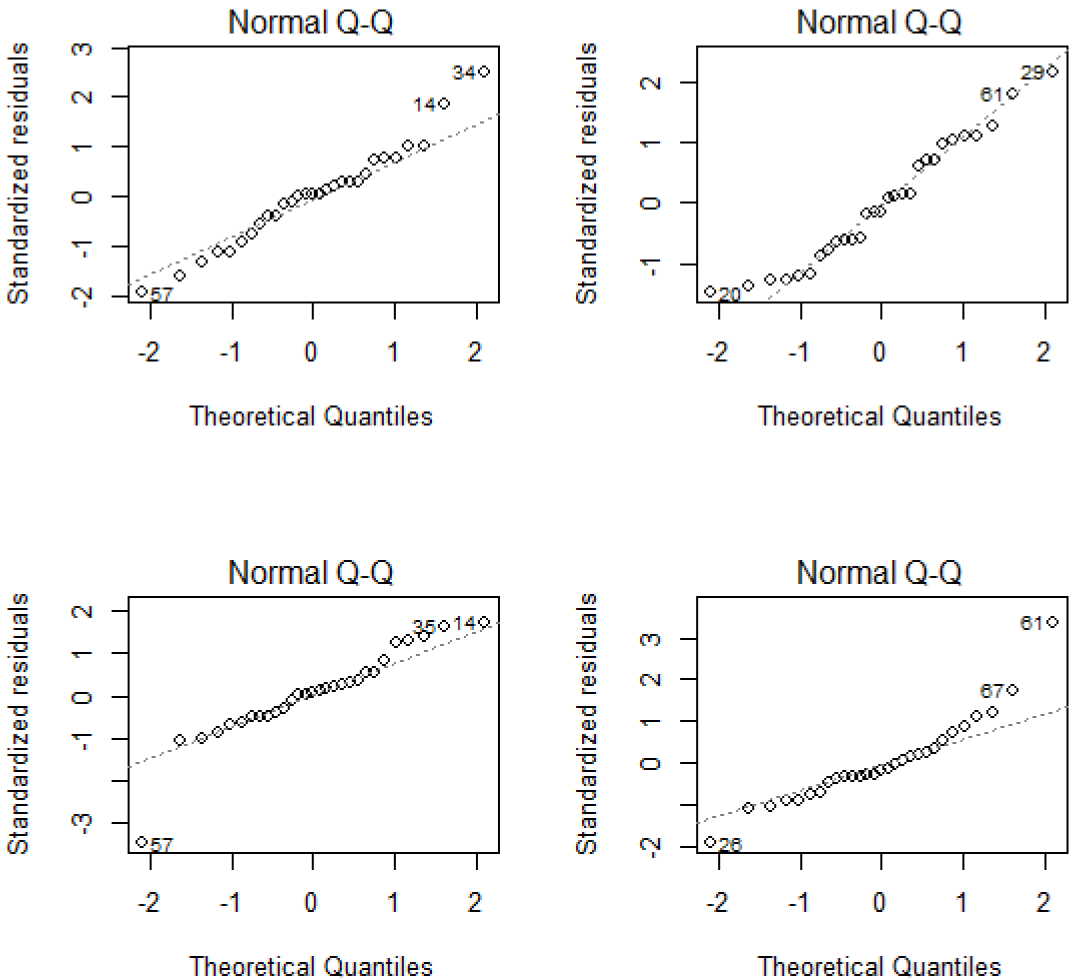


Figure S7. Normal Q-Q Plots of the model residuals from minimum adequate models of geese grazing. From right to left and top to bottom. *Alopochen aegyptiaca*, *Anser anser*, *B. canadensis* & *B. leucopsis*.

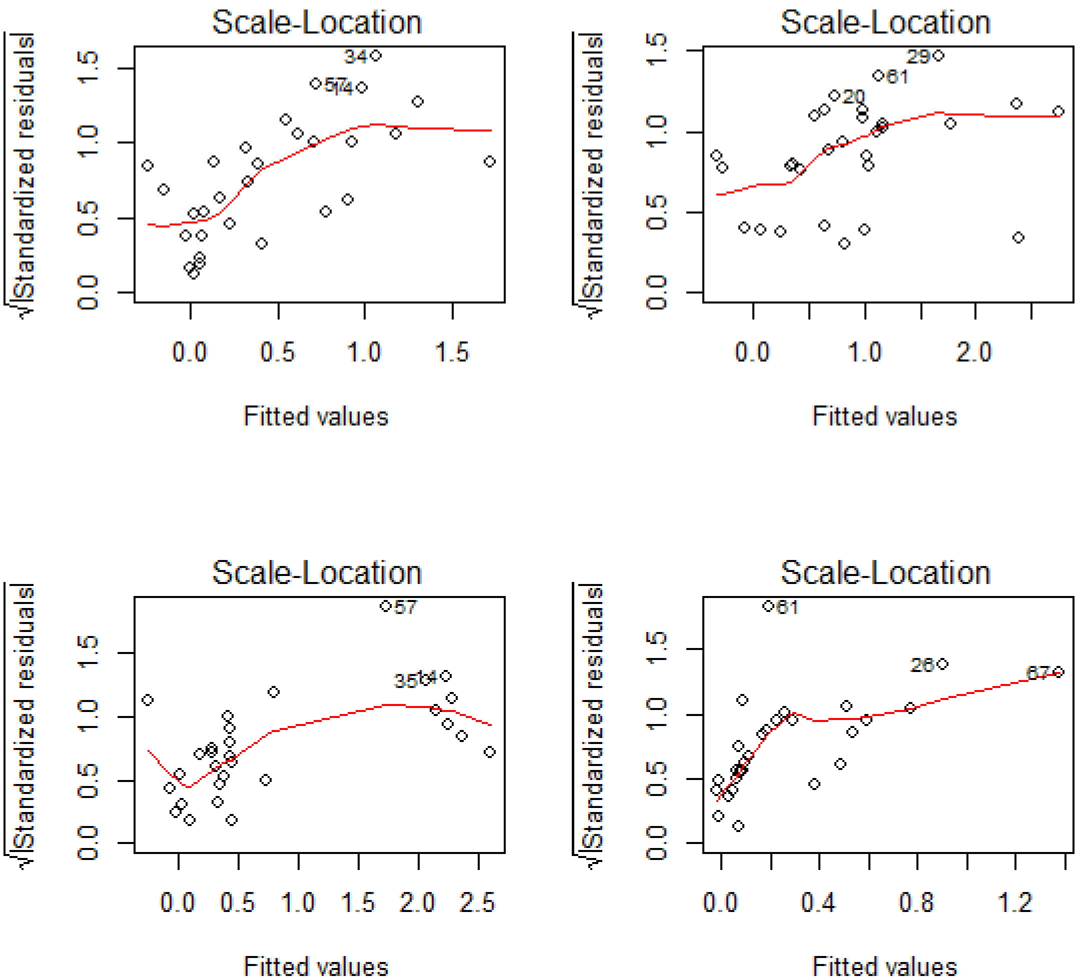


Figure S8.Scale-Location Plots of the model residuals from minimum adequate models of geese grazing. From right to left and top to bottom. *Alopochen aegyptiaca*, *Anser anser*, *B. canadensis* & *B. leucopsis*.