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RESEARCH ARTICLE

Arctic migrating barnacle geese utilize accommodation fields in a new agricultural staging area

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Abstract

1. The recovery of threatened species after conservation measures can lead to human–wildlife conflicts. One example of such is the recent population growth of the Barnacle Goose *Branta leucopsis*, a large herbivorous bird. During migration, geese stage in large numbers on agricultural fields in range countries and cause substantial damage to farms. A combination of repelling fields, where geese were chased off by humans, and accommodation fields, which provide refuge sites for foraging geese, has been suggested as an effective management tool to mitigate conflicts.
2. Using high-resolution satellite tracking data, we investigated habitat selection of 41 barnacle geese staging in Northern Karelia, Finland, during spring 2021. We estimated relative habitat use by these geese and conducted a fine-scale analysis of their use of different fields by employing Hidden Markov Models and integrated step-selection analysis. Fields included normal crop (no goose management), project and other (private and Nature 2000 area) accommodation fields and repelling fields. Project accommodation and repelling fields were established on areas known to have a long history of high grazing pressure by barnacle geese.
3. We found that behavioural data of geese can be categorized into three different states (static, slow and fast movement). Static and slow states were used for local field selection, fast state for field selection in the regional area, and all states for field selection after leaving a repelling field.
4. Overall, relative habitat use indicated that geese utilize accommodation fields more than expected by their availability. Integrated step-selection analyses revealed that geese avoided normal and repelling versus project accommodation fields at the regional scale. At the local scale, they preferred project accommodation fields over all other fields. After leaving a repelling field, geese did not show preference for any accommodation over repelling fields.
5. *Synthesis and application*. Geese show individual selection for accommodation fields compared to normal or repelling fields across several scales. Our results

suggest that the accommodation field concept—consisting of refuge areas and no-go areas where geese are repelled from—can help to mitigate the human–wildlife conflict using local stakeholders' knowledge.

KEYWORDS

Branta leucopsis, habitat selection, hidden Markov model, human–wildlife conflict, integrated step-selection analysis, Karelia (Finland), population management, tracking (telemetry)

1 | INTRODUCTION

When animal populations increase in size and expand their range, they often come into conflict with human interests. This can create serious human–wildlife conflicts, especially in areas where there is intensive land use by humans. Human–wildlife conflicts often concern economic losses for farmers (Braczkowski et al., 2023; Schwerdtner & Gruber, 2007). Large migratory birds, such as geese, cranes and swans are increasingly causing substantial damage to farms by consuming cultivated plants such as grass, cereals, potatoes or sugar beets, all which are aimed for animal fodder or human consumption (Montràs-Janer et al., 2020; Nilsson et al., 2016). Agricultural fields provide better feeding grounds than natural habitats, because crops provide higher quality and more easily accessible food and reduce competition between grazers (Fox & Abraham, 2017). Geese grazing on agricultural fields on their wintering grounds and along their migration routes cause damage that costs millions of euros annually (Koffijberg et al., 2017; Tombre et al., 2013). In Europe and North America, hunting regulations, conservation efforts, climate change and intensified agriculture, have resulted in strongly increased population sizes of many goose species (Fox et al., 2017; Fox & Leafloor, 2018; Fox & Madsen, 2017). With goose populations still increasing, this conflict is therefore likely to intensify and require increasing mediation between farmers and conservationists (Stroud et al., 2017).

To mitigate economical damage, active population management by reducing local population sizes through hunting is a seemingly obvious method. However, hunting may not always result in reduced yield losses (Buitendijk et al., 2022), and it is also not feasible if the focal species, such as the barnacle goose (*Branta leucopsis*), is protected. As an alternative to hunting, repelling methods such as human approach, derogation shooting or the use of lasers are regularly used to scare grazing birds from crop fields and meadows (Heim et al., 2022; Heldbjerg et al., 2022). In some cases, the possibilities for repelling may be restricted if the damage is caused by species that have a protected status or where repelling is harmful to non-targeted wildlife. In spring, the migration and habitat use of the barnacle goose overlaps with many protected birds, such as waders (e.g. breeding northern lapwing (*Vanellus vanellus*)) and ducks, which may be disturbed by the repelling of the barnacle goose. Another non-lethal approach to mitigate damage to crops caused by grazing birds is the establishment of so-called accommodation fields. These set-aside fields work as small nature refuges where birds can forage without disturbance and the field owners are paid compensation for letting birds forage on crop plants and keeping fields attractive for birds (Madsen, 1985; Vickery & Gill, 1999).

Here, we address the functionality of accommodation fields in mitigating the damage at a new staging site of barnacle geese belonging to the population breeding in the Russian Arctic. Over the last decades, barnacle goose populations, in particular the population breeding in the Russian arctic, have strongly increased in size, growing from a few tens of thousands up to 1.5 million individuals (Jensen et al., 2018) and the species can now be considered the most common goose in Europe (Fox & Leafloor, 2018). Previously, these geese used other areas in the Baltic as staging grounds during spring migration (Eichhorn et al., 2006). The first staging barnacle geese in the study area were observed in 2006. Within just 15 years, up to 50% of this population stage now in South-Eastern Finland, a shift that is not linked to changes in agricultural practises or other land use changes (Hiedanpää et al., 2023). The area is an important region for dairy farming and hence, most fields yield fodder plants for livestock, such as grasses (e.g. *Phleum*, *Lolium*) and clover. The cost for geese grazing in spring and autumn is substantial. In 2020, the Finnish government paid more than 3 million euros of compensation to farmers for damage caused by barnacle geese (Ministry of the Environment, Report VN/13432/2020) and in 2022, the compensation was close to 4 million euros. Most of these compensations were paid to farmers in Northern Karelia, reflecting the local intensity of this human–wildlife conflict. The current evidence suggests that both high quality set-aside fields for geese to forage and rest and 'no-go' fields where geese are actively repelled from are required to allow the accommodation field concept to function (Hiedanpää et al., 2023; Madsen et al., 2014; Teräväinen et al., 2022). Focusing solely on repelling geese increases their unnecessary flying, resulting in increased energy use and subsequent crop damage (Nolet et al., 2016). In addition, accommodation fields alone may not guide geese effectively onto allowed fields and damage spreads also to fields targeted for agricultural production (Koffijberg et al., 2017; McKenzie & Shaw, 2017).

The impact of accommodation fields on the distribution of foraging geese have usually been estimated as the number of observed geese, grazing pressure or costs of damage (Madsen et al., 2014; McKenzie & Shaw, 2017). However, we do not know one of the most important pieces in the puzzle: the individual behavioural responses of geese in the network of fields consisting of accommodation fields, repelling fields and other fields as a function of relative availability in the landscape. We address this knowledge gap by employing an individual-based approach and investigating foraging habitat choice based on high-resolution satellite tracking (telemetry) data of 41 individual barnacle geese in an agricultural landscape consisting of accommodation fields, fields with coordinated repelling and other control fields. Based on the concept of set-aside fields, we were expecting that barnacle geese would prefer accommodation fields over repelling fields and normal (control) fields, because there they would be undisturbed. Furthermore, we anticipated that geese would avoid repelling fields after leaving them.

2 | MATERIALS AND METHODS

2.1 | Study area

Our study was conducted in Northern Karelia, Finland, which has become an important staging area for migrating barnacle geese during spring and autumn over the last 15 years. Specifically, the study area included the regions of Tohmajärvi and Kitee (Figure 1). We categorized available habitats into fields, lakes and other habitats (e.g. forests, buildings, riparian strips, ditches or areas in Russia across the Finnish border for which no information was available). The lake information was obtained from the National Land Survey of Finland Topographic Database 12/2022. Fields were further classified into normal fields (two categories: edible and non-edible according to geese' foraging preferences), accommodation fields (two categories: project vs. private and Natura 2000 fields) and repelling fields. On normal (edible and non-edible) fields, no goose management took place. The crop type in normal edible, project accommodation and repelling fields was grass cultivated for cattle fodder and was of comparable quality. Crop type and quality in private accommodation fields and in Natura 2000 fields was not always similar to project accommodation and repelling fields. Accommodation fields in our study included fields of farmers that collaborated with the Natural Resources Institute Finland ('project accommodation field'), fields of farmers that set-aside fields for geese on their own initiative without our cooperation ('private accommodation field') and fields that were situated in Natura 2000 areas ('Natura accommodation field'). The project accommodation fields were set aside in those areas that were known to be heavily used by geese in earlier years. Private and Natura accommodation fields were pooled into the category 'other accommodation fields'

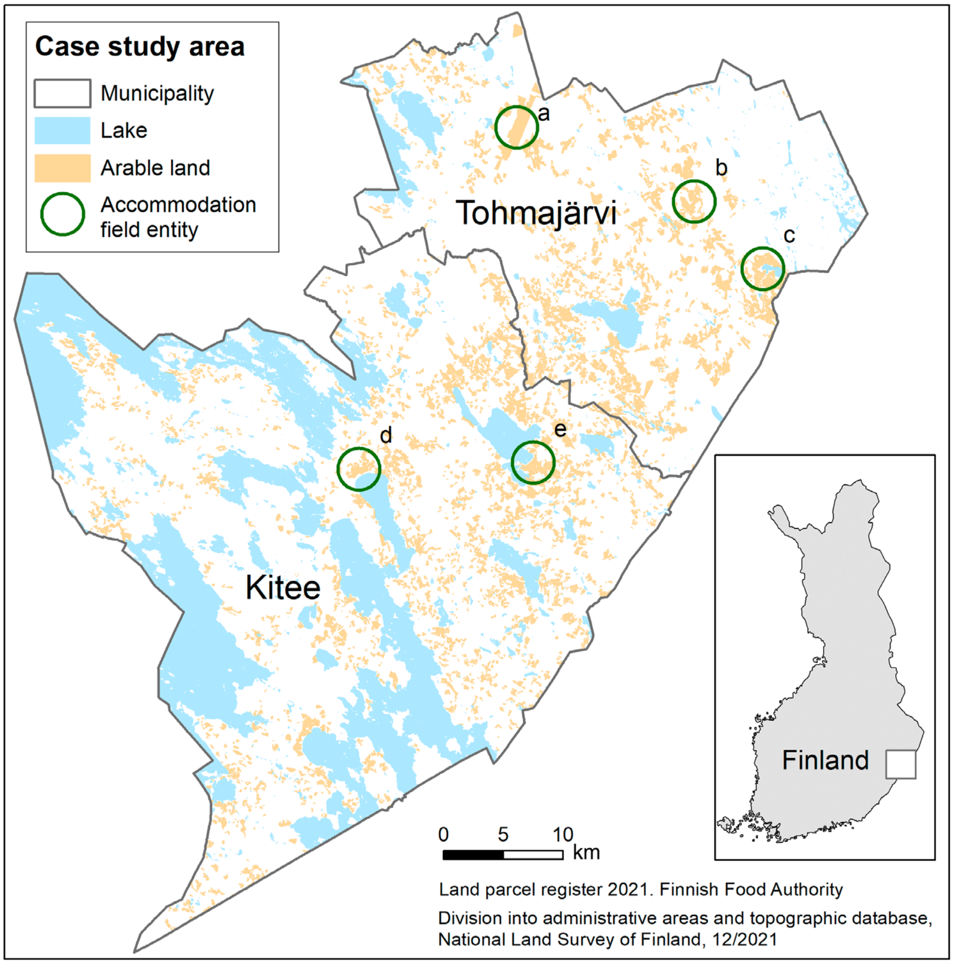

FIGURE 1 Location of the study area and accommodation field entities in Finland.

because we did not have any influence about their setup. On these accommodation fields, geese were allowed to forage freely and were not chased away by humans. Together with farmers providing fields as accommodation fields and other farmers, we established 'no-go' fields (repelling fields) where geese were actively repelled in a coordinated way by project workers and a team of local farmers and hunters. Repelling fields were also established on fields preferred by geese which have previously suffered yield losses due to geese grazing. As 'project accommodation fields' and no-go 'repelling fields' were established on similar grounds, the effects of the accommodation—repelling field concept on the habitat use of geese can be compared. However, the inclusion of 'private accommodation field' and 'Natura accommodation field' followed different criteria and hence comparing those to project accommodation and repelling field types should be done carefully.

Geese were repelled from dusk to dawn by approaching, by hand-held lasers and by shotgun blank shots. Normal, accommodation and repelling fields were all in agricultural use and crops were harvested two to three times between spring and autumn migration. Data on location and delimitation of individual fields as well as information on field use (crop) were obtained from the Finnish Food Authority. Our study area included ca. 197 km^2 of arable land (mean field plot size 2.5 ha, range 0.01–74.4 ha), of which ca. 3.3% were declared as accommodation fields (ca. 6.4 km^2). Accommodation fields were clustered in five specific areas (accommodation field entities; see Figure 1) within the study area, where project accommodation field plots ranged from 0.01 to 43.4 ha, other accommodation field plots ranged from 0.7 to 27.4 ha (partly outside of entities) and repelling fields ranged from 0.5 to 35.1 ha. The average dairy farm size in the study area is quite low—about 44 ha—meaning that farmers do not have much flexibility to adjust fodder production to replace losses due to geese browsing.

2.2 | Study population and bird tagging

Birds were trapped during early May 2021 with a cannon net while they were grazing on fields. We equipped 50 adult barnacle geese (30 males and 20 females) with solar-powered GPS-GSM/GPRS transmitter neckbands (OrniTrack OT-NL40-3GC, Ornitela, UAB, Lithuania) and individually numbered metal leg rings. The Centre for Economic Development, Transport and the Environment provided permission to capture, mark and tag geese with satellite transmitters (ELY-keskus, permission numbers VARELY/1288/2021 and VARELY/1313/2021). The weight of the GPS tags (22 g) added less than 2% of the weight of the lightest bird, which is well below the commonly used 5% threshold (Portugal & White, 2018). The whole procedure followed the ethical guidelines of the Finnish Bird Ringing Centre. GPS resolution was set to record positions every 10 min and the transmission interval was set to 1 h. When the battery level of the transmitters dropped below 50%, data recording and transmission intervals were increased accordingly for individual devices until they were charged again.

2.3 | Statistical analysis

Habitat selection was analysed both by computing use-availability ratios (Section 2.3.3) and with integrated step-selection analysis (iSSA, Section 2.3.4). These analyses relied on classification of movement steps, based on hidden Markov models (HMM, Section 2.3.2). Some pre-processing (Section 2.3.1) was necessary to implement the analyses.

2.3.1 | Pre-processing the data

Data for this study were collected between 10 and 27 May 2021. We selected observations from the regions Tohmajärvi and Kitee where the accommodation field entities were situated. To assure high accuracy, we filtered out GPS-locations with hdop (horizontal dilution of precision) >2, which led to the removal of 3667 GPS-locations (5.2% of the data). Furthermore, we only used observations of geese that were within a radius of 2 km of any of the accommodation fields at some point. The threshold was chosen based on the step lengths extracted from the data with an idea that geese would have had a possibility to choose an accommodation field. A total of 96.9% of all the steps were less than 2 kilometres long and approx. 80% of the steps were less than 100 metres, thus the majority of the steps being rather short. One of the project fields was half-accommodation field and half-repelling field with no clear boundary in between, hence all observations from this field were removed for clarity. This left us with observations from 41 individual geese that remained in the area on average for 6 days (range: 16 h–14 days). For reliable modelling, we had to make sure that the data is collected at a constant fix rate: hence, we included only the sequences of consecutive GPS-locations with a 10 min interval but allowing a tolerance range of 2 min (see Figure 2). Each sequence, called burst, needed to have at least three observations to be able to calculate movement angles (see below). GPS-locations outside these requirements were excluded.

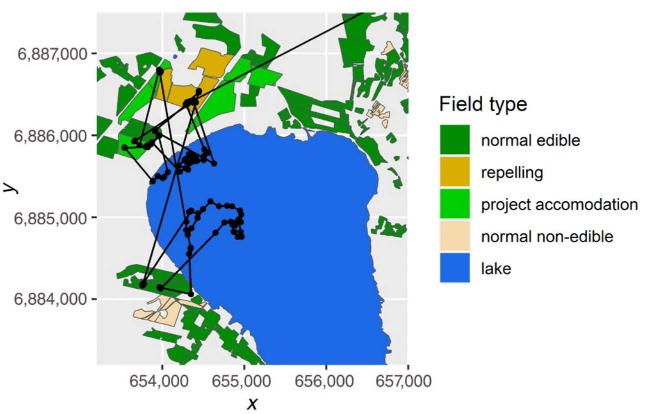

FIGURE 2 GPS-locations of one individual goose (ID 37) during its staging at lake Ätäskö in accommodation field entity *d* (see Figure 1), using the Coordinate Reference System.

2.3.2 | Hidden Markov model

HMMs are widely used state-switching time series models for movement data (see e.g. Langrock et al., 2012; Zucchini et al., 2017). The general idea is that there is an underlying (hidden) state process producing the observed movement and those hidden states are considered to represent different behavioural modes, such as foraging or moving. The HMM then classifies the movement behaviour based on the observations. In the case of GPS-tracking data measured at regular time intervals, the model utilizes step length, bearing and turning angle calculated from consecutive location observations. The movement within a state can be modelled by correlated random walk or biased random walk, of which the former contains correlation in direction and the latter contains a tendency towards (or away from) a particular central location. For fitting an HMM, one has to specify the number of states, that is the behavioural modes. As a result, the model produces movement characteristics for each state, probabilities to switch between the states and the most likely sequence of states given by Viterbi algorithm (Viterbi, 1967). This information can then be used to study further e.g. the foraging behaviour of animals (e.g. Ylitalo et al., 2021) or as in input to iSSA (Picardi et al., 2022).

We built a three-state HMM and expected the model to contain states that would reflect roosting and foraging, and movement indicating changes between roosting and foraging sites or between foraging sites. Movement in each state was modelled by correlated random walk, because we did not expect that geese would show a tendency to a specific central place in the study area. For the three-state model, we chose the initial values such that they represented different step length and turning angle distributions. The model was fitted for all geese together, meaning that the same parameters were assumed for each individual. For the state process, we allowed all transitions between the three states. We labelled the three hidden states that were clearly different from each other: 'static movement', 'slow movement' and 'fast movement'. The mean step length for static movement was 14 m with a mean turning angle 6.5°, whereas slow movement showed a mean step length of 75 m and a mean turning angle of 0.7°. In contrast, fast movement had a rather long mean step length of 1226 m and a mean turning angle of −1.7°. The estimated concentration of the turning angle varied from 0.04 (static movement) to 0.18 (fast movement) to 0.66 (slow movement), with higher concentrations indicating more persistent movement. We interpreted static movement as foraging behaviour, slow movement as roosting behaviour on lakes, and fast movement as leaving/arriving to the foraging area or going to/coming from roosting areas based on the field type data (see Figure 3) and time of day (see Figure S1). The probabilities of geese changing from static movement to slow movement or fast movement were low (1% and 12%, respectively; Table S1), as were the probabilities of geese changing from slow movement to static movement of fast movement (4% and 9%, respectively), meaning that geese continued foraging or roosting once they started this behaviour. However, the probability of geese changing from fast movement to static movement, meaning that geese would change from flying to foraging, was noticeable (37%). The HMM analyses were carried out with the R Statistical Software (v4.3.3) (R Core Team, 2024), using package *momentuHMM* v1.5.5 (McClintock & Michelot, 2018).

2.3.3 | Relative habitat use

We first estimated selection ratios by dividing the proportion of all ends of steps of a state recorded a specific habitat by the availability of that habitat, where availability is the proportion of that habitat compared to all fields and lakes in the entire study area. We excluded the 'other habitat' type in these calculations because this type is reflecting non-relevant habitats such as buildings or forests, which are not used by geese, and riparian strips or ditches close to lakes and fields. These can be real observations or due to GPS error, and since these points are not located within the field and lake polygons, we cannot specify the habitat of those locations in more detail. Relative habitat use was then calculated as the proportion of a selection ratio for one habitat in the overall sample.

2.3.4 | Integrated step-selection analysis

Step-selection analysis (SSA) is a method for modelling habitat selection of moving animals by comparing the distribution of environmental covariates (habitats) at used versus available locations (Fortin et al., 2005; Thurfjell et al., 2014). It uses individual's observed movements to determine habitat availability: for each observed movement step a set of random steps is sampled originating from the same location and following the typical movement characteristics of the animal. Fitting a conditional logistic regression model to the used (response = 1) versus available (response = 0) locations results in estimates of selection coefficients β_k for each habitat category k such that $\exp(\beta_k)$ can be interpreted as the relative selection strength of category k (Avgar et al., 2017). More concretely, the pairwise comparison $\exp(\beta_k - \beta_l)$ quantifies the ratio probabilities to select habitat k versus habitat l. Statistical significance of pairwise differences between the β_k's can be assessed by Tukey's HSD test (Tukey, 1949). In SSA the inference regarding habitat selection is conditional on movement, whereas movement is assumed to be independent on habitat selection (Avgar et al., 2016). iSSA tackles this issue by allowing simultaneous inference of habitat selection and habitat-dependent movement. In practise, the movement parameters (step length and turning angle) are included in the model as covariates, and they are allowed to depend on the habitat at the beginning of the movement step. Integrated step selection has been used, for example in analysing the influence of roads on movement behaviour of elks (Prokopenko et al., 2017) and in studying brown bear habitat selection during moose hunting (Brown et al., 2023). An example of applying SSA to an avian species can be found in (Eisaguirre et al. 2020).

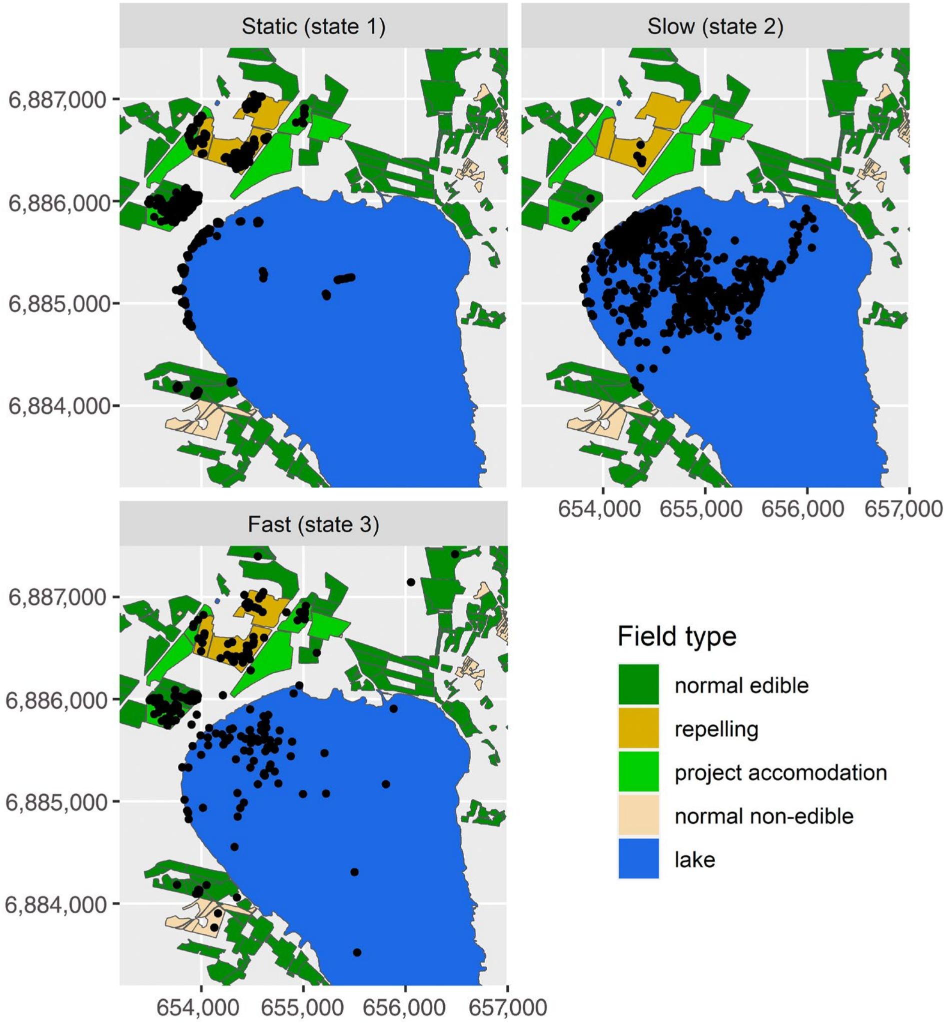

FIGURE 3 End points of steps of all individuals at accommodation field entity *d* (see Figure 1) at lake Ätäskö, according to the three different HMM states, using the Coordinate Reference System.

We modified the iSSA approach to reflect our interest in specific field selection by foraging geese at different scales. In general, instead of sampling available locations based on step length and turning angle distributions, we sample from available fields. Hence, for each step that ends in a field (see Figure 3), we chose a circular area with a radius of 5 km (Heim et al., 2022) from the starting point of the step (or GPS-location). For each field within that radius (also including fields that are only partly within this area), we calculated the distance to the starting point. When sampling these fields randomly, the size of the field and the distance to the starting point were used as sampling weights. This means that larger fields are more likely to be chosen, reflecting geese' general preference for larger fields (Fox et al., 2017 and references therein). For the distance to the starting point, we used an empirical step length distribution as the probability distribution that is a fitted gamma distribution. Hence, closer fields are favoured over the more distant ones. When fitting our iSSA model, the size of the field is used as a covariate. For every observed step in our data, we sampled 19 control steps that represent field availability. We included step length and the logarithm of the step length in the model as covariates to account for the underlying movement patterns of the geese in their field selection process (Avgar et al., 2016). The iSSA analyses were carried out with the R Statistical Software (v4.3.3) (R Core Team, 2024), using package *amt* v0.1.7 (Signer et al., 2019) for simulating the random steps, package *survival* (Therneau, 2022) for fitting the conditional logistic model and package *emmeans* (Lenth, 2023) to implement pairwise comparisons between habitat categories.

Observations in normal edible fields at night show that some geese probably also feed at night (Figure 4). These geese are perhaps very hungry or might reflect some rarer chronotype, but these circumstances do not reflect the larger population pattern. We therefore restricted our further data analyses to daytime hours (4 AM–11 PM), where we would expect most foraging behaviour and hence habitat selection taking place.

We built three different models. In model 1, we analysed field selection at a regional scale, using only steps arriving in a field but originating from another field. Here, we included steps from the HMM state 'fast' as the regional field selection scale can take place in fields

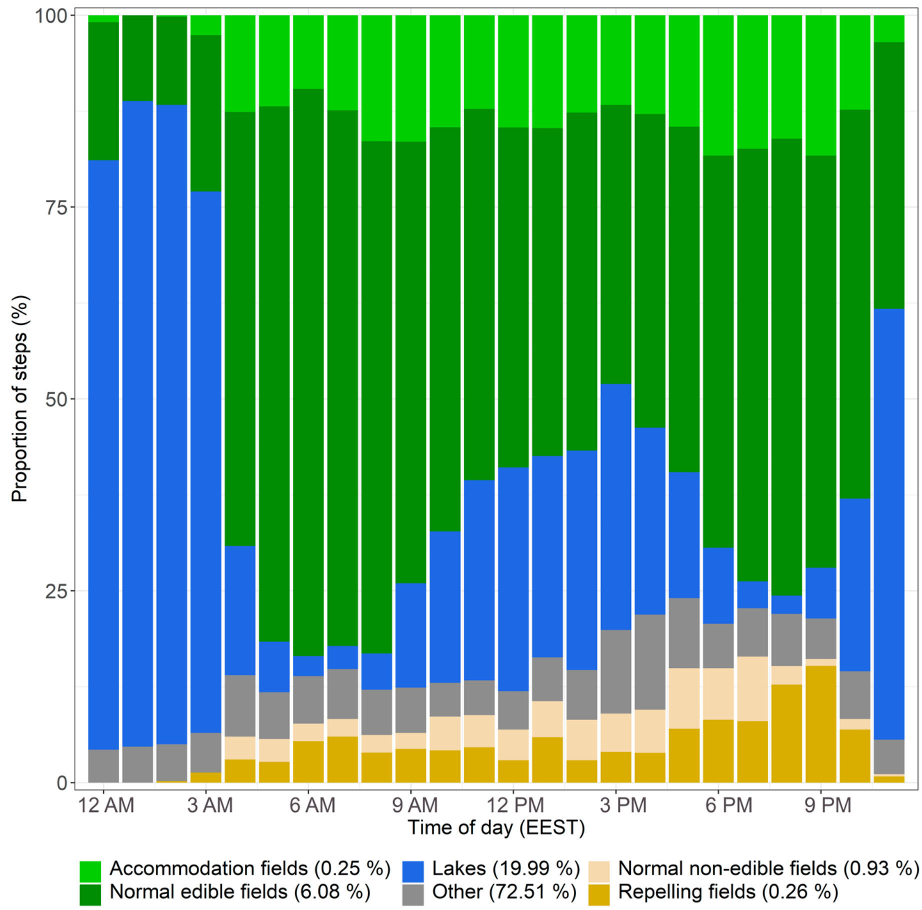

FIGURE 4 Distribution of steps by habitat during the time of the day. Every bar represents one full hour, so 12 AM means 12 AM to 12:59 AM Percentages are the proportions of the habitat type compared to the whole study area.

further away than neighbouring fields. In model 2 we analysed field selection on a local level, using all steps ending in a field originating from the same or another field. For model 2 we used steps from the HMM states 'static' and 'slow' as the local field selection level is represented by the original and neighbouring fields, representing the relative likelihood that geese will continue to occupy a particular field type after initiating use of that field. Therefore, the distinction between 'static' and 'slow' movement did not impact step-selection analyses. In model 3, we analysed field selection specifically after geese leave from a repelling field. Here, we included all steps originating from a repelling field but ending in another field. We used steps from all three HMM states as the individual flight distance can vary substantially after being repelled (Heim et al., 2022).

3 | RESULTS

3.1 | Distribution of observed steps

The distribution of steps revealed that during the night (ca. 60 min after mean sunset—ca. 10 min after mean sunrise), most geese observations (56% to 84%; Figure 4) were located on lakes where they were roosting. Occurrence of steps in all categories of fields increased after 4 a.m. when most geese start foraging. There is a slight drop in the occurrence of steps on all fields in the afternoon when geese rest, followed by a repeated increase of observed steps in fields. Observations of geese are overall low in repelling fields throughout the day, except that there is an increase of goose observations on repelling fields after 8 PM (Figure 4). This increase in the evening hours could reflect the lower repelling efforts at that time of the day. There were few observations of geese in non-edible fields and other habitats during the day. While these observations are not surprising, they do correspond to general patterns of goose behaviour.

3.2 | Availability and usage of fields and lakes

During the entire observation time, 66% of all starting steps associated with the state 'static movement' were ending in normal edible fields, 18% in accommodation fields (all types combined), 7% in repelling fields and 6% in non-edible fields. For the state 'static movement' relative habitat use was estimated to be about 76% for the combined project and other accommodation fields, about 6% for edible fields, almost 0% for lakes, about 3% for non-edible fields and about 14% for repelling fields (Table 1). Similar relative habitat use was found for the state 'slow movement'.

TABLE 1 Overview of habitats, their availability (proportion of that habitat type compared to all fields and lakes in the study area), number of starting steps and their step-ending habitat, the associated state from the hidden Markov model, the proportion of steps, the proportion of steps divided by availability and the relative habitat use.

Habitat	Availability (%)	State	Start steps	Proportion of steps (%)	Selection ratio	Relative habitat use (%)
Project accommodation fields	0.46	Static	1347	12.31	27.01	51.84
		Slow	192	5.75	12.61	65.56
Other accommodation fields	0.44	Static	611	5.58	12.77	24.50
		Slow	29	0.87	1.99	10.32
Normal edible fields	22.10	Static	7247	66.23	3.00	5.75
		Slow	921	27.59	1.25	6.49
Lakes	72.71	Static	315	2.88	0.04	0.08
		Slow	2083	62.40	0.86	4.46
Normal non-edible fields	3.37	Static	657	6.00	1.78	3.42
		Slow	47	1.41	0.42	2.17
Repelling fields	0.93	Static	766	7.00	7.51	14.41
		Slow	66	1.98	2.12	11.01

3.3 | Integrated step (field) selection analysis

When selecting a new field (Model 1, state 'fast') barnacle geese favoured project accommodation fields over all other field types (Table S2). They were over nine (exp(2.272)) times as popular as normal non-edible fields and over four (exp(1.562)) times as popular as normal edible fields. As expected, non-edible fields were significantly less preferred in comparison to all other field types.

When considering all 'static' and 'slow' steps ending in a field (Model 2), project accommodation fields were favoured over all other field types (Table S3); they were eight (exp(2.081)) times more popular than other accommodation fields and almost twice (exp(0.528)) as popular as normal edible fields. Other accommodation fields were clearly and significantly less favoured than any other field type; their selection ratio varied between 12.5% (exp(−2.081)) and 56.2% (exp(−0.577)) (Table S3). Repelling fields were less favoured in comparison to normal edible and project accommodation fields.

Pairwise comparison post-hoc analyses showed no significant differences between field types, when considering steps originating from a repelling field (Model 3, Table S4).

4 | DISCUSSION

We found evidence supporting that the accommodation field concept can be applied successfully. During the spring migration period, barnacle geese staging in Eastern Finland utilized certain accommodation fields that were specifically established on areas known to be preferred by geese and that have a high and consistent damage risk across years (i.e. project accommodation fields). The observed step distribution confirmed that our high-resolution satellite tracking data caught biologically relevant behaviour of our studied barnacle geese. Barnacle geese strongly preferred project accommodation fields regarding their availability in the study area and compared to the use and availability of normal edible fields. However, other accommodation field types in our data providing safe foraging areas for geese (private accommodation fields and Natura 2000 areas) were less preferred regarding their availability than project accommodation fields.

Information on relative habitat use does not allow predictions on habitat selection on an individual level, because relative habitat use represents habitat selection at a regional scale rather than at the level of the individual (Johnson, 1980). The partitioning of goose behaviour into three different states helps to better address our question of individual habitat selection in different contexts, an approach that has recently gained attention in the field (Picardi et al., 2022; Thorsen et al., 2022). In addition, an iSSA approach allows assessment of individual habitat selection (Thorsen et al., 2022). With our methodological changes to a field-selection analysis, we could address individual field selection by barnacle geese on several scales. First, on a regional scale (model 1), our findings show that faster-moving geese (state 3) landing in a field further away from the origin of their movement, favoured project accommodation fields over all other field types and avoid normal non-edible fields. The other accommodation fields were only favoured over normal non-edible fields. This might suggest that on a regional scale, other accommodation fields were not as suitable to attract geese as the project accommodation fields. Here, repelling fields were not avoided compared to normal edible fields, but they were avoided compared to project accommodation fields and repelling fields were only favoured over normal non-edible fields. Second, on a local scale (model 2), our findings show that generally slow-moving geese (states 1 and 2) favoured project accommodation fields over all other fields, almost always avoided other accommodation fields compared to other fields and preferred normal edible fields over repelling fields. Since all those field types were growing the same crop (grass) and we controlled for field size and distance to the surrounding fields, these results suggest that the accommodation and repelling field approach works to a certain extent in our study area. Geese select specific fields of high quality where they can forage undisturbed and avoid fields of similar quality where they are repelled.

Reasons for why barnacle geese seem to avoid private accommodation fields and fields in the Natura 2000 area (together 'other accommodation fields') can be manifold. Private accommodation fields were in a high damage risk area, but their cultivation history and crop quality may be such that it does not attract geese as project accommodation fields did. The Natura 2000 area mainly consists of a water body and surrounding riparian area, where the size of the suitable field area for browsing is small consisting a narrow riparian strip, making it potentially unattractive for geese. It is also possible that the food quality was lower in the Natura 2000 areas than in the project accommodation fields, which would indicate the lack of disturbance alone is not sufficient to attract geese. Yet, another explanation might be that Natura areas attract birds of prey such as the White-tailed Sea-eagle *Haliaeetus albicilla* and other potential predators and hence geese would avoid these areas (Jonker et al., 2010). Taken together, these results suggest that establishing a functional accommodation field for geese needs careful planning, knowledge on the behaviour of geese and information on the history of agricultural damage and recognition that conservation status of the area alone does not guarantee success.

Despite the observed preference of geese for project accommodation fields over normal edible fields on different scales, we cannot conclude exhaustively that the designation to (project) accommodation field is the dominant explanatory factor because we were not able to fully randomize different accommodation and repelling field types. This is because barnacle geese prefer high quality (energy content and short sward length) grass fields (Fox & Abraham, 2017; Fox et al., 2017) and certain landscape characteristics, such as open landscapes with larger distances to forests and human structures, but with proximity to proper roosting sites (Fox et al., 2017; Madsen, 1985; Madsen et al., 2022). This, and taking into account farmers' opinions makes full randomization impossible. However, our results suggest that functional and attractive accommodation fields most likely work better in areas that have a long history of goose preference and agricultural damage. Indeed, in our study fields were designated as project accommodation fields because (1) collaborating farmers allowed the designation as accommodation field and (2) we chose fields that had data on previous high goose damage and rejected fields for which no data had been recorded. Our repelling fields were often situated in the proximity of accommodation fields and they also were known to be preferred by geese, farmers therefore wanted to protect the crop of those fields. Hence, repelling fields are comparable with project accommodation fields in terms of crop quality and grazing pressure by the geese. The results of post-hoc tests between field types suggest that geese prefer project accommodation fields over repelling fields suggesting that the concept of providing accommodation fields in concert with repelling geese from no-go fields is functional.

After leaving from a repelling field (model 3), slow- and fast-moving geese showed no significant preferences for any field type; hence, we found no evidence that geese would favour any accommodation fields over normal edible fields or repelling fields. This is somewhat surprising since we expected that geese would show similar patterns as in model 1 and 2 and favour at least project accommodation fields. One explanation for why repelling fields would be chosen in this instance is that repelling fields were very attractive fields for geese (as measured by higher damages), the reason they were assigned to be a repelling field. Another explanation might be that repelling was not always as efficient and regular as planned, and thus the geese landed in the same field area soon after repelling (Heim et al., 2022). Repelling only works properly when performed systematically and repeatedly (Heim et al., 2022; Simonsen et al., 2016). Repeated scaring, however, leads to an increase in energetic costs for the geese that have to take flight more often when repelled (Nolet et al., 2016) and often lead to an increased usage of a larger field area compared to before scaring (Jensen et al., 2008). These increased costs must be considered when planning the distribution and size of repelling and accommodation fields (Nolet et al., 2016). The combination of repelling fields and accommodation fields to 'teach' them to utilize accommodation fields more than other fields seems intuitive at first, has been suggested before (Simonsen et al., 2016) and was coined a 'carrot and stick approach' (Koffijberg et al., 2017). However, a long-term study on four goose species in the Netherlands has shown that this approach has no effect, with geese using refuge sites after the experiment just as much as before (Koffijberg et al., 2017). This is a somewhat similar pattern as in our study for field selection when leaving a repelling field and repeatability of the site usage is low among non-breeding barnacle geese (Heim et al., unpublished data). This finding supports the importance of coordinated repelling when establishing refuge sites. One reason for why geese that have just left a repelling field would choose other accommodation fields, is that they might have been actively repelled and are not selecting fields to forage, but rather fields to rest. Private accommodation fields and Nature area fields where no repelling in any form is conducted might work as sanctuaries for geese to recover from stress.

Compensation, subsidies schemes and other strategies such as setting aside refuge areas have been suggested and implemented in other European countries years ago (Koffijberg et al., 2017; Madsen et al., 2014; Stroud et al., 2017; Teräväinen et al., 2022; Tombre et al., 2013) and should serve as an example for Finnish authorities and decision-makers. However, this has to be considered with care, because it has been shown that habitat selection estimates are not always comparable between regions (Yates et al., 2018). We conclude that the accommodation field concept in concert with 'no-go' fields with repelling fulfil the goals of attracting the geese (Madsen et al., 2022) and diverting them away from foraging on fields devoted to food production (De Jager et al., 2023; Teräväinen et al., 2022). However, more information is needed about the damage done to accommodation fields by grazing geese and if this leads to a damage reduction on non-accommodation fields in the area. Recent studies give some insight in grazing damage caused by foraging geese (Buitendijk et al., 2022; Montràs-Janer et al., 2019). Yield loss has been shown to have a nonlinear relationship with barnacle goose grazing pressure, with increasing grazing pressure leading to increased damage with a decelerating rate (Buitendijk et al., 2022). The nature of the human-goose agriculture conflict is complex involving a manifold of societal and natural factors. Our study provided insights into barnacle goose field selection and foraging behaviour and suggests that, using stakeholder knowledge, the coordinated use of well-designed accommodation and repelling fields can help to mitigate the costs of this conflict. However, the costs of management actions can exceed the yield losses caused by abundant geese (De Jager et al., 2024), which highlights the importance to assess the cost-effectiveness of the chosen management actions.

AUTHOR CONTRIBUTIONS

Toni Laaksonen and Jukka T. Forsman conceived the idea and designed the project with contributions from Wieland Heim and Antti Piironen. Antti Piironen planned and led the GPS-tagging of geese with contributions from Tuomas Seimola. Wieland Heim, Markus Piha, Tuomas Seimola, Antti Piironen, Toni Laaksonen and Jukka T. Forsman conducted fieldwork. Ron Store processed the GIS data. Anna-Kaisa Ylitalo analysed the data with contributions from Juha Heikkinen and Martin W. Seltmann. Martin W. Seltmann led the writing of the manuscript. All authors discussed the results, contributed critically to previous drafts and gave final approval for publication. All authors contributed in revising the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

Data available from the Dryad Digital Repository https://doi.org/10.5061/dryad.tb2rbp0bt (Seltmann et al., 2024).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Figure S1. Distribution of hidden Markov model states during the time of the day.

Table S1. Probabilities of state changes between the three behavioural states.

Table S2. Differences $\beta_k - \beta_l$ ('estimate') between estimated selection coefficients for all pairs k, l of field types in an iSSA analysis using all steps ending in a field, but originating from another field, including only state 'fast' ($n = 1214$).

Table S3. As Table S2, but using all steps ending in a field, including hidden Markov model states 'static' and 'slow' ($n = 11{,}883$).

Table S4. As Table S2, but using steps leaving from a repelling field and ending in another field, including hidden Markov model states 'static', 'slow' and 'fast' ($n = 144$).

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