Zoological Studies
a SpringerOpen Journal

RESEARCH Open Access

Nest site selection by the hazel dormouse *Muscardinus avellanarius*: is safety more important than food?

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Abstract

Background: Vegetation parameters determining nest site selection by the hazel dormouse *Muscardinus avellanarius* were studied in a typical habitat where dormice are relatively common in Lithuania, the northern periphery of its distributional range.

Results: Dormice preferred nest sites with a better-developed understory, particularly with a good cover of hazel shrubs taller than 4 m and plentiful bird cherry trees, a high diversity of woody plant species in the understory and overstory, and better connectivity of the nest tree with its surroundings. They avoided sites with a high number of mature Norway spruce trees in the canopy and a high density of young trees. In a stepwise multiple regression analysis, three vegetation parameters of the number of shrub species, the cover of hazel shrubs, and the number of Norway spruce trees in the canopy determined over 85% of the index of nestbox use by *M. avellanarius*. The number of shrub species in the surroundings of the nest site had the highest impact of all. Nest sites used by dormice for breeding were distinguished by a better-developed understory, particularly by a significantly higher number of bird cherry trees and a lower number of Norway spruce trees in the canopy, as well as a higher diversity of plants in the understory and overstory.

Conclusions: Selection of nest sites by *M. avellanarius* is a combination of safety from predators and the presence of food. A well-developed inter-connected understory ensures the safety of nest sites from predators, and the diversity of understory and overstory species guarantees continuity of the food supply in the vicinity of nest sites.

Keywords: Common dormouse; Vegetation parameters; Breeding; Nestboxes; Lithuania

Background

Nest site selection by animals is understood to be a choice of certain features of the environment that differ from generally available sites (Skórka et al. 2011). Nests provide a place for individuals to rest, raise young, avoid predators, and escape inclement weather. When selecting a nest site, animals have to find the best compromise between the risk of encountering predation, the availability of food nearby the nest, and microclimatic requirements (Cudworth and Koprowski 2011; Rosalino et al. 2011). Knowledge of habitat characteristics important to nest placement is critical for managing species of conservation concern (Bright and Morris 1990; Cudworth and Koprowski 2011; Skórka et al. 2011; Atiénzar et al. 2012).

The hazel dormouse *Muscardinus avellanarius* is considered an endangered species in many European countries and is listed in Annex IV of the *EU Habitat Directive* (Amori et al. 2008; Juškaitis 2008). Habitat loss and fragmentation, and forest management practices unfavorable for this species are the major reasons for the decline of *M. avellanarius* (Bright et al. 2006; Juškaitis 2007a; Juškaitis and Büchner 2013). Particular attention to the conservation of *M. avellanarius* is being given in some countries of Western Europe, e.g., Great Britain, Germany, Denmark, the Netherlands, and Belgium (Juškaitis and Büchner 2013). In contrast, in Lithuania, which is situated on the northern periphery of the species' distributional range, *M. avellanarius* is widespread and relatively common (Juškaitis 2007a, 2008).

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M. avellanarius has been the subject of many studies carried out in different parts of its distributional range (reviewed in Juškaitis 2008), including investigations into habitat and nest site selection. General habitat preferences of *M. avellanarius* were studied in several countries, e.g., in Great Britain, Italy, Lithuania, and Germany (Bright and Morris 1990; Capizzi et al. 2002; Juškaitis 2007b; Wuttke et al. 2012). Nest site selection by this species was studied in two different landscapes in southern Sweden (Berg and Berg 1998), in two habitat types in central Italy (Panchetti et al. 2007), and in a specific hedgerow habitat by (Wolton 2009). This was also done in mature 75- to 180-year-old mixed forest stands in Lithuania, which are typical habitats for the fat dormouse *Glis glis*, but not for *M. avellanarius* (Juškaitis and Šiožinytė 2008).

M. avellanarius willingly occupies both ordinary bird nestboxes (Juškaitis 2008) and special dormouse nestboxes (Morris et al. 1990). The use of nestboxes, which represent artificial substitutes for tree hollows, is a common technique used in studies of this elusive species (e.g., Bright and Morris 1990; Panchetti et al. 2007; Juškaitis and Šiožinytė 2008). A great number of evenly spaced nestboxes over a large area provide dormice the possibility to use them for resting and breeding. However, diverse environmental conditions in the surroundings of the nestboxes determine the quality of these nest sites and result in differing extents to which the nestboxes are used by *M. avellanarius* (see Figure 1). This presents the possibility to identify which habitat parameters determine nest site selection in this species.

Results of previous studies on site selection of nest sites and resting places by dormice and other small mammals indicated that it may be related to safety from predators (Bertolino 2007; Panchetti et al. 2007; Rosalino et al. 2011), the availability of continuous suitable food supplies (Sherman 1984; Kopij 2009), or a possible combination of both factors (Bertolino et al. 2011; Cudworth and Koprowski 2011).

The diet of *M. avellanarius* was investigated at our study site, and the main feeding plants important for this species are known (Juškaitis and Baltrūnaitė 2013). This allowed us to assess whether safety of nest sites from predators is more important to *M. avellanarius* than food presence near their nest sites. Nest site selection should correlate with environmental variables securing nest sites (e.g., vegetation cover or connectivity) in the first case and with the presence of the main food plants in the vicinity of nest sites in the second case. However, some woody plants may be important for both secure movement and feeding.

Another issue we tested was related to breeding by *M. avellanarius*. In Sweden, no significant differences were found in the habitat composition of natural nests used for breeding and those used only for resting (Berg and Berg 1998). However, we hypothesized that nest sites used for breeding should be of somewhat better quality compared to other nest sites.

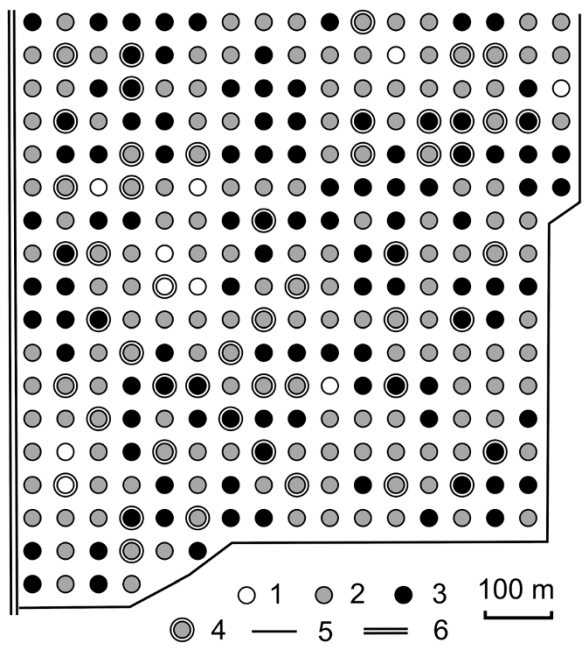

Figure 1 Scheme of the dormouse study site in Lithuania and use of nestboxes by *Muscardinus avellanarius* in 2007 to 2011. 1, Nestbox not used by dormice; 2, nestbox used by dormice for resting; 3, nestbox used by dormice for breeding; 4, nestbox around which vegetation parameters were evaluated; 5, forest edge; 6, forest road.

Thus, the two aims of the present study were to: identify vegetation parameters which determine nest site selection by *M. avellanarius* and determine differences between nest sites of *M. avellanarius* used for breeding and not used for breeding.

Methods

Study site

The dormouse study site is situated in Šakiai District, southwestern Lithuania (55°03′N, 23°04′E). The study site covers an area of 60 ha and contains 272 standard wooden nestboxes for small hole-nesting birds spaced in a grid system at 50-m intervals between boxes. Most nestboxes were put up at a height of 3 to 4 m off the ground. The study site incorporates a typical Lithuanian habitat of *M. avellanarius*, i.e., a mixed deciduous-coniferous forest dominated by birches *Betula pendula* and *Betula pubescens* and Norway spruce *Picea abies*. Other major tree species growing at the study site are black alder *Alnus glutinosa*, grey alder *Alnus incana*, ash *Fraxinus excelsior*, aspen *Populus tremula*, small-leaved lime *Tilia cordata*, and pedunculate oak *Quercus robur*. Hazel *Corylus avellana*, glossy buckthorn *Frangula alnus*,

bird cherry *Padus avium*, rowan *Sorbus aucuparia*, and dwarf honeysuckle *Lonicera xylosteum* are the main shrub species in the understory. Over most of the study site, the forest is of middle age (about 60 to 70 years old). Various forest management operations, including clear felling, are routinely carried out by foresters. In the area of the study site, there are no old trees with natural hollows; the only natural hollows are those made by woodpeckers *Dendrocopos* spp. These hollows are usually high up in aspen trees without branches, where it would be unsafe for dormice to reach them.

Sampling

The approval from the Environmental Protection Agency of Lithuania was obtained for the field studies of *M. avellanarius* at study site.

The indices of nestbox use were calculated for all 272 boxes using data from their controls in 2007 to 2011. Use of nestboxes by dormice in separate years was scored in points: 0 points, no use of the nestbox at all; 1 point, short-term use of the nestbox (a dormouse, its excrement, or food remains found in an empty nestbox); 2 points, long-term use of the nestbox during one activity season (dormouse nest or one dormouse found in a nest); 3 points, more than one individual (but not a litter) found in a nest; 4 points, a female with a litter of juveniles in a nest; and 5 points, a female with a litter of juveniles and one or more other dormice in a nest.

Points from 5 years were totaled for every nestbox, and the sum of the points was used as an index of nestbox use. The index of nestbox use by *M. avellanarius* was considered to be an indicator of nest site suitability for dormice: the higher the index, the better the quality of nest site for *M. avellanarius*.

To evaluate vegetation parameters around nest sites of *M. avellanarius*, 50 of the 272 nestboxes were selected (Figure 1), using the procedure of stratified random sampling according to Krebs (1999). After calculating the indices of nestbox use, the sample of 50 nestboxes was allocated to quotas proportional to numbers of nestboxes with the same index among the 272 nestboxes. For example, if 10% nestboxes ($n = 27$) among all 272 nestboxes had the same index, then 10% of nestboxes ($n = 5$) with the same index were also chosen among the 50 selected nestboxes. Locations of the particular nestboxes used in the sample were selected randomly. However, nestboxes situated at the forest edge or the edge of clear-felled plots were not included in the analysis, as the vegetation sampling technique described below could not be applied in such cases.

Evaluation of vegetation parameters around nest sites was performed by applying Dueser and Shugart's (1978) detailed sampling technique using plots and transects of various sizes. This method was adopted by other authors for studies of nest site selection and microhabitat use in different dormouse species (Bertolino 2007; Bertolino and Cordero di Montezemolo 2007; Panchetti et al. 2007). Four rectangular transects (each 10 × 25 m) starting at the nestbox tree and representing nest site surroundings were selected. Overlapping areas of transects in close proximity to the nestbox-carrying tree were sampled only once. The total sampled area around each nestbox was 900 m^2, and the following groups of vegetation parameters were evaluated: (1) the number of individuals of each species in the overstory (canopy trees and sub-canopy trees separately) and the understory (young trees 1 to 4 m in height and shrubs separately); (2) the number of tree stumps (with a diameter of >10 cm), logs, dead standing trees, and trunks (dead trees taller than 1 m without branches); (3) the number of trees and shrubs with a crown or a trunk connected to the crown of the nestbox tree; (4) the canopy cover of hazel shrubs and mature oak trees (in m^2); (5) the cover of raspberries *Rubus ideus*, stone brambles *Rubus saxatilis*, and wild strawberries *Fragaria vesca* in the ground vegetation layer (in %); and (6) areas of glades, forest roads, and rides (in m^2).

The number and canopy cover of hazel shrubs were evaluated separately for hazels lower than 4 m and taller than 4 m. The cover of selected plants in the ground vegetation layer was visually estimated at randomly located 10 × 10-m squares in each transect. During the evaluation process, the following canopy-forming tree species were recorded: Norway spruce, silver and downy birches *B. pendula* and *B. pubescens*, grey and black alders, pedunculate oak, ash, aspen, willow *Salix* spp. (mostly *Salix caprea*, but also *Salix cinerea* and *Salix myrsinifolia*), small-leaved lime, Scotch pine *Pinus sylvestris*, Wych and field elms *Ulmus glabra* and *Ulmus minor*, Norway maple *Acer platanoides*, wild apple *Malus sylvestris*, common buckthorn *Rhamnus cathartica*, and common hornbeam *Carpinus betulus*. Understory species recorded were hazel, glossy buckthorn, bird cherry, rowan, dwarf honeysuckle, European spindle *Euonymus europaeus*, blackcurrant *Ribes nigrum*, red elderberry *Sambucus racemosa*, and mezereon *Daphne mezereum*.

Data analysis

Overall, 70 variables, including direct field measurements, combinations of them (e.g., total area of glades, forest roads, and rides, total number of overstory trees, etc.), and derived variables (e.g., the density of the shrub layer, Shannon-Wiener index, etc.) were used in the initial data analysis. The inter-correlation of all vegetation parameters was checked using Spearman's correlation analysis. Highly inter-correlated variables, with r_S values of >0.70, were excluded from further analysis, leaving a

total of 51 variables. Exclusion was based on a lower correlation with the index of nestbox use and on the possible biological interpretation of results. Spearman's correlation coefficients between vegetation parameters evaluated in the surroundings of nestboxes and indices of nestbox use were calculated.

Subsequently, the relationship between the dependent variable (index of nestbox use by *M. avellanarius*) and independent vegetation parameters were explored using general linear model (GLM) procedures in Statistica for Windows vers. 6.0 software (StatSoft 2004). We selected the best multiple linear regression model, using a forward stepwise method (StatSoft 2010). Variables were tested for normality using the Kolmogorov-Smirnov one-sample test; variables failing the test were transformed. Counts were transformed by taking the square root after adding 0.5, percentages were arcsine square root-transformed after adding 0.01, and other variables were log-transformed after adding 0.01 (Zar 1999).

Nest site selection by *M. avellanarius* was also analyzed using comparisons of different nest site categories. All 50 nest sites investigated were grouped into five categories according to the extent of nestbox use over 5 years (2007 to 2011): (1) nest sites avoided for resting, i.e., nestboxes used for resting in 0 to 1 year; (2) nest sites occasionally used for resting, i.e., nestboxes used for resting in 2 to 3 years; (3) nest sites preferred for resting, i.e., nestboxes used for resting in 4 to 5 years; (4) nest sites used for breeding once, i.e., nestboxes used for breeding in 1 year (irrespective of the use for resting); and (5) nest sites preferred for breeding, i.e., nestboxes used for breeding in 2 to 4 years (irrespective of the use for resting). No nestbox was used for breeding in all 5 years.

A Kruskal-Wallis analysis of variance (ANOVA) was used to compare vegetation parameters among these five nest site categories. To compare characteristics of nest sites used by *M. avellanarius* for breeding and not used for breeding, categories 4 and 5, and 1 to 3 were pooled and Student's *t* test was applied.

Rényi's diversity numbers (Tóthmérész 1998) were used to test for differences in the diversity of the understory and overstory around nestboxes used by *M. avellanarius* for breeding (categories 4 and 5) and not used for breeding (categories 1 to 3). The major advantage in applying the Rényi's diversity numbers is that they display not just a single index but also a family of indices, many of which are currently applied and widely used in ecology and have varying sensitivities to the presence of rare and abundant species (Carranza et al. 2007; Juškaitis et al. 2012; Rudolf et al. 2012).

The scale parameter $\alpha = 0$ gives a Rényi's diversity equal to the logarithm of the number of species; $\alpha = 1$ yields a Rényi's diversity equal to Shannon's H; $\alpha = 2$ is related to Simpson's index of dominance; while $\alpha = 3$ and 4 represent a growing emphasis on the dominant species (Tóthmérész 1998; Carranza et al. 2007). Rényi's diversity curves for the understory and overstory around nestboxes used by *M. avellanarius* for breeding and not used for breeding were created using the freeware DOS-Box vers. 0.74, running the DivOrd program vers. 1.90 (Tóthmérész 1993). If the diversity curves produced by this method do not intersect, the diversity of either the understory or overstory in the areas around nestboxes used for breeding and not used for breeding significantly differs. According to the theory of diversity ordering, one community can be regarded as more diverse than another only if all its Rényi's diversity numbers are higher (Tóthmérész 1998).

Results

Of the 272 nestboxes in the area of the study site (Figure 1), only ten boxes (3.7%) were not used by *M. avellanarius* at all in the period 2007 to 2011; 157 (57.7%) were used for resting, but not for breeding; and 105 (38.6%) were used for breeding. Among the 50 nest sites selected for evaluation of vegetation parameters, 3, 26, and 21 nestboxes were in the respective categories.

The correlation analysis between indices of nestbox use and vegetation parameters yielded a list of variables significantly related to nestbox use by *M. avellanarius* (Table 1). Several understory species, hazel, bird cherry, European spindle, young black alder, and young Wych elm trees, were positively correlated with the indices of nestbox use. Use of nestboxes by *M. avellanarius* was also positively correlated with higher diversities of plant

Table 1 Significant Spearman's correlations between indices of nestbox use by *Muscardinus avellanarius* and vegetation parameters

Vegetation parameters	Coefficient of Spearman's correlation	*p*
Cover of hazel shrubs taller than 4 m	0.491	<0.001
Number of bird cherry trees	0.452	<0.001
Number of Norway spruce trees in canopy	−0.337	0.017
Number of Scotch pine trees in canopy	0.381	0.006
Number of young Wych elm trees	0.323	0.022
Number of young black alder trees	0.284	0.046
Number of European spindle shrubs	0.361	0.010
Density of young trees, individuals/ha	−0.346	0.014
Connectivity of nestbox tree with its surroundings[a]	0.352	0.012
Shannon-Wiener index of overstory species	0.337	0.017
Number of woody plant species in understory	0.309	0.029
Number of shrub species	0.332	0.018

[a]The number of trees and shrubs which had a crown or a trunk connected to the crown of the nestbox tree.

species in the understory and overstory, as well as with better connectivity of nestbox trees with surrounding trees and shrubs. A significant negative correlation was found between indices of nestbox use by *M. avellanarius* and the number of Norway spruce trees in the canopy and the density of young trees in the vicinity of nestboxes (Table 1).

In the stepwise multiple regression analysis, three vegetation parameters were significantly correlated with indices of nestbox use by *M. avellanarius* in the most parsimonious model, yielding a very efficient equation, that described over 85% of the indices:

$$Y = 3.41X_1 + 0.01X_2 + 0.075X_3,$$

where Y is the index of nestbox use, X_1 is the number of shrub species, X_2 is the cover of hazel shrubs taller than 4 m, and X_3 is the number of Norway spruce trees in the canopy.

The number of shrub species had the greatest impact on the index of nestbox use by *M. avellanarius*, while inputs of the other two variables were much less (Table 2).

Comparison of vegetation parameters among categories of nest sites of *M. avellanarius* using the Kruskal-Wallis ANOVA revealed statistically significant differences in the cover of hazel shrubs taller than 4 m ($H_{(4,\ 50)} = 15.74$, $p < 0.002$), the number of bird cherry trees ($H_{(4,\ 50)} = 11.30$, $p < 0.025$), the number of young birch trees ($H_{(4,\ 50)} = 10.24$, $p < 0.05$), the density of young trees ($H_{(4,\ 50)} = 9.59$, $p < 0.05$), connectivity of the nestbox tree with its surroundings ($H_{(4,\ 50)} = 9.77$, $p < 0.05$), and the number of woody plant species in the understory ($H_{(4,\ 50)} = 10.45$, $p < 0.05$) (Figure 2).

Nest sites used by *M. avellanarius* for breeding were distinguished by a significantly higher number of bird cherry trees and a significantly lower number of Norway spruce trees in the canopy compared to the remaining nest sites. Connectivity of the nestbox tree with its surroundings, the numbers of shrub species, and some other vegetation parameters also tended to be higher at nestbox sites used by dormice for breeding (Table 3).

Rényi's diversity profiles of the understory around nestboxes used and not used by *M. avellanarius* for breeding showed that the diversity of the understory was significantly greater at all scale parameters in nestbox sites used for breeding (Figure 3A). Diversities of the overstory around nestboxes used and not used for breeding were very similar in terms of rare species (at scale parameter $\alpha = 0$ to 0.5). However, the overstory was more diverse around nestboxes used for breeding in terms of more-frequent species (Figure 3B).

Discussion

In most cases, nest site selection by mammals has been studied using comparisons of characteristics of nest sites with randomly selected sites or sites not used by the animals (e.g., Bertolino and Cordero di Montezemolo 2007; Gregory et al. 2010; Cudworth and Koprowski 2011). At our study site, only 10 of the 272 nestboxes were not used at all by *M. avellanarius* in the period 2007 to 2011. Such a small proportion of nestboxes not being used during this 5-year period suggests that the absolute majority of nest sites are more or less suitable as quality nest sites for this species in the area of the study site. For this reason, comparison of dormouse nest sites and randomly selected sites would be incorrect in our case.

Different statistical methods used to analyze vegetation parameters determining nest site selection by *M. avellanarius* revealed that two groups of variables related to safety and food are important to dormice.

In the stepwise multiple regression analysis, three vegetation parameters, namely the number of shrub species, the cover of hazel shrubs, and the number of Norway spruce trees in the canopy, determined over 85% of the index of nestbox use by *M. avellanarius*. The number of shrub species in the vicinity of the nest site had the highest impact among these. Hazel (especially hazel shrubs taller than 4 m) and bird cherry were the most important understory species for *M. avellanarius*. Typically, hazel shrubs have several stems, which grow apart from each other and form a large distaff-shaped shrub. Every stem has several diagonal or nearly horizontal branches which are in contact with branches of other hazel shrubs or other trees. In this way, inter-communicating hazel shrubs form excellent routes for the movement of *M. avellanarius* in a three-dimensional space. Branchy bird cherry trees can also be used by *M. avellanarius* in the same way.

Interlocking trunks and branches provide more access routes to and from the nest for tree-climbing rodents. A positive correlation between the index of nestbox use and the number of trees or shrubs which have a crown

Table 2 Results of a stepwise multiple regression

Variable	B	Standard error	$t_{(47)}$	p	Input to adjusted R^2
Number of shrub species	3.413	0.559	6.100	0.0001	0.809
Cover of hazel shrubs taller than 4 m	0.013	0.003	3.949	0.0002	0.041
Number of Norway spruce trees in canopy	−0.075	0.025	−2.955	0.005	0.020

These results relate indices of nestbox use by *Muscardinus avellanarius* with vegetation parameters in the vicinity of the nestboxes in the most parsimonious model (adjusted $R^2 = 0.870$; $F_{(3,47)} = 112.95$; $p < 0.0001$).

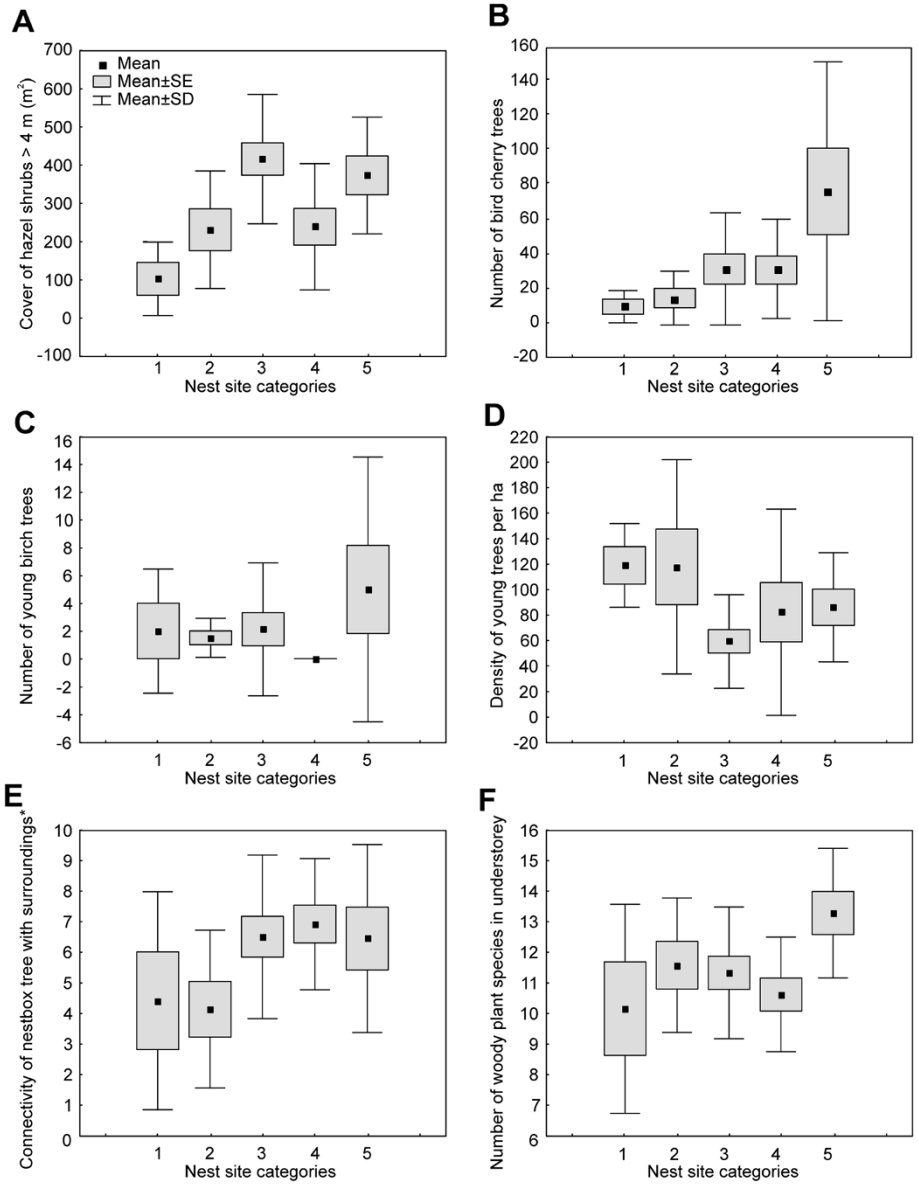

Figure 2 Comparison of some vegetation parameters in different nest site categories of *Muscardinus avellanarius*. (A) Cover of hazel shrubs taller than 4 m, **(B)** number of bird cherry trees, **(C)** number of young birch trees, **(D)** density of young trees, **(E)** connectivity of the nestbox tree with its surroundings, **(F)** number of woody plant species in the understory. 1, nest site avoided for resting; 2, nest site occasionally used for resting; 3, nest site preferred for resting; 4, nest site used for breeding once; 5, nest site preferred for breeding. *The number of trees and shrubs which had a crown or a trunk connected to the crown of the nestbox tree.

or a trunk connected to the crown of the nestbox tree proves the importance of safe connectivity of nest sites with its surroundings for *M. avellanarius*. Connectivity of the nestbox tree with the surroundings was the best in nest sites used by *M. avellanarius* for breeding and preferred for resting. Nest site connectivity for arboreal travel was also a significant predictor of nest site selection by the western grey squirrel *Sciurus griseus* (Gregory et al. 2010) and Abert's squirrel *Sciurus aberti* (Edelman and Koprowski 2005).

In a similar manner to *M. avellanarius*, a well-developed and diverse understory was the main habitat component which determined nest site preference of the forest dormouse *Dryomys nitedula* (Juškaitis et al. 2012). A dense understory protects animals from both areal and tree-climbing predators. All potential predators, including the pine marten *Martes martes*, would be more easily detected by dormice because of their movements through thick vegetation (Panchetti et al. 2007). For example, in tangles of the bramble *Rubus fruticosus*, the long twines of

Table 3 Comparison of some vegetation parameters around nestboxes used by *Muscardinus avellanarius*

Vegetation parameter	Nestboxes used for breeding, mean ± SD	Nestboxes not used for breeding, mean ± SD	*t* value	*p*
Cover of pedunculate oaks	56.00 ± 80.77	129.14 ± 174.13	−1.79	0.08
Number of grey alder trees	12.29 ± 22.28	4.45 ± 6.72	1.79	0.08
Number of Norway spruce trees in canopy	17.95 ± 15.61	33.52 ± 24.12	−2.59	0.01
Number of bird cherry trees	49.86 ± 56.46	22.59 ± 27.11	2.27	0.03
Number of common hornbeam trees	7.38 ± 23.45	0.48 ± 1.27	1.59	0.12
Connectivity of nestbox tree with its surroundings[a]	6.71 ± 2.53	5.48 ± 2.95	1.54	0.13
Number of shrub species	5.71 ± 0.90	5.17 ± 1.14	1.81	0.08

Nestboxes used for breeding and not used for breeding at study site in Lithuania are compared (Student's *t* test, d.f. = 48). [a]The number of trees and shrubs which had a crown or a trunk connected to the crown of the nestbox tree.

these plants work like antenna, signaling to the nest occupier if something is approaching from the outside (Juškaitis and Büchner 2013).

M. avellanarius avoids nest sites with high numbers of Norway spruce trees in the canopy because the understory is shaded, and both the density and diversity of the understory are significantly reduced in such places. Similar results on nest site selection by *M. avellanarius* were also obtained in a mature 75- to 180-year-old mixed forest where *M. avellanarius* preferred forest stands with a well-developed understory and avoided nest sites with a high number of coniferous trees forming the canopy (Juškaitis and Šiožinytė 2008).

The forest understory consists of shrubs and young trees, but the importance of these two groups is discrepant for *M. avellanarius*. Dormice avoided nest sites with the highest density of young trees. Young deciduous trees (e.g., lime or ash trees) grow vertically with few diagonal branches and are much less suitable for movement of *M. avellanarius* in a three-dimensional space compared to hazel shrubs and bird cherry trees. Although the index of nestbox use was positively related to the number of young black alder trees, the last parameter was positively inter-correlated with the total cover of hazel shrubs.

Except with hazel, no statistically significant positive correlations were found between indices of nestbox use and numbers or cover of plants important as food to *M. avellanarius*, such as the willow, Norway spruce, pedunculate oak, raspberry, dwarf honeysuckle, or glossy buckthorn. The correlation with the number of Norway spruce trees in the canopy was significantly negative. However, selection of nest sites by *M. avellanarius* was related to the diversity of understory and overstory species in the vicinity of nestboxes, particularly with the number of shrub species. Because the main food sources and accordingly the food plants of *M. avellanarius* vary during the active season (Juškaitis and Baltrūnaitė 2013), the diversity of understory and overstory species is related to the continuity of the food supply in areas with diverse woody plant communities.

When possible, tree-climbing rodents combine the safety of nest sites and food availability. For example, Arizona grey squirrels *Sciurus arizonensis* select nest sites with greater canopy cover which may provide more protection from diurnal birds of prey. However, most nest tree species selected by Arizona grey squirrels also provide potential food resources, possibly minimizing travel distances to food sources (Cudworth and Koprowski 2011). Fat dormice prefer denser forest stands with well-connected tree

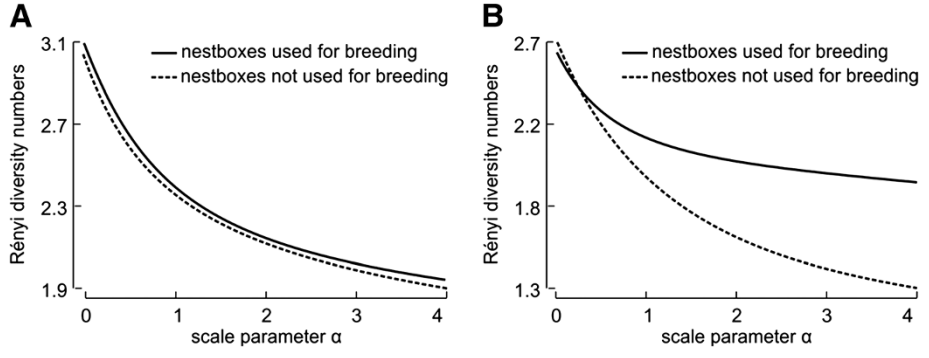

Figure 3 Rényi's diversity profiles of the understory (A) and overstory (B) around nestboxes used by *Muscardinus avellanarius*. Nestboxes used for breeding and not used for breeding at the study site in Lithuania are compared.

canopies and higher numbers of oak trees, the acorns of which are an important food source (Eiberle 1977; Schlund et al. 1997; Juškaitis and Šiožinytė 2008).

When selecting nest sites in a typical Lithuanian habitat, *M. avellanarius* also combines the safety of nest sites and food availability in the vicinity of nest sites. A well-developed and inter-connected understory ensures the safety of nest sites from predators. A diversity of understory and overstory species guarantees continuity of the food supply. Similar results were obtained in Sweden where the number of shrub species and cover of different shrub species were among the main factors that were related to the occurrence of *M. avellanarius* (Berg and Berg 1998). An unshaded well-developed interdigitating understory with high species diversity was shown to provide an optimal habitat for *M. avellanarius* in England (Bright and Morris 1990, 1996). Meanwhile in Italy, *M. avellanarius* preferred nest sites with a more-developed understory, but no correlation was found between dormouse presence and shrub species diversity. Telemetric observations showed that dormice traveled rather long distances to reach food sources (Panchetti et al. 2007).

When selecting nest sites for breeding, females of *M. avellanarius* seek greater safety and better feeding conditions compared to the remaining nest sites. Nest sites used by *M. avellanarius* for breeding were distinguished by a better-developed and more diverse understory. Nest sites used for breeding were characterized by a higher number of bird cherry trees in the understory, but a lower number of Norway spruce trees in the canopy and a lower cover of oak trees, both of which reduce understory cover. Around nestboxes used for breeding, the diversity of the overstory was also higher among common tree species, including the willow, Norway spruce, and pedunculate oak, which are important feeding plants for *M. avellanarius* (Juškaitis and Baltrūnaitė 2013).

Conclusions

In summary, the results of our study showed that (a) when selecting nest sites with a diverse and well-developed inter-connected understory, *M. avellanarius* combines the presence of food in the surroundings with safety from predators; and (b) nest sites used by *M. avellanarius* for breeding are distinguished by a better-developed understory and a more diverse understory and overstory compared to the remaining nest sites.

M. avellanarius also lives in similar habitats in the adjacent countries of Latvia and Belarus (Pilāts 1994; Kashtalian 2004). It is expected that the results of our study would characterize the situation with nest site selection by *M. avellanarius* in rather large areas on the northern periphery of its range.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All authors participated in the design of the study. RJ collected data on nestbox use by *M. avellanarius* at study site. VŠ evaluated vegetation parameters around nestboxes. LB performed the statistical analyses of data. RJ and LB drafted the manuscript. All authors read and approved the final manuscript.

Acknowledgements

This research was funded by the European Social Fund under the Global Grant Measure (grant no. VP1-3.1-ŠMM-07-K-01-026). We thank two anonymous reviewers for their helpful comments on an earlier version of the manuscript, G. Vaitonis for his help in preparing the figures, and J. Stratford for revision of the English.

Received: 25 March 2013 Accepted: 10 July 2013
Published: 9 December 2013

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doi:10.1186/1810-522X-52-53
Cite this article as: Juškaitis *et al.*: Nest site selection by the hazel dormouse *Muscardinus avellanarius*: is safety more important than food?. *Zoological Studies* 2013 **52**:53.