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The tragedy of the science-policy gap – revised legislation fails to protect an endangered species in a managed boreal landscape

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Abstract

Unsustainable use of forest resources poses a serious threat to biodiversity worldwide. This threat is particularly important in boreal biomes, where intensive production-oriented forestry is widely applied. Legislation is one of the key tools for preserving nature from anthropogenic damage. Designation of environmental legislation should be grounded on sound scientific evidence in order to be effective. We assess the impact of guidelines enforcing the Finnish ad-hoc legislation aimed at preserving breeding sites and resting places of the Siberian flying squirrel (*Pteromys volans*), a protected species in Finland and in the European Union under the Habitats Directive. Its habitat is under pressure from widespread forest clear-cutting practices. We collected data on site occupancy by breeding female Flying squirrels from 81 sites spanning 12 years (2005 – 2016) and on relevant habitat variables around the site. Using generalized linear mixed models we quantified the predicted occupancy of breeding female flying squirrels in relation to the cover of breeding habitat around a site. We then compared the resulting habitat requirements of breeding females with the habitat that would be retained according to the initial national legislation guidelines and their proposed first revision. We show that both the initial and the proposed revision of the habitat protection guidelines allow the retention of breeding habitat patches of minimal size, which would yield a very low (less than 5%) predicted occupancy by a breeding flying squirrel female. The current revised guidelines are not science-driven and remain ineffective in safeguarding the species habitat from expanding forestry. These results expose the wide gap between science and policy for the implementation of environmental legislation, in this case the Habitats Directive, to protect species of conservation concern. There is an urgent need to fill the science-policy gap in order to achieve the preservation in of biodiversity in a world under rapid transformation.

Keywords: Science-policy interface; evidence-based conservation; conservation effectiveness; environmental legislation; decision making.

Keywords: Conservation policy; forest management; forestry legislation; species conservation; environmental legislation; conservation evidence

Highlights:

We assess the impact of ad-hoc legislation to protect flying squirrels

We compare the species habitat needs with new habitat protection guidelines

New habitat protection guidelines are ineffective

Revision of guidelines was not based on scientific evidence

The large science-policy gap hinders forest species conservation

1 Introduction

The biodiversity in forest environments worldwide is under increasing pressure from anthropogenic resource extraction resulting in habitat loss, fragmentation and the deterioration of extant habitats (Pimm *et al.* 2014). The boreal forests currently form a third of the earth's woodland cover but are under imminent and increasing pressure from intensive industrial-oriented resource extraction (Bradshaw *et al.* 2009). This poses a threat to the persistence of boreal species (Schmiegelow & Mönkkönen 2002). Boreal forests are fundamental not only for ensuring the persistence of boreal biodiversity but also for preserving the important services this ecosystem provides, including carbon sequestration and clean water provision (Moen *et al.* 2014).

Beginning after World War II industrial-scale forestry has been practiced throughout the Circumboreal regions. This practice is based on even-aged forest stand management, clear cut harvesting and thinning (Kuuluvainen *et al.* 2012). In Fennoscandia, industrial type of forestry has caused a progressive deterioration of the ecological value of forests and resulted in many forest habitats becoming endangered or near threatened (e.g. Raunio *et al.* 2008**).** The Red Lists of threatened species of Finland, Sweden and Norway are disproportionately represented by forest living species (Rassi *et al.* 2010, Westling 2015, Henriksen & Hilmo 2015).

Effective nature protection is often achieved by means of regulatory top-down approaches, such as the establishment of protected areas and the enforcement of legislation based on scientific evidence (Watson *et al.* 2014, Santangeli *et al.* 2016). For implementing effective species-specific conservation measures it is imperative to gain a clear understanding of the species habitat requirements across its different life-stages (Courchamp *et al.* 2015). This information can then be used to define ad-hoc protection measures, which can then be updated as new evidence becomes available within an adaptive management framework (McCarthy and Possingham 2007).

One of such species that has been the focus of ad-hoc legislation is the Siberian flying squirrel (*Pteromys volans*), hereafter flying squirrel. The flying squirrel is one of those boreal forest species heavily threatened by modern age intensive forest management regimes in the boreal region. As a result the species is listed in Annex IV of the Habitats Directive (92743/EC), which means its habitat should be protected by the law within its range of occurrence in the European Union (EU). In Finland the flying squirrel was given protection status according to the National Conservation Act (§ 49). Flying squirrel breeding sites and resting places are since 1.1.1997 legally protected from destruction and deterioration. A guidance document, for implementing the above legislation during forest logging operations, was published in 2004 (Anon. 2003). However, those guidelines proved to be ineffective (Santangeli *et al.* 2013a, Jokinen *et al.* 2014). One main reason for that failure was that the initial habitat protection guidelines were not based on science. Instead, an arbitrary and minimal forest area (size 0.03 – 0.07 ha), was defined as the breeding site and resting place to be retained during forest logging operation in compliance with the Nature Conservation Act (§ 49). In 2014 the Finnish Ministry of Environment initiated a revision of the old guidance document from 2004. Through this revision process an enquiry regarding an updated guidance document, suggesting 0.1 – 0.3 ha as a sufficient area for a flying squirrel breeding site and resting place, was distributed among stakeholders (Anon. 2015). However, the resulting guidance document (Anon. 2016a) contained no science-based guidelines regarding the required size of a breeding site and resting place to be protected. Consequently the issue was surpassed by referring to high court decisions establishing 0.18 ha as too small and 3.7 ha as too large areas for the species (Korkein Hallinto-oikeus 2014, 2015). During the revision process the only scientific studies preliminarily addressing the issue of required habitat area were ignored (Hanski *et al.* 2001, Jokinen *et al.* 2104). The lack of specific guidelines resulting from revised legislation leaves stakeholders in a situation where they are taking conservation decisions in the dark. Ultimately this leaves the species at the mercy of largely unregulated forestry, as most of the breeding sites and resting places are protected according to the judgement of forest harvesters and forest owners (Jokinen *et al.* 2014, Anon. 2016a). Therefore, there is a need for providing robust scientific evidence on the habitat requirements of the species that can then be used to inform decisions. Without this evidence, conservation measures are likely to fail (Cook *et al.* 2010).

Here we aim to fill the above mentioned gap in ecological knowledge of flying squirrels habitat requirements in Finland. We quantify the habitat requirements of breeding female flying squirrels using a unique study design composed of forest patches along a gradient of different size and fragmentation. Specifically we aim to quantify possible thresholds in the effect of cover of habitats of different suitability for breeding female flying squirrels. In doing so, we consider different spatial scales that are biologically relevant. We then compare the habitat requirements with the initially enforced legislation, the proposal for its revision and the current regulations (Anon. 2003, Anon. 2015, Anon. 2016a). Finally, we discuss the implications of the study results with regards to implementing effective, sustainable and publicly acceptable conservation measures for the species in privately owned boreal forests.

2 Methods

2.1 Study species and enforced conservation guidelines

The flying squirrel is a small nocturnal tree squirrel widely spread throughout the Eurasian taiga. Within the European Union, the vast majority of the species population occurs in the southern part of Finland (Santangeli *et al.* 2013b). Here flying squirrels are declining due to destruction of their primary habitat, layered mature spruce dominated mixed forests (Koskimäki *et al.* 2014, Liukko *et al.* 2016). These forests provide key elements such as food, nesting places and shelter. The flying squirrel is a herbivore and mainly feeds on leaves, buds, catkins, flowers and seeds of deciduous trees. Large spruces are perceived to provide cover against predators and are used for storing catkins as winter food (Mäkelä 1996). Litters are reared in cavities built by the Great spotted woodpecker (*Dendrocopus major*) but nest boxes are readily used (Lampila *et al.* 2009, Koskimäki *et al.* 2014). Dreys are mostly used by females outside the breeding season. A female typically has one litter per year. Adults have a strong site fidelity, with males' home range being about 60 ha while that of females is about 8 ha (Hanski *et al.* 2000).

The flying squirrel is globally classified as Least Concern according to the IUCN Species Red List, but is classified as Near Threatened in Finland (Liukko *et al.* 2016). In the "State of Nature in the EU") the status of the population of flying squirrels in Finland, despite enforced conservation guidelines, was reported as unfavourable (Anon. 2013). The density of flying squirrels in the study area was estimated to be 0.01 – 0.02 females/ha (Wistbacka *et al.* 2009, 2010).

2.2 Study area and forest management

The study area (Figure 1) is about 7000 ha (70 km^2) and located on the coast of the Baltic Sea in central-western Finland. The area is largely covered by boreal forests (dominated by Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*), the majority of which are intensively managed using a rotational tree-growing cycle usually lasting 60–100 years and terminating with the clear-cutting of all the standing trees (see more details of the study landscape in Santangeli *et al.* 2013a). Other more environmentally sustainable means of wood harvesting, i.e. continuous cover silviculture or clear cuts smaller than 0.3 ha, are still rarely used in the region (Sjölind, M., personal communication 5.12.2016). Since 1.1.2014 there is no regulation of the minimum dimension of diameter at breast height below which trees cannot be clear-cut in the Finnish Forest Act. Only 2.8 % of the forests in the region are strictly protected (National Resources Institute Finland 2014).

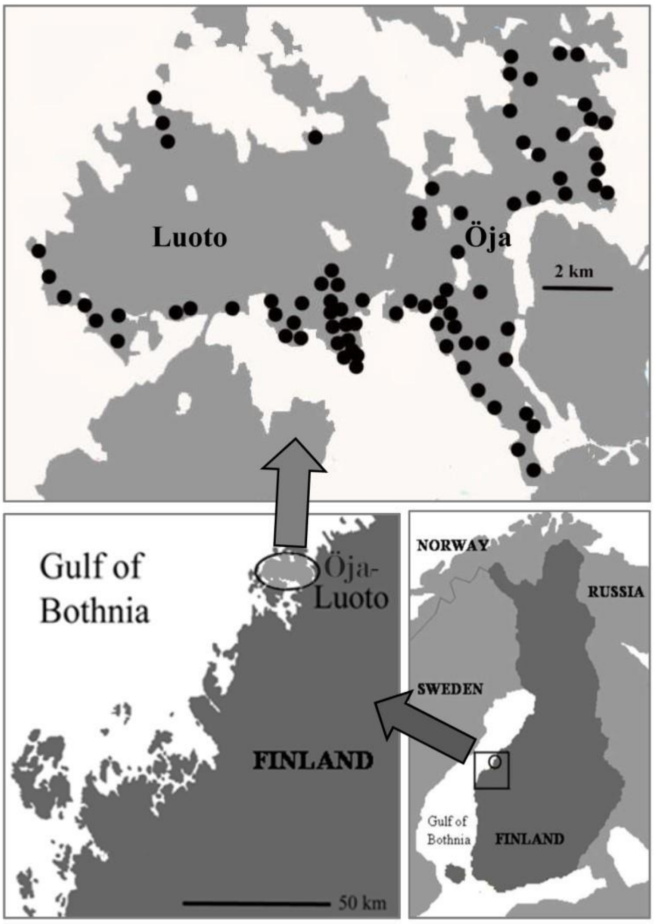

Figure 1. Study area. Black circles in the upper panel depict the location of each study site. Lower panels show the location of the study are in Finland.

2.3. Site occupancy and landscape variables

We classified habitats in the study area in three classes according to Selonen *et al.* (2001), Santangeli *et al.* (2013a) and Jokinen *et al.* (2014). Habitat suitable for breeding females (hereafter "breeding habitat") is defined as layered spruce dominated mixed forests, containing trees of different size and age (Table 1). The trees have a mean diameter at breast height > 18 cm (i.e. mature forests) and the amount of deciduous trees is over 5%. Semi-suitable habitat is defined as mono specific (typically pine plantations) forests with mean tree diameter at breast height > 8 cm, where flying squirrels can move but cannot breed because of lack of some resources (such as food provided by deciduous trees or shelter provided by spruce trees; Table 1). The semi-suitable habitats were further split into two categories: pine dominated plantations i.e. areas where flying squirrels can move and thinned even-aged deciduous tree forests where flying squirrels can move and feed. Unsuitable habitat is represented by open areas covered by young sapling stands or clear-cuts, roads, fields, water or built up areas i.e. areas unusable for flying squirrels for moving, feeding and breeding (Table 1).

We established 81 study sites (hereafter sites) by placing 1 – 5 nest boxes at a short distance to each other (within 100 m radius) in homogeneous patches of spruce-dominated forest (breeding habitat). Patches were clearly separated from the others by intermittent unsuitable habitat for breeding (e.g. open areas, pine-dominated forest or saplings). In six occasions, the forest fragment considered was very large and had multiple groups of nest boxes separated by at least 200m. We considered each of these groups as independent sites following Santangeli *et al.* (2013a), because each of them can support a breeding female. The initial areas of the patches formed a continuum between 0.03 and 22.7 ha (mean 3.11 ha ± 3.79 SD, median 1.5 ha, n = 75). Circular buffers of radius 100 and 200 m were then centered on the geographic mean derived from the location of the nest boxes. These radii include the core area used by breeding flying squirrel females (mean distances that females move from the nest in March-December between 111 m/night and a maximum of 153 m/night in August (Hanski *et al.* 2000). Within the 100 and 200 m radii we measured the cover of breeding habitat, semi-suitable habitat (from both classes, suitable for moving or for moving and feeding) and unsuitable habitat (see Table 1 for a description of each variable). All the forested areas around the sites have been mapped in the field and digitized in a Geographic Information System (GIS) database. These maps have been updated yearly during fieldwork.

We mapped the location of natural cavities made by *Dendrocopus major* in each site. We also calculated the distance from the edge of each breeding habitat patch to the closest shoreline. This was done because shorelines typically provide narrow corridors of habitat suitable for moving and feeding, hence breeding habitat patches may be more easily located, and thus occupied by flying squirrels, if they are closer to the shoreline.

Finally we calculated the percentage of the perimeter of breeding habitat patches bordered by semi-suitable habitat. This was done in order to test whether additional visual cover (hereafter called embedding) provided by the semi-suitable habitat along the edge of the focal patch, could enhance the use of the breeding habitat patch by means of improved cover against predators.

All nest boxes for flying squirrel in each site were checked during May-June every year from 2005 onwards. At each visit we recorded if a box was empty, or there was a nest made by a flying squirrel and if it was in use by a male, female or female with pups. Sites that contained a female without pups in spring in any of the boxes were checked again in August. For the analysis we used only observations of females with pups vs. empty boxes in any given site and year. Thus we did not use years when only a nest, a male or a female without pups were found in the boxes of a given site. We also excluded observations from years when a site was under disturbance, by forest logging (thinning or clear-cutting) in the proximity (within 100 m) of the nest boxes, as this would have introduced unnecessary noise in the analysis, due to increased disturbance.

Table 1. Name and description of the variables used in the generalized linear mixed models (see Table 2) for explaining occupancy by breeding female Flying squirrels in central western Finland.

Variablename	Description
Dist. Shore	Distance to the nearest shoreline
Embedding	Proportion of perimeter of the focal breeding patch bordered by covering forest (DBH > 8cm)
N. Box/Cavities	Total number of natural cavities and nest boxes for Flying squirrel in the study site
Breeding habitat 100 m	Area (hectares) of breeding habitat within 100 m radius around the center of the study site
Semi-suitable pine 100 m	Area (hectares) of pine dominated forest suitable for moving within 100 m
Semi-suitable deciduous 100 m	Area (hectares) of deciduous dominated forest suitable for moving and foraging within 100m
Breeding habitat 200 m	Area (hectares) of breeding habitat within 200m radius around the center of the study site
Semi-suitable pine 200 m	Area (hectares) of pine dominated forest suitable for moving within 200 m
Semi-suitable deciduous 200 m	Area (hectares) of deciduous dominated forest suitable for moving and foraging within 200 m
Patch_size	Total area of the focal breeding habitat patch

2.4 Statistical analyses

We run generalized linear mixed models (GLMM; binomial distribution with logit link), always considering as the binary response whether a site was occupied by a breeding female (i.e. a female with pups was found within any of the boxes in the site) or empty (i.e. no signs of flying squirrels found in any of the boxes in the site) in any given year. Thus the sample unit for the response variable was the occupancy per site and year. A total of 416 observations (i.e. site occupancy per year) from 81 study sites were available (average of 5 observations per site), with an overall average of 40 % occupancy by breeding females. These data span a 12 years period from 2005 to 2016. As potential predictors of occurrence by breeding females we considered the most biologically relevant factors known to affect the overall occurrence of the species in Finland (see above and e.g. Santangeli *et al.* 2013 b). Specifically, we considered amount of breeding habitat, amount of semi-suitable forest dominated by pine or deciduous trees and amount of unsuitable habitat (Table 1). All the above variables were considered within the radius of 100 m and 200 m. We also included in the model the distance to shorelines, embedding (see above), size of the breeding habitat patch, and the number of boxes and natural cavities available in the study site (Table 1).

Prior to fitting the models, we run variance inflation factor (VIF) analyses to quantify the level of collinearity between the potential predictors. We decided *a priori* to include predictors calculated within the 100m and within 200m radius in separate models, because they are inherently correlated (i.e. one includes the other). Moreover, we also a priori excluded the amount of unsuitable habitat from the analyses as this is strongly correlated with amount of breeding habitat and also because it is not a variable of main interest. VIF analyses indicated that the size of a breeding habitat patch had a high VIF value (well over 3) and was highly correlated ($r = 0.8$) with the amount of breeding habitat at the 100 and 200 m radius. All other variables had a very low VIF value (≤ 2), suggesting very minor correlation between them (Zuur *et al.* 2009). Based on the above collinearity issues, we decided to run three separate GLMMs. Each of the three models had the same structure, including the same response (see above), and a shared set of predictors, including distance to shoreline, embedding and number of boxes/cavities. However, in one of the three models (hereafter named the "100m model") we also included the three habitat variables (amount of breeding habitat, amount of semi-suitable pine and deciduous forest) calculated within 100m radius, in a second model (hereafter "200m model") we included the same three variables as above but calculated within the 200m scale, and in a third model (hereafter "breeding habitat patch size model") we included the patch size, in addition to the other three variables (distance to shoreline, embedding and number of boxes/cavities; see Table 2 for a list of predictors included in each of the three models). In the latter only, we also included an interaction between patch size and embedding. The rationale for this was that the embedding (i.e. visual cover provided by semi-suitable stands) would play a more important role when the size of a breeding habitat patch is small rather than large. The interaction was removed from the following model selection if it was not significant. Finally, as we had multiple observations per site, we included site identity as a random factor in each of the three models.

Model selection was performed separately for each of the three models, using multi model inference starting from the full model (i.e. the model with all predictors) in each case and by running and comparing all model combinations (Burnham and Anderson 2002). If model uncertainty was apparent, i.e. multiple models equally supported with $\Delta AIC < 4$, we then proceeded with multi-model averaging (Burnham and Anderson 2002) based on the set of best supported models with $\Delta AIC < 4$ (see support Table S1). Availability of nest boxes or natural cavities was previously found to have a strong impact on site occupancy by flying squirrels (Santangeli *et al.* 2013a). Thus, - we forced this variable in all models during the multi-model inference and averaging procedure.

Spatial autocorrelation was assessed by visual investigation of spline correlograms on the residual values of the final models (Zuur *et al.* 2009). Spatial correlograms show the extent of the residual correlation by distance among observations by plotting the mean correlation coefficient and its confidence level. We did not detect any sign of residual spatial autocorrelation in any of the three models. All analyses were run in R version 3.0.3 (R Core Development Team 2013) using the lme4 package for the GLMM and the MUMIN package for the multi-model inference and model averaging analyses.

3 Results

Across all model combinations within each of the three sets of models (100 m, 200 m and breeding habitat patch size model), a strong model uncertainty was apparent, with no clearly best supported model within each set (see Table S1). Model averaging indicates that the occurrence of breeding female flying squirrels was highest at sites with high amount of breeding habitat within 100 and 200m radii, at sites close to shorelines and with a high number of nest boxes or natural cavities (Table 2). The importance of the amount of breeding habitat is particularly striking at the small 100m scale, which depicts the immediate habitat surrounding the breeding site (i.e. the nest box; Table 2 and Figure 2a). Conversely, the amount of semi-suitable forest dominated by pine or deciduous trees had no significant impact on occurrence of breeding female flying squirrels, nor had the embedding of the focal breeding habitat patch (Table 2). Similarly the interaction between patch size and embedding was not significant (mean estimate = -2.79 ± 2.25SE, $z = -1.24$, $p = 0.21$).

As expected, the size of the breeding habitat patch was strongly and positively associated with occurrence of breeding female flying squirrels (Table 2). Occupancy of breeding female flying squirrels increases rapidly as the size of the breeding habitat patch increases from near zero to over five hectares, and appeared to reach a plateau when the size of the patch reaches values of over 10 hectares (Figure 2b). As Figure 2 (inset in panel b) clearly shows, neither the initially enforced legislation guidelines from 2004, nor its proposed revision from 2015 seem to be able to ensure adequate areas of breeding habitat for the occurrence of breeding female flying squirrels in the studied region.

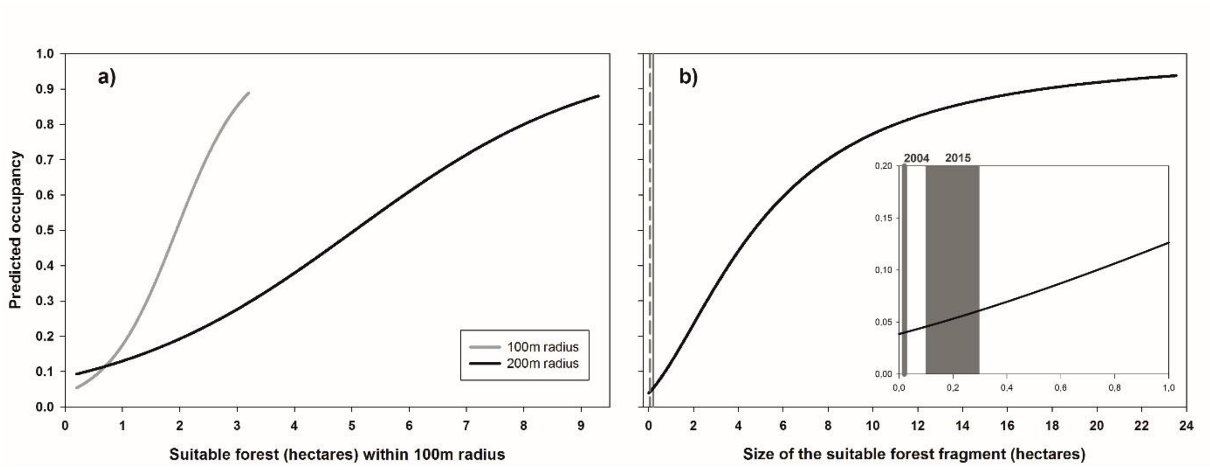

Figure 2. Predicted occupancy of breeding female flying squirrels in relation to: a) the amount of breeding habitat within 100m (grey line) and 200m (black line) radius around the center point of the focal study site; b) the total size of the focal patch of breeding habitat. In the right panel, the vertical grey bars show the area to be retained according to the habitat protection guidelines from 2004 (left bars; x = 0.03 – 0.07 ha) and the proposed revised guidelines from 2015 (right bars; x = 0.1 – 0.3 ha). The inset in panel b shows the zoomed in situation at the lowest end of the forest patch size where the guidelines (grey areas marked as year 2004 and 2015) apply. Note the range and scale difference in the inset axes as compared to the larger figure in panel b.

Table 2. Effect of landscape variables on study site occupancy by breeding female Flying squirrels considering landscape variables measured within a) 100m radius and b) within 200m radius. In model c) the effect of the size of the suitable breeding habitat patch (Patch size) spanning beyond any spatial radius is also assessed. Breeding habitat patch size was included within a separate model due to its collinearity with the amount of suitable breeding habitat within 100 and 200m radii. All statistics presented are the result of a model averaging exercise across the best set (Δ AIC < 4) of candidate models (see Table S1) for each of the 3 groups of models. See Table 1 for a description of each variable.

	Variable	Estimate	SE	z	p	Rel. Imp.
a)	Intercept	-7,364	1,035	7,10	< 0,001	

	Dist. shore	**-0,003**	**0,001**	**2,95**	**0,00**	**0,72**
	Breeding habitat 100 m	**1,650**	**0,398**	**4,13**	**< 0,001**	**0,95**
	Semi-suitable pine 100 m	-0,721	0,634	1,13	0,26	0,36
	Semi-suitable deciduous 100 m	-0,889	1,147	0,77	0,44	0,33
	Embedding	-0,332	1,106	0,30	0,76	0,28
	N. Box/Cavities	**1,750**	**0,221**	**7,90**	**< 0,001**	
b)	Intercept	-5,909	1,619	3,64	< 0,001	
	Dist. Shore	**-0,004**	**0,002**	**2,32**	**0,02**	**0,87**
	Breeding habitat 200 m	**0,515**	**0,247**	**2,08**	**0,04**	**0,80**
	Semi-suitable pine 200 m	-0,420	0,234	1,79	0,07	0,67
	Semi-suitable deciduous 200 m	-0,178	0,558	0,32	0,75	0,30
	Embedding	1,101	2,073	0,53	0,60	0,32
	N. Box/Cavities	**1,826**	**0,352**	**5,17**	**< 0,001**	
c)	Intercept	-7,374	1,276	5,76	< 0,001	
	Dist. Shore	-0,002	0,002	1,45	0,15	0,53
	Patch_size	**1,731**	**0,496**	**3,48**	**< 0,001**	**1,00**
	Embedding	-0,523	1,631	0,32	0,75	0,28
	N. Box/Cavities	**1,674**	**0,337**	**4,95**	**< 0,001**	

4 Discussion

We show that site occupancy by breeding female flying squirrels strongly increases when the amount of breeding habitat increases within 100 and 200 m around the focal study site. Most importantly our results also indicate that areas of breeding habitat patches retained following the initial guidelines for forestry (size 0.03 – 0.07 ha from 2004; Anon. 2003) and the outcast for the first revision (size 0.1 – 0.3 ha from 2015; Anon. 2015) are clearly inadequate for ensuring occupancy of breeding sites by female flying squirrels. Occupancy of sites with such small breeding habitat patches as mentioned above was predicted to be around or below 5 %. However retaining breeding habitat patches according to the current guidelines (Anon. 2016a), i.e. 0.2 – 3.7 ha, would imply a predicted site occupancy ranging from less than 5 to about 40 %. The current guidelines provide no guidance regarding the impact of retaining

0.2 ha vs. 3.7 ha. Consequently neither regional environmental authorities (Centers for Economic Development, Transport and the Environment) nor other stakeholders can evaluate the impact of retaining different sizes of breeding habitat patches and comply with the National Conservation Act § 49. In practice stakeholders are doing conservation in the dark, lacking any science-based evidence of the impact of their decisions (Cook *et al.* 2010). Furthermore only 3 % of the logging taking place at breeding sites for flying squirrels are reported to the regional environmental authorities (Jokinen *et al.* 2014). This means that the whole procedure of protecting breeding sites of flying squirrels is currently implemented on a voluntary ground and based on subjective decisions as to how much forest should be spared (Jokinen *et al.* 2014, Anon. 2016a).

An earlier study based on radio-tracking of flying squirrel females (Hanski *et al.* 2001) suggested 4 ha as a minimum patch size for regular use by breeding flying squirrel females. According to our breeding habitat patch size model the predicted use by breeding female flying squirrels of patches of the above mentioned area would be only 40 – 45 %. Jokinen *et al.* (2014) estimated that regular occupancy by flying squirrel can be achieved if more than 50 % of the area within 150 m radius consists of suitable breeding habitat, i.e. over 3.5 ha. This estimate is however based on occurrence of flying squirrel pellets and thus it cannot be used for evaluating presence of breeding females.

Our study exposes the wide gap between science and policy with regards to the implementation of the Habitats Directive to protect breeding sites of flying squirrels in Finland. The situation highlighted here clearly indicates that, when balancing between nature conservation and nature exploitation, the latter was largely favored, due to the strong economic and political weight that the forestry industry has within Finland.

The Habitats Directive, along with the Birds Directive of the European Union, are internationally considered as effective tools for counteracting the ongoing collapse of biodiversity (see e.g. Donald *et al.* 2007). The current results provide clear evidence that with the latest revision of habitat protection guidelines for flying squirrels Finland missed its chance to effectively comply with the requirements of the Habitats Directive. This is very unfortunate given that the initial guidelines from 2004 were found to be largely ineffective (Santangeli *et al.* 2013a). This case adds to the many cases recently reported in which legislation for nature protection is poorly designed or enforced. (Pykälä 2007, Holloway *et al.* 2012, Leivits *et al.* 2015, Chapron *et al.* 2017). The yet ineffective revision of the guidelines also highlights a failure in seeking and using the available evidence, a phenomen that has recently been exposed (Sutherland and Wordley 2017) and that can severely hamper efforts to conserve nature.

At the practical level, achieving a network of protected forest areas is a prerequisite for the protection of the flying squirrel (Koskimäki *et al.* 2014). At present 5.7 % of the forests in Finland are strictly protected and they are largely concentrated in the northern part of the country (National Resources Institute Finland, 2014). According to Ilkka Hanski a protection of 10 % of the forest area in the whole country could permit a sustainable level for conservation of forest species and could also save the Flying squirrel (Harkki *et al.* 2003).

At present the conservation of forest biodiversity in Finland is largely a voluntary effort. The Forest Biodiversity Programme for Southern Finland (METSO) could represent a valuable oppourtunity for creating a viable network of small and connected protected forests (Korhonen *et al.* 2013). Forest owners get full financial compensation equivalent to the value of timber present at the protected site. With permanent protection, the private forest owner's income from protecting the site is tax free. According to the action plan for METSO for 2016-2019 the overall goal is set to adding 96 000 ha of protected forests in southern Finland before 2025, if funding is provided (Anon. 2016c). This would in total constitute only 3.6 % of the forests in Southern Finland. This further underscores the need to also define and enforce adequate legislation, which, in addition to voluntary forest protection programmes, could ensure the persistence of valuable habitat for the flying squirrel, and likely many other forest species, in Finland. Within a complex socio-ecological landscape, such as the privately owned forests in this study, the conservation toolbox must include a variety of means. Protecting areas by legislative delineation decisions could be a fundamental tool when aiming for a sufficient network. Compensation for the economic losses for stakeholders should however be carefully evaluated when top-down measures require large opportunity costs, as it seems to be the case here. An alternative approach would be to enforce the application of continuous cover silviculture to forest buffers around core areas used by flying squirrels as breeding sites (Jokinen *et al.* 2014). The use of the voluntary Forest Stewardship Council (FSC) forest certification could also be a valuable solution. Stakeholders could be compensated by a higher price for timber for accomplishing predefined measures for preserving of biodiversity. Breeding sites and resting places for the flying squirrel are in fact included in the Finnish FSC-standard (Anon. 2011). Another option could be the introduction of forestland conservation easements – a concept that is gaining increasing popularity internationally. According to this scheme landowners can gain tax benefits from preserving forests by for example permanently setting aside ecologically valuable parts (Mortimer *et al.* 2007).

5 Conclusions

We here show that not only the former guidelines for protecting breeding sites for female flying squirrels are inadequate, as previously shown (Santangeli *et. al* 2013a), but also that their recent revision provides no measurable improvement as compared to the initial guidelines. This is likely the result of the large divide between science and policy on one side, and of the strong importance given to the forestry business at the expense of the environment on the other side. The ultimate outcome is that the guidelines, as they are currently defined, will not provide adequate protection to flying squirrel habitat. Therefore the current implementation of the National Conservation Act (§ 49) of Finland does not seem to comply with the mandates stated by the Habitats Directive of the European Union.

At present the gap between science and policy makers in Finland, as well as in most other countries (Chapron *et al.* 2017), seems rather large and difficult to bridge. If such a gap is not filled rapidly by openly discussing key issues between scientists, practitioners, policy makers and the public, by acknowledging trade-offs and seeking and using the available evidence, the biodiversity decline in man-managed landscapes is unlikely to be halted (Toomey *et al.* 2016, Chapron *et al.* 2017, Sutherland and Wordley 2017).

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