Department of Physics, Chemistry and Biology

Master Thesis

Influence of landscape scale and habitat distribution on individual bat species and bat species richness

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Habitat fragmentation is one of the most important factors affecting species extinction and biodiversity loss, fragmentation causing habitat to split up and spread out in the landscape. Species habitat response expects to differ with habitat feature at different spatial scales. In this survey, the local bat species richness was observed in 156 different locations in Östergötland and the proportion of different habitats were calculated for circular areas with diameters ranging from 400 m. to 12 km. from each location. Although we found that the individual bat species responded differently to the amount of each habitat at different spatial scales, the bat species richness showed a decreasing response with increasing spatial scale. The strongest response of bat species richness to habitat characteristics was at a scale of 939 m.

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Content

1 Abstract

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2 Introduction

Fragmentation of natural habitats is one of the most important factors affecting species extinction and loss of biological diversity (Gorresen *et al.* 2005). Fragmentation split up large continuous habitats into several smaller patches in the landscape (Hanski 2005). Populations in smaller habitat patches have a higher extinction risk (Stéphane *et al.* 2008). Conserving species in these fragmented landscapes requires knowledge of the proper scale for management measures (Bergman *et al.* 2012). Species expect to show different responses to habitat features at different spatial scales depending on their characteristics, such as; behavior, body size, dispersal ability, niche extent and habitat stability. Species may respond to both local and regional characteristics of the landscape (Gorresen *et al.* 2005). Fuhlendorf *et al.* (2002) showed that population of lesser prairie-chicken (*Tympanuchus pallidicinctus*) were linked to edge density and patch size at a s scale of 452-1810 ha, while amount of cropland, trees and general landscape changes were only important at a scale of 7238 ha.

During the last three decades, changes in agriculture practices have markedly altered the composition of farmland in Western Europe, creating a more homogeneous landscape (Söderström and Pärt 2000) with small fragments of semi-natural grasslands and woodlands. One of the groups that are affected by the landscape changes are the bats (Chiroptera) and many species in this group is declining throughout Europe (Wickeramasinghe *et al.* 2003). Their diets consist mainly of insects (Wickeramasinghe *et al.* 2003, Dietz *et al.* 2009), preferably in the Lepidoptera family (Wickeramasinghe *et al.* 2003) but also Trichoptera, Culicidae and Tipuloidea insects are on the menu. Some of the larger species is known to also take Scarabaeidae and Geotrupidae beetles (Wickeramasinghe *et al.* 2003, Jensen 2004). Bats are characterized as woodland specialists (Boughey *et al.* 2011). They depend on woodlands both as a roosting and a foraging habitat (Boughey *et al.* 2011, Dietz *et al.* 2009). The majority of them forage in sparse forests, forest edges and in semi-open landscapes (de Jong 1961). Bat species that roost more frequently in larger woodland patches are more negatively affected by forest fragmentation than species that roost in human-made structures (Boughey *et al.* 2011).

Understanding the response of a bat species to its landscape characteristics is essential because bats are an important part of the biodiversity (Ahlén 2012). A large bat species richness is a good indication that the landscape has a high biological diversity (Claesson *et al.* 2004). Improving the living condition for bats may as well improve the conditions for other animal species in the landscape, and since they are sensitive to changes they are also good for detecting long-term environmental changes in the landscape that are otherwise hard to detect (Gerell & Gerell Lundberg 2003). The aim of this study was to identify how bat diversity and individual bat species respond to different habitat amounts at different spatial scales, and to find the combination of habitats types that the local bat fauna responds to.

3 Materials and Method

3.1 Survey method

The survey took place from June to the beginning of August following Ahléns (2012) recommendations. It is during the two summer months, June to July that the bats give birth to their young in reproduction colonies (Dietz *et al.* 2009). During this time the bats are relatively stationary, which means that they are likely to be associated within the areas which they were observed (Claesson *et al.* 2004). The survey took place, from dusk to approximately one hour after midnight (Claesson *et al.* 2004). During this time the survey is most efficient (Ahlén 2012).

The survey 1994-2011 was conducted by Calluna AB. It consisted of 136 sites that were surveyed one to three hours each, distributed in one to two visits. The survey started from dusk and ended approximately one hour after midnight (Claesson *et al.* 2004).

In the 2012 survey, 20 different sites were surveyed by me on location that was left out by Calluna, each of the 20 sites was surveyed twice, both at different days and times during the night. The surveys started one hour after sunset and continued to approximately one hour after midnight. The first site was surveyed during about an hour. If the area showed indications of a species rich bat fauna (several different species observed during the first part of the survey), the survey was extended with 30 min just to make sure that the majority of the species would be recorded. After that, the survey continued on a second site using the same method.

Before every survey (1994-2012), a specific walking route that contained all the interesting habitats was laid out on each site. The route was walked with a speed of approximately one meter per second. Each time a bat was observed it took approximately two minutes to transfer the sound to a digital storage. During this time the walking stopped.

3.2 Study sites

The bat study took place in the county of Östergötland, Sweden. It is an area of 11 646 km^2 and the landscape consists mainly of forest (55%) (common species; Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), birch (*Betula spp*)) and agriculture areas (23%) (Eriksson 2008). A total of 156 sites were surveyed between the years 1994 to 2012. The criteria for selecting these sites was presence of, older buildings, deciduous forest, old growth trees, connection to water and park-like settings (Claesson *et al.* 2004).

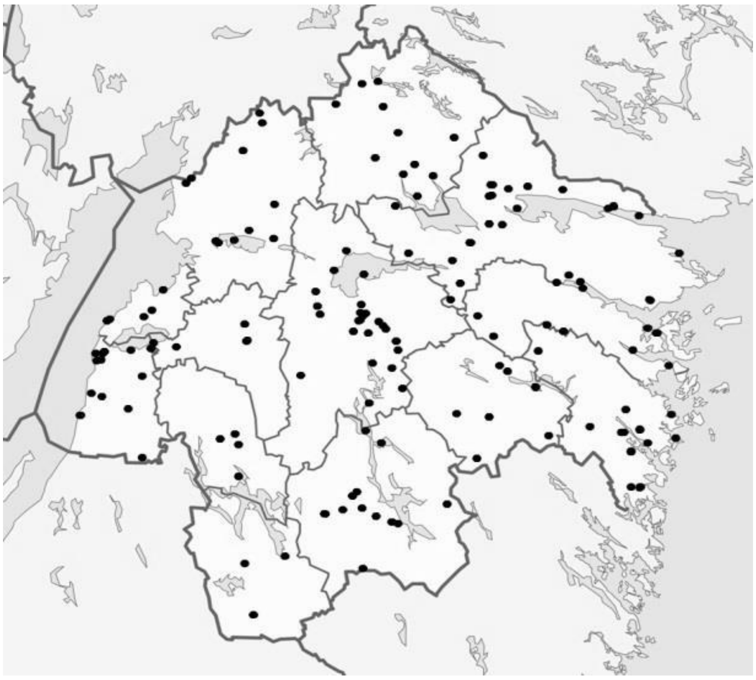


Figure 1. Overview of the 156 unique sites that was surveyed in this study.

3.3 Study species

The order Chiroptera contains over 1000 different species that can be found on every continent except Antarctica. This makes this animal group the species richest among the mammals after the rodent (Jensen 2004). They occupy virtually every trophic level, from primary to tertiary consumers and due to that, their food source varies extremely. They can eat everything from fruit, nectar, pollen, fish, vertebrates and even blood of animals (Medellín *et al.* 2000), although most of the bat species in the world live of insects (Dietz *et al.* 2009). Because of the bats varied food sources they help other species, e.g. with seed dispersal, pollination and they do also regulate the insect population (Medellín

& Gaona 1999, Medellín *et al*. 2000, Gorresen & Willig 2004, Henry *et al*. 2007). All Swedish bat species belong to the family Vespertilionidae (Vesper or plain-nosed bats), the largest family in the order Chiroptera with a least 410 different species (Dietz *et al*. 2009). In Sweden, 19 Vesper bats have been documented (Table 1).

3.4 Equipment

The equipment used during this survey (1994-2012) was the ultra-sonic detector D240x from Petterson AB (Pettersson electronik AB 2012). The sound was recorded with an Edirol R-05 Mp3-recorder. Both audio and visual identification were performed in field, when possible. The bat calls that could not be identified in field were recorded with the Mp3 recorder, in heterodyne (original sound

Table1. List of the Swedish bat species with their scientific and common English names. In the column "Presence in Ög" (Ög=Östergötland) every species mark with an "x" has been observed in Östergötland and the other with an "-" have not been found here before. "Obs." Is the number of observations of this species in this study between the years 1994-2012. "Occurrence proportion" is the proportion of sites where the species was observed among all the 156 sites. "Status" is the Swedish species status (Länsstyrelsen i Östergötlands län 2013).

Species	English name	Presence in Ög.	Obs.	Occurrence proportion	Status
Barbastella barbastellus	*western barbastelle bat*	-			Rare
Eptesicus nilssonii	*Northern Bat*	x	135	86%	Common
Eptisicus serotinus	*serotine bat*	-			Rare
Myotis alcathoe	*Alcathoe whiskered bat*	-			One find
Myotis bechsteinii	*Bechstin's bat*	-			Very rare
Myotis dasycneme	*pond bat*	?[1]	0	0%	Very rare
Myotis daubentonii	*Daubenton's bat*	x	103	66%	Common
Myotis myotis	*greater mouse-eared bat*	-			One find
Myotis mystacinus/brandtii	*whiskered bats/Brandt's bat*	x	98	62%	Relatively common
Myotis nattereri	*Natterer's bat*	x	13	8%	Relatively common
Nyctalus leisleri	*Leisler's bat*	-			Temporary
Nyctalus noctula	*common noctule*	x	115	73%	Relatively common
Pipistrellus nathusii	*Nathusiu's pipistrelle*	x	5	3%	Rare
Pipistrellus pipistrellus	*common pipistrelle bat*	-			Temporary
Pipistrellus pygmaeus	*soprano pipistrelle*	x	111	71%	Common
Plecotus auritus	*brown long-eared bat*	x	63	40%	Common
Plecotus austriacus	*grey long-eared bat*	-			Temporary
Vespertilio murinus	*parti-coloured bat*	x	35	22%	Common

[1] It is unclear if the pond bat (*Myotis dasycneme*) should count to the bat fauna of Östergötland. It has only been speculations and suspicious recordings of it but no clear observation exists.

speed) and Times Expansion (TimExp, 10 times speed, from 3,4 sec recording to 34 sec recording) mode for further computer analysis. The "TimExp" file was put in the computer software Omnibat (Ecocom 2011). The program then analyses the files and gives either a high percentage certainty for a species, uncertain species identification, or unable to identify a species. Omnibat is covering the *Pipistrellus* and *Eptisicus* family, but also *N. noctula*, *P. auritus* and *B. barbastellus* (Ecocom 2011). The recordings for which the Omnibat could not give a high certain species identification were then manually identified using the Batsound software (Pettersson electronik AB 2012).

3.5 Habitat amount at different spatial scales

The habitats that were included in the analysis were, Agricultural land, Coniferous forest that also contained some part of mixed forest, Deciduous forest, Open landscape like meadows, Settlements (human) and Water surface. For the spatial analysis, 20 different radii were used spanning from 400 up to 12000m (474, 562, 666, 790, 939, 1110, 1559, 1848, 2191, 2597, 3078, 3649, 4326, 5127, 6078, 7205, 10123) for all the 156 sites. The 400 meter scale was chosen as the smallest scale to match the distance of the survey route, and the 12000 m to match the greatest distance between the bat's roost and foraging sites according to Dietz (2009). These scales were then used to calculate the areas for the different habitats within the different radii (Figure 2) using ArcMap (ESRI® ArcMap™ 9.3) software and a map from Lantmäteriet© (Medgivande I2012/0021).

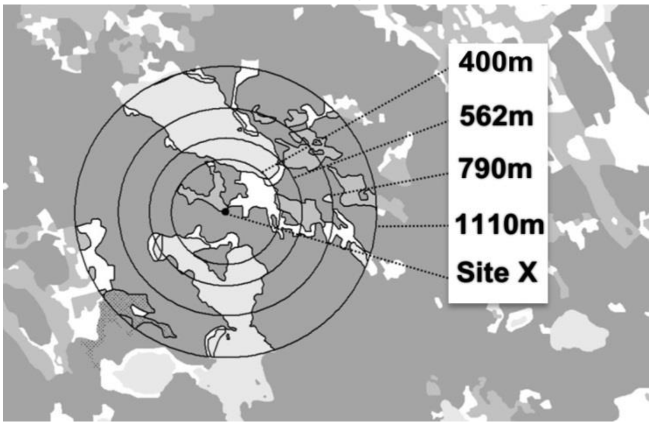


Figure 2. Example of areas (circles) around a bat survey site for which the spatial coverage of six different habitats (Agricultural land, Coniferous forest, Deciduous forest, Open landscape, Settlement and Water surface) were measured.

3.6 Statistical analysis

To avoid pseudoreplication due to site overlap in the bigger radii analyses of the bat species richness and individual species response to the amount of the different habitats, analyses were conducted in the software "Focus" (Holland 2004). This software used bat abundance, amount of habitats and a site distance matrix for all the 20 radii. "At each spatial scale, focus conducts multiple simple liner regressions of each ecological response on the landscape predictors. Each regression at each scale involves a different set of independent and randomly chosen data points" (Holland 2004). A more detailed description about the software is found in Holland (2004).

Table 2. Comparing the habitat proportion with the bat species richness at different spatial scales. Lower AIC-value indicates higher bat species richness response.

AIC	653.227	652.436	651.948	652.089	652.316	649.715	653.122	…
Spatial scale (m)	400	474	562	666	790	**939**	1110	…

To analyze at what scale the bat Species richness responded to different amount of the habitats, Akaike's Information Criterion (AIC) value was obtained through a generalized linear model. AIC is a measure of how well the results of a statistical model fits the distribution of a dependent variable, in this case which habitat variables that best explained the bat species richness. The species richness was the dependent variable and all the different habitat amounts for every scale were the factors. The better a certain combination can explain the fauna, the lower the AIC value gets. To find the best responding scale, the model were run with every habitat variable for each radius. The output gave us 20 different AIC values. The scale with the lowest AIC value was then used to determine the habitat combination that could best explain the bat occurrence at that scale. The same generalized linear model that was used to find the best responding scale was used once again to determine the best habitat combination, the species abundance as the dependent variable, but this time the factor was every combination of the habitats within that scale.

Table 3. Lowest AIC values for the best habitat combination at the spatial scale of 939m, which had the lowest AIC values in.

AIC	Agricultural land	Coniferous forest	Settlement	Deciduous forest	Open landscape	Water surface
645.048			x		x	x
646.438	x		x		x	x
646.439		x	x			
646.465		x	x		x	x
646.562		x	x			x
646.770			x			x
646.885					x	x

4 Results

A total of 686 bats belonging to 10 different species were observed on 156 sites. The number of species varied from one to nine species per site (mean 4.4 species per site). The species most frequently observed were *E. nilssonii*, which were observed in 86% of the 156 sites. The bat species richness showed the strongest response at a scale of 939 m. with an AIC value 2.039 lower than the next one (Table 2). In this scale the habitat combinations were analyzed. The combination of Water surface, Open landscape and Settlement received the lowest AIC value (1.39 lower than the second) (Table 3) and were the habitats that best explained the bat species richness. In general, the bat species richness response decreased with increasing scale (Figure 3). The bat species richness was negatively affected by Coniferous forest and showed a negative response to this variable at all the scales. Bat species richness also showed a negative response to an increasing area of Settlements, but only below 939 m; in scales larger than 939 m. the bat species richness showed a positive response.

The species richness showed the highest positive response to increasing Water surface and Open landscape for the majority of scales. Coniferous forest, Water surface and Open landscape were the habitats that the bat species richness showed the highest response to, irrespective of if it was positive or negative.

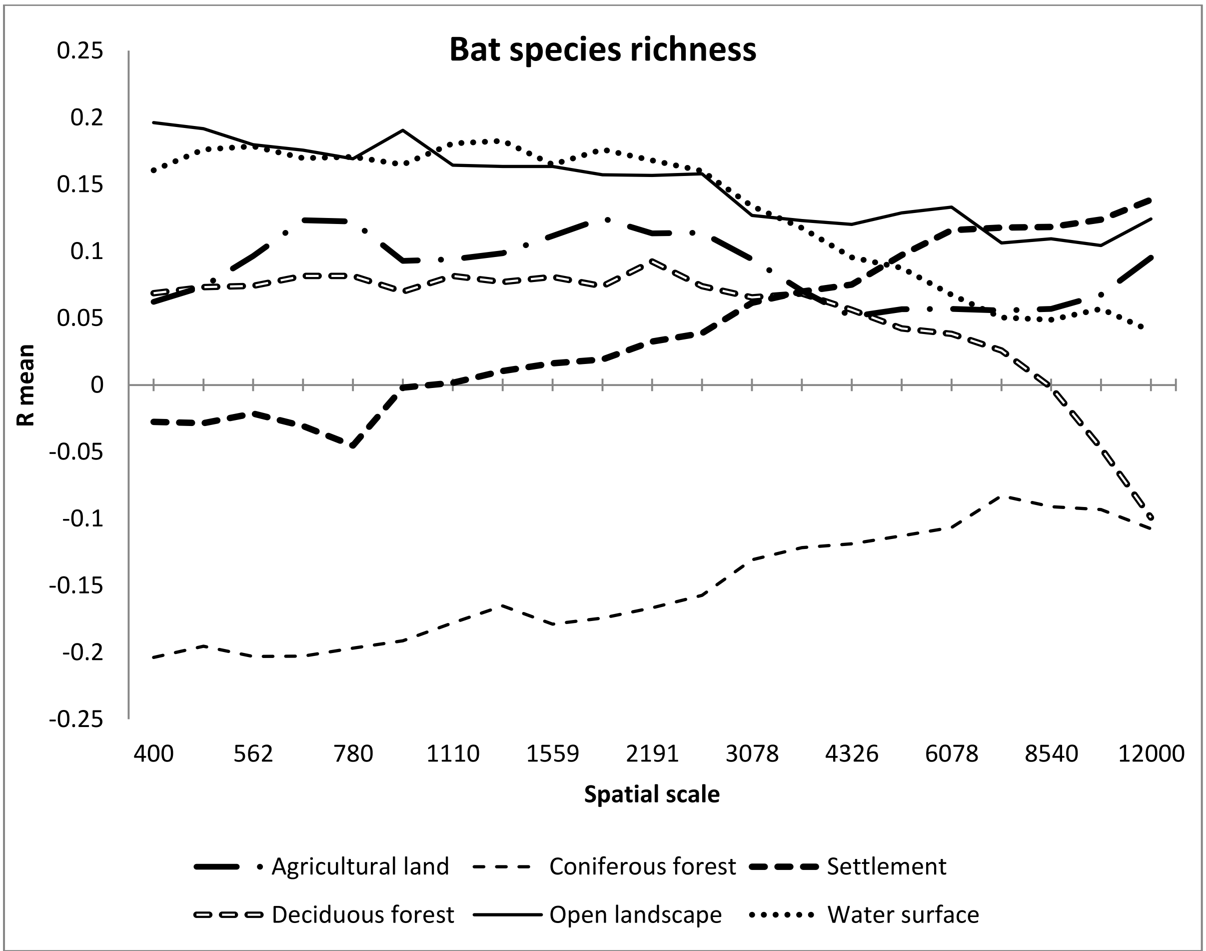
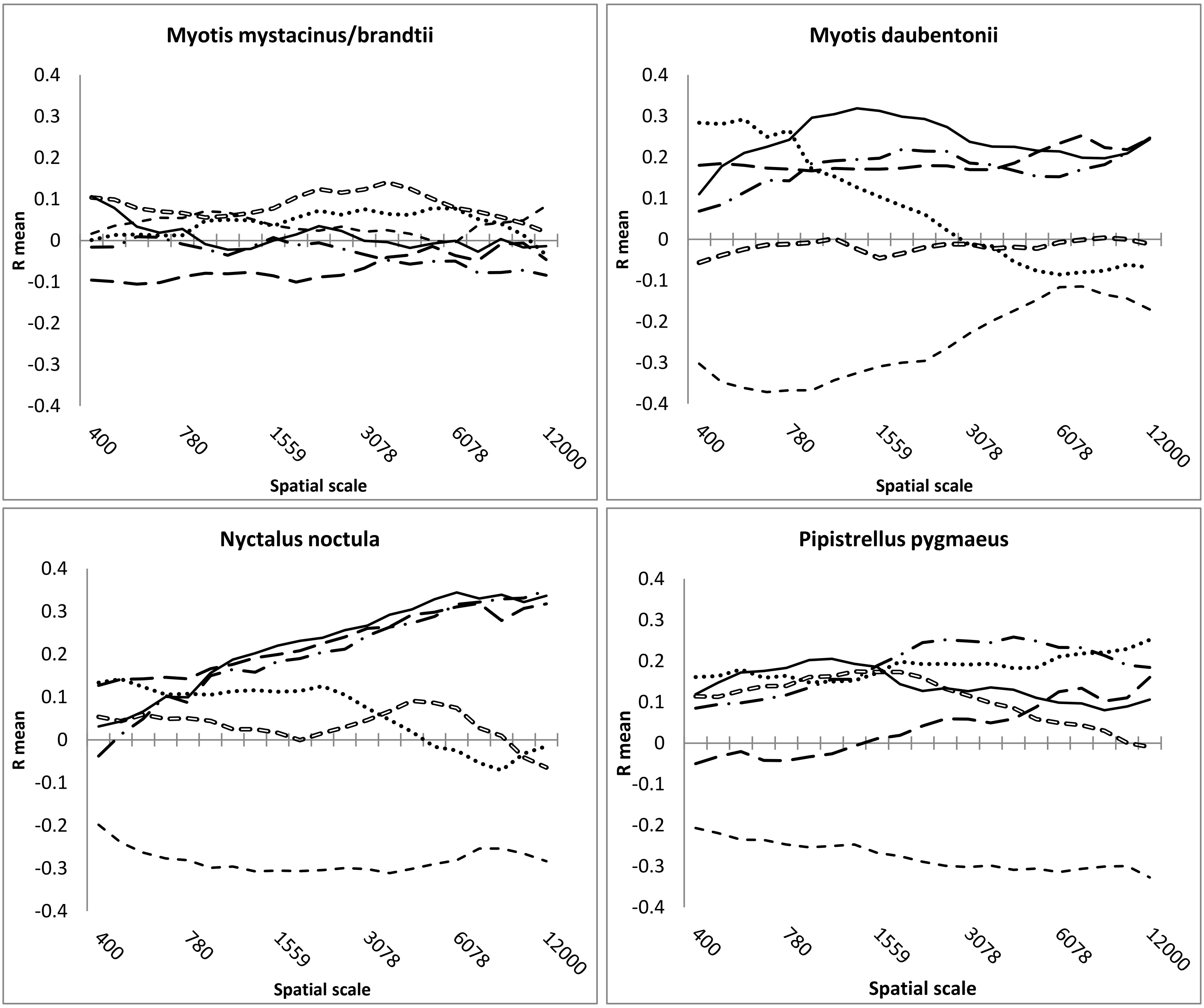


Figure 3. Bat species richness response (R_{mean} in the linear regression output from Focus software) to different amount of the habitats at different spatial scales.

All bat species did not react in the same way to the landscape composition. For the five most commonly observed species (except *E. nilssonii* that had a too high observation rate to be analyzed with observations in 86% of the sites) in this



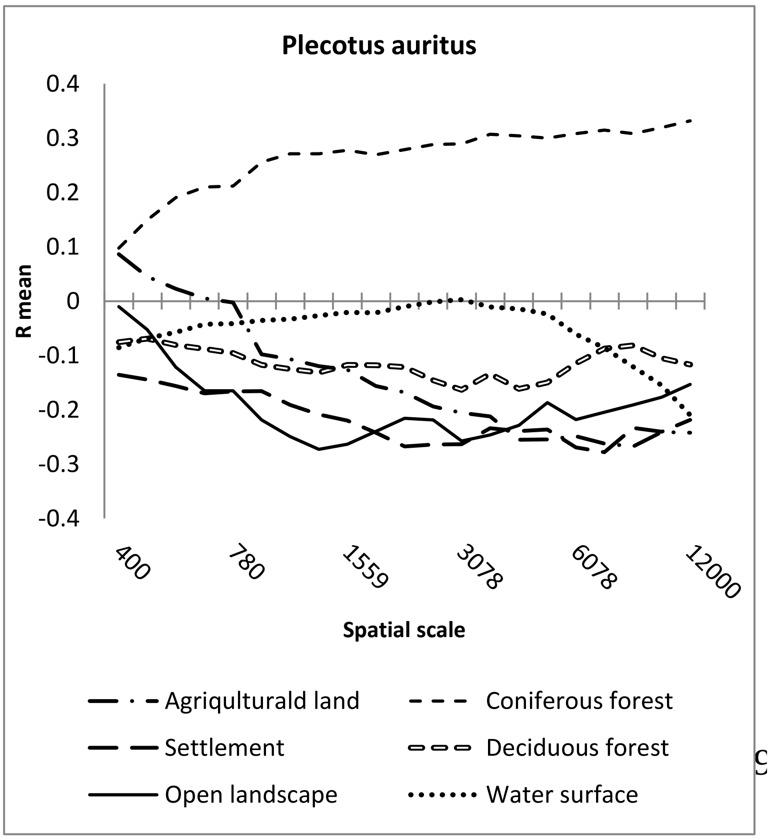


Figure 4. Habitat response for the 5 most commonly observed, (except for E. nilssonii*) at different spatial scales.* E. nilssonii *was not included because of too high observation frequency (*E. nilssonii *was observed in 87% of the sites)*

study, there were huge differences among the species (Figure 4). *M. daubentonii* had a high overall response, but particularly to an increasing area of Water surface in the small scale, and Open landscape in the large scale.

N. noctula responded to an increasing area of Water surface in the small scale. In the large scale however, the species showed an increasing response with increasing scale to Agricultural land, Open landscape and Settlement.

P. auritus showed a completely different response then the other species. This bat showed a positive response towards an increasing area of Coniferous forest with increasing scale while the other bats showed a more or less negative response. It also had a negative response to almost all the other habitat variables.

P. pygmaeus showed similar positive responses to the area of Water surface, Open landscape, Agricultural land and Deciduous forest up to the 1559 m. scale. Beyond that, it showed the highest response to Agricultural land. This bat also responded negatively to the area of Coniferous forest on all the scales and to area of Settlements up to a scale of 1559 m.

M. mystacinus/brandtii, had a very low response to all the different habitat types across all scales compared to the other species.

5 Discussion

5.1 Bat species richness and landscape use

Overall the bat species richness showed a decreasing response to the amount of the different habitats with increasing scale. They responded positive over all scales to an increasing area of Water surface, Open landscape, Agricultural land and Deciduous forest, and showed a negative response to increasing area of Coniferous forest. Bat species richness responded negative to the amount of Settlements in the small scale and showed a positive response in the large scale. My results indicate that the bat species richness positive habitat response is almost constant up to a scale of 3 km. and then starts to decreased rapidly. However, Gorresen *et al.* (2005) have found that the bat species richness was associated with landscape characteristics of a scale of 5 km, and that this scale probably would include all or most of the bat's home range.

The bat species richness positive response to Water surface, Open landscape, Deciduous forest and Agricultural land may be because they respond to the insect concentration within the landscape (de Jong & Ahlén 1991). Their habitat preferences does however, shift during the season, In May-June, bats hunt mainly in deciduous forest near water surface (Entwistle et al. 1996). Water bodies offer higher densities of insects then coniferous forest, generally because of many insects that the bat feeds on have an aquatic larva stage (Walsh & Harris 1996). During this time, the Lepidoptera insects that the bats prefer to feed on are scarce except at location close to water bodies (Entwistle et al. 1996). Later in the summer the insect abundance will even out in the landscape and the bats species will move over to their specialized niches. *E. nilssonii* will move over to hunt in most of the different forest types while *P. pygmaeus* will mainly hunt within deciduous forest (de Jong & Ahlén 1991). Also, at the end of the summer (August to September) bats will be more concentrated around street-lamps or other illuminated areas since those attract insects (de Jong & Ahlén 1991, Gehrt & Chelsvig 2003). This habitat shift does not display in my results, but is important to take into consideration when planning to protect bat habitats.

The bat species richness responds to the amount of the different habitats in the landscape was more or less constant up to the 3 km radius (except for settlement and coniferous forest) and then the response decreased. The scale that the bat species richness responded the strongest to was at a radius of 939 m, and at this scale; Settlement, Open landscape and Water surface was the habitats that could best explain the bat species richness in the landscape. Species like *P. auritus* and *E. nilssonii* that usually does not move more than 1 km between their roost and their foraging grounds (Dietz *et al.* 2009), most likely have their roost within this "common species response" (<939 m) radius. Other species like the *Myotis spp*, can move a distance from 2.8 km. up to 10 km from their roost to their foraging ground (depending on species) (Dietz *et al.* 2009), and can have their roost outside the "common species response" radius. However, Gorresen *et al.* (2005) have shown that the bat abundance responds to landscape characteristics at a scale as large as 5 km radius, and de Jong *& Ahlén* (1991) states that "it is common that bats fly several km between their roost and hunting grounds". Even if specific bat species can have up to 10 km distance between their roost and their foraging ground, my results indicates that they usually have their roost closer to their foraging grounds even though they can fly several km to reach their hunting grounds.

5.2 Individual species responses

My results show that the bat species response to different amount of habitat at different spatial scales is more or less individual for each species. This is due to each species characteristic food requirements, foraging behavior, habitat choice, flight style and frequency in their supersonic calls (de Jong & Ahlén 1991, Gorresen *et al.* 2005, Dietz *et al.* 2009).

M. daubentonii have one of the strongest response overall (R_{mean} <0.32). My result shows that *M. daubentonii* responded strongly to the amount of water surface, probably because their main hunting grounds are just centimeters over water surfaces (Kalko & Schnitzler 1989, Dietz *et al.* 2009). Warren *et al.* (2000) have found that *M. daubentonii* prefer stretched rivers with smooth surface and trees on both banks. However, they are also known to hunt in forests, parks or meadows with fruit trees (Dietz *et al.* 2009).

Nyctalus noctula is the largest bat in Sweden, according to my results this bat has the strongest habitat response on a scale bigger than 10 km, particularly to Open landscape, Agricultural land and deciduous forest. This bat also responded locally (<780m radii) to amount of Water surface and Deciduous forest as Rachwald (1992) suggested even if it was a very weak response in my results. It can forage in almost every type of landscape due to its hunting behavior (Dietz *et al.* 2009). Both its hunting calls and wing formation is designed for a so-called long-range strategy (Rachwald 1992), locating insects far away in the open air space above the tree-canopy and catch its prey in fast flight. Although it can hunt above almost any type of habitat, it mainly forages near river and forest edges (Rachwald 1992).

The species response curves that differed the most compared to the other bat species was *P. auritus*. It responded positive on increasing coniferous forest, but negative on deciduous forest. Entwistle (1996) have shown that *P. auritus* spend most of its time in self-sown coniferous forest, but also in mixed woodland and mature deciduous woodlands, and that all feeding sites were associated with either woodland of some sort or individual trees (Entwistle *et al.* 1996).

P. pygmaeus is an agile bat that can hunt in a limited area, such as within the canopy of trees or under branches overhanging water in almost all forest types (de Jong & Ahlén 1991, Dietz *et al.* 2009). This bat showed similar positive response to Water surface, Open landscape, Agricultural land and Deciduous forest up to 1559 m. This suggests that this bat species have a wide range of habitats that it uses in the small scale. In the larger scale (>1559 m) it responded positively to amount of Agricultural land and Water surface and responded negatively to amount of Coniferous forest in all the scales. However, this bat prefer to hunt in riparian habitats over all other habitat types (Davidson-Wattsa *et al.*2006).

M. mystacinus and *M. brandtii* showed an overall very low response to different habitats. This could be because they actually are two species that is counted as one because of difficulties in separating them acoustically. However, both forage in the woodlands and they are characterized as forest species (Dietz *et al.* 2009). Unfortunately, no conclusion about their habitat could be drawn for these two bat species.

6 Conclusion

Bat species richness responded to landscape characteristics up to a scale of 3 km, and the habitat variables that they responded the strongest to were amount of Water surface and Open landscape. If a conservation project would be conducted to improve the habitats for bats, it should focus on a minimum 1 km scale, since the bat species richness responded strongest to the habitat characteristics at the 939 m radii.

Since this study has shown that each bat species has a more or less individual response to the amount of different habitat variables, it is crucial to take this into account when planning bat conservation management. In this study, it was only possible to do a response analysis for the five most common bat species. When planning to conserve or reintroduce rarer and red-listed bat species it is important to thoroughly investigate at what scale and what habitat variables they respond strongest to before doing any conservation management.

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