ÉCOSCIENCE 19 (3): 191-197 (2012)

Landscape composition weakly affects home range size in Blanding's turtles (*Emydoidea blandingii*)[1]

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Abstract: Landscape composition and habitat quality influence the abundance, population structure, and movements of animals. Understanding how an animal interacts with elements of the landscape helps predict its response to habitat loss and changes in land cover. We tested the hypothesis that the extent of movement depends on landscape composition in a threatened freshwater turtle, *Emydoidea blandingii*. We measured habitat composition at multiple spatial scales, ranging from the home range to the landscape scale. We built multiple linear regression models to predict home range size from the proportional use of 5 land-use categories, while controlling for intrinsic factors (sex, body size). We found that landscape composition significantly influenced home range size in the Blanding's turtle; however, the models explained a low proportion of the observed variation in home range size, meaning that landscape composition had a weak effect on movement. Our results also suggest that sex and body size have little influence on home range size in Blanding's turtles. More research is needed to determine the factors driving movement in this species, and overall, we recommend cautious use of models predicting space use as a function of landscape composition in a conservation context.
Keywords: Blanding's turtle, conservation, habitat loss, home range, landscape composition, movement modelling.

Résumé : La composition du paysage et la qualité d'habitat influencent l'abondance, la structure et les déplacements des populations animales. Comprendre l'interaction entre une espèce et son environnement permet de prédire sa réponse à la perte d'habitat et aux changements dans la composition du paysage. Nous avons étudié la relation entre la composition du paysage et l'étendue des déplacements chez *Emydoidea blandingii*, une tortue d'eau douce au statut menacé. Nous avons mesuré la composition de l'habitat à plusieurs échelles spatiales, allant du domaine vital à l'échelle du paysage. Nous avons construit des modèles de régression linéaire multiple afin de prédire la taille du domaine vital à partir des proportions de 5 types d'habitats, en contrôlant pour le sexe et la taille des animaux. Nos résultats montrent que la composition du paysage influence significativement la taille du domaine vital chez la tortue mouchetée. Par contre, les modèles ne prédisaient qu'une faible proportion de la variation observée dans la taille des domaines vitaux, suggérant que la composition du paysage a peu d'influence sur les déplacements. Nos résultats suggèrent également que la taille corporelle et le sexe influencent peu la taille du domaine vital chez la tortue mouchetée. Des recherches supplémentaires seront nécessaires afin d'identifier les facteurs déterminants dans les déplacements de l'espèce. De façon générale, nous recommandons l'utilisation prudente des modèles prédisant l'utilisation du territoire en fonction de la composition du paysage dans un contexte de conservation.
Mots-clés : composition du paysage, conservation, domaine vital, modélisation des déplacements, perte d'habitat, tortue mouchetée.

Nomenclature: Ernst & Lovich, 2009.

Introduction

The concept of landscape refers to an area composed of heterogeneously dispersed habitat patches and matrix elements (non-habitat: roads, fields, urban areas, etc.; Wiens, 2002). Quality of a landscape can be attributed to both matrix and patch features. In many recent studies, authors have investigated how landscape structural characteristics influence animal movements (Reunanen *et al.*, 2002; Bowne, Bowers & Hines, 2006; Kindlmann & Burel, 2008). For instance, some reptile and mammal species have larger home ranges (Collins & Barrett, 1997; Kapfer *et al.*, 2010) and cover longer distances in search of high quality habitat patches (Bowne, Bowers & Hines, 2006) in disturbed habitats. Long movements caused by habitat loss combined with habitat fragmentation by roads can have serious consequences for vagile animals because they become more susceptible to collision with vehicles (Aresco, 2005; Fahrig & Rytwinski, 2009). In highly degraded or fragmented landscapes, animals can also be constrained to the few remaining habitat patches and thus move shorter distances (Ahlers *et al.*, 2010; Row, Blouin-Demers & Lougheed, 2012). Landscape composition can therefore influence habitat use, and ultimately long-term survival of a species. Spatial scale is also important to consider in landscape ecology. It is necessary to study habitat use at many spatial scales since behaviour at one scale does not necessarily predict the animal's behaviour at other scales (Nams & Bourgeois, 2004; Mayor *et al.*, 2009).

Large intraspecific variation in movement patterns is typical for many animal species. Commonly studied

[1]Rec. 2010-02-02; acc. 2012-05-29.
Associate Editor: Patrick Thomas Gregory.
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DOI 10.2980/19-3-3528

intrinsic factors that affect movement include sex, age, and reproductive status (Austin, Bowen & McMillan, 2004; Blouin-Demers, Bjorgan & Weatherhead, 2007; Kapfer, Coggins & Hay, 2008; Millar & Blouin-Demers, 2011; van Beest *et al.*, 2011). Food and cover are fundamental habitat characteristics that animals select, and so these variables drive movement patterns (Noyce & Garshelis, 2011). Targeting the main factors that affect movement in a species is a key element in an evaluation of its habitat requirements. Studying spatial and temporal movement patterns is a step towards understanding a species' ecological needs, and ultimately can lead to recommendations for its protection. Among all determinants of animal movement, our study focuses on the spatial distribution of resources and matrix elements in a complex landscape.

We used the Blanding's turtle (*Emydoidea blandingii*) as a case study. It is considered a semi-aquatic turtle that uses both aquatic and terrestrial habitats (Joyal, McCollough & Hunter, 2000). According to the Committee on the Status of Endangered Wildlife in Canada, it is threatened by habitat loss and modification across most of its Canadian range (COSEWIC, 2005). Blanding's turtles primarily inhabit wetlands with abundant aquatic vegetation such as forested swamps, ponds, marshes, bogs, fens, and other shallow water habitats (Ross & Anderson, 1990; Joyal, McCollough & Hunter, 2001; Grgurovic & Sievert, 2005; Edge *et al.*, 2010; Millar & Blouin-Demers, 2011). Edge *et al.* (2010) showed that Blanding's turtles selected all wetland types over lotic and upland habitats at the home range scale. However, Blanding's turtles commonly move long distances on land, mainly to reach other wetlands and also to find nesting sites (Joyal, McCollough & Hunter, 2001; Millar & Blouin-Demers, 2011). For example, gravid females can move > 1 km to reach nesting sites (Congdon *et al.*, 1983; Ross & Anderson, 1990; Joyal, McCollough & Hunter, 2000). Previous studies have reported home range sizes ranging from 1 to 255 ha, with lengths ranging from 140 to 3200 m (Ross & Anderson, 1990; Grgurovic & Sievert, 2005; Millar & Blouin-Demers, 2011). As is typical of many species, large variations in movement patterns have been found, with little explanation for such variation.

The aim of our study was to determine the effects of landscape composition on movements in the Blanding's turtle, using a gradient of landscape characteristics. We hypothesized that variation in movement patterns is caused by heterogeneity and quality of the landscape. Because movement is required to reach dispersed resources, individuals in poor quality habitats have to cover larger areas to fulfill their ecological needs. Wetlands being considered preferred (Edge *et al.*, 2010) habitats for Blanding's turtles, individuals located in landscapes poor in wetlands should move longer distances. Presence of anthropogenic activity should also increase movement extent, because it reduces the proportion of suitable habitat. The study area has not undergone major development, so we did not consider the possibility that turtles were constrained to isolated habitat patches. We examined the relationship between habitat composition and movements at many spatial scales to identify the extent to which each physical component of the landscape affects movement. We then sought to model this relationship, enabling us to predict movement from simple measures of landscape composition. The resulting models could be applied to presence/absence data to determine the extent of protection that is required. Habitat models are also powerful tools to determine habitat requirements in different landscapes, and to evaluate the consequences of habitat loss.

Methods

Study sites

We conducted this study from April to September 2010 in southwestern Quebec, Canada. The study area encompassed 5 study sites located along the north shore of the Ottawa River (Figure 1). The study sites were 60 to 130 km^2 in size and were chosen to represent a gradient of landscape characteristics where Blanding's turtles are still found in the study area. Four sites were characterized by a mixed forest cover. They generally showed low elevation and high wetland density (mainly marshes, swamps, and ponds). There was a gradient of human activity (wood mills, active mines, urban areas, and crops) across those sites. The fifth site had a high proportion of mixed forest cover, high elevation, low wetland density (mainly bogs and fens), and low human disturbance.

Radiotelemetry and movement patterns

In spring, Blanding's turtles were captured by hand or using baited hoop nets. They were given a unique ID by notching the marginal scutes of the carapace. Carapace and plastron lengths were measured using a calliper. Sex was determined from the plastron concavity. In total, 44 turtles (22 females, 19 of them gravid; 22 males) were equipped with radio-transmitters (AI-2F, 33 g, 36 months battery life, Holohil Systems, Carp, Ontario, Canada) that were fixed to the rear carapace margin with 2 screws. The transmitter and screws did not exceed 5% of the animal's mass. Turtles were distributed in the 5 study sites as follows: 9 in each of sites A, B, and C, 11 in site D, and 6 in site E. Telemetry tracking took place from May 9th to September 30th, corresponding to the active season in the study area. Turtles were located with a receiver coupled with a three-element folding

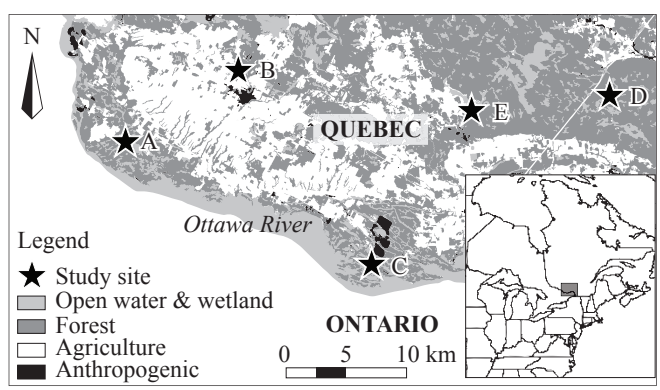

Figure 1. Map of southwestern Quebec, Canada, showing landscape composition of the Blanding's turtle study area and location of the 5 study sites.

Yagi antenna. From May to August, the turtles were located every 2-4 d, and once a week in September. The turtles were located either directly or using triangulation. All coordinates (triangulation stations and animal locations) were recorded with a GPS (GPSMap 60CSx, Garmin, Olathe, Kansas, USA). In the case of triangulation, the turtle locations were calculated using the software Locate III (Pacer Computing, Tatamagouche, Nova Scotia, Canada).

All precise turtle locations were imported into ArcGIS 10 (ArcView, Environmental Systems Research Institute, Redlands, California, USA). We used triangulated turtle locations that had a precision better than 30 m. The data set was randomly resampled using Hawth's tools (Beyer, online) to get 34–35 locations per animal for the active season (May–September). To investigate the relationship between movement patterns and landscape composition, we chose home range size (HRS) as the dependent variable. The HRS of each animal was measured using minimum convex polygons (MCPs), as recommended for amphibians and reptiles (Row & Blouin-Demers, 2006). HRS (ha) was log transformed to reach a normal distribution as determined by Shapiro–Wilk test.

Landscape composition measurements

Land use maps for the study area were obtained through the Quebec Topographic Database, the Ecoforestry Information System, the Insured Crop Data Base, and Ducks Unlimited Canada. We distinguished 5 land use categories: wetlands (WET), forest (FOR), agriculture (AGRI; agriculture and agroforestry), open water (OW), and anthropogenic land (ANT; gravel pits, urban areas, and other disturbed sites). We measured habitat composition at 8 spatial scales. The first scale was the MCP of each animal; we then built buffers around the MCPs with increasing radii of 250, 500, 1000, 1500, 2000, 3000, and 4000 m. The maximal buffer radius was chosen to include the largest Blanding's turtle home range length observed in this study and reported in the literature (Ross & Anderson, 1990; Grgurovic & Sievert, 2005; Millar & Blouin-Demers, 2011). We measured the proportions of the 5 land uses within each buffer, using standard tools from ArcGIS 10. All the landscape composition variables were square root transformed.

Modelling

We built models to predict the HRS of Blanding's turtles using multiple linear regressions. The predictors were the proportions of the 5 land use types, sex (SEX), and plastron length (PL), a body size indicator. The last 2 variables were included because other studies on reptiles have suggested they influence movements (Blouin-Demers & Weatherhead, 2002; Blouin-Demers, Bjorgan & Weatherhead, 2007; Kapfer *et al.*, 2010; Millar & Blouin-Demers, 2011). The distribution of plastron length was normal according to a Shapiro–Wilk test. For each landscape composition variable, we used univariate regressions to determine the spatial scale at which it influenced HRS the most. Each landscape composition variable was included as a predictor in the models only at the spatial scale that showed the highest correlation (Pearson's *r*) with HRS, enabling us to reduce the number of predictors.

We split the data set into 5 subsets, each time excluding data from 1 of the 5 study sites (referred to as sites A–E). We used each subset as a training set, and the excluded data were subsequently used to test the model's ability to predict HRS in the corresponding site. We examined each training set for multicollinearity among the landscape composition variables, using both pairwise regressions between all variables and variance inflation factors (VIFs) for each variable (Burnham & Anderson, 2002; Smith *et al.*, 2009). The VIFs were calculated using the "car" package in R 2.12.1 (R Development Core Team, Vienna, Austria). For each training set, we built models including all the predictors and examined all the possible models using the "MuMin" package in R. We calculated the second-order Akaike's Information Criterion (AIC_c) for each candidate model, and model selection was based on ΔAIC_c and Akaike weights (Burnham & Anderson, 2002). All candidate models with a $\Delta AIC_c \leq 4$ were used to average the parameters of an averaged best model, based on the relative weight of each candidate model. To validate the 5 averaged models, we first evaluated their fit with the training data by predicting HRS from the training data of each set. We then used simple linear regression to estimate the correlation between the observed (OBS) and the predicted (PR) HRS, with PR on the x axis and OBS on the y axis (Piñeiro *et al.*, 2008). We then evaluated the ability of each averaged model to predict HRS on external data. We predicted HRS for the validation data initially excluded from each training set and estimated the correlation between predicted and observed HRS in the same way we did for the internal data. For each relationship, we tested whether the slope deviated significantly from a 1:1 linear fit with Student's *t*-tests. All the statistical analyses were performed with JMP 7 (SAS Institute Inc., Cary, North Carolina, USA) and R. 2.12.1. We considered tests significant at $\alpha = 0.05$.

Results

The landscape composition variables were measured at 8 spatial scales and included as predictors in the models only at their spatial scale of maximal influence on HRS (Table I). The landscape composition variables used in modelling showed low inter-individual variability, meaning that the turtles used somewhat similar habitats across the study area (Table II). The variability in plastron length was also low across the 44 turtles measured. We examined the 5 training sets for multicollinearity among the landscape composition variables and found

Table I. Correlation coefficients (Pearson's *r*) of the landscape composition variables, at the spatial scale used in modelling, plotted against home range size of Blanding's turtles ($n = 44$).

Variable	*r*	Spatial scale[a]
Wetland proportion	0.20	MCP + 500 m
Forest proportion	–0.26	MCP + 4000 m
Agriculture proportion	0.34	MCP + 3000 m
Open water proportion	–0.42	MCP
Anthropogenic land proportion	–0.16	MCP + 3000 m

[a] Spatial scale is presented as MCP + the radius length added to build the buffer.

VIFs ranging from 1.42 to 31.98 and | r | ranging from 0.01 to 0.95. Collinearity was strong between the proportions of forest and agriculture but relatively weak among the other landscape composition variables. We included all 5 landscape composition variables in the multiple linear regression models.

We obtained between 14 and 44 candidate models with $\Delta AIC_c \leq 4$ for each training set. Akaike weights were generally low and similar among the candidate models of a training set, making it more appropriate to average a global model than to identify the best model. For each training set, we averaged a model from all candidate models (Table III). Plastron length and sex ranked as the 2 weakest predictors of HRS across the averaged models. Proportions of agriculture, open water, and anthropogenic land appeared to be the 3 most important predictors. While an increase in the proportion of agriculture resulted in larger home ranges, an increase in the proportions of open water and anthropogenic land resulted in smaller home ranges. The proportions of wetland and forest did not show a consistent relationship with HRS across all models.

Pooling data from the 5 study areas, mean observed HRS (± SD) was 29.7 ± 32.3 ha (from 2.8 to 130.5 ha). The 5 averaged models significantly predicted HRS from internal data, but the coefficients of determination (R^2) were low for all relationships (Table III). Between 59 and 75% of the variation in HRS remained unexplained by the averaged models. The 5 averaged models were also used to predict HRS on independent data, with data from 6 to 11 turtles per study site. The correlation between predicted and observed HRS was low for all the external data sets examined, with no significant correlation (Table IV; Figure 2). A good predictive model has a linear fit close to a 1:1 relationship when plotting observed values against predicted values, with parameters ($mx + b$) close to $m = 1$ and $b = 0$ (Piñeiro *et al.*, 2008). Compared to a 1:1 linear fit, the models showed deviation from 60 to 197% for the slope, but none significantly differed from $m = 1$. Overall, the predictive power of the averaged models was low, and they provided biased HRS estimates.

TABLE II. Inter-individual variability of the predictors used to model home range size of the Blanding's turtles ($n = 44$). Landscape composition variables were measured at the spatial scale used in modelling; see Table I for spatial scales used.

Variable	Range	Mean ± SD
Plastron length (mm)	183.0 – 247.0	220.9 ± 12.5
Wetland proportion (%)	3.8 – 63.5	25.2 ± 2.2
Forest proportion (%)	27.3 – 82.3	59.1 ± 0.9
Agriculture proportion (%)	0.3 – 58.6	15.1 ± 3.9
Open water proportion (%)	0.0 – 51.5	5.5 ± 3.2
Anthropogenic land proportion (%)	0.0 – 11.4	1.7 ± 1.2

TABLE III. Parameter coefficients for 5 averaged multiple linear regression models, excluding (–) sites A–E, and predicting home range size in the Blanding's turtle ($n = 33$–38). Coefficients of determination (R^2) and P-values (P) are indicated for each model.

Parameter	–Site A	–Site B	–Site C	–Site D	–Site E
Intercept	1.330	2.550	1.480	1.090	1.170
SEX	–0.002	–0.200	–0.020	0.009	–0.009
PL	0.000	–0.001	0.001	0.003	–0.001
WET	0.140	–0.020	–0.040	–0.050	0.140
FOR	–0.080	–1.240	–0.430	–0.210	0.260
AGRI	0.150	0.680	0.270	0.150	0.670
OW	–0.890	–0.060	–0.780	–1.230	–0.260
ANT	–0.080	–3.840	–0.220	–0.430	–0.250
R^2	0.250	0.410	0.250	0.340	0.250
P[a]	0.002	< 0.001	0.002	0.000	0.002

[a] All relationships were significant at $\alpha = 0.05$.

Discussion

Landscape characteristics have previously been shown to influence movements in many animals (Reunanen *et al.*, 2002; Bowne, Bowers & Hines, 2006; Kindlmann & Burel, 2008). By modelling the relationship between movements and landscape composition, some researchers have successfully identified the effects of landscape modification and human activity on habitat use (Ahlers *et al.*, 2010; Kapfer *et al.*, 2010). For instance, a study by Ahlers *et al.* (2010) in the USA suggested that muskrats (*Ondatra zibethicus*) located their home ranges linearly along available streams and could not move freely to upland habitat in a landscape deeply modified by agriculture. This type of study is an important tool for evaluating the response of wildlife to landscapes modified by human activity.

In our study, we attempted to model the relationship between landscape composition and home range size (HRS) in Blanding's turtles inhabiting a gradient of landscape characteristics. HRS represents the area needed by an animal to complete its normal activities, and thus is a good indicator of habitat use, often used to define critical habitat for species at risk. The models were validated on internal data and showed only a moderate fit to the data used to build them. Over 60% of the variability in HRS remained unexplained by the 7 variables included in the models. The proportions of agriculture, open water, and anthropogenic land seemed to influence HRS more than the other variables, but those relationships were weak. The proportions of wetland and open water seemed to influence HRS at much smaller spatial scales than forest, agriculture, and anthropogenic land. This might reflect the selection of aquatic habitats by the Blanding's turtle, with other habitat types occupying a limited portion of the home range or surrounding it. The importance of individual variables in predicting HRS varied a lot among the 5 models, even though over 75% of the training data were constant across the models.

TABLE IV. Estimation of the predictive power of the 5 averaged models predicting Blanding's turtles home range size from an independent data set ($n = 6$–11). Coefficients of determination (R^2), P-values (P), and values for the slope (m) and intercept (b) of the linear fit are presented for each relationship between observed and predicted HRS.

Data set	R^2	P	m	B
Site A	0.020	0.708	0.40	0.95
Site B	0.001	0.931	–0.12	1.21
Site C	0.000	0.980	0.05	1.40
Site D	0.030	0.609	0.23	0.91
Site E	0.240	0.319	2.97	–2.97

It is thus difficult to interpret the effect of each variable on HRS, especially for the variables that showed both positive and negative relationships with HRS depending on the model examined, which is the case for the proportions of wetland and forest. Our prediction that turtles in landscapes poor in wetlands would have large home ranges was not supported, nor was the positive effect of agriculture and human disturbance on HRS. Not surprisingly, the models also failed at predicting HRS on independent data from an external study site. The main goal of predicting HRS on external data was to evaluate the potential of the models to be extrapolated to other study areas. None of the 5 averaged models predicted significantly HRS on external data, and the predictions made by all of the models had large biases. Therefore, these models cannot be used with confidence to predict habitat use of Blanding's turtles in other areas.

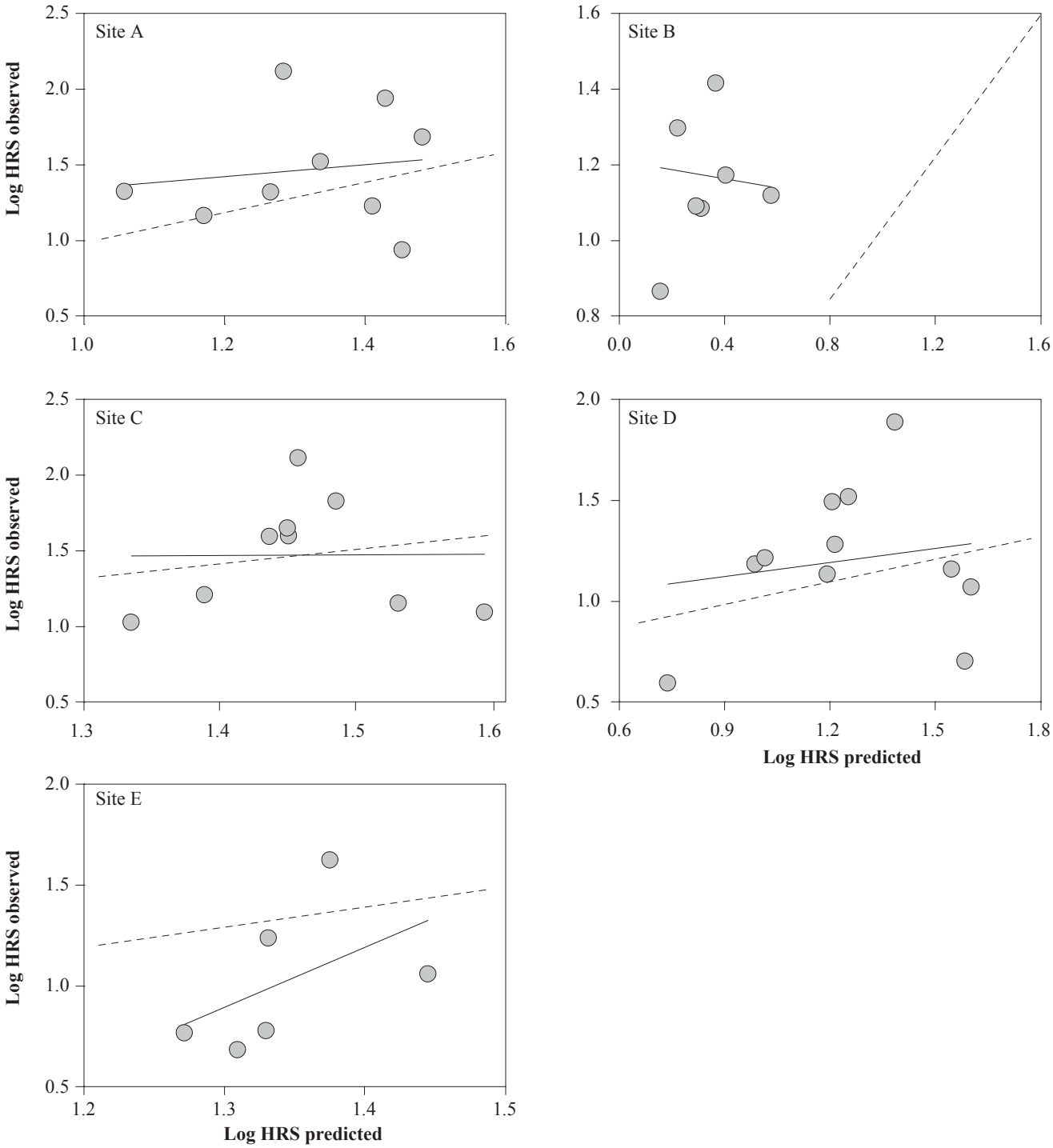

FIGURE 2. Correlation plots of observed against predicted home range size (both log transformed) of Blanding's turtles (n = 6–11). The linear fit for each plot (solid line) is compared to a 1:1 linear fit (dashed line).

Because we were unable to predict home range area from landscape composition accurately and precisely in Blanding's turtles, it is possible that landscape composition is not the main factor driving movements. Other physical attributes of the landscape, such as configuration, fragmentation, and connectivity, could also influence movement patterns in Blanding's turtles (Bowne, Bowers & Hines, 2006; Mitrovich, Diffendorfer & Fisher, 2009).

The weak correlation between landscape composition and home range size may also be due to the low variability in landscape composition across the individual turtles' home ranges. The range of proportions obtained for the 5 land use types within the areas used by turtles was generally broad, except for anthropogenic land, which varied between 0 and 11%. The standard deviation was low for all variables, however, meaning that most of the turtles used similar habitats, with a few individuals accounting for most of the variability. The low variability of the predictors used in the modelling probably impaired the predictive power of the averaged models. Not being able to model the response of Blanding's turtles to the full potential range (0 to 100% cover) of any of the landscape composition variables was the main limitation of our study. Studying turtles in a landscape that had limited variation, especially in anthropogenic land covers, may have biased our inferences of their response to elements of the landscape (Eigenbrod, Hecnar & Fahrig, 2011). Future studies should attempt to examine the relationship between movement and landscape composition in heavily disturbed areas.

The selection of study sites for this study was based on a Blanding's turtle visual survey of the entire study area (Fortin, 2012). Besides the study sites mentioned here, several other areas were surveyed, including more urban and agricultural zones. Blanding's turtle sightings were rare in disturbed landscapes, however, and the animals caught for the telemetry survey on which our study is based were in areas with high wetland density and extensive forest cover. This suggests either that Blanding's turtles select high quality habitats at a larger scale than we considered here or that Blanding's turtles have already disappeared from the more impacted sites. In either case, all Blanding's turtles are currently using high quality habitats, which limits our ability to detect an effect of landscape composition on movements. Further investigation is needed to determine the effect of landscape composition on the probability of presence of Blanding's turtles at larger spatial scales. At present, we recommend that conservation strategies in the case of Blanding's turtles be based on descriptive studies of movement patterns and habitat selection at local scales and habitat suitability modelling studies that provide insights into habitat requirements at very large spatial scales (Millar & Blouin-Demers, 2012). A general caveat is that it seems likely that many species at risk have already declined to the point where they are now only occupying a fraction of their original distribution, most probably the highest quality patches, thus confounding efforts to define suitable habitat at intermediate and small spatial scales.

Acknowledgements

We thank the members of the Quebec Blanding's and Musk Turtles Recovery Team for their constant participation in the project. S. Giguère, C. Daigle, C. Gagné, I. Beaudoin-Roy, D. Toussaint, J. Caron, D. St-Hilaire, and others contributed to the orientation or provided feedback on this work. We thank S. Pelletier, A. Orjikh, P. Michaud-Whalen, and J. Boisvert for their participation in the telemetry survey. We thank the National Capital Commission for giving us access to Gatineau Park and private land owners who let us access their properties. Environment Canada, the Quebec Department of Natural Resources and Wildlife, and the Nature Conservancy of Canada provided field equipment, funding, and participated in fieldwork. This work was also supported by grants from the Natural Sciences and Engineering Research Council of Canada, the University of Ottawa, the Quebec Department of Sustainable Development, Environment and Parks, and the Quebec Wildlife Foundation. Our protocol was approved by the University of Ottawa Animal Care Committee (protocol BL-253), and permits were obtained from Environment Canada (SARA-QR-2010-0154), the National Capital Commission (9965 and 11089), and the Quebec Department of Natural Resources and Wildlife (09042300707SF, 10012103807SF, and CPA-FAUNE 2009-15).

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