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Original article

Landscape factors affecting relative abundance of gray foxes *Urocyon cinereoargenteus* at large scales in Illinois, USA

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Evaluation of wildlife-habitat relationships at the landscape level provides insight into how habitat connectivity, fragmentation and land-use changes may affect wildlife populations. Although previous studies have demonstrated that habitat composition and configuration at large scales may affect the presence, survival and movement of carnivore species, no such analyses have been conducted for the gray fox *Urocyon cinereoargenteus*. We used a generalized correlative mapping approach to investigate the relationship of gray fox relative abundance to landscape variables at the county scale in Illinois, USA. Relative abundance of gray foxes was high in 37 of 102 (36%) counties. Four models were competitive based on ΔAIC_c scores, and these models indicated that standard deviation of the perimeter-area ratio of agricultural patches, interspersion and juxtaposition index of grassland patches, coefficent of variation of the proximity index of forest patches and relative patch richness of the landscape affected gray fox relative abundance. The variables occurring in our competing models indicate that the relative abundance of the gray fox is higher in counties containing a high level of fragmentation of preferred habitat types (i.e. forests and grasslands) and lower dispersion of less preferred habitat types (i.e. agriculture). Our results reflect gray fox habitat use at smaller scales, and at the landscape scale, gray fox abundance is influenced by how cover-type patches are configured.

Key words: carnivores, FRAGSTATS, gray foxes, habitat model, landscape, Urocyon cinereoargenteus

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Analysis of habitat at multiple spatial scales is widely recognized as important, as habitat affects the distribution of wildlife geographically, regionally and locally (Donovan et al. 1997, Gehring & Swihart 2003, Ecke et al. 2006). At large scales, more effective evaluation of habitat connectivity, complexity and fragmentation, as well as changes in land use can be made (Donovan et al. 1997, Guisan & Zimmermann 2000, Osborne et al. 2001, Kie et al. 2002), and these factors affect presence, survival (Sovada et al. 2000, Rohm et al. 2007) and movements of wildlife (Knick & Dyer 1997, Dijak & Thompson 2000, Constible et al. 2006, Ecke et al. 2006). Habitat analyses at large scales typically utilize animal information, a geographic information system (GIS) and remotely-sensed satellite imagery (Knick & Dyer 1997, Carroll et al. 1999, Osborne et al. 2001, Woolf et al. 2002). Oftentimes, the goal of such analyses is to predict habitat suitability or potential colonization of previously unused areas (Buckland & Elston 1993, Corsi et al. 1999, Mladenoff et al. 1999, Osborne et al. 2001). Many of these studies use a correlative approach that relates species occurrences to predictor variables available across the entire study area (Osborne et al. 2001:459).

Habitat analyses at large scales have been conducted for many carnivore species in North America (LaRue & Nielsen 2008, McDonald et al. 2008, Zielinski et al. 2010, Scheller et al. 2011). These analyses have employed various approaches in model building. Researchers oftentimes select landscape predictor variables based on information and data acquired from local or smaller-scale studies (Osborne et al. 2001, Woolf et al. 2002). The expectation that predictor variables at one scale would relate to those at another scale makes biological sense but could overlook variables that, while less ecologically intuitive, actually predict species occurrence at larger scales better.

Habitat analyses for gray foxes *Urocyon cinereoargenteus* have occurred primarily at the home-range scale (Haroldson & Fritzell 1984, Sawyer & Fendley 1994, Chamberlain & Leopold 2000, Temple 2007). These studies characterize gray foxes as habitat generalists with some preference for wooded cover. Constible et al. (2006) attempted to relate home-range size to landscape patterns using variables selected on assumed ecological importance for gray foxes, bobcats *Lynx rufus* and coyotes *Canis latrans*, but only found this useful for bobcats. This finding may indicate that habitat patterns at the home-range scale for gray foxes do not predict patterns at a large scale.

Gray foxes are widely distributed throughout North America (Cypher 2003), and although the International Union of Conservation of Nature and Natural Resources lists the gray fox as a species of least concern (Fuller & Cypher 2004), recent trends in Illinois, USA, indicate that the population is declining statewide (Bluett 2007). Several factors may be contributing to this decline, including intraguild predation and competition with coyotes and bobcats, and transmission of disease from other wildlife species (Nicholson & Hill 1984, Fedriani et al. 2000, Gosselink et al. 2003, Chamberlain & Leopold 2005). As Illinois' human population increases (U.S. Census Bureau 2008), land-use changes, such as exurban development (Harden & Woolf 2005, Storm et al. 2007a,b) and forest maturation (Schmidt et al. 2000), may also occur and affect already declining gray fox populations. Therefore, knowledge of habitat factors that can be used to predict the relative abundance of gray foxes in Illinois is important for understanding how landscape changes may affect populations. To address this gap in knowledge, our goal was to conduct an exploratory analysis to assess what landscape patterns influence the relative abundance of gray foxes at the county scale in Illinois, USA.

Material and methods

Study area and general approach

Data regarding gray fox relative abundance was collected throughout the state of Illinois, USA. We evaluated landscape-level habitat characteristics for Illinois at the county scale ($N = 102$). Habitat throughout Illinois varies from highly cultivated agriculture lands throughout much of central Illinois, to rolling hills and wooded areas in the northern and southern areas of the state, to urbanized areas (e.g. Chicago) in the northeast and other isolated portions of the state. Land cover in Illinois is about 80% cropland pastures, 15% forest and 5% consists of urban lands, wetlands, lakes and rivers (Illinois Natural History Survey 2003). Forest cover at the county level varies from 40-60% in the unglaciated Shawnee Hills region in the southern part of the state to $< 5\%$ in east-central Illinois (Illinois Natural History Survey 2003).

Because we did not want to eliminate variables which we assumed were unimportant based on home-range level habitat analyses, we took an inclusive approach in our variable selection process. We used a generalized correlative mapping approach to investigate the relationship of gray fox relative abundance to landscape variables (Saab 1999, Burnham & Anderson 2002, Weyrauch & Grubb 2004, Russell et al. 2007). We used remotely-sensed land-cover information and FRAGSTATS 3.3 (McGarigal et al. 2002) to produce a suite of class and landscape metrics for each Illinois county. After standard variable reduction procedures (see below), we used these metrics to develop and rank *a priori* and *post hoc* models to determine which landscape characteristics may be useful in predicting gray fox relative abundance at the county level. We used SAS Version 8 (SAS Institute, Cary, North Carolina, USA) and STATISTIX (Analytical Software 1996) for all statistical analyses and ARCGIS Version 9.1 (Environmental Systems Research Institute, Inc. 2004) for all GIS analyses.

Relative abundance of gray foxes

The Archery Deer Hunter Survey (ADHS) is conducted annually by the Illinois Department of Natural Resources. Based on the ADHS, sighting indices for Illinois' major wildlife species are calculated using sightings and effort of deer hunters during the archery deer season (Bluett 2007). With an average of 2,323 survey participants per year, we calculated a gray fox sighting index for each Illinois county during 1998-2006, excluding 1999 when data were unavailable, based on the number of hunter sightings and number of field hours per hunter (Ver Steeg & Warner 1997). We classified the index data into two categories as we were more confident in the ability of the data to separate gray foxes as high and low relative abundances rather than as a continuous index (Seber 1992, Slade & Blair 2000, Joseph et al. 2006). Based on patterns in the data, we considered relative abundance of gray foxes in a county to be high at index values > 0.6 and low at index values ≤ 0.6 (Fig. 1). Additionally, this value provided approximately similar sample sizes for logistic regression analysis.

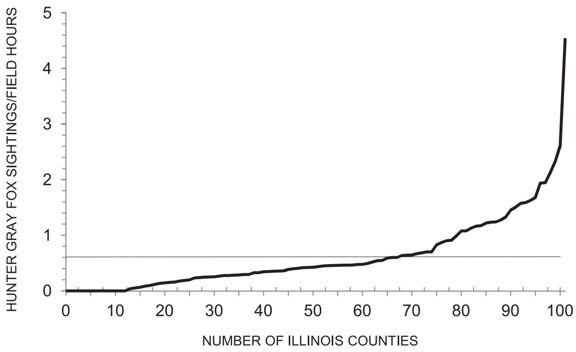

Figure 1. Number of gray fox sightings per field hours for hunters in each Illinois county was used to categorize the relative abundance of gray foxes for each county as high (> 0.6) or low (< 0.6) in Illinois, USA.

Landscape variable selection

We assessed landscape characteristics at the county level using remotely-sensed land-cover data with 30× 30 m ground spatial resolution from the Illinois Critical Trends Assessment Project (Illinois Natural History Survey 2003). Using the program ERDAS (Leica Geosystems GIS and mapping 2003), we reclassified the original 29 land-cover types in this data set into six categories which are the most representative of Illinois' landscape: agriculture, forest, grassland, urban, water and wetland. We then used FRAGSTATS 3.3 (McGarigal et al. 2002) to quantify class- and landscape-level metrics for each county. While class-level metrics were calculated based on specific cover types, landscape-level metrics were calculated based on land cover within each county (McGarigal et al. 2002).

We used standard variable reduction techniques to reduce the number of variables for further analysis (Nelson 2001, Rohm et al. 2007, Wilson & Nielsen 2007) by 1) eliminating variables represented in < 40% of the counties, 2) transforming non-normally distributed variables to improve normality and removing variables that were unable to be transformed, 3) removing variables that did not differ among counties where gray fox relative abundance was high vs low, 4) grouping all correlated variables in a cluster analysis and 5) assessing simple pairwise correlations between variables included in each model to ensure avoidance of issues with collinearity.

After eliminating poorly represented variables, we tested variables for approximation of the normal distribution and transformed non-normally distributed variables to improve normality using square root or log transformations (Shapiro-Wilk > 0.85). Because only numerical variables could be used as input in our analyses, conversion to multi-level factor variables was not an option. Therefore, we removed those variables that deviated too strongly from normality. Then, we determined if variables differed ($\alpha = 0.05$ throughout) between counties where gray foxes were present vs absent using ANOVA (PROC GLM, SAS). Finally, we used cluster analysis (PROC VARCLUS, SAS; Nelson 2001, Iniquez et al. 2005, Rohm et al. 2007) with an eigenvalue cut-off of 0.7, which creates groups of variables that are as correlated as possible among themselves and as uncorrelated as possible with variables in other clusters (Nelson 2001). We then selected the most representative variable from each cluster and added survey effort to account for any effort bias, and used these 15 remaining variables for further analysis (Table 1). To further assess potential variable collinearity, we assessed simple pairwise correlations between variables included in each model using the r-correlation coefficient (see below; Table 2) . Of all possible pairwise comparisons, only two were >|0.40|. Hence, variables were generally not correlated for analyses following cluster analysis. While we admit that the number of variables may be higher than most studies include, we selected this approach as an all-inclusive exploration that may provide new ecological insight at a larger scale.

Landscape variables affecting relative abundance

To assess the relationship between 15 landscape variables and relative abundance of gray foxes at the county scale, we developed *a priori* binary logistic regression models (two response categories, high vs low relative abundance) based on different levels of spatial heterogeneity and different categories of landscape metrics, and then fitted a number of *post*

Table 1. Description of variables (McGarigal et al. 2002) used for modeling landscape characteristics affecting relative abundance of gray foxes in Illinois, USA, 1998-2006.

Acronym	Name	Definition (units)
AgGyMed	Median radius of gyration of agricultural patches	Median value of patch extent of agricultural patches, accounting for patch size and compaction (m)
AgParaRange	Range of the perimeter-area ratio of agricultural patches	Range of the lowest and highest perimeter-area ratio of agricultural patches
AgParaSD	Standard deviation of the perimeter-area ratio of agricultural patches	Variation around the mean of the perimeter-area ratio of agricultural patches
Effort	N/A	Sum of all hours of all sampling units (hours)
ForDivis	Landscape division index of forest patches	Probability that two randomly chosen pixels are not situated in the same forest patch (proportion in m^2)
ForEdgeDens	Edge density of forest patches	Density of the edge of forest patches (m/ha)
FornLSI	Normalized landscape shape index of forest patches	Forest patch aggregation
ForProxCV	Coefficient of variation for the proximity index of forest patches	Percent based on the standard deviation and mean proximity index, taking into account forest patches < 500 m from the focal forest patch (%)
GrassIJI	Interspersion and juxtaposition index of grassland patches	Observed interspersion of grassland patches over the maximum possible interspersion (%)
GrassnLSI	Normalized landscape shape index of grassland patches	Grassland patch aggregation
LandRPR	Relative patch richness of the landscape	Percentage of cover types present from the maximum number possible (%)
LandTA	Total area of landscape	Total landscape area (ha)
UgyCV	Coefficient of variation for the proximity index of urban patches	Percent based on the standard deviation and mean proximity index, taking into account urban patches < 500 m from the focal urban patch (%)
WDCAD	Disjunct core area density of wetland patches	Number of disjunct wetland patches (#/100 ha)

Table 2. Model selection based on binary logistic regression used to determine landscape variables affecting relative abundance of gray foxes in Illinois, USA, 1998-2006.Variables are defined in Table 1. K = the number of parameters estimated including intercept. Models were ranked using Akaike's Information Criterion corrected for small sample sizes (AIC_c). w_i = Akaike weights, which can be used to interpret the probability that models would be similarly ranked on repeated sampling of data.

Model	K	AIC_c	ΔAIC_c	w_i
AgParaSD + GrassIJI + LandRPR	4	108.594	0	0.225
AgParaSD + ForProxCV + GrassIJI + LandRPR	5	108.718	0.124	0.212
AgParaSD + GrassIJI	3	109.363	0.769	0.153
AgParaSD + ForProxCV + GrassIJI	4	110.208	1.614	0.100
AgParaSD + Effort + ForProxCV + GrassIJI + LandRPR	6	110.766	2.172	0.0760
AgParaSD + GrassIJI + UGyCV + WDCAD	5	111.881	3.287	0.0435
AgParaSD + ForProxCV + GrassIJI + GrassnLSI	5	112.240	3.646	0.0364
AgParaSD + ForProxCV + GrassIJI + UGYCV + WDCAD	6	112.309	3.715	0.0351
AgParaSD + Effort + ForEdgeDens + GrassIJI	5	112.561	3.967	0.0310
AgParaSD + GrassnLSI + LandRPR	4	112.942	4.348	0.0256
AgParaSD + ForProxCV + GrassnLSI + LandRPR	5	112.989	4.395	0.0250
AgParaSD + Effort + FornLSI + GrassIJI	5	113.625	5.031	0.0182
AgParaSD + Effort +ForProxCV + GrassIJI + LandTA + UGyCV	7	114.459	5.865	0.0120
AgParaSD + ForProxCV + LandRPR	4	117.164	8.570	0.00310
AgParaSD + LandRPR + UGyCV + WDCAD	5	117.847	9.253	0.00220
AgParaSD + ForP roxCV + GrassnLSI + UGyCV + WDCAD	6	119.789	11.195	0.000835
LandRPR + UGyCV + WDCAD	4	121.151	12.557	0.000423
ForProxCV + GrassIJI + LandRPR	4	124.190	15.596	9.24E-05
AgParaSD + UGyCV	3	127.961	19.367	1.40E-05

hoc exploratory models (see Table 2; Li & Reynolds 1994, Burnham & Anderson 2002). We tested each model for lack of fit using the Hosmer-Lemeshow statistic (Hosmer & Lemeshow 1989). We then calculated AIC_c values and considered those models with $\Delta AIC_c < 2$ from the top model as competing models.

Habitat model validation procedures often employ using a portion of the data (i.e. 75% of observations) to build the model and a smaller portion (i.e. the remaining 25% of observations) to test the model (Verbyla & Litvaitis 1989, Pereira & Itami 1991). Because of sample size concerns (i.e. only 102 observations), we used data from all counties to build habitat models, leaving none behind for model testing. However, we were able to test the validity of our classification of counties into high vs low relative abundance of gray foxes using an independent data set. Based on a request in the Illinois Digest of Hunting and Trapping Regulations, records of gray fox sightings throughout the state were collected during October 2005 - February 2008. We sent each respondent a map and asked them to pinpoint live and road killed gray fox locations, and mail the maps back to us. With these data, we calculated the ratio of the number of gray fox sightings:number of counties for high abundance and low abundance counties. We reasoned that this ratio should be considerably higher for counties with high relative abundance of gray foxes, and if it was, that our classification of counties was appropriate.

Results

Relative abundance of gray foxes was high in 37 of 102 (36%) Illinois counties (Fig. 2). Counties were generally accurately classified as high vs low abundance of gray foxes. The ratio of gray fox sightings in high-abundance counties was 1.51 (56 sightings:37 counties) and 0.77 (50 sightings:65 counties) for low-abundance counties.

No models showed lack-of-fit based on the Hosmer-Lemeshow statistic. Of the 19 candidate models, four were competitive based on ΔAIC_c scores (see Table 2). Competing models indicated that standard deviation of the perimeter-area ratio of agricultural patches, interspersion and juxtaposition index of grassland patches, coefficent of variation of the proximity index of forest patches and relative patch richness of the landscape affected gray fox relative abundance. Counties with a high relative abundance of gray foxes had higher interspersion

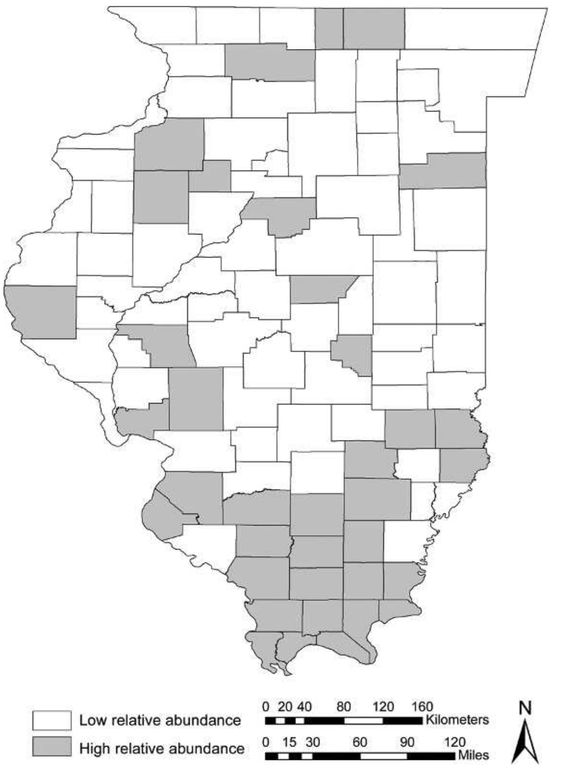

Figure 2. Relative abundance of gray foxes at the county level in Illinois, USA, 1998-2006.

and juxtaposition indices of grassland patches and coefficient of variation of the proximity index of forest patches, whereas counties with a low relative abundance of gray foxes had higher standard deviation of the perimeter-area ratio of agricultural patches and relative patch richness of the landscape (Table 3).

Discussion

Our study represents an exploratory analysis that is the first to investigate how large-scale landscape

Table 3. Comparison of variables found in competing models of relative abundance of gray foxes in Illinois, USA, 1998-2006. Variables are defined in Table 1.

	High abundance		Low abundance	
Varibles	Mean	SE	Mean	SE
AgParaSD	282.199	2.761	296.300	2.841
ForProxCV	381.506	18.836	333.444	10.944
GrassIJI	63.583	2.053	57.316	1.257
LandRPR	102.252	0.950	106.410	1.010

patterns affect relative abundance of gray foxes. In general, the four variables important in competing models had similarities with habitat characteristics preferred by gray foxes at smaller spatial scales (Haroldson & Fritzell 1984, Sawyer & Fendley 1994, Chamberlain & Leopold 2000, Cypher 2003). The variables also provided insight into habitat configurations important to gray fox relative abundance in Illinois.

Standard deviation of the area-perimeter ratio of agricultural patches was higher in counties where the relative abundance of gray foxes was lower, indicating a gray fox preference for habitats with less dispersion of agricultural patch complexity and size (McGarigal et al. 2002). Illinois' agricultural areas are either large and monotypic or complex, fragmenting other habitat types, such as forests and grasslands. Lower abundance of gray foxes in counties with large amounts of these types of agricultural areas is an indication of their avoidance of this habitat configuration as has been similarly indicated by home-range level studies (Haroldson & Fritzell 1984, Sawyer & Fendley 1994, Chamberlain & Leopold 2000, Temple 2007).

The interspersion and juxtaposition index of grassland patches was higher in those counties with high relative abundance of gray foxes. Gray foxes are often described as habitat generalists but with some preference for wooded areas interspersed with grassland and dense understory vegetation (Sawyer & Fendley 1994, Fuller & Cypher 2004). Neale & Sacks (2001) reported a negative association between coyotes and grassland habitat, so the relationship between gray fox abundance and the interspersion and juxtaposition index of grassland patches may also reflect gray foxes' selection of habitats less utilized by coyotes (Crooks & Soule 1999, Fedriani et al. 2000, Chamberlain & Leopold 2005). Therefore, this habitat characteristic is important at both a smaller and larger scale.

Relative patch richness of the landscape is a percentage that takes into account the maximum number of patch types that could be considered in each county, and how many were actually present (McGarigal et al. 2002). Those counties with higher relative patch richness of the landscape had a low relative abundance of gray foxes. Counties with higher relative patch richness may be more fragmented or be more likely to contain cover types not as suitable for gray foxes, such as water, urban areas and agriculture. Coyotes and red foxes *Vulpes vulpes* are often located in more agriculturally-dominated and urban landscapes, influencing gray fox avoidance of this cover type (Gosselink et al. 2003).

The coefficient of variation of the proximity index of forest patches was higher where gray fox relative abundance was high. This indicates that more variability of forest patch size and proximity existed in counties with a high relative abundance of gray foxes. This likely reflects that many of Illinois' counties lack forest habitat, but where forest does occur it is still highly fragmented. Smaller-scale studies have indicated a preference for forested habitat by gray foxes (Haroldson & Fritzell 1984, Sawyer & Fendley 1994). While it is clear that gray foxes prefer forest habitat, our results may also indicate a preference for fragmented forest, which could provide more open corridors for travel and foraging.

While we can interpret our findings as reflections of smaller-scale gray fox ecology, larger-scale analyses can provide information to describe patch-corridor matrices not detectable at other scales (McGarigal et al. 2002). The variables occurring in our competing models indicate gray fox relative abundance to be higher in counties containing a high level of fragmentation of preferred habitat types (i.e. forests and grasslands) and lower dispersion of less preferred habitat types (i.e. agriculture). A threshold likely exists for each of these variables beyond which they no longer serve as useful predictors of gray fox occurrence because the habitat has changed to either a more or less preferred state. Although the threshold levels are unknown, they will likely be met with increases or decreases in fragmentation of these habitat types as our results suggest that gray fox abundance is influenced by how cover type patches are configured in the landscape.

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