

A COMPARISON OF DISTANCE-BASED AND CLASSIFICATION-BASED ANALYSES OF HABITAT USE

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Abstract. Quantifying habitat use is vital to understanding animal ecology. Herein, we contrast classification-based (i.e., animal locations are placed into habitat categories for subsequent analyses) and distance-based (i.e., distance between animal locations and habitat features are used in subsequent analyses) approaches for analyzing habitat use data. Compositional analysis (CA) and a distance-based analysis (DA) were used to quantify habitat selection of Northern Bobwhite (*Colinus virginianus*). We qualitatively compared the outcome of these different procedures to illustrate advantages of the DA approach. The DA approach identified edges as an important habitat feature, and location error did not alter conclusions from DA. In contrast, CA did not detect the importance of edge, and presence of location errors altered conclusions. Moreover, modeling the distribution of location error did not effectively reduce sensitivity to error within CA. Distance-based approaches to habitat analyses are not restricted to linear or point habitat features, require no explicit error handling, and permit extraction of more information from the data than classification-based analyses alone.

Key words: *compositional analysis; Euclidean distance; habitat analysis; habitat selection; habitat use; multivariate analysis; Northern Bobwhite; radio telemetry; telemetry bias; triangulation error.*

INTRODUCTION

Understanding habitat selection is of fundamental importance to understanding the natural history of animals (Manly et al. 1993). Thus, it is no surprise that much research has been devoted to developing habitat analysis metrics (e.g., Neu et al. 1974, Johnson 1980, Marcum and Lohftsgaarden 1980, Aebischer et al. 1993, McCracken et al. 1998).

Describing the relationship between animals and their habitat can lead to confusing terminology. Herein, we refer to “habitat selection” as a difference between observed habitat utilization and expected habitat utilization as determined from a null model (Johnson 1980). We define the habitat that was used most relative to expectation as “most preferred” and the habitat that was used least relative to expectation as “least preferred.” Moreover, we define any habitat that is used more than expected as a “preferred habitat” and any habitat that is used less than expected as an “avoided habitat” (Neu et al. 1974). Many habitat selection metrics rely on classifying animal locations by habitat type

and determining proportional use of habitats (Neu et al. 1974, Johnson 1980, Aebischer et al. 1993), and we define such techniques as “classification approaches.” In contrast, we define methods based on measuring the Euclidean distance from animal locations to habitat features as “distance-based approaches.”

Aebischer et al. (1993) argued that a habitat selection metric should: use individual animals as sampling units, be unaffected by the unit-sum constraint, permit tests for differential habitat use among meaningful groups (e.g., sexes or age classes), and allow habitat assessment at multiple spatial scales. They went on to introduce compositional analysis (CA) as a tool for analyzing resource selection data. Since its introduction, CA has become one of the most widely used habitat analysis procedures (Pendleton et al. 1998, Conner et al. 1999, Miller et al. 1999, Gabor and Hellgren 2000).

Euclidean distances between animal locations and habitat features have been used in studies of animal habitats but for only a restricted set of applications that involved linear (e.g., creeks and roads) or point (e.g., trees and burrows) habitat features (Clark et al. 1993, Boal and Mannan 1998, 1999, Jorgensen et al. 1998, McKee et al. 1998, Ormsbee and McComb 1998). Use

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of Euclidean distances for areal features (e.g., habitat types) has received much less attention (but see Miller et al. 2000). Our objectives were to discuss unique features of a distance-based analysis (DA) to habitat analysis (Conner and Plowman 2001) and then to illustrate advantages of DA by qualitatively comparing the results obtained from DA to CA (Aebischer et al. 1993)

METHODS

Radiotelemetry

Data collected on 62 Northern Bobwhites (*Colinus virginianus*), hereafter "quail," were used as the basis for our analysis. These data were used because quail were located via homing (i.e., walking in the direction of the strongest signal until a positive determination of the quail location was obtained); thus, location errors did not occur. Tracking took place during 1997 and 1998 in Mississippi, USA. Locations were obtained more or less uniformly throughout the annual cycle, and locations were considered to be serially independent. Only those animals with ≥ 30 locations were used in analysis. The study area is described in Henner (2000) and the protocol for capturing, tagging, and processing quail is in Taylor (1996).

Habitat delineation

Habitats on the 7100-ha study area were delineated based on management regimes and/or similarities in vegetation. Pasture/hay fields, Conservation Reserve Program fields, and grassy field borders were classified as GRASS because of structural similarity, species composition, and lack of disturbance (i.e., no burning, disking, or grazing). Fields that received a prescribed burn during the previous fall or winter were classified as BURN. Woodlots, fencerows and ditches, and road rights-of-way containing woody vegetation were grouped as WOODY. Soybean (*Glycine max*) fields, corn (*Zea mays*) fields, and food plots were grouped as ROWCROP. Due to rarity of remaining habitats such as roads, buildings, and water, these habitats were grouped into a single class (ODD). All habitats were digitized into ARC/INFO (ESRI 1997) from scanned and georeferenced 1:640 monochromatic aerial photos to facilitate analysis. Mean patch sizes for WOODY, GRASS, ROWCROP, ODD, and BURN were 4.2, 10.2, 14.7, 17.0, and 4.2 ha, respectively. Edge density was ~ 11 km/km².

Assigning habitat attributes to telemetry data

Quail locations were georeferenced using differentially corrected global positioning (Trimble Navigation 1996), and these locations were then intersected with the habitat map using ARC/INFO (ESRI 1997). To demonstrate a classification approach to habitat analysis, the habitat at each location was recorded and the percentage of points falling within each habitat was

reported for each quail. For the distance approach to habitat analysis, the NEAR command in ARC/INFO (ESRI 1997) was used to determine distances between each quail location and each habitat type. The distance to the habitat type containing the quail location was set to zero. The average distance between quail locations and each habitat type was calculated for each quail.

The program HOME RANGER (Hovey 1997) was used to derive 95% adaptive kernel home ranges (Worton 1989), hereafter "home ranges," for all quail. ARC/INFO (ESRI 1997) was then used to determine the proportion of each habitat within each animal's home range.

Error simulation

Because quail locations did not contain location error, error was simulated for each animal location. A FORTRAN program was used to incorporate random error or "noise" into each real location. Noisy locations were generated from a uniform distribution in such a way that noisy locations occurred within 50 m of real locations. We arbitrarily chose a 50-m radius, but suggest that this distance is actually lower than one would expect from triangulation (examples illustrating error associated with triangulation can be found in Lee et al. [1985], Samuel and Kenow [1992], and Kenow et al. [2001]). Thus, influence of error in subsequent analysis should be small, because relatively little noise was incorporated into the analysis. Habitat attributes were derived for noisy locations as with actual locations.

When classifying animal locations into habitats, steps should be taken to account for error associated with location estimates (Samuel and Kenow 1992). To model the error distribution of the noisy data, error circles (i.e., circles with a 50-m radius) were generated around each noisy location. Proportions of each habitat type within error circles were determined using ARC/INFO (ESRI 1997), and proportions were summed over all locations to estimate habitat use for each animal. Because noise was simulated from a uniform circular distribution with a 50-m radius, each error circle was guaranteed to contain the real location.

Analysis of habitat selection

For all examples, habitats within home ranges were considered available habitat and habitat use was derived from animal locations. Thus, Johnson's (1980) third-order habitat selection was evaluated.

Compositional analysis (CA; Aebischer et al. 1993) was used to represent a classification approach for comparison because it is arguably the most popular classification approach for assessing habitat selection. We calculated log-ratio differences and used them as dependent variables in a multivariate analysis of variance (MANOVA) as an omnibus test of habitat selection. A

TABLE 1. Habitat rankings (most preferred [1] to least preferred [5]) resulting from compositional analysis (CA) and distance analysis (DA) approaches to habitat analysis.

Method	Data set†	Habitat ranking‡				
		1	2	3	4	5
CA	Real	WOODY ^a	BURN ^b	GRASS ^b	ROWCROP ^c	ODD ^c
CA	Noisy	WOODY ^a	GRASS ^a	BURN ^{a,b}	ROWCROP ^{b,c}	ODD ^c
CA	Circles	WOODY ^a	BURN ^{a,b}	ODD ^{a,b}	GRASS ^b	ROWCROP ^b
DA	Real	WOODY ^a	BURN ^{a,b}	GRASS ^{a,b}	ODD ^b	ROWCROP ^b
DA	Noisy	WOODY ^a	BURN ^{a,b}	GRASS ^{a,b}	ODD ^{b,c}	ROWCROP ^c

Note: Data are from a study of Northern Bobwhite (*Colinus virginianus*) in Mississippi, USA (1997–1998).

† Real = based on error-free locations, Noisy = random noise added to real data, Circles = noisy data summarized using error circles in attempt to reduce bias.

‡ Within each row, habitats with the same superscript letter do not differ significantly in relative preference (*t* test, $P > 0.05$).

ranking matrix of pair-wise habitat comparisons was used to rank relative habitat preferences (Aebischer et al. 1993). Because assumptions associated with parametric tests may not have been met, we based all hypothesis tests on 999 randomizations of the data (Aebischer et al. 1993). Three CAs were performed: one using real data, one using noisy data and no error modeling correction (i.e., noisy point data were used to estimate habitat use instead of using proportions from error circles), and one with habitat use being derived from summaries of error circles.

A technique that compares the average distances between locations and habitat types to expected distances was used for our distance-based analysis (DA). Two DAs were conducted: one with real data and one with noisy data. This method was introduced in Conner and Plowman (2001) and is described below.

One thousand locations were simulated from a uniform random distribution within a rectangle bounding the home range of each animal, and only those locations falling within the home range were used in subsequent analyses. For each animal, distance from each random point to the nearest representative of each habitat type was determined, and the average distance from random points to each habitat type was calculated. This created a vector of mean distances (\mathbf{r}_i) for each animal (i). This vector represented expected values under a null hypothesis of no selection. These steps were then repeated using animal locations to establish (\mathbf{u}_i), the average distance from each animal's locations to each habitat type. A vector of ratios (\mathbf{d}_i) was created for each animal by dividing each element in \mathbf{u}_i by the corresponding element in \mathbf{r}_i . The expected value of each element in the \mathbf{d}_i is 1.0 under the null hypothesis of no selection. The mean of the \mathbf{d}_i was calculated as $\boldsymbol{\rho}$ and a MANOVA was used to determine if $\boldsymbol{\rho}$ differed from a vector of 1's. Habitat selection was considered to occur if $\boldsymbol{\rho}$ differed from a vector of 1's. To determine which habitat types were used disproportionately, each element within $\boldsymbol{\rho}$ was tested to determine if it differed from 1 using a paired *t* test. If an element in $\boldsymbol{\rho}$ is < 1 (i.e., \mathbf{u}

$< \mathbf{r}$), then the corresponding habitat was preferred. Alternatively, if an element in $\boldsymbol{\rho}$ is > 1 (i.e., $\mathbf{u} > \mathbf{r}$), then the corresponding habitat was avoided.

The elements in $\boldsymbol{\rho}$ provide a ranking of habitat use relative to habitat availability. The habitat with lowest value was used most relative to availability (i.e., animal locations are closest to this habitat relative to random points), whereas the element with the largest value was used least relative to availability. This ranking, however, says nothing about whether a particular habitat is selected significantly more than other habitats. Therefore, pair-wise *t* tests were used to compare relative habitat selection. These pair-wise tests provided a ranking matrix similar to the CA approach of Aebischer et al. (1993). As with the CA approach, we used 999 randomizations of the data for all hypothesis tests to avoid concerns associated with parametric assumptions.

Compositional analysis and DA were compared based on the conclusions that would have been drawn from the analyses. Specifically, the results of the omnibus test for selection and the relative preference of habitat types were compared. Because all hypothesis tests were based on 999 randomizations of the data, the minimum *P* value attainable was 0.001. We rejected the null hypothesis if $P \leq 0.05$. All statistical analyses were performed using SAS (SAS 2001).

RESULTS

Real data within compositional analysis (CA) indicated that habitat selection occurred (randomization test, $P = 0.001$). Pair-wise comparisons indicated that WOODY was preferred ($P < 0.05$) over all other habitats. BURN was preferred over ROWCROP ($P = 0.004$) and ODD ($P = 0.001$), but similar in preference to GRASS ($P = 0.282$). GRASS was preferred over ROWCROP ($P = 0.01$) and ODD ($P = 0.002$), and ROWCROP was preferred over ODD ($P = 0.004$; Table 1).

Noisy data within CA also indicated that habitat selection occurred ($P = 0.001$). Pair-wise comparisons

TABLE 2. The ratio (ρ) of the mean distance between quail locations and habitat types to the mean distance between random locations and habitat types and associated P values of univariate tests of habitat selection.

Analysis†	Habitat	ρ	$P‡$
Real	WOODY	0.81	0.001
	GRASS	0.88	0.001
	ROWCROP	0.94	0.089
	ODD	0.91	0.001
	BURN	0.86	0.001
Noisy	WOODY	0.79	0.001
	GRASS	0.87	0.001
	ROWCROP	0.94	0.074
	ODD	0.91	0.001
	BURN	0.85	0.001

Notes: Values for $\rho < 1.0$ indicate that animal locations were closer to the habitat than expected. Data are from a study of Northern Bobwhite (*Colinus virginianus*) in Mississippi, USA (1997–1998).

† Real = based on error-free locations; Noisy = random noise added to real data.

‡ The probability that $\rho = 1.0$ was derived using 999 randomizations of the data.

indicated that WOODY was preferred over ROWCROP ($P = 0.001$) and ODD ($P = 0.004$) but similar in preference to GRASS ($P = 0.260$) and BURN ($P = 0.293$). GRASS was preferred over ROWCROP ($P = 0.002$) and ODD ($P = 0.008$) but similar in preference to BURN ($P = 0.750$). BURN was preferred over ODD ($P = 0.038$) but similar in preference to ROWCROP ($P = 0.108$). Preference for ROWCROP and ODD did not differ ($P = 0.436$; Table 1).

When habitat selection was assessed using error circles and CA, habitat selection occurred ($P = 0.006$). Pair-wise comparisons indicated WOODY was preferred over GRASS ($P = 0.004$), ROWCROP ($P = 0.001$), and ODD ($P = 0.041$) but similar in preference to BURN ($P = 0.465$). BURN was preferred over ROWCROP ($P = 0.035$) and all other habitat types were similar ($P > 0.05$) in preference (Table 1).

Real data within the distance-based approach (DA) indicated that habitat selection occurred ($P = 0.001$). All elements in ρ were < 1 ($P = 0.001$) with exception of ROWCROP ($P = 0.089$, Table 2). Pair-wise comparisons indicated that WOODY was preferred over ODD ($P = 0.001$) and ROWCROP ($P = 0.003$) but similar in preference to grass ($P = 0.101$) and BURN ($P = 0.275$). BURN was preferred ($P = 0.44$) over ROWCROP. All other habitat types were similar ($P > 0.05$) in preference (Table 1).

Noisy data within DA also indicated that habitat selection occurred ($P = 0.001$). Again, all elements in ρ were < 1 ($P = 0.001$) with the exception of ROWCROP ($P = 0.074$, Table 2). Pair-wise comparisons indicated that WOODY was preferred over ODD ($P = 0.001$) and ROWCROP ($P = 0.001$) but similar in preference to grass ($P = 0.075$) and BURN ($P = 0.263$). All other

habitat types were similar ($P > 0.05$) in preference (Table 1).

DISCUSSION

Features unique to a distance-based approach

Distance-based analyses must use random points to derive expected distances. Thus, derivation of expected distances involves sampling error. In contrast, expected habitat use within a classification approach is based on availability of habitats. Using modern GIS packages, areal availability of habitats should be less prone to sampling error. Thus, distance-based approaches to analysis of habitat use may appear to be a retrograde step to classification-based approaches. However, the calculation of expected distances, even when considering associated sampling variability, provides several distinct advantages over classification-based approaches.

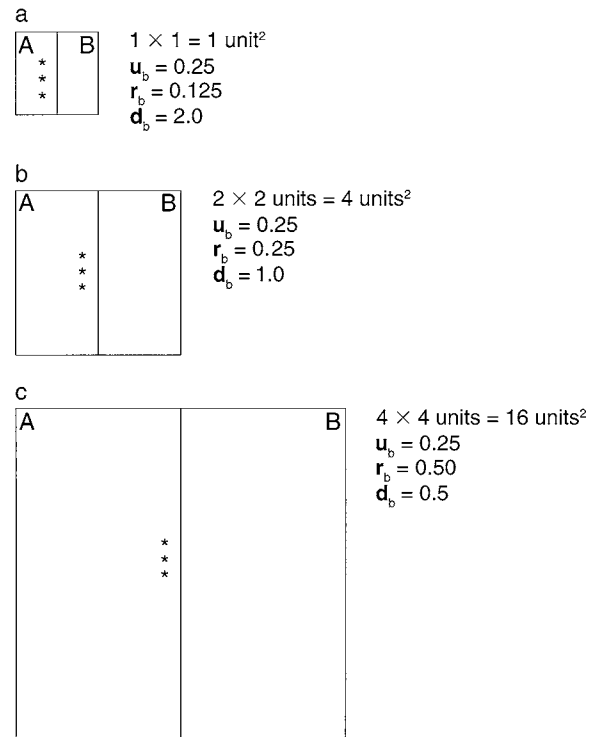


FIG. 1. Graphical depiction of the importance of patch size on the outcome of a distance approach to habitat analysis. In each example, the distance from animal locations (*) to habitat type B remains unchanged, but as the landscape becomes larger an increased affinity for habitat type B becomes apparent because of changes in expected distances (r_b). The value of d_b is 1.0 under the null model that expected distances = observed distances. Values of $d_b < 1$ indicate locations are closer to B than expected, whereas values > 1 indicate locations were farther from B than expected. Classification-based approaches to habitat analysis would conclude that A is the only habitat of importance because B is always used less than available.

One advantage of DA over classification approaches is that the \mathbf{d}_i (the vector of distance ratios) are influenced by patch size and shape, features that influence habitat preference (Vickery et al. 1994, Helzer and Jelinski 1999). For example, consider a square landscape of 1 square unit comprised of two habitat patches, A and B. Assume half of the area is A and the remainder is B. Further, assume an animal is located only in habitat A at a distance of 0.25 units from B ($\mathbf{u}_b = 0.25$). If random points were generated on this landscape we would find $\mathbf{r}_b = 0.125$; thus $\mathbf{d}_b = 2.0$, indicating points are farther from B than expected (Fig. 1a). Now assume the landscape is 4 square units (i.e., 2×2 units). Again, all locations fall in A at a distance of 0.25 units from B ($\mathbf{u}_b = 0.25$). Here, however, it can be shown that $\mathbf{r}_b = 0.25$; thus $\mathbf{d}_b = 1.0$, indicating points are located at the expected distance from B (Fig. 1b). Finally, assume the landscape is 16 square units (i.e., 4×4 units). As before, all locations fall in A at a distance of 0.25 units from B ($\mathbf{u}_b = 0.25$). Now, it can be shown that $\mathbf{r}_b = 0.50$; thus $\mathbf{d}_b = 0.5$, indicating that points are located closer to B than expected (Fig. 1c). Using DA, both habitats would be deemed important to the species in question. In all cases, a classification approach reveals 100% use of A, 0% use of B, and a preference for A. If conservation issues were addressed from the classification analysis, conversion of B into A appears to be a reasonable management option. The last scenario indicates that this is clearly not the case.

Johnson (1980) suggested that habitat selection is a hierarchical process. Thus, selection at any one level of this hierarchy is based on prior selection at a more general level. It is reasonable to assume, then, that animals that exist on a given study area use the study area based, at least partially, on surrounding habitats. Similarly, it is reasonable to assume that an animal establishes a home range based, in part, on habitats surrounding the home-range boundary. Because a distance-based approach uses distances to the nearest habitat feature of interest regardless of whether the feature is within the home-range or study-area boundary, surrounding habitats have an opportunity to influence results of the analysis.

Although inaccurate telemetry locations will reduce statistical power associated with any test of habitat selection (White and Garrott 1986), there is no need to model the error distribution (Samuel and Kenow 1992) when using a distance-based metric (Conner and Plowman 2001). Consider a data set of estimated animal locations and their error distributions. If we generate a sample of points for each error distribution (Samuel and Kenow 1992) and use these points in distance calculations, then the mean distance to each habitat will approach the mean distance from the point estimates to each habitat.

Insights from comparison to compositional analysis

The statistical analyses used in the DA and CA approaches were similar. Both procedures relied on

MANOVA and randomization as an omnibus test of habitat selection, and both techniques used a ranking matrix, based on pair-wise habitat comparisons, to rank relative habitat preferences. The techniques differed only in terms of dependent variables (i.e., distances between habitats or log-ratio differences) used in the analysis. Because the analytical procedures were similar, differences in results between DA and CA can be most attributed to inherent differences in classification and distance-based approaches.

With all data sets, both DA and CA approaches indicated that habitat selection occurred. However, habitat rankings differed between DA and CA, and these differences were especially pronounced with noisy data (Table 1). Moreover, rankings differed among data sets within CA. WOODY was the only habitat that retained the same relative ranking among data sets within CA. In contrast, rankings were consistent with both real and noisy data using the DA approach. The difference in ranking of habitats within CA was likely due to misclassification of quail locations resulting from simulated telemetry error (Samuel and Kenow 1992).

Much information about why an animal was located at a particular location is lost after a point is assigned to a habitat type. The DA approach indicated that quail locations were closer to all habitats than expected (i.e., all $\mathbf{d}_i < 1.0$), but not significantly so for ROWCROP. This could occur only if quail locations were found closer to edges than expected. Therefore, we conclude that quail prefer edges. Although this "discovery" represents no new knowledge regarding quail ecology (Stoddard 1931, Rosene 1984), we emphasize that classification approaches cannot detect preferences for features that lack area (e.g., line or points) without taking explicit steps to address these features. For example, one method to evaluate preference of edge within a classification approach is to establish buffers around edges to detect selection of linear or point habitat features (for example, see Aebischer and Robertson 1992). Buffering an edge to convert a linear feature to an areal feature is conceptually acceptable, but the choice of buffer width must be determined based on the ecology of the species in question and the inherent accuracy of the telemetry system being used. Using the DA approach requires no such a priori information.

Perhaps the greatest concern associated with any analysis of habitat selection is incorrect identification of important habitat features. In our example, the classification-based analysis revealed preferences for certain habitat types, but did not detect what appeared to be an important habitat element (i.e., edge). If a management plan were implemented based only on the results of the classification-based analysis, this plan could justifiably promote homogeneous blocks of "preferred" habitat while excluding important, yet undetected, habitat features.

Although we only compared the DA technique of Conner and Plowman (2001) to CA, we emphasize that

benefits of distance-based approaches carry over into other analytical procedures (e.g., logistic and linear regression, discriminate function analysis). Moreover, use of Euclidean distances to analyze habitat data permits analysis of linear, point, and areal habitat features within the same analytical framework. In contrast, classification-based approaches require explicit measures to incorporate non-areal components into the analysis.

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