

AN EXPLORATORY USE OF CORRESPONDENCE ANALYSIS TO STUDY RELATIONSHIPS BETWEEN AVIAN FORAGING BEHAVIOR AND HABITAT

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Abstract. Correspondence analysis was used to investigate foraging behaviors of an insectivorous bird community in a bottomland hardwood in Louisiana. The graphical summaries of correspondence analysis depicted the relationships among the species and the habitat variables in an easily interpretable manner. The correspondence analysis ordinated the birds of this community along a foraging-maneuver gradient from hang to perch-glean to flush-chase to sally-glean to aerial-hawk. A foraging-height gradient as well as bird-species relationships with habitat substrates were also identified. The correspondence analysis led to log-linear and logistic regression models that further aided in the exploration of data from this bird community.

Key Words: Bottomland hardwoods; community structure; exploratory analysis; reciprocal averaging; resource partitioning.

Many forest-inhabiting birds are extremely sensitive to habitat change. To understand which habitat variables are most important to a species' distribution, it is necessary to understand how each species uses its habitat and which components influence abundance and survival. In most studies of bird-habitat relationships, many variables are measured, necessitating multivariate approaches to the data analysis (see, e.g., Robinson and Holmes 1982, Airola and Barrett 1985, Lebreton and Yoccoz 1987).

In testing and exploring multivariate hypotheses many researchers found factor analysis, principal component analysis, cluster analysis, or discriminant function analysis to be useful (see James 1971, Morrison 1981, Landres and MacMahon 1983, Holmes and Recher 1986b). Variants of correspondence analysis have also been used including reciprocal averaging (Landres and MacMahon 1983) and detrended correspondence analysis (Sabo and Holmes 1983).

Multivariate techniques often require the distributional assumption of multivariate normality. Further, large sample sizes are often needed to provide sufficient power to detect real relationships (Morrison 1984b, 1988). In many cases, the relationships among the variables are complex and may be nonlinear, resulting in incorrect and inappropriate model specifications (see Noon 1986). Sometimes an analysis consists of so many tests that some of them will appear significant by chance. Thus, we may declare as important factors that are not, or we may overlook important relationships that the methods may be insensitive to.

Tukey (1980) and others (e.g., Hoaglin et al. 1983, James and McCulloch 1985, Cleveland and McGill 1987) have stressed the need for exploratory probing of data sets to aid in the interpretation of results and in generating hypotheses. In

this paper we demonstrate how exploratory correspondence analysis can clarify relationships among bird species and their foraging attributes and habitat substrates. In addition we show how log-linear and logistic regression models can be used to supplement the correspondence analysis results.

CORRESPONDENCE ANALYSIS

Variables measured on bird-habitat surveys are often categorical, such as the species of bird or type of substrate, or are easily converted to interpretable categorical values, such as to foraging-height classes, with little loss of information. Techniques that have become popular for exploring the cross-classification of categorical variables or contingency tables are correspondence analysis (Greenacre 1984, Greenacre and Hastie 1987), log-linear models (see Bishop et al. 1975) or a combination of the two (Van der Heijden and Leeuw 1985). Correspondence analysis has been a popular ordination technique for vegetation data (Oksanen 1983, Brown et al. 1984, Fowler and Dunlap 1986), especially detrended correspondence analysis (Hill and Gauch 1980). These techniques ordinate the vegetation along a set of environmental gradients by determining the relative abundances, often presence-absence or a relative frequency score, of plant species occurring on sampled plots. Usually correspondence analysis is performed on two-way tables, although the technique can be used to explore Burt tables (see Greenacre 1984:140–143). A Burt table contains each variable in both the rows and columns of the table and thus contains all of the component two-way tables in a single two-way table. Gauch et al. (1981) discuss the relative merits of correspondence analysis for ordination of ecological data, especially for environmental gradient analysis.

Correspondence analysis identifies a low-dimensional subspace to represent the rows and columns of the two-way table as points in Euclidean space, and therefore is useful for exploring the table graphically while still preserving most of the original information. Row profiles or row points are constructed by dividing each cell frequency of the table by its corresponding row total. Each row profile is assigned a weight called a row mass by dividing the row total by the grand total of the table frequencies. The subspace that has the closest fit, in this case minimizing the weighted chi-square distances of the points to the subspace, is then found. Column profiles (points) and masses can be similarly constructed for the columns and a subspace of closest fit can be found for these as well. Both problems, however, are related by the singular value decomposition of the table that results in the correspondence between the row and column solutions, and therefore either variable may be taken as the row or column variable. This further permits the simultaneous display of the row and column profiles through the biplot (Gabriel 1971, see Greenacre and Hastie 1987). The theoretical development of correspondence analysis along with examples can be found in Greenacre (1984).

The biplot is probably the most useful exploratory result of the correspondence analysis. In a biplot the rows and columns of the table are simultaneously plotted with respect to the principal axes. The amount of variation associated with each axis gives an indication to the dimensionality of the subspace needed to accurately describe the table. Often the first two principal axes are sufficient. For the Burt table analyses, either the row or column solution is displayed, but not both, and the percentage variation explained by each axis computed using the standard formulas needs adjustment based upon the number of variables in the table (Greenacre 1984: 145).

The interpretation of the biplot is based upon the relative association of row and column points on the graph. For a column of the table where a row profile is large, both the column and the row point will be found relatively close together, and vice versa. Distances between row points and the origin and between column points and the origin are interpreted as chi-square contributions to the hypothesis of the independence between the rows and columns. However, the distance between a row and a column point are meaningless, since different scales (metrics) are used for the axes of each point type; rather it is the relative positioning of row with column points and column with row points that is interpreted.

When the table can be sufficiently represented

in three or fewer dimensions, the association of row and column points can be found through the directions of the points from the origin or centroid on a plot containing these dimensions. Points lying in the same direction from the centroid are associated by having large profiles in the corresponding rows and columns of the table identified by those points. When the table cannot be sufficiently represented in three or fewer dimensions, then plots consisting of the projections of the points from the higher dimensional space to the lower dimensional subspaces (e.g., two- or three-space) are used. Directions on these plots may not be sufficient to indicate associations, since the correct directions may require use of the other principal axes. Points that appear to be in the same direction from the origin may be far apart when viewed using other important principal axes. However, since the higher dimensional table is projected onto a subspace, points that lie in the same direction in the full space will usually appear spatially close on the plot of the subspace. In these situations, plots of several different subspaces (combinations of axes) should be considered. When three-dimensional representations are used, they should be rotated about the axes or plotted from several different angles so that the relationship among the points is clear.

STUDY AREA AND METHODS

Foraging observations and habitat variables were measured in a bottomland hardwood forest of the Texas River National Wildlife Refuge in northeastern Louisiana during March through July of 1984–1987. The refuge is described elsewhere (U.S. Fish and Wildlife Service 1980). Three broad habitat types were selected for study. The first consisted of a first terrace flat or backswamp totaling 80 ha. These areas are poorly drained flats of the floodplain with water standing well into the growing season. The dominant forest type is overcup oak-water hickory (*Quercus lyrata*-*Carya aquatica*) with green ash (*Fraxinus pennsylvanica*), sugarberry (*Celtis laevigata*), American elm (*Ulmus americana*), honey locust (*Gleditsia triacanthos*), Nuttall oak (*Q. nuttallii*), and swamp privet (*Forestiera acuminata*). The understory is restricted to small trees and shrubs. The area will be identified as the flat habitat type.

The forest habitat type is a second terrace flat and is found on slightly higher elevations than the flat habitat type. The area sampled consisted of approximately 160 ha. This habitat type is not seasonally flooded and is dominated by sweetgum (*Liquidambar styraciflua*) and willow oak (*Q. phellos*). Sugarberry, green ash, American elm, and Nuttall oak are also major components while overcup oak, water hickory, cedar elm (*U. crassifolia*), red maple (*Acer rubrum*), and bald cypress (*Taxodium distichum*) occur less frequently. The undergrowth includes greenbrier (*Smilax* sp.), swamp palmetto (*Sabal minor*), switchcane (*Arundinaria gigantea*), and several vines: peppervine (*Am-*

TABLE 1. BIRD SPECIES SURVEYED IN THE BOTTOMLAND HARDWOODS OF THE TENSAS RIVER NATIONAL WILDLIFE REFUGE DURING MARCH–JULY OF 1984–1987

Species	Code	Sample size	Foraging height (m) ^a
Eastern Wood-Pewee (<i>Contopus virens</i>)	EP	66	10.8 ± 6.3
Acadian Flycatcher (<i>Empidonax virescens</i>)	AF	131	6.6 ± 3.1
Carolina Chickadee (<i>Parus carolinensis</i>)	CC	112	7.9 ± 4.0
Tufted Titmouse (<i>Parus bicolor</i>)	TT	79	7.1 ± 4.9
Carolina Wren (<i>Thryothorus ludovicianus</i>)	CW	54	2.3 ± 2.3
Blue-gray Gnatcatcher (<i>Poliophtila caerulea</i>)	BG	74	12.1 ± 5.2
White-eyed Vireo (<i>Vireo griseus</i>)	WV	98	5.1 ± 3.0
Yellow-throated Vireo (<i>Vireo flavifrons</i>)	YV	47	16.3 ± 5.0
Red-eyed Vireo (<i>Vireo olivaceus</i>)	RV	85	10.4 ± 4.2
Northern Parula (<i>Parula americana</i>)	NP	218	9.7 ± 5.2
Yellow-throated Warbler (<i>Dendroica dominica</i>)	YW	100	14.9 ± 5.2
American Redstart (<i>Setophaga ruticilla</i>)	AR	52	11.3 ± 3.7
Prothonotary Warbler (<i>Protonotaria citrea</i>)	PW	146	3.6 ± 3.5
Swainson's Warbler (<i>Limnothlypis swainsonii</i>)	SW	17	0.4 ± 0.5
Kentucky Warbler (<i>Oporornis formosus</i>)	KT	50	1.4 ± 1.8
Hooded Warbler (<i>Wilsonia citrina</i>)	HD	90	5.4 ± 3.9

^a Mean ± SD.

pelopsis arborea), rattan (*Berchemia scandens*), poison ivy (*Toxicodendron radicans*), and Virginia creeper (*Parthenocissus quinquefolia*).

The oxbow habitat type occurs along the edges of oxbow lakes. Approximately 8 km of water-forest edge were selected for study. Bald cypress is the dominant species, with associates of water hickory, overcup oak, and cedar elm. Common buttonbush (*Cephalanthus occidentalis*) is the prominent shrub.

FIELD METHODS

We recorded foraging behaviors as we regularly and repeatedly traversed the study areas, moving from one foraging bird to another. For each individual we recorded: the species of bird, sex, time of day, type of foraging maneuver, height at which the maneuver took place, substrate (usually plant species) at which the maneuver was directed, and a general classification of the substrate. The substrate was classified as air, branch, flower, leaf, moss, trunk, or twig, where air indicates aerial foraging and moss indicates foraging in Spanish moss (*Tillandsia usneoides*). The substrate species were classified into habitat management categories of bald cypress and Spanish moss; ground litter, herbs, and fallen logs; overstory including midstory species; snags; understory, particularly shrubs; and vines. The categories were intended to represent habitat characteristics that could be addressed through habitat management. Bird foraging maneuvers were defined as sally-glean, a bird in flight takes a prey item from a substrate; perch-glean, the prey is taken from vegetation while the bird is perched or slowly moving; flush-chase, the prey is flushed from a substrate and is pursued; hang, the bird clutches a leaf or twig and hangs in order to glean prey from the surface; aerial-hawk, a sally into the air in pursuit of a flying prey; and ground-forage, any of the above maneuvers, initiated while the bird is on the ground. A bird was followed until 10 foraging maneuvers were observed or until it was lost from sight. In this analysis, only the first foraging ma-

neuver was used so as to avoid serial correlation problems. Raphael (this volume), however, discusses a Markov chain approach that could be used to model these serially correlated data. Foraging heights were classified as: ground (0–0.5 m); shrub (0.5–2.0 m); midstory (2–10 m); and canopy (> 10 m). Foraging and microhabitat data collections were restricted to the bird species listed in Table 1.

The foraging microhabitat was characterized at locations directly under or on the site where a bird's first foraging maneuver was observed. An imaginary cylinder centered at the location with a diameter of 2 m was divided into the four height layers described above. The radius of the cylinder in the canopy layer was extended to 10 m. The percentage of vegetation density was determined for each of the four strata. Additionally, the height of the canopy was also estimated with a range-finder. Availability of habitats was estimated by using the above method at randomly located plots.

DATA ANALYSIS

Correspondence analysis was performed using the CORRESP procedure of Young and Kuhfeld (1986). The principal axes and corresponding coordinates were saved for constructing biplots. In a purely exploratory framework, no assumptions about the data are required. However, since the interpretation of the graphical analysis will refer to the dependencies among the variables, and the results will be used to help specify log-linear models, the log-linear model assumptions discussed below are required. Log-linear models of the contingency tables were fit using the CATMOD procedure of SAS/STAT (SAS 1985). The log-linear models provide methods for examining the dependencies among variables in a contingency table. These models assume independent observations usually from multinomial, product-multinomial, or poisson distributions, and depend upon the large sample, asymptotic properties of maximum likelihood (see Bishop et al. 1975:435–530). Roscoe and Byars (1971) suggested that

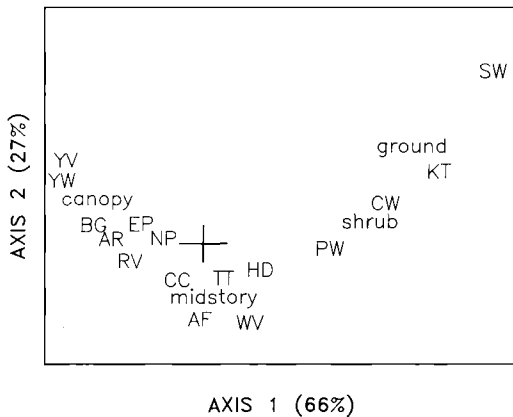


FIGURE 1. Correspondence analysis of bird species with foraging-height class: ground = <0.5 m, shrub = 0.5–2 m, midstory = 2–10 m, and canopy = >10 m. See Table 1 for bird species codes. The origin is located at the crosshairs.

the average expected frequency in the contingency table be at least five for reliable tests of hypotheses, although they found that an average expected frequency of one to two was satisfactory in some instances. Habitat use-availability comparisons were made using logistic regression (see Kleinbaum et al. 1982:419–446) as implemented in the CATMOD procedure of SAS/STAT (SAS 1985). Logistic regression does not require multivariate normality of the explanatory variables. The usual assumptions require that the dichotomous responses be from independent Bernoulli distributions (or binomial counts of “successes” in a known number of trials) and that the probability parameter of these distributions can be modeled as a logistic function of the explanatory variables (see Kleinbaum et al. 1982: 419–446, Weisberg 1985:267–271). Since maximum likelihood was used to estimate the parameters of our logistic models, the large sample, asymptotic properties of maximum likelihood are again assumed to hold. Logistic regression has been found to be more robust than discriminant analysis, probably because its formulation arises from many types of modeling assumptions (Press and Wilson 1978).

The foraging data provided a variety of categorical variables that could have been explored with correspondence analysis, but only the relationships of the bird species with foraging-height classes, substrate types, habitat management categories, habitat types, and foraging maneuvers were explored in this paper. The Tufted Titmouse and Carolina Chickadee were widespread on this study area and so specific hypotheses concerning their respective niches, generated as a result of the correspondence analyses, were examined using log-linear and logistic regression techniques. Log-linear models were fit using the cross-classification of these two bird species with the foraging maneuver, substrate type, habitat management category, and foraging-height class variables to determine factors that might separate their foraging patterns. To simplify the analysis and to insure that the average expected cell frequencies of the table

were at least five, only the predominant factor levels of the variables were included. They were the perch-glean and hang maneuvers; the branch, leaf, and twig substrate types; the overstory, understory, and vines habitat management categories; and the midstory and canopy foraging-height classes. The substrate type and habitat management category variables were not included together in a model because of the resulting small cell frequencies. A logistic regression model was used to discriminate between the microhabitat measurements made at the species' foraging locations. Logistic regression was also used to compare the microhabitat characteristics measured at the bird foraging locations with those measured at random locations within the forest.

RESULTS

CORRESPONDENCE ANALYSIS

The first two principal axes from the correspondence analysis of the cross-classification of the bird species with the foraging-height classes explained 93% of the table chi-square variation. This indicated that the contingency table could be projected from three dimensions to two, with little loss of information. The bird species (rows) and the foraging-height classes (columns) were plotted simultaneously using the first two principal axes to produce a biplot (Fig. 1). Since the row profile (Table 2) for Swainson's Warbler was large in the ground column of the table, Swainson's Warbler was positioned in the direction of the ground value of the foraging-height variable. The Prothonotary Warbler profile was large in both the shrub and midstory columns of the table and so was ordinated between them on the plot. The remaining species were ordinated according to their row profiles indicating their positions along the foraging-height gradient. Since there were no birds with large profiles for both ground and canopy values, the region of the plot opposite midstory is empty.

The sightings of species of birds were then cross-classified with the habitat-management categories. The first three principal axes from the correspondence analysis of this table explained 90% of the total table variation. This analysis indicated that the Yellow-throated Warbler was strongly associated with the bald cypress-Spanish moss category (Fig. 2) and a closer examination of the specific chi-square contributions made by each bird species in the table showed that most of the chi-square variation was due to this particular association. The ground and understory categories were ordinated in a similar direction from the centroid, but the Prothonotary Warbler, for example, was more associated with the understory than with the ground category. Swainson's Warbler used the understory species as well as the ground debris, as expected

TABLE 2. ROW PROFILES AND ROW MASSES FOR THE CROSS-CLASSIFICATION OF BIRD SPECIES WITH FORAGING-HEIGHT CLASS FOR 1419 BIRD FORAGING OBSERVATIONS

Bird species	Foraging-height class				Row mass
	Ground	Shrub	Midstory	Canopy	
Eastern Wood-Pewee	0.00	0.11	0.32	0.58	0.05
Acadian Flycatcher	0.00	0.05	0.77	0.18	0.09
Carolina Chickadee	0.01	0.04	0.64	0.30	0.08
Tufted Titmouse	0.09	0.06	0.58	0.27	0.06
Carolina Wren	0.15	0.50	0.35	0.00	0.04
Blue-gray Gnatcatcher	0.00	0.04	0.28	0.68	0.05
White-eyed Vireo	0.02	0.16	0.73	0.08	0.07
Yellow-throated Vireo	0.00	0.00	0.09	0.91	0.03
Red-eyed Vireo	0.00	0.00	0.51	0.49	0.06
Northern Parula	0.06	0.05	0.43	0.47	0.15
Yellow-throated Warbler	0.00	0.00	0.13	0.87	0.07
American Redstart	0.00	0.00	0.40	0.60	0.04
Prothonotary Warbler	0.16	0.29	0.50	0.05	0.10
Swainson's Warbler	0.71	0.29	0.00	0.00	0.01
Kentucky Warbler	0.30	0.54	0.14	0.02	0.04
Hooded Warbler	0.07	0.21	0.56	0.17	0.06

from the previous correspondence analysis, but the Kentucky Warbler and Carolina Wren were additionally identified as using vines as well. The White-eyed Vireo and Hooded Warbler were also important users of vines. The Eastern Wood-Pewee was associated more often with snags and the overstory, more specifically in bald cypress and water hickory. This explains why the Eastern Wood-Pewee was ordinated between these categories and more in the direction of the bald cypress-Spanish moss category (Fig. 2). The remaining species were generally associated with the overstory category.

The bird species were then ordinated by their sample sizes in the three major habitat types to explore the relative number of encounters in each habitat type (Fig. 3). This table could be exactly represented in two dimensions, as it consisted of only three columns defined by the habitat types. The Yellow-throated Warbler was almost exclusively found in the oxbow habitat type, whereas the Hooded Warbler and the Swainson's Warbler were only observed in the forest habitat type. The Northern Parula, Prothonotary Warbler, and the Eastern Wood-Pewee were also highly associated with the oxbow habitat type. The majority of the other species were sighted most often in the forest and flat habitats.

The midstory and canopy foragers were then subjected to a correspondence analysis with the substrate types. The Eastern Wood-Pewee was found foraging almost entirely on insects in the air; these data contributed to most of the chi-square variation in the table (Fig. 4). The Acadian Flycatcher and American Redstart were often foraging on insects in the air but, just as important, they were identified here as sally-

gleaning arthropods from leaves. The Yellow-throated Warbler was again shown strongly associated with Spanish moss. The Yellow-throated Vireo, Tufted Titmouse, and Carolina Chickadee all foraged on foods associated with tree trunks, branches, and twigs of plants, whereas the remaining species appeared associated more with the leaves of the substrate. Although the Yellow-throated Vireo and Yellow-throated Warbler were found high in the canopy, each appeared to differ in their selection of habitat substrates.

The dominant source of variation in the correspondence analysis of the bird species with the first encountered foraging maneuver was produced by the almost exclusive use of aerial-hawking by the Eastern Wood-Pewee. The analysis, however, identified a gradient, primarily along axis 2, from aerial maneuvers to flush-chasing to perching to hanging while foraging (Fig. 5). This three-dimensional ordination explained 97% of the chi-square variation in the table. An analysis, not shown, with the Eastern Wood-Pewee removed from the table, resulted in a single important axis (71%), with aerial-hawking at the extreme end of the axis beyond sally-gleaning.

LOG-LINEAR MODELS

The first log-linear model comparing the Tufted Titmouse and Carolina Chickadee used the variables bird species, foraging maneuver, substrate type, and foraging-height class. The correspondence analysis of the Burt table (Table 3) showed no strong associations of the foraging variables with the species (Fig. 6). The resulting log-linear model, however, identified a depen-

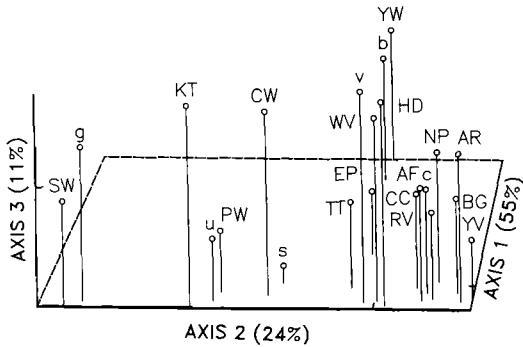


FIGURE 2. Correspondence analysis of bird species with habitat-management category: b = bald cypress and Spanish moss, g = ground litter, c = overstory, s = snags, u = understory, and v = vines. See Table 1 for bird species codes. The origin is located at the intersection of the axis tic marks.

dependency between the species and the foraging maneuver (Table 4, $P = 0.0173$), with only a suggestion that the bird species and substrate type were dependent ($P = 0.1689$). This particular log-linear model corresponded to a logit model for bird species containing only the substrate type and foraging maneuver variables. This logit model was a test of the ability of the variables substrate type and foraging maneuver to discriminate between the two bird species' frequencies of usage. These results suggested that the chickadee did relatively more hanging than the titmouse, but the titmouse did relatively more perch-gleaning. A secondary result was that the hanging maneuver was associated more often with leaf substrates, and perch-gleaning more often with branch substrates.

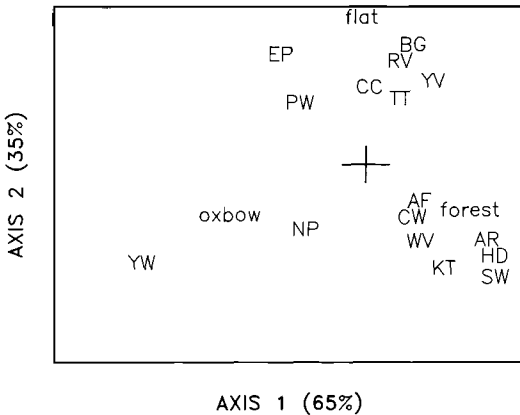


FIGURE 3. Correspondence analysis of bird species with habitat type. See Table 1 for bird species codes. The origin is located at the crosshairs.

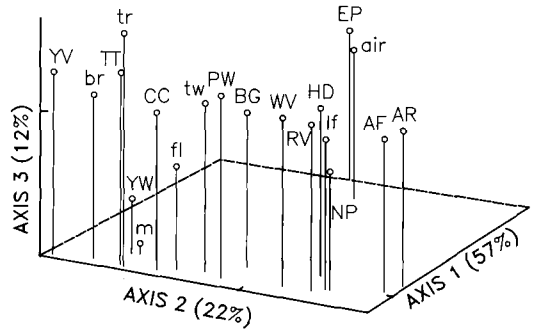


FIGURE 4. Correspondence analysis of bird species with substrate type: air = air, br = branch, fl = flower, lf = leaf, m = Spanish moss, tr = trunk, and tw = twig. See Table 1 for bird species codes. The origin is located at the intersection of the axis tic marks.

When the substrate type was replaced with the habitat-management category in the log-linear models analysis, the bird species were found to be related to the foraging maneuver interacting with the habitat-management category (Table 5, $P = 0.0091$). This model corresponded to a logit model containing habitat-management category, foraging maneuver, and their interaction. Thus, there appeared to be some differences in the foraging behaviors of these two species, particularly in their maneuvers.

LOGISTIC REGRESSION

None of the variables in the logistic regressions comparing the microhabitat selection of chickadee and titmouse, including substrate height, were good discriminators of foraging microhabitats. Further, there is only an indication that the proportion of canopy vegetation was less at random sites than at sites selected by the titmouse ($P = 0.09$). The chickadee, however, appeared to select sites with a smaller percentage of ground litter ($P = 0.005$) and a larger percentage of bare ground ($P = 0.05$) than random sites. There was also an indication that the proportion of canopy vegetation at chickadee foraging locations was less than at the random plots ($P = 0.07$). Thus, there appeared to be some differences between foraging sites selected by these two birds with sites selected at random, although no differences were detected between the birds when comparing the two species alone.

DISCUSSION

The foraging-height and foraging-maneuver variables were important in distinguishing the bird species of this community. Examination of the substrate types, habitat-management categories, and habitat types further helped to iden-

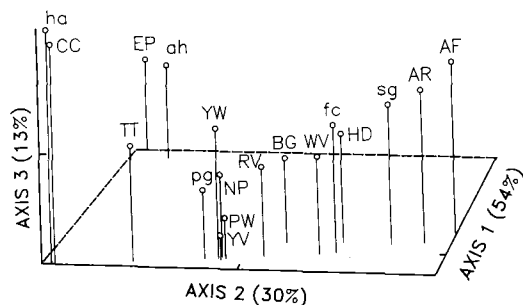


FIGURE 5. Correspondence analysis of bird species with foraging maneuver: ah = aerial-hawk, fc = flush-chase, ha = hang, pg = perch-glean, and sg = sally-glean. See Table 1 for bird species codes. The origin is located at the intersection of the axis tic marks.

tify species with specific habitat associations. For example, the Eastern Wood-Pewee foraged on flying insects by aerial-hawking from snags, bald cypress, and water hickory. The Yellow-throated Warbler was associated with bald cypress and Spanish moss.

In building a model (e.g., a log-linear model) of associations between the bird species and the habitat variables, where one species' association with a specific habitat variable or variables dominates the correspondence analysis, one would probably include a separate parameter or set of parameters to account for the association. Our analysis of the bird species with the habitat-management categories suggested that a model for these data should include a parameter to account for the relationship between the Yellow-throated

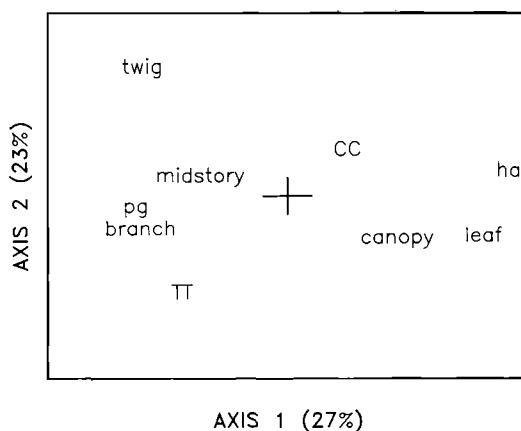


FIGURE 6. Correspondence analysis of the Burt table for bird species, substrate type, foraging maneuver, and foraging-height class. See Table 1 for bird species codes and Figures 1 and 5 for foraging-height class and foraging maneuver codes. The origin is located at the crosshairs.

Warbler and the bald cypress-Spanish moss category. In the analysis of the bird species with the foraging maneuvers, we took the graphical analysis one step further through the deletion of the influential Eastern Wood-Pewee. This resulted in a much simplified table, reducing the variation to along one axis, and was probably a more successful summary than that of displaying the complete table analysis. The deletion of the Yellow-throated Warbler in the analysis of the habitat-management categories would have permit-

TABLE 3. BURT TABLE FOR THE CAROLINA CHICKADEE AND TUFTED TITMOUSE CONTAINING THE SELECTED SUBSTRATE TYPES BRANCH, LEAF, AND TWIG; THE FORAGING MANEUVERS HANG AND PERCH-GLEAN; AND THE FORAGING-HEIGHT CLASSES MIDSTORY AND CANOPY

	Bird species		Substrate type			Foraging maneuver		Foraging-height class	
	CC	TT	Branch	Leaf	Twig	HA	PG	Midstory	Canopy
Bird species									
Carolina Chickadee (CC)	73	0	28	30	15	34	39	53	20
Tufted Titmouse (TT)	0	41	18	19	4	11	30	29	12
Substrate type									
Branch	28	18	46	0	0	14	32	36	10
Leaf	30	19	0	49	0	27	22	32	17
Twig	15	4	0	0	19	4	15	14	5
Foraging maneuver									
Hang (HA)	34	11	14	27	4	45	0	32	13
Perch-glean (PG)	39	30	32	22	15	0	69	50	19
Foraging-height class									
Midstory	53	29	36	32	14	32	50	82	0
Canopy	20	12	10	17	5	13	19	0	32

TABLE 4. MAXIMUM LIKELIHOOD LOG-LINEAR MODELS ANALYSIS OF THE CROSS-CLASSIFICATION OF BIRD SPECIES (SPECIES) WITH SUBSTRATE TYPE (SUBTYPE), FORAGING MANEUVER (MANEUVER), AND FORAGING-HEIGHT CLASS (FORHTCL) FOR THE CAROLINA CHICKADEE AND TUFTED TITMOUSE

Source	df	Chi-square ^a	P
SUBTYPE	2	15.43	0.0004
MANEUVER	1	9.58	0.0020
FORHTCL	1	12.67	0.0004
SPECIES	1	13.14	0.0003
SPECIES•SUBTYPE	2	3.56	0.1689
SPECIES•MANEUVER	1	5.66	0.0173
SUBTYPE•MANEUVER	2	9.90	0.0071
SUBTYPE•FORHTCL	2	3.16	0.2064
MANEUVER•FORHTCL	1	0.00	0.9959
SUBTYPE•MANEUVER•FORHTCL	2	3.63	0.1627
LIKELIHOOD RATIO ^b	8	2.19	0.9746

^a Wald Statistics.

^b Test for lack-of-fit comparing the current model to the saturated or full model.

ted a more detailed exploration of the remaining bird species of that table, which would then be modeled by other parameters in the log-linear model. A modeling approach alone might have required several steps to isolate these individual sources of variation, although they were clear in the biplots. This illustrates how correspondence analysis can provide support to modeling. A further important outcome was that axes two and three often provided considerable detail about many of the bird relationships with the habitat variables, since a single species was often responsible for the variation along the first axis. Thus, axes associated with the smaller singular values can be informative, and approaches using only the first or first two axes may be inadequate.

Our foraging data were not sampled with the goal of estimating species relative abundance.

Therefore, caution should be applied when interpreting the association between the bird species and the habitat types in which they were found, because some associations could be an artifact of the sampling process. However, encounters of birds within a habitat are assumed to be random so that stratified modeling approaches are possible. We think that the correspondence analysis of these variables was useful because some species were associated with specific habitat types, such as the Hooded Warbler and Yellow-throated Warbler. Further, the analysis provides a basis for developing hypotheses about distribution that can be examined in subsequent field studies.

In general, correspondence analysis was useful for the examination of two-variable models and for interpreting the log-linear model results from more complex tables, as was done for the Burt tables. Correspondence analysis appeared, however, to provide much less insight into the actual

TABLE 5. MAXIMUM LIKELIHOOD LOG-LINEAR MODELS ANALYSIS OF THE CROSS-CLASSIFICATION OF BIRD SPECIES (SPECIES) WITH HABITAT-MANAGEMENT CATEGORY (HABCAT), FORAGING MANEUVER (MANEUVER), AND FORAGING-HEIGHT CLASS (FORHTCL) FOR THE CAROLINA CHICKADEE AND TUFTED TITMOUSE

Source	df	Chi-square ^a	P
HABCAT	2	267.93	0.0001
MANEUVER	1	0.00	0.9874
FORHTCL	1	161.43	0.0001
SPECIES	1	4.03	0.0447
HABCAT•MANEUVER	2	1.33	0.5145
HABCAT•FORHTCL ^b	2		
MANEUVER•FORHTCL	1	0.00	0.9904
SPECIES•HABCAT	2	1.00	0.6060
SPECIES•MANEUVER	1	0.21	0.6487
HABCAT•MANEUVER•FORHTCL	2	1.20	0.5501
SPECIES•HABCAT•MANEUVER	2	9.41	0.0091
LIKELIHOOD RATIO ^c	6	1.69	0.9462

^a Wald Statistics.

^b One or more parameter estimates are infinite.

^c Test for lack-of-fit comparing the current model to the saturated or full model.

specification of a model for the Burt tables. Part of this difficulty may be due to the design of the Burt table itself, since it only contains pairwise relationships among the variables, and therefore, higher-order dependencies in the data are not preserved in the table. More research is needed into graphical ways for exploring complex dependencies in contingency tables.

The logistic regression results must be carefully interpreted. The differences between the microhabitat variables at Carolina Chickadee locations and those from random plots do not necessarily indicate that the habitat use of these birds was based upon the variables declared significant; these variables might have been related to unmeasured qualities that the birds were using. Further, our ability to distinguish between foraging sites and random plots may not have been very powerful, due to the large variation associated with random sites. The power for discriminating between two species' sites should be at least that for discriminating between a particular species' sites and randomly located sites, since the variation in measurements made at sites selected by a species would tend to be no greater than those from randomly selected sites. Determining how sample size affects the power of this analysis, given the amount of random variation, would be a desirable next step (see Morrison 1988). Further exploration of our tables could proceed by using the actual substrate species and by separating the overstory according to the foraging-height classes. The generality of our conclusions requires repetition of the study both temporally and spatially until relationships are clear and stable.

We have demonstrated the power of correspondence analysis for exploring and illustrating graphically the relationships among bird species with habitat variables. Miles (this volume) also

found correspondence analysis to be valuable for analyzing foraging behavior. Greenacre and Vrba (1984) demonstrated its usefulness for exploring ecological relationships among African antelopes. Our exploratory analysis suggested that we may associate the bird species with specific habitat conditions as well as with specific foraging behaviors. The graphical displays of these associations suggested hypotheses that we explored using other techniques such as log-linear modeling and logistic regression. This combination of several exploratory (and confirmatory) techniques resulted in a better understanding of the data than the use of a single technique alone, mainly because each technique is only sensitive to particular kinds of dependencies among the variables.

A visual examination of categorical data through correspondence analysis provides valuable insight and confidence in the analysis. Further, the biplot graphics make convenient devices for explaining complex relationships among species to those not trained in avian ecology. With the abundance of categorical data collected during bird foraging studies, the use of exploratory techniques aimed specifically at categorical variables must be encouraged.

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