EVALUATION OF RESOURCE SELECTION METHODS WITH DIFFERENT DEFINITIONS OF AVAILABILITY

SETH A. McClean, Department of Geography and Recreation, University of Wyoming, Laramie, WY 82071, USA
MARK A. RUMBLE, U.S. Forest Service, Rocky Mountain Research Station, 501 East Street Joe, Rapid City, SD 57701, USA
RUDY M. KING, U.S. Forest Service, Rocky Mountain Research Station, 240 West Prospect, Fort Collins, CO 80526, USA
WILLIAM L. BAKER,[1] Department of Geography and Recreation, University of Wyoming, Laramie, WY 82071, USA

Abstract: Because resource selection is of paramount importance to ecology and management of any species, we compared 6 statistical methods of analyzing resource selection data, given the known biological requirements of radiomarked Merriam's wild turkey ***(Meleagris gallopavo merriami)*** hens with poults in the Black Hills of South Dakota. A single variable, habitat, was used for the comparisons. Hen turkeys with poults are ideal for these comparisons because poults have narrow dietary protein requirements, and habitats that meet these requirements are well documented. We also tested the effects on the statistical methods of varying the habitats considered as available. Availability of habitats was defined by 100-, 200-, and 400-m-radii buffers around individual poult locations and also as the total study area. The 6 statistical techniques gave different results because of how the methods addressed variability in habitat use of individual birds and how availability was defined. These differences made identification of a "best" technique difficult. Only 1 method (Neu's) identified habitat selection patterns consistent with known requirements of poults at all levels of habitat availability. However, defining availability at the study-area level was generally superior to use of circular buffers. We recommend that during analyses of resource selection researchers include the study-area level of habitat availability based on the distribution of radiomarked animals.

JOURNAL OF WILDLIFE MANAGEMENT 62(2):793-801

Key words: availability, Merriam's turkeys, poults, resource selection analysis.

Analysis of how wildlife use habitat is among the most important aspects of wildlife science. Among the major difficulties in statistical analysis of habitat selection, however, is choosing among the profusion of methods (Manly et al. 1993). The most common test is chi-square goodness-of-fit analysis (Fleiss 198 1) coupled with the placement of Bonferroni confidence intervals around proportional use to estimate if habitats are selected disproportionate to their availability (Neu et al. 1974). Among other approaches, 2 nonparametric methods, the Friedman and Quade methods (see Alldredge and Ratti 1986) have been used. Multivariate methods of testing for habitat selection include habitat preference analysis (Johnson 1980), compositional analysis (Aebischer et al. 1993), and the multiresponse permutation procedure (MRPP; Mielke 1986, Alldredge et al. 1991). Other approaches include log-linear models (Heisey 1985), logistic regression (Pereira and Itami 1991), and the geometric method (Kincaid and Bryant 1983).

Regardless of the analytical method used, the definition of availability is a key element of resource selection studies. This definition is a difficulty because the size of the study area can influence the results of resource selection analyses, if habitats are aggregated (Porter and Church 1987). Also, the area defined as available may contain habitats not actually available to the animal (Johnson 1980). Second, a hierarchy of several spatial and temporal scales may be involved in the habitat selection of a species (Orains and Wittenberger 1991), but often only 1 scale is analyzed. This scale effect can be important because animals may be selecting habitat features at different scales such as micro- and macrohabitat. Third, if habitat quantity and quality are not interchangeable, then results of habitat use-availability may not reflect carrying capacity (Hobbs and Hanley 1990), which can be a serious problem if many low-quality habitats occur in the study area.

Poults of Merriam's wild turkey are ideal for comparing use-availability analyses because poults have very narrow dietary requirements for growth and development during the first 4-7 weeks after hatching (Robbins 1983, Hurst 1992). Dietary animal protein obtained from invertebrates is required in substantial quantities, or young gallinaceous birds will not grow and

[1]E-mail: bakerwl@uwyo.edu

develop (Johnson and Boyce 1990). Hence, turkey poults forage along edges of meadows where invertebrates are abundant (Rumble and Anderson 1993), and abundance of invertebrates is directly related to herbaceous biomass in these meadows (Healy 1985, Rumble 1990). Indeed, the selection of habitats with abundant herbaceous vegetation by hens with poults is the most consistent of any habitat relation for turkeys (Porter 1992). Therefore, given dietary requirements of poults, we expected that hens with poults should be selecting for meadow habitats, and that statistical evaluation of resource selection methods should reflect that selection.

The objective of our study was to assess the sensitivity of 6 resource selection analysis techniques to 4 definitions of habitat availability and to compare consistency of analysis results with what we believe are the habitat requirements of turkey poults <7 weeks old. While comparison of competing tests via simulation allows a broad range of hypothetical conditions to be considered, empirical comparisons provide a direct link with real-world situations and interpretation of results.

METHODS

Collection of Field Data

We collected habitat use data from radiomarked Merriam's wild turkey hens with poults in the Black Hills of South Dakota between 1986 and 1991. The study area was approximately 25 km west of Rapid City. The predominant vegetation type in the study area was ponderosa pine ***(Pinus ponderosa)*** forest. Other vegetation types included aspen ***(Populus tremuloides)***-birch ***(Betula papyrifera),*** meadows, white spruce ***(Picea glauca),*** and bur oak (Quercus ***macrocarpa).*** Habitat descriptions are based on vegetation type and overstory canopy cover (OCC; Rumble and Anderson 1992). We defined 3 ponderosa pine habitats on the basis of OCC (PA was <40% OCC, PB = 41-70% OCC, PC was >71% OCC), a grass-forb habitat (GF), and an aspen-birch habitat (AS). We excluded white spruce and bur oak habitats from the analyses because they occupied <1% of our study area, and observations in them were rare. We described habitats via modifications of the U.S. Forest Service Region 2 criteria for modeling wildlife habitat relations (Buttery and Gillam 1983). We delimited habitats on 1:24,000 scale U.S. Geological Survey topographic contour maps based on aerial photographs.

We trapped hens in late February-early March and monitored them until it appeared each hen had initiated a nest. After hatching, hens were normally located 3 times/week. We collected data between June and August of each year, and only birds with >10 observations/bird were included in the analysis. We used 15 radiomarked Merriam's turkey hens with poults for the statistical analyses. Mean observations per bird was 16, and 4 birds were observed during successive summers. Patterns of habitat use among years for these 4 birds did not differ; thus, we pooled observations over years.

We located radiomarked hens with poults via a hand-held Yagi antenna. In the field, we marked locations of hens on maps that contained habitat polygons. If locations were near the boundary of a polygon, we verified the location by encircling the radiomarked hen while continuously monitoring her location. We also attempted to obtain visual verification of each hen's location without disturbing it. Approximately half the locations were visual observations of birds.

Geographic Information System (GIS) Analyses

We used a GIS to construct a database of habitats and poult locations via ARC/INFO software (Environmental Systems Research Institute 1992). We delineated 607 habitat polygons encompassing 4,380 ha and digitized them from topographic maps into a vector database. The habitat polygons were typically between 4 and 32 ha (Fig. 1). We constructed a GIS map of poult locations from ASCII input of their Universal Transverse Mercator (UTM) coordinates. Occasionally (<10%), the nearest 100-m UTM coordinates fell outside the recorded habitat polygon where the birds were observed. The UTms for these observations were moved to the nearest location within the habitat polygon or dropped if >100 m from the nearest correct habitat polygon.

We used the GIS to vary the definition of available. habitat to test the effect of multiple spatial scales on the statistical methods. First, the area encompassing all observations of birds was considered as available for all birds. This approach is typical of most applications of the chi-square method (Neu et al. 1974). Availability also was determined as circular buffers of

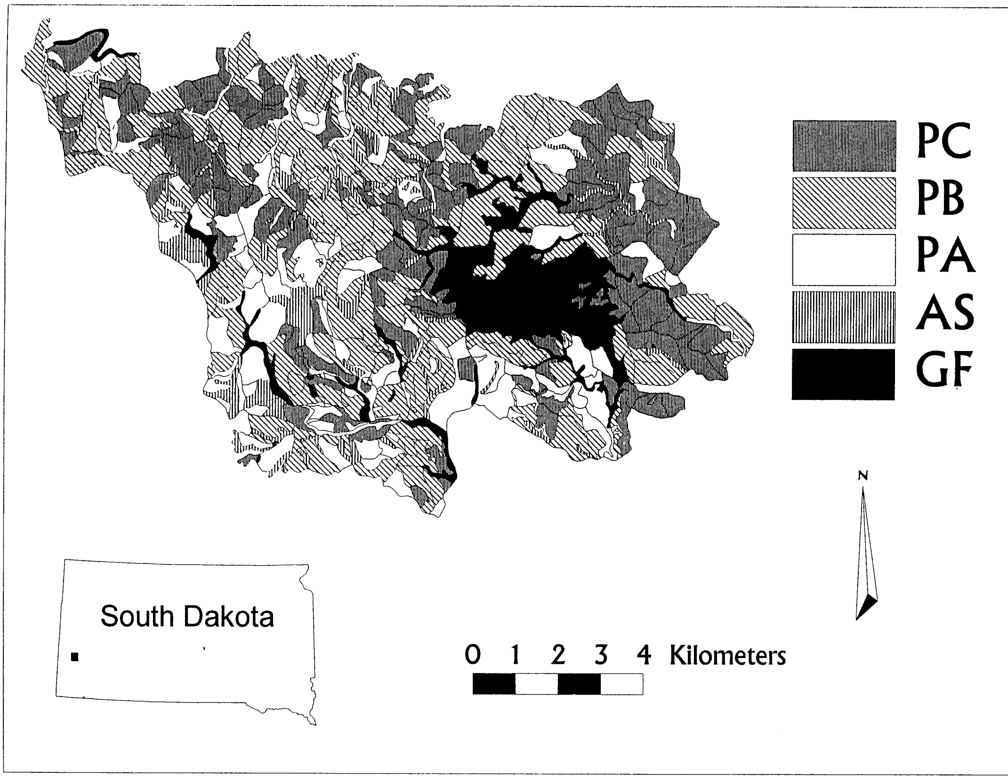

Fig. 1. The study area in the Black Hills of South Dakota and the 5 habitats: PA = ponderosa pine <40% overstory canopy cover, PB = ponderosa pine 41–70% overstory canopy cover, PC = ponderosa pine >70% overstory canopy cover, GF = grass–forb, and AS = aspen–birch.

100 m, 200 m, and 400 m around poult locations. The buffers were introduced as a more systematic attempt to estimate availability for each bird.

Statistical Analyses

We compared 6 statistical methods: the chi-square goodness-of-fit test (Neu method), Johnson's method, Friedman test, Quade test, compositional analysis, and MRPP. Statistical calculations were made via modifications to the PREFER program (Johnson 1980), which incorporates the Neu, Johnson, Friedman, and Quade tests into a single program (G. E. Brink, U.S. Forest Service, Rocky Mountain Research Station, unpublished software). We programmed compositional analysis computations with SPSS (SPSS 1993). We computed MRPP tests via the National Ecology Research Center's BLOSSOM statistical software (Slauson et al. 1991. BLOSSOM statistical software, unpublished. National Ecology Research Center, Fort Collins, Colorado, USA). We compared results of the 6 analysis methods from 2 perspectives: (1) whether the omnibus test rejected the null hypothesis that used and available habitats did not differ, and (2) whether multiple comparison analyses suggested that all habitats received the same use.

The 6 methods differ in the specific form of these general null hypotheses tested, the Multiple Comparison Procedure (MCP), and distributional assumptions. All MCPs were applied using experimentwise error rates. This approach focuses attention on the hypothesis tested, not on whether a comparisonwise or experimentwise error rate should be used.

Comparison of Statistical Methods

The 6 methods assume 2 of 3 possible sampling designs (Thomas and Taylor 1990). In design 1, individuals are pooled together and availability is determined and held constant for the entire study area. We pooled individuals only for designating the size and shape of the study area, although Neu's method inherently pools data across individuals. Design 2 treats animals as individuals, but availability, in this case the study area, is considered the same for all individuals. Design 3 also treats animals as individuals but estimates availability for each individual separately (the buffers). Designs 2 and 3 were used for Neu, Johnson's, Friedman, Quade, MRPP, and compositional analysis. The Neu method assumes that observations are independent, both within and between animals (a condition that is rarely met),. and that all habitats are equally available to all animals (Jelinski 1991). The other methods assume independence between animals, but not for each animal's observations.

The Neu method is the most common test used in resource selection studies. A chi-square goodness-of-fit test is used to test the null hypothesis that animals use habitats in proportion to their area, and all habitats and animals are considered together. A correction for continuity was included in the computation of the overall individual confidence intervals for the chi-square statistic (Fleiss 1981). Following Neu, we used a Bonferroni correction to the Z-statistic to maintain an experimentwise error rate (Miller 1981). The confidence interval approach only allows relative statements about habitats; thus, if 2 habitats are used more than expected, it is difficult to determine which habitat is more important. The chi-square test is not necessary to maintain experimentwise error of the confidence intervals, but computation of the confidence intervals may be informative even for borderline, omnibus chi-square tests. The simplicity of the method is appealing to many researchers and, if animals are not recorded as individuals, it is the only choice of the techniques evaluated in this paper.

Johnson's method uses a Hotelling T^2 statistic to test the null hypothesis that differences between ranks of use and availability are equal. Johnson's method uses ranks to account for situations where inclusion or exclusion of certain habitats is questionable (Johnson 1980). If the null hypothesis is rejected, Johnson used the Waller-Duncan MCP to make inferences about selection of individual habitats relative to each other. Habitats could also be compared via the mean difference between the use and availability ranks. To determine if animals selected for habitats, against habitats, or neither, we compared these mean differences: (1) against zero, to test use versus available; and (2) among habitats, with multivariate analysis of variance contrasts. Experimentwise error for these tests and contrasts was maintained by assessing T^2 statistics against the F-distribution (Morrison 1967).

The Friedman and Quade methods are similar. Both use ranked data and treat animals as blocks (Conover 1980). The omnibus null hypothesis for the Friedman test is that ranks of the differences between use and availability are equal for all habitats (Alldredge and Ratti 1986). We compared mean Friedman ranks among habitats with a studentized range procedure (Hochberg and Tamhane 1987). The Quade test is a modification of the Friedman test, which weights each individual's observations. Larger variance between use and availability is weighted heavier and assumed indicative of greater habitat selection (Alldredge and Ratti 1992). The null hypotheses are the same as with the Friedman test. Experimentwise multiple comparisons for the Quade test were computed via Bonferroni-corrected least significant difference (LSD) confidence intervals. Because these tests only use ranks, there are,cases where the null hypothesis may better match the precision of biological data than is the case with the Neu method (Johnson 1980, Alldredge and Ratti 1986).

Compositional analysis uses a log-ratio transformation of proportional used and available values to overcome the unit-sum constraint on proportional data (Aebischer et al. 1993). Aitchison (1985) claims the unit-sum constraint invalidates the use of many statistical techniques with proportional (compositional) data. However, there is no consensus on the unit-sum constraint in the statistical community, and there is some controversy over the effectiveness of the transformation (Tangri and Wright 1993). Aebischer et al. (1993) suggest a 2-stage process. First, proportional availability of each habitat in the study area is compared to proportional availability of habitats in home ranges. Second, proportional availability of habitats in the home range is compared to proportions of radiolocations for each individual.

For our analysis, we compared the proportional availability of habitats in the study area with radiolocations to the proportional availability of habitats in the buffers with radiolocations. We used a Hotellings T^2 statistic to test the omnibus null hypothesis of no difference (used-available) among the components of the transformed data matrix. We then used paired t-tests (Bonferroni corrected) to determine whether there was selection for particular habitats, if the omnibus null hypothesis was rejected (Aebischer et al. 1993).

Compositional analysis and Johnson's method both use multivariate analysis of variance techniques. Both techniques assume multivariate normality; if this is not met, then randomization techniques may be needed to obtain a valid test statistic (Manly 1991).

The MRPP is a permutation procedure developed by Mielke (1986) and has the advantage of avoiding distributional assumptions made by both parametric multivariate and nonparametric rank techniques. Differences in proportional use and availability are used to test the null hypothesis that habitat use did not differ from habitat availability. When data occur in blocks (animals), a slight modification of the MRPP model is used (Mielke 1986), and the resulting model is referred to as the multiresponse blocked permutation procedure (MRBP). If the omnibus null hypothesis is rejected, matched-pairs permutation tests (Mielke and Berry 1982) are used to make all possible pairwise comparisons among the habitats. A Bonferroni correction was used to control experimentwise errors.

RESULTS

The Neu method rejected the null omnibus hypothesis at all 4 levels of availability (Table 1). The Bonferroni confidence interval indicated that GF was used more than expected and PA was used less then expected at all 4 levels of availability. The PC habitat was used less then expected only at the level of the total study area. Relative proportion of each habitat did not change much between the 100-, 200-, and 400-m levels, which accounts for the stability of the results among these 3 levels. Availability of PC habitat increased at the level of the total study area, which accounts for PC appearing less used at that level. The Neu method consistently identified the GF habitat as being selected by poults.

Johnson's test also rejected the null omnibus hypothesis at all 4 levels of habitat availability (Table 1). The Mean rank MCP test, which tests a similar hypothesis as the Bonferroni confidence intervals in Neu's method, showed that AS was selected more then expected at the 100- and 200-m levels. Using our modified Johnson's method, we found that GF was not selected by poults at any level of availability.

The Friedman and Quade methods rejected the null omnibus hypothesis only at the level of total study area (Table 1). Both methods found GF selected relative to the 3 pine habitats (PA, PB, PC) at the total study area level. These results are somewhat different from the Neu method. Although the Friedman and Quade tests imply selection for the GF habitat, such selection was only over the pine habitats. The MCP did not identify GF as the most preferred habitat at this level.

Compositional analysis resulted in rejection of the null omnibus hypothesis only at the 200-m level (Table 1). The paired t-tests found AS the highest ranked habitat; PA, PB, and PC ranked the lowest, and GF ranked in between (Table 2). Compositional analysis also did not identify GF as the most important habitat for poults.

The permutation technique, MRBP, led to rejection of the null omnibus hypothesis at the 100-m, 400-m, and study area levels (Table 1). However, differences among habitats were apparent only at the 100-m availability, where AS was selected relative to PC. The MRBP technique also failed to find GF as a selected habitat.

DISCUSSION

These comparisons demonstrate that choice of method used to evaluate resource selection and how availability is determined affects inferences regarding habitat requirements for wildlife. When availability is defined as the whole study area, all the techniques, with the exception of compositional analysis, rejected the omnibus null hypothesis. After the MCP analysis, however, the set of habitat selection interpretations was unique to the method of resource selection used. This lack of agreement among methods is troubling but not surprising, as other studies have reported such disagreement (Alldredge and Ratti 1986, 1992; Manly et al. 1993).

If grass-forb is assumed the most important habitat, the Neu method yielded results consistent with poult habitat and dietary requirements. The Friedman and Quade methods at the study area level of availability also indicated that GF was an important habitat. However, these tests did not consistently find GF important at all levels of availability. The remaining methods for determining resource selection

Table 1. Test statistics for omnibus null hypotheses of no significant difference between used and available habitats (α = 0.05) and the appropriate multiple comparison procedure (MCP) if H_o was rejected.

Analysis method MCP	Estimate of habitat availablility 100-m buffer	200-m buffer	400-m buffer	Study area
Neu Bonferroni confidence intervals[a]	$\chi^2 = 15.2$ $P < 0.01$ More / None / Less GF / PB AS PC / PA	$\chi^2 = 20.2$ $P < 0.01$ More / None / Less GF / PB AS PC / PA	$\chi^2 = 25.6$ $P < 0.01$ More / None / Less GF / PB AS PC / PA	$\chi^2 = 86.7$ $P < 0.01$ More / None / Less GF / PB AS / PA PC
Johnson Mean rank test[a]	$F = 4.1$ $P = 0.03$ More / None / Less AS / PA PC PB GF /	$F = 4.9$ $P = 0.02$ More / None / Less AS / PA PC PB GF /	$F = 5.1$ $P = 0.01$ More / None / Less / PA GF PB AS PC /	$F = 11.8$ $P < 0.01$ More / None / Less / PA GF PB AS PC /
Friedman Studentized MCP[b]	$T_2 = 2.1$ $P = 0.09$	$T_2 = 2.0$ $P = 0.08$	$T_2 = 2.2$ $P = 0.08$	$T_2 = 3.7$ $P = 0.01$ PC PA PB AS GF
Quade Fisher's LSD[b]	$T_1 = 1.9$ $P = 0.12$	$T_1 = 1.8$ $P = 0.15$	$T_1 = 1.0$ $P = 0.40$	$T_1 = 2.6$ $P = 0.05$ PC PA PB AS GF
Compositional analysis	$F = 2.3$ $P = 0.13$	$F = 6.0$ $P = 0.01$ See Table 2.	$F = 2.7$ $P = 0.09$	$F = 1.2$ $P = 0.37$
MRBP Matched pairs test[b]	$\delta = -1.9$ $P = 0.05$ PA PB PC GF AS	$\delta = -1.4$ $P = 0.10$	$\delta = -1.9$ $P = 0.05$ PA PB PC GF AS	$\delta = -3.8$ $P < 0.01$ PC PA PB AS GF

[a] Selection of habitats more than, less than, or equal to availability.
[b] Selection of habitats that do not differ (α = 0.05) are underlined. Habitats are listed in increasing order of preference. Fisher's LSD and matched pairs test MCPs include a Bonferroni correction to the probability to maintain experimentwise error rates.

Table 2. Rank matrices for selection of habitats at 200-m buffers of habitat availability for compositional analysis.[a]

Habitats	PA	PB	PC	GF	AS	Rank 1[b]	Rank 2
PA		−	−	−	—	1	1
PB	+		+	−	—	3	1
PC	+	−		−	—	2	1
GF	+	+	+		−	4	4
AS	+++	+++	+++	+		5	5

[a] Elements in the matrix are replaced by + if selection is >0, − if selection is <0; triple signs indicate a significance from zero (paired *t*-test, $\alpha <$ 0.05).

[b] Ranks show in ascending order least to most selected habitats. Rank 1 depicts ranks of habitat selection if significance from zero is ignored, Rank 2 depicts ranks of habitat selection considering significance from zero.

suggest that patterns of habitat selection are dependent upon the method used for analysis.

Individual animals select habitats differently and in accordance with availability. The Neu method is relatively insensitive to individual variability because data are pooled. The other methods we evaluated treat individual animals as sample units and are affected by differences among animals both in habitat use and availability estimates. Neu's method is possibly less sensitive to individual variation in both use and availability estimates, which appears to be associated with greater consistency of results. The apparently desirable attribute that the ranking procedures (Johnson, Friedman, Quade) more closely approximate the precision of real data may be negatively balanced by inconsistent results associated with attention to individual variation.

Johnson's method at the 100- and 200-m levels, compositional analysis at the 200-m level, and MRBP at the 100-m level showed selection for aspen habitat. This pattern of habitat selection may have resulted from the shape and size of aspen habitats. Most of the aspen polygons were long and narrow and composed a small proportion of the study area; hence, there was seldom much total aspen habitat available within the buffers. As a result, infrequent selection of aspen habitat tends to differ from availability.

Aspen habitats had the second highest invertebrate abundance, but most invertebrates were rare in diets of poults (Rumble and Anderson 1996). Because hens do not nest adjacent to brood-rearing areas, hens with poults sometimes used aspen as travel lanes to meadows, and hens occasionally moved long distances to brood-rearing meadows (Rumble and Anderson 1993). Identification of AS as important is thus biologically plausible, but birds eventually terminated their movements when reaching large GF habitats.

We used circular buffers for assessing availability in an attempt to constrain habitat availability only to habitats accessible to birds. Turkeys are highly mobile, even at a young age; thus, we believe all habitats <200 m and probably those <400 m away were available from the standpoint of accessibility to hens with poults. Although there were exceptions, there was a general trend toward less difference between use and availability as buffer size declined. This trend was expected because use and availability ultimately become equal as the size of the availability buffer approaches the size of the bird location. Thus, there is a tradeoff between the confidence placed on the accuracy of habitats available to animals and the ability to detect statistical differences that infer selection of resources. Including habitats unavailable to animals increases chances for Type I errors of resource selection, but excluding habitats that are available to animals increases chances of Type II errors. In our study, however, use of circular buffers produced less sensitive results than use of the whole study area.

Given the degree to which the methods are affected by habitat availability, researchers should look critically at how availability is determined. Home range approximations have been used to assign habitat availability, but there was great difficulty in determining the home range boundaries for turkey poults in our study. The linear nature of their movements precluded assigning home ranges for any given individual. Further, even in ideal situations, not all habitats within a home range can be considered actually available. The hierarchical nature of habitat selection further complicates the situation. Estimation of availability for individual animals is necessarily "noisy" and imprecise, unless substantial data per individual are obtained. Availability at the study area level reduces animal-to-animal variation, but at the cost of possibly misrepresenting reality. Buffer size and shape estimates may be equally arbitrary decisions.

Another important consideration in the choice of a statistical method is whether the MCP adequately controls for experimentwise error. If Type I error protection is more important than Type II error protection, then experimentwise error is generally recommended (Hochberg and Tamhane 1987). Conversely, if Type II error is an important consideration, comparisonwise error may warrant more emphasis. In this case, since we were analyzing a group of habitats, we believe experimentwise error is the most appropriate.

Overall, Neu's method identified selection for GF across all levels of habitat availability tested. Friedman and Quade methods, at the study area level of habitat availability, ranked habitat selection patterns compatible with our assumption that poults select habitats with herbaceous vegetation to meet dietary requirements for protein. Johnson, MRBP, and compositional analysis did not suggest selection of GF habitats by hens with poults and were insensitive to patterns of selection by brood hens for our dataset.

The determination of availability should be carefully considered, albeit there presently is no simple criterion for such a determination. From our empirical results, it may be useful to include the study area level of availability in resource selection studies, no matter which statistical method is used.

ACKNOWLEDGMENTS

This research was supported by Cooperative Agreement 28-CR3-748 with the U.S. Forest Service Rocky Mountain Research Station, Fort Collins, Colorado. We thank J. R. Alldredge, R. W. Hoffman, D. H. Johnson, J. R. Squires, J. Pedlan, and an anonymous reviewer for comments on an earlier draft.

LITERATURE CITED

AEBISCHER, N. J., P. A. ROBERTSON, AND R. E. KENWARD. 1993. Compositional analysis of habitat use from animal radio-tracking data. Ecology 74: 1313-1325.

AITCHISON, J. 1985. The statistical analysis of compositional data. Chapman & Hall, New York, New York, USA.

ALLDREDGE, J. R., AND J. T. RATTI. 1986. Comparison of some statistical techniques for analysis of resource selection. Journal of Wildlife Management 50:157-165.

_____, AND _______. Further comparison of some techniques for analysis of resource selection. Journal of Wildlife Management 56:1-9

ALLDREDGE. W. A.. R. D. DEBLINGER. AND J. PETERSON. 1991. Birth and fawn bed site selection by pronghorns in a sagebrush-steppe community. Journal of Wildlife Management 55:222-227

BUTTERY, R. F., AND B. C. Gillam. 1983. Forest ecosystems. Pages 43-71 in R. L. Hoover and D. L. Wills, editors. Managing forested lands for wildlife. Colorado Division of Wildlife in cooperation with U.S. Forest Service, Rocky Mountain Region, Denver, Colorado, USA.

Conover, W. J. 1980. Practical nonparametric statistics. Second edition. John Wiley & Sons, New York, New York, USA.

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE. 1992. Understanding GIS: the ARC/INFO method. ESRI, Redlands, California, USA.

FLEISS, J. L. 1981. Statistical methods for rates and proportions. Second edition. John Wiley & Sons, New York, New York, USA.

HEALY, W. M. 1985. Turkey poult feeding activity, invertebrate abundance, and vegetation structure. Journal of Wildlife Management 49:466-472.

HEISEY, D. M. 1985. Analyzing selection experiments with log-linear models. Ecology 66:1744-1748.

HOBBS, T. N., AND T. A. HANLEY. 1990. Habitat evaluation: do use/availability data reflect carrying capacity? Journal of Wildlife Managment 54:515-522.

Hochberg Y., AND A. C. TAMHANE. 1987. Multiple comparison procedures. John Wiley & Sons, New York, New York, USA.

Hurst, G. A. 1992. Foods and feeding. Pages 66-83 in J. G. Dickson, editor. The wild turkey: biology and management. Stackpole Books, Harrisburg, Pennsylvania, USA.

JELINSKI, D. E. 1991. On the use of chi-square analyses in studies of resource utilization. Canadian Journal of Forest Research 21:58-65.

JOHNSON, D. H. 1980. Comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65-71.

JOHNSON, G. D., AND M. S. BOYCE. 1990. Feeding trials with insects in the diet of sage grouse chicks. Journal of Wildlife Management 54:89-91.

KINCAID, W. B., AND E. H. BRYANT. 1983. A geometric method for evaluating the null hypothesis of random habitat utilization. Ecology 64:1463-1470.

MANLY, B. F. J. 1991. Randomization and Monte Carlo methods in biology. Chapman & Hall, New York, New York, USA.

______, L. L. MCDONALD, AND D. L. THOMAS. 1993. Resource selection by animals: statistical design and analysis for field studies. Chapman & Hall, New York, New York, USA.

MIELKE, P. W., JR. 1986. Non-metric statistical analyses: some metric alternatives. Journal of Statistical Planning and Inference 13:377-387.

_____, AND K. J. BERRY.1982. An extended class of permutation techniques for matched pairs. Communications Statistics-Theorv Methods A 11: 1197-1207.

MILLER, R. G., JR. 1981. Simultaneous statistical inference. Second edition. Springer-Verlag, New York, New York, USA.

MORRISON, D. F. 1967. Multivariate statistical methods. McGraw-Hill, New York, New York, USA.

NEU, C. W., C. R. BYERS, AND J. M. PEEK. 1974. A technique for analysis of utilization-availability data. Journal of Wildlife Management 38:541-545.

ORIANS, G. H., and J. F. WITTENBERGER. 1991. Spatial and temporal scales in habitat selection. American Naturalist 137:S29-S49.

PEREIRA, J. M., AND R. M. ITAMI. 1991. GIS-based habitat modeling using logistic multiple regression: a study of the Mt. Graham red squirrel. Photogrammetric Engineering and Remote Sensing 57: 1475-1486.

PORTER, W. F. 1992. Habitat requirements. Pages 202-213 *in* J. G. Dickson, editor. The wild turkey: biology and management. Stackpole Books, Harrisburg, Pennsylvania, USA.

______, AND K. E. CHURCH. 1987. Effects of environmental pattern on habitat preference analysis. Journal of Wildlife Management 51:681-685.

ROBBINS, C. T. 1983. Wildlife feeding and nutrition. Academic Press, New York, New York, USA.

RUMBLE, M. A. 1990. Ecology of Merriam's turkeys (*Meleagris gallopavo merriami*) in the Black Hills, SD. Dissertation, University of Wyoming, Laramie, Wyoming, USA.

______, AND S. H. ANDERSON. 1992. Stratification of habitats for identifying habitat selection by Merriam's turkeys. Great Basin Naturalist 52:1-6.

______, AND ______. 1993. Habitat selection of Merriam's turkey hens with poults in the Black Hills, South Dakota. Great Basin Naturalist 53:131-136.

______, AND ______. 1996. Feeding ecology of Merriam's turkeys (*Meleagris gallopavo merriami*) in the Black Hills, South Dakota. American Midland Naturalist 136: 157-171.

STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES. 1993. SPSS for windows: base system user's guide. Release 6.0. SPSS, Chicago, Illinois, USA.

TANGRI, D., AND R. V. S. WRIGHT. 1993. Multivar- analysis of compositional data: applied comparisons favour standard principal components analysis over Aitchison's loglinear contrast method. Archaeometry 35: 103-l 12.

THOMAS, D. L., AND E. J. TAYLOR. 1990. Study designs and tests for comparing resource use and availability. Journal of Wildlife Management 54: 322-330.

Received 20 March 1996.
Accepted 29 April 1997.
Associate Editor: McDonald.