The Effects of Changing Weighting Factors on Wildlife Habitat Index Values: A Sensitivity Analysis

Joel T. Heinen
School of Natural Resources, University of Michigan, Ann Arbor, MI 48109
John G. Lyon
Department of Civil Engineering, The Ohio State University, Columbus, OH 43210

ABSTRACT: The effects of changing model weighting factors on the species-specific calculation of a qualitative juxtaposition index are assessed. The index used here was first developed by Mead *et al.* (1981) to aid in meeting legal mandates to assess wildlife habitat quality over remote areas. The results indicate that, as more weighting factors were increased above threshold values, index values over test maps also increased. The results of these threshold tests were highly dependent on the spatial distribution of the original cover type map. This work has important theoretical and practical implications in the area of resource management.

INTRODUCTION

THE DETERMINATION of variable characteristics or benchmarking is a necessary element of modeling in geographic information systems development. Sensitivity analyses characterize the impact of the contribution of individual variables on model ratings. Knowledge of variable behavior allows for better simulations and can lead to improved verification of model quality.

Mead *et al.* (1981) proposed a habitat analysis technique designed for use with raster-format data, such as Landsat, which can potentially provide for rapid analysis over large areas covered by satellite borne sensor systems. Heinen and Cross (1983) discussed the use of this system in small management units as well. The approach described by Mead *et al.* (1981) is beneficial in that it meets legal mandates, is mathematically simple, and can be used to simulate management prescriptions to assess impacts on habitat quality (Heinen and Mead, 1984).

Variable behavior was examined in this study to better utilize the model proposed by Mead *et al.* The objectives were to test the influence of edge type of land covers, the relative weighting of variable contributions to the model, and the random assortment of cover types on model ratings.

BACKGROUND

The spatial distribution of habitat types is considered to be very important for overall habitat value. Leopold (1933) defined the edge effect as a response of wildlife species to community junctions. Odum (1971) defined it as a tendancy for increased diversity and abundance of species in such areas. However, the edge effect may vary greatly for different species. For example, certain types of community junctions may be very beneficial for some species but not others. Also, some species prefer monotypic habitat and may actually decrease in abundance near community edges (e.g., Lovejoy *et al.*, 1986; Yahner, 1986).

For these reasons, qualitative weighting factors are used in analyses and hence must be tested to understand their characteristics and sensitivity to individual variables. Sensitivity analyses are needed for such models before they can be widely implemented (Lyon *et al.*, 1987).

An important concern is how changes in model parameters affect the mathematical calculations of a model. It is important to consider how sensitive the model may be to changes in its parameters, and how the weighting factors are chosen when applying such models to wildlife species. In this paper, we explored the effects of changing edge weighting factors in the calculation of the juxtaposition index proposed by Mead *et al.* (1981).

JUXTAPOSITION AND ITS CALCULATION

Juxtaposition was defined by Giles (1978) as some measure of the proximity of different habitat types. Most attempts at juxtaposition measurements include relative weighting factors assigned by the importance of the adjacency of two cover types for the species in question. Using this approach, juxtaposition is a species-specific measurement for reasons discussed above. This is an important distinction.

Interspersion, as defined by Giles (1978), is a measurement of the spatial intermixing of habitat types and it can be calculated in a non species-specific manner. Areas of high interspersion may, for example, hold more species due to edge effect, but may represent poor habitat for some species of interest. This should be reflected in the edge weighting factors chosen for the juxtaposition index for the selected species in the area. Other examples of species-specific analyses are give by Isaacson *et al.* (1982) and Ormsby and Lunetta (1987).

Furthermore, juxtaposition calculations are sight-specific because the critical habitat characteristics of a single species may vary in different regions. This is especially true of wide ranging species such as many large game animals (e.g., white-tailed deer). Qualitative weighting factors have been used extensively in wildlife habitat analysis procedures (e.g., Roller, 1978; Lyon, 1983).

The calculation of juxtaposition using Mead's (1981) model has been described elsewhere. It is briefly presented here for clarity. Juxtaposition (*Jx*) is calculated by a "moving window" technique with respect to a central cell in raster-format data.

Consider the example in Table 1, where A, B, and C represent different cover types. *Jx* for the central cell (designated B) was calculated by multiplying the quantity of that particular edge type by a qualitative weighting factor for each edge type, and adding the total. In this model, diagonal edges counted as one and vertical or horizontal edges counted as two because the distance over which the two types meet is greater for the latter type of edge. The grand total was then divided by 12 to constrain the *Jx* index to values between 0 and 1. In the analysis

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 55, No. 10, October 1989, pp. 1445-1447.

0099-1112/89/5510–1445$02.25/0

TABLE 1. AN EXAMPLE CALCULATION OF *Jx* USING THE METHOD PROPOSED BY MEAD ET AL. (1981). A, B, AND C REPRESENT DIFFERENT COVER TYPES. *Jx* IS CALCULATED WITH RESPECT TO THE CENTRAL CELL (B IN THIS CASE). THE WEIGHTING FACTORS MAY ASSUME VALUES FROM 0 TO 1. THE TOTAL IS THEN DIVIDED BY 12 TO CONSTRAIN THE INDEX TO VALUES BETWEEN 0 AND 1. HORIZONTAL OR VERTICAL EDGES COUNT AS 2, WHILE DIAGONAL EDGES COUNT AS 1.

			Edge type	Quantity	Weight	Total
A	C	B	B/A	3	0.30	0.90
A	B	B	B/B	4	0.60	2.40
C	C	B	B/C	5	0.25	1.25
					Grand total =	4.55
					Jx = 4.55/12 =	0.38

presented here, the range of *Jx* values was further subdivided to categories of low (0.00 to 0.33), medium (0.34 to 0.67), and high (0.68 to 1.00) juxtaposition for statistical analysis.

Also note that weighting factors can be assigned for the adjacency of two cells of the same cover type designation (the B/B edge in Table 1). This B/B interface is not an edge in the ecological sense, but rather the edge of two cells. This edge measurement capability is important for species-specific analyses because some species prefer homogeneous over heterogeneous areas.

METHODS

The two thresholds considered in this analysis were between low and medium index values (0.33), and between medium and high index values (0.67). The input maps used to generate base maps contained five cover types, and the proportion of cells comprising each cover type was approximately equal. The cover types were aggregated in space to simulate natural community types in the first input map, and were randomly distributed in the second input map.

Base maps of *Jx* were generated by assigning weighting factors to all edges below the threshold value. For example, all weighting factors were assigned a value of 0.20 to generate a base map to test between low and medium *Jx*, and a value of 0.50 to generate a base map to test between medium and high *Jx*. The five cover types on the input data resulted in a total of 15 possible edge types, as weighting factors may be assigned to the adjacency of cells containing the same cover type.

A designated number of weighting factors was then changed above the threshold value on a total of five different test maps for each of the two threshold tests. These test maps were generated by increasing (1) one, (2) two, (3) three, (4) five, and (5) seven out of the total of 15 possible weighting factors. In the case of the low to medium threshold test, the designated number of weighting factors was changed from 0.20 to 0.40, and in the case of the medium to high threshold test, weighting factors were changed from 0.50 to 0.70.

The chi-square test of homogeneity (Feinberg, 1980) was used in each case to test the null hypothesis that changing the designated number of weighting factors does not change the proportion of cells classed as low *Jx* (low to medium threshold test) or medium *Jx* (medium to high threshold test).

Another way to look at the effects of changing these factors on the resultant *Jx* index is the calculation of an adjusted index for the entire base and test maps. The adjusted *Jx* index is calculated by the following formula:

$$Jx_{adj} = \frac{1\,(\text{number of low } Jx \text{ cells}) + 2\,(\text{number of medium } Jx \text{ cells}) + 3(\text{number of high } Jx \text{ cells})}{\text{Total number of cells}}$$

The adjusted index values for *Jx* range between 1.00 and 3.00. Higher adjusted *Jx* values indicate higher overall values of *Jx* over the entire area represented by the map. This allowed for a qualitative assessment of the overall effect on the index value when a single parameter in the input data is changed.

RESULTS

The results indicated that, as additional weighting factors were increased beyond the threshold value in the low to medium test, the chi-square results were higher, tending more toward the rejection of the null hypothesis (Table 2). Note that there were two test maps generated by changing two weighting factors in Table 2.

In one case (map 2), the weighting factors for non-similar cover types were increased. In the other case (map 3), the weighting factors for one similar and one non-similar cover type were increased. Due to the non-random distribution of cover types on the original map, each cell had a greater possibility of being located next to a cell of the same cover type than by any of the other four cover types. Therefore, when cells dominated by the same cover type were given higher weighting factors, this tended to greatly increase *Jx* for the area regardless of the number of weighting factors that were changed. This was also seen in the adjusted *Jx* values (Table 3) which were higher for Map 3 (with only two weighting factors changed) than for map 4 (with three weighting factors changed).

The low to medium threshold test was then repeated using the second base map in which the distribution of the five cover types was random. There was, again, a general trend toward increasing chi-square values as the weights of additional cover types were increased above the threshold value (Table 4). However, in this instance test maps 1 and 3 produced *Jx* totals identical to the base map, resulting in a chi-square value of 0.00. Test map 3 was again derived by assigning the higher weighting factors to the adjacency of one similar and one non-similar cover type combination.

The input data were the cause of these differing results when compared to the previous low to medium threshold test. Because the input data were randomly generated, no cell had a greater probability of being located next to any other cell dominated by the same cover type. Therefore, test map 3 was not

TABLE 2. CHI-SQUARE RESULTS FOR THE LOW TO MEDIUM THRESHOLD TEST USING THE FIRST (NON-RANDOM) BASE MAP.

Test map	Number of weights increased	p-value
1	1	$0.25 > p > 0.1$
2	2	$0.25 > p > 0.1$
3	2	$p < 0.005$
4	3	$p < 0.005$
5	4	$p < 0.005$
6	7	$p < 0.005$

TABLE 3. ADJUSTED *Jx* VALUES FOR THE LOW TO MEDIUM THRESHOLD TEST USING BASE MAP 1. THE VALUES INDICATE THE INCREASING TRENDS FOR *Jx* AS MORE WEIGHTING FACTORS ARE CHANGED.

Map	Number weights increased	Adjusted *Jx*
Base	0	1.00
1	1	1.01
2	2	1.01
3	2	1.14
4	3	1.04
5	4	1.18
6	7	1.30

TABLE 4. CHI-SQUARE RESULTS FOR THE LOW TO MEDIUM THRESHOLD TEST USING THE SECOND (RANDOM) BASE MAP.

Test Map	Number of weights increased	p-value
1	1	1.0
2	2	$p<0.005$
3	2	1.0
4	3	$0.5>p>0.25$
5	4	$p<0.005$
6	7	$p<0.005$

TABLE 5. CHI-SQUARE RESULTS FOR THE MEDIUM TO HIGH THRESHOLD TEST USING THE FIRST (NON-RANDOM) BASE MAP

Test Map	Number of weights increased	p-values
1	1	$p = 0.9$
2	2	$p = 0.9$
3	2	$p<0.005$
4	3	$p<0.005$
5	4	$p<0.005$
6	7	$p<0.005$

expected to inflate the test statistic as it did in the previous case. This expectation was supported by the chi-square results (Table 4), but test map 3 produced a lower test statistic than test map 2. This probably represented an anomoly on the input data and was not expected.

The input for the medium to high threshold test was the same as that used for the first low to medium threshold test (Table 5). Test map 3 was also generated by assigning the higher weighting factor (0.70 in this case) to the adjacency of one similar and one non-similar cover type combination, which inflated the test static as in the previous (first low to medium) example. The general trend of greater differences as additional weighting factors were increased above the threshold value was once again demonstrated in the medium to high threshold test.

DISCUSSION

The results of the threshold tests were highly dependent on the original input data. Because of this, there are no conclusions which can be drawn concerning a number or proportion of weighting factors which, when increased, will yield significant differences in *Jx* values. However, the general trends observed in these tests should be true regardless of the spatial characteristics of the input data.

The trends here show that, as more weighting factors were changed, the test maps were increasingly different from the base map. The results of this sensitivity analysis indicated that rather small changes in the input data can lead to significantly different *Jx* values.

There are various problems inherent in simulations using models of this sort. In general, these problems arise from the initial spatial arrangement of cover types on the input data and the methods employed in selecting weighting factors. In this respect, results would vary as the initial number of cover types, the average size of areas dominated by one cover type, and the spatial aggregation of cover types changed.

Of concern to resource managers is how to choose the appropriate initial weighting factors. In the future it may be necessary to test weighting factors directly with biological data, such as home range size and habitat use, in areas for which detailed cover type information is available. Until such time, choosing appropriate factors is problematic.

Based on the *Jx* index, it is possible to compare the value of two or more areas for any species. The qualitative nature of such indices will not allow the prediction of the density of animals in an area based on habitat criteria alone. However,the qualitative predictive ability made possible with this approach is generally all that is needed for multiple-use management objectives such as those of the U.S. Forest Service. If management objectives are general, this approach is warranted. In other cases (e.g., critical habitat designation for endangered species) more detail is needed.

ACKNOWLEDGMENTS

We would like to thank Drs. R.A. Mead, J.L. Smith, G.H. Cross, and T.L. Sharik for comments and criticism regarding this work. The effort was made possible through a grant from the U.S. Forest Service Nationwide Applications Center, Houston Texas to Dr. R.A. Mead as part of the first author's graduate research at Virginia Polytechnic Institute and State University, School of Forestry and Wildlife Resources, Blacksburg, Va. Special thanks go to Dr. P. Weber and M.J. Bell of the Houston Office for critical reviews. We would also like to thank the administration and staff of our current home institutions for making this work possible, and two anonomous reviewers who provided many helpful comments.

REFERENCES

Feinberg, S.E., 1980. *The Analysis of Cross-Classified Data*. MIT Press, Cambridge, Mass. 198 p.

Giles, R.H., Jr. 1978. *Wildlife Management*. W.H. Freeman and Co., San Francisco, California. 416 p.

Heinen, J.T., and G.H. Cross, 1983. An approach to measure interspersion, juxtaposition, and spatial diversity from cover type maps. *Wildlife Soc. Bull.*, 11:232–237.

Heinen, J.T., and R.A. Mead, 1984. Simulating the effects of clear-cuts on deer habitat in the San Juan National Forest, Colorado. *Can. J. Rem. Sens.* 10(1):17–24.

Isaacson, D.L., D.A. Leckenby, and C.J. Alexander, 1982. The use of large-scale aerial photography for interpreting Landsat data in an elk habitat-analysis project. *J. Appl. Photogr. Engrg.* 8:51–57.

Leopold, A., 1933. *Game Management*. Charles Scribner's Sons. New York. 481 p.

Lyon, J.G., 1983. Landsat-derived land cover classification for locating potential kestrel nesting habitat. *Photogrammetric Engineering and Remote Sensing* 49:245–258.

Lyon, J.G., J.T. Heinen, R.A. Mead, and N.E.G. Roller, 1987. Spatial data for modeling wildlife habitat. *J. Surv. Engrg.* 113(2):88–100.

Lovejoy, T.E., R.O. Bierregaard, A.B. Rylands, J.R. Malcolm, C.E. Quintela, L.H. Harper, K.S. Brown, A.H., Powell, G.V.N. Powell, H.O.R. Schubart, and M.B. Hays, 1986. Edge and other effects of isolation on Amazon forest fragments. *Conservation Biology* (M.E. Soule, ed). Sinauer Associates, Sunderland, Mass.

Mead, R.A., T. Sharik, S. Prisely, and J.T. Heinen, 1981. A computerized spatial analysis system for assessing wildlife habitat from vegetation maps. *Can. J. Rem. Sens.* 7(1):34–40.

Odum, E.P., 1971. Fundamentals of Ecology. W.B. Saunders Co. 546 pp.

Ormsby, J.P., and R. Lunetta, 1987. Whitetail deer food availability maps from thermatic mapper data. *Photogrammetric Engineering and Remote Sensing* 8:1081–1085.

Roller, N.E.G., 1978. Quantitative evaluation of deer habitat. *Pecora IV*. National Wildlife Federation. Scientific and Technical Series 3.

Yahner, R.H., 1986. Spatial distribution of white-footed mice (*Peromyscus leucopus*) in fragmented forest stands. *Proc. Penn. Acad. Sci.* 60:165–166.

(Received 23 January 1989; accepted 29 March 1989; revised 12 April 1989)