SITE AND SPECIES SPECIFIC WILDLIFE HABITAT ASSESSMENT

by

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ABSTRACT

INTRODUCTION

This document contains three manuscripts presented to the graduate faculty of the School of Forestry and Wildlife Resources of Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of Master of Science in Fisheries and Wildlife Sciences. These manuscripts were submitted in lieu of a standard thesis in agreement with the Graduate Committee.

The first manuscript is a sensativity analysis conducted on the wildlife habitat analysis system proposed by Mead et al. (1981). The second manuscript describes the use of that habitat analysis system in a diverse area which was type mapped from large scale color infrared aerial photography. This was submitted for publication to The Wildlife Society Bulletin and is presently in the review process. The third manuscript describes the simulation of different sizes and shapes of clearcuts and their predicted effects on deer habitat in an 1800 acre area in the San Juan National Forest, Colorado. This illustrates the potential for this habitat analysis system to be used in the planning process by the Forest Service as mandated by some recent legislation. This paper was submitted to the Journal of Forestry, and is also now in the review process.

This document is arranged such that each manuscript comprises a separate chapter. An introduction and methods, results, and discussion sections are provided within the body of each manuscript. The literature citation for each chapter is provided at the end of that respective chapter.

CHAPTER 1

A Sensativity Analysis of the Site and Specific Wildlife Habitat Analysis System Proposed by Mead et al. (1981)

Section 1

Introduction

As human population densities and demands for land resources increase, so does the need to develop effective means of evaluating wildland resources and wildlife habitat in areas designated, in part, for this purpose. This need was specifically addressed in the Resources Planning Act of 1974 (Mead et al. 1981). As a result, multiple use agencies within the United States have recently implemented procedures of evaluation and inventory of natural areas. For example, the Forest Service released its preliminary Wildlife Habitat Management Handbook in 1971, which includes habitat requirements of selected wildlife species to be used in selecting a featured species for each tract of land managed by the agency in the southern region. The U. S. Geological Survey has addressed similar concerns in its implementation of a wetland habitat classification scheme (Stewart et al. 1980).

Various remote sensing technologies have gained wide acceptance in the field of wildlife management (Colwell 1978). Such technologies have been applied to both population and habitat inventories. Some problems have been addressed in habitat inventories and research is needed in the refinement of habitat analysis. Despite this, operational habitat analysis systems relying on remotely sensed information have been implemented by Kansas Forestry, Fish and Game Commission (1976), the Texas Department of Parks and Recreation (Frye 1978) and the Tennessee Valley Authority (Davis 1980), to name a few.

Many state and federal agencies have the responsibility of managing large areas of land for multiple use. This elucidates the utility of computer evaluation of data collected to assess the status of such areas. In many instances, the advent of computer technology has made large-scale land use inventories and habitat evaluation feasible. The computer aided system called IMGRID, for example, was developed at Harvard (Sinton 1976), and has proven particularly effective in multiple use area evaluation. It is presently used by T.V.A., where it has been applied to wildlife habitat evaluation (Davis 1980).

The use of various remote sensing procedures coupled with computer technology has facilitated great strides in habitat evaluation. This does not, however, eliminate the need for ground truthing (Carter and Garrett, 1977). The ultimate decision of the goodness of an area for any particular purpose rests on an educated land use manager. This reflects on possible errors in classification of cover types by landsat, or interpretation errors by people working with aerial photography. These factors stress the importance of accuracy measurements in studies relying on remotely sensed information systems (Frentress and Frye 1975). The potential sources of error should, therefore, be addressed in any habitat assessment procedure.

The main assumptions underlying any system designed to assess habitat is that all the land under consideration has some wildlife habitat value, and that this value can be quantified (Daniels and Lemaire 1974). Indices developed to assess habitat should ideally produce consistent results with an acceptable margin of error, compare well with other indices designed to assess similar relationships, and be constructed so as to be easily and economically useful to practicioners of land management.

The Forest Service is now legally mandated to maintain diversity of plant and animal communities in accordance with multiple use objectives. This concern is to be considered throughout the planning process (Federal Registrar 1979). The agency is, therefore, interested in testing economic and expedient methods of measuring diversity in natural communities.

The major objective of this study is to test a proposed index (Mead et al. 1981) designed to measure spatial relationships as an index of wildlife habitat quality. The index is species specific and is a function of interspersion, juxtaposition, and the presence of exclusion factors within the area, and for the species in question (see Appendix I).

A sensitivity analysis will be conducted to determine how changes in various parameters affect the index value. These parameters include: cell size, cell shape, number of cover types, weighing factors, and classification accuracy.

Section 2

Literature Review

Section 2.1

Vegetation Classification

Two major problems inherent in vegetative classification schemes is whether classification is appropriate, and under what conditions may the use of any scheme be warranted. Two major conflicting theories regarding these problems were described by McIntosh (1967). These include:

1) The Community Concept of Vegetation, which asserts that vegetation is composed of well-defined units which can be grouped naturally into communities. Classification schemes in this case would follow a natural order.

2) The Continuum Concept of Vegetation, which states that plant communities are not discrete. Any classification scheme would in this case be arbitrary.

It is possible that in presettlement times the structure of plant communities may have more closely approximated that expected by the Continuum Concept. For the purposes of this study, however, it shall be assumed that classification is appropriate and communities are definable, and, therefore, the Community Concept is valid. This assumption is a direct result of land management and other activities imposed on land resources by modern man. Forest Service land, for example, may readily be classified by age of stands, clearcuts, and burning activities. This may be accomplished by conducting site observations, or by reviewing the agencies' management prescription records for the areas under consideration.

Despite the potential sources of error in vegetative classification, various proposed systems have been proven effective. Vegetative type maps developed by the state of Texas, for example, have been used to determine acreages of various cover types and changes in land use. There is a potential in this system for predicting future changes in land use, and the system has been used as an aid in management decision making (Frye et al. 1978). Type-mapping has been conducted extensively on the Great Dismal Swamp, and Carter and Garrett (1977) cite the utility of using Landsat and color infrared photography in monitoring future vegetative changes in this 84,890 hectare wildlife refuge. In both the aforementioned studies, the relative ease of classification was probably due to habitat alteration by human means. For reasons previously mentioned, classification may prove to be more difficult in large, unaltered ecosystems.

The method of classification is the major concern in any study regarding the distribution of vegetative types. Classifications systems must be developed which are biologically meaningful. This criterion may vary greatly depending on the nature and location of the study.

Section 2.2

Spatial Distribution of Habitat

Various concepts concerning the spatial distribution of habitat have been discussed in reference to their importance for wildlife. Included in these are the edge effect, ecotone, zone of influence, interspersion, and juxtaposition. Each is addressed below.

The edge effect describes a response by organisms to community junctions (Leopold 1933). This is defined by Odum (1971) as the tendency for increased variety and density at community junctions. This definition is very general, and the effect itself may vary greatly between species. The edge effect is most pronounced among animals with relatively low mobility and diverse ecological requirements (Leopold 1933). Some more recent publications indicate that species diversity for various taxa is directly proportional to habitat diversity. These include studies by Pianka (1966) on desert lizards, and Recher (1969) on various bird species. Leopold (1936) explains game abundance as a consequence of edge. He further clarifies this by stating that game abundance should increase in situations where various food and cover types can be found in close proximity. This clarification is warranted, as edge, in itself, is probably not the key factor. The occurrence of the biological requirements for a species within a relatively small area is the main concern. Animals must be capable of reaching such requirements daily, or nearly so (Leopold 1933).

We may expect any natural community to have some potential for the maintenance of wildlife, but the degree to which this is true may vary greatly in different plant communities, and with different wildlife species. An animal may be limited to more specific areas within its broad geographical range by various ecological factors. It is the combination of these factors which defines the animal's habitat (Rekas 1978).

The term ecotone, commonly discussed in combination with the edge effect, has been loosely applied but refers generally to a gradation between two plant communities (Odum 1971). This transition may take on a variety of characteristics depending on the environmental characteristics of an area, or the amount of human disturbance. Odum (1971) describes forest edges as being among the most important ecotones for human concerns. This statement may reflect the fact that large, well-defined forest edges are usually the result of human activities such as timbering practices and agriculture. A similar, but much less pronounced, natural phenomenon is the creation of light gaps in forest communities. It is probable that few natural cases exist in which ecotones are as well-defined as those created by human disturbance, though some exceptions occur (Spurr and Barnes 1973).

Giles (1978) describes the concept of 'zones of influence' emanating from a habitat edge or point habitat. Some examples of the latter include patches of food or cover, or water sources in otherwise relatively homogenous areas. He defines this term as a distance over which wildlife is attracted, from which views are possible, or from which behavior may emanate. It can readily be pointed out that the zone of influence surrounding any edge depends largely on the mobility of the organism in question. This concept and that of the edge effect are closely interrelated.

Interspersion and juxtaposition are terms which in their usual context refer to measurements of the spatial relationships of habitat types. Giles (1978) refers to interspersion as a measurement of the spatial intermixing of habitat types, and to juxtaposition as some measure of the proximity of different habitat types. Thus, an area of high interspersion would be characterized as having a good distribution of cover types in space, while an area of high juxtaposition would be one in which different cover types are found adjacent to one another frequently. Most attempts at species specific juxtaposition measurement include relative weighting factors assigned by the importance of the adjacency of two cover types for the species in question (Roller 1978). Interspersion and juxtaposition within an area may vary in a directly proportional manner, but this is not necessarily the case. Species specific juxtaposition measurement may be low in an area of high interspersion if the weighting factors of the adjacent habitat types are low. The habitat quality of an area for any species can thus be considered a function of both juxtaposition and interspersion.

Section 2.3

Habitat Assessment Procedures

Williamson et al. (1978) define habitat evaluation as a process of assigning a qualitative rating to a given area based on how well that area meets the requirements of the wildlife species under consideration. Habitat analysis may be divided into two broad categories: site and non site-specific. Site-specific analysis includes that in which classification is is complete throughout the area in question, while non site-specific analysis includes analysis which attempts to provide gross estimates of habitat types, without addressing all components within an area (Meyer 1978).

Various procedures have been utilized in assessing habitat. There is an increasing trend in both public and private sectors in the use of remote sensing in site-specific analyses (Meyer 1978). Many of these analyses are not uniform in that they test different relationships with varying degrees of success. Roller (1978) devised a rather successful technique for obtaining habitat conditions for white-tailed deer on the University of Michigan's George Reserve. This consisted of evaluating trends for habitat changes based on interpretation and comparisons of old and new aerial photos. In many situations, however, this procedure may be impractical. Accurate records of the George Reserve are available due to the large amount of research conducted in this two square mile enclosure. This may not be the case over many broad areas. In other studies, computer simulation of vegetation changes has been used to predict future vegetational characteristics (Williamson et al. 1978).

Ffolliet and Rasmussen (1978) developed a habitat ranking (HABRAN) procedure designed to estimate the impact of management decisions on available habitat. The authors include species response functions which are graphs of the potential habitat rating vs. percent crown closure, and indicate that the functions are both species and ecosystem dependent. Correlations between crown closure and habitat potential are important, but this fails to address the multitude of other spatial variables which may be equally pertinent. This work may prove most adequate in providing gross estimates of suitability in areas with lumbering activities. Habitat data bases need not include all environmental factors within an area to be useful (Russell et al. 1980). Economic constraints may, in some cases, put limitations on data collection. It is, however, an over-simplification to rank habitat by one parameter alone.

Rekas (1978) provides guidelines for habitat analysis. His criteria include:

Identification of habitat requirements for the species in question.

Location of these requirements within the study area.

Preparation of map overlays showing the extent of each factor in the study area.

Preparation of composite map.

Verification of composite map.

These procedures are generally consistent with those used in other studies. However, the use of a resource within an area by any particular animal may change depending on the nature of the resource. For example, if one assumes that white-tailed deer require water, the nature of the water source would be of prime importance in determining its suitability for the deer in question. The water may be stagnant vs. free-flowing, seasonal vs. permanent, or brackish vs. fresh, and these variables may alter the importance of the water source for deer. A more thorough analysis would include the attempt to quantify the habitat potential for the species in the area in question. This may include the assignment of relative rankings of various resources within an area, depending on their importance for the species in question. Recognition and numerical assignment of exclusion factors may further improve habitat analyses.

Davis (1980) describes the use of IMGRID by the T.V.A. in determining fall and spring habitat suitability for wild turkey. Those habitat components of most importance for the turkey must first be recognized and assigned weights. The components include hard mast, soft mast, greens, insect availability (important in spring only), presence of surface water, escape cover, and roosting sites. Proximity analyses were conducted which measured distance to water and distance to roosting sites. The distances over which turkey will travel to these requirements are assumed to vary seasonally. All components must be located within one square mile. Weights were then assigned on a relative scale increasing with their importance to the turkey. The implementation of the IMGRID program then sums all components within each cell. Those cells with higher final values are thus designated as representing areas of better turkey habitat. This method is reported as being very effective.

Katibah and Graves (1978) describe another method used to designate turkey habitat which involves the recognition of vegetative associations using Landsat II imagery. Areas known to contain viable turkey populations were used as training sets so the researchers could learn to recognize the vegetative associations which the turkey preferred. This is a relatively inexpensive method, but can only produce rough approximations in designating good habitat when compared to the method previously described. The ability to define those components most important to the animal in question is of prime importance in habitat evaluation (Davis 1980). This ability may diminish using only small scale Landsat imagery.

Pettinger et al. (1978) describe the Habitat Evaluation Procedure (H.E.P.) developed by the Fish and Wildlife Service. Curves were presented in this study which consist of environmental parameters on the x-axis (such as distance to cover or water, forage availability, etc.), and a Habitat Suitability Index (HSI) ranging from 0 to 1 on the y-axis. The product of the habitat quality (HSI) and the habitat quantity (area) produces the total amount of Habitat Units (H.U.) for each vegetation type in the study area. The H.U.'s for elk and sage grouse were determined by measuring the important parameters from high altitude color infra-red photography (scales of 1:15,000 to 1:20,000 were used). One problem with this study is that the habitat value for sage grouse using remotely sensed information alone was inconsistent with that obtained from the total inventory data sets, which combined both remotely sensed data sets as well as ground inventory data sets. This discrepancy presumably was the result of some habitat parameters for grouse being inadequately measured by such small scale photography. The comparative values for elk were consistent between data sets. Larger scale photography and ground truths may, therefore, be increasingly important in designating habitat for small vs. large game.

The location and designation of potential prairie dog habitat is described by Rekas (1978). Information on slope, soil characteristics, and vegetation associations was used. The vegetation was interpreted from 1:20,000 black-and-white photography. Slope and soil characteristics were obtained from soil survey maps of the area. Ninety-three percent of existing prairie dog colonies were located within areas designated as potential prairie dog habitat. In this case, the soil characteristics are probably the major factor in habitat identification for this small burrowing mammal. Also, the social structure of the prairie dog (large colony sizes) may permit easier identification of habitat than is the case with many other small animals. This illustrates the importance of having knowledge of many aspects of a species' biology before effective habitat assessment is possible.

The Forest Service is attempting to meet the requirements of timber and wildlife in national forests of the Southern Region with the implementation of the featured species program (Holbrook 1974).

The biological requirements of the featured species in an area are used in part to determine the silvicultural practices to be used on the unit. Detailed descriptive analyses are available from the Forest Service which specify habitat requirements of game animals in different regions (USDA Forest Service 1971).

Various edge indices have been proposed in the recent wildlife literature. Schuerholz (1974) describes a method of determining the total edge in an area by using the total number of edge points encountered on transects drawn over aerial photographs. The transects may be horizontal, vertical or radial lines. The radial lines produced the highest correlation between edge length on the photo (x-axis, in cm.) and the total number of edge points (y-axis).

Morrison (1972) describes an edge index determined by dividing the sampling area into a grid and drawing diagonals within each cell. The edge index (I) can be calculated by counting the number of cover changes along the diagonals, and is expressed as the number of cover type changes per unit area.

There is unfortunately a dearth of information on the relationship of total edge in an area to animal populations the area may support (Taylor 1977). We may expect an increase in the number of species in areas with greater amounts of edge (Odum 1971), but for reasons previously discussed, edge in itself yields little information on habitat quality for most species (see section on Spatial Distribution of Habitat).

Roller (1978) used edge relationships to calculate juxtaposition. This was accomplished by determining the linear distance associated with different kinds of edge, and multiplying this distance by an edge weighting factor. The product is then divided by the total amount of edge occurring in an area. This index is probably more realistic than total edge alone, as it allows the weighting of various edge combinations depending on the importance of the edge type for the species in question.

Edge is, of course, only a linear relationship, and habitat evaluation studies should focus primarily on area. Roller (1978) included a shape factor which he determined by dividing the edge length by $2\sqrt{\text{Area }\pi}$. This is used to normalize the shape of the significant cover type to that of a circle. This procedure, however, can only yield approximate analysis and the error margin would increase as more cover types in an area deviate from circular form.

Other spatial considerations in habitat analysis include the size and shape of grid cells used to delineate an area. The mobility and home range size of an organism should ideally be used in determining grid cell size. Shape may be important if different shaped cells produce different results in calculating interspersion. Hexagonal cells have been effectively used in some habitat studies (Keller et al. 1978), and discussed in other publications (Giles 1978). There have been no studies to my knowledge which compare hexagonal or triangular cells with square cells in the calculation of interspersion or juxtaposition. Most studies employ grids with square cells apparently as a matter of convention.

Section 3

Procedures, Results, and Discussion

This section outlines the procedures and results of the testing of five hypotheses on the calculation of the indices proposed by Mead et al. (1981). A discussion on the utility and limitation of each test is also included in the subsection for that test. The five tests and the index (indices) on which each was completed are as follows:

1. The test of changing cell size on the computation of interspersion.
2. The test of changing classification similarity on the computation of interspersion.
3. The test of changing the level of classification (i.e., the number of cover types) on the computation of interspersion.
4. The test of changing cell shape on the computation of interspersion.
5. The test of changing weighting factors on the computation of juxtaposition and spatial diversity.

In each of the five cases listed above, the variable to be evaluated is changed on the input data. The input data consist of a representation of a cover type map digitally coded into a computer. The program which calculates the indices is then implemented on both the base map (no change in the input data) and the test map (one parameter changed in the input data). The number of cells falling into each of the three categories of interspersion, juxtaposition, or spatial diversity (1-low, 2-medium, and 3-high) is then tallied for both the base and the test map. The chi-square test of homogeneity is then used in each case to test the null hypothesis that there is no change in the proportion of cells in each of the three index categories (low, medium, and high) between the base map and the test map. Thus, the null hypothesis may be written as follows:

$$H_o: p_{1_j}=p_{2_j}$$

where p_{1_j} refers to the proportion of cells in each category (low, medium, and high) of index values on the base map, and p_{2_j} refers to the same on the test map.

The adjusted index is provided for each set of tests. The adjusted index is computed as follows:

$$\text{Adjusted Index}=\frac{1(\text{No. cells classed as 1})}{\text{Total No. Cells}}+\frac{2(\text{No. cells classed as 2})}{\text{Total No. Cells}}+\frac{3(\text{No. cells classed as 3})}{\text{Total No. Cells}}$$

The adjusted index values for interspersion, justaposition, or spatial diversity may thus range between 1.0 and 3.0. Higher adjusted index values indicate higher overall values of the index in question over the entire area. This allows the assessment of the overall effect on the index values of changing a single parameter in the input data.

Section 3.1

The Test of Changing Cell Size on the Resultant Interspersion Index.

Procedure: A grid cell overlay was obtained for each of two fictitious base maps (map 1 and map 2) to provide a replicate of the test. The predominant cover type was coded into each cell. The cell dimensions were then doubled both vertically and horizontally resulting in cells containing four times the area of those on the base maps. The original cover type maps were then overlayed with the medium sized cells and the predominant cover types were again coded into each cell. This procedure was repeated, resulting in large cells which contained four times the area of the medium sized cells. The cell totals in each of the three categories of interspersion were obtained for all maps. The chi-square test of homogeneity was completed on the proportion of cells classed in each of the three categories for each combination of cells sizes for each of the two original maps. Thus, the interspersion maps which resulted from using small vs. medium cells, medium vs. large cells, and small vs. large cells were tested for both map 1 and map 2.

Results and Discussion: Significant differences between treatments were found in all cases (Table 3.1A).

In each case, the null hypothesis that the proportion of cells classed in each of the three categories of interspersion does not change with cell size was rejected. The adjusted interspersion indices in all cases increase with cell size (Table 3.1B). The larger

Table 3.1A. Chi-Square Results and p-Values Obtained from the Tests of Cell Size

TEST	MAP 1		MAP 2	
	Chi-square	p-Value	Chi-square	p-Value
Small vs. Medium	176.4	.005	506.4	.005
Small vs. Large	150.3	.005	98.64	.005
Medium vs. Large	43.7	.005	166.4	.005

Table 3.1B. The Adjusted Interspersion Index Values Resulting from Using Different Cell Sizes

TREATMENT	MAP 1	MAP 2
Small Cells	1.74	1.64
Medium Cells	2.11	2.09
Large Cells	2.49	2.53

cell sizes result in a higer proportion of cells classed in category 3, or high interspersion.

The results obtained from the tests of cell size are probably due to the non-random structure of the vegetative communities delineated on the original cover type maps. Such a structure is common to most natural communities. Because of the heterogeneity of natural communities, using small cell sizes results in a high number of cells surrounded by other cells containing the same cover type. Since interspersion is calculated by counting the total number of cells surrounding a centroid cell which are predominately of a different cover type, more cells are classed as low using smaller cell sizes. Conversely, as cell sizes increase, there is an increasing probability that an adjacent cell will be dominated by another cover type category, thus tending to increase interspersion over the entire area.

In this case, the original maps (maps 1 and 2) represent artificial cover type maps and, thus, the area on the ground covered by any of the small, medium, or large cell sizes used is arbitrary. As long as vegetative communities are spaced non-randomly, interspersion as calculated here should increase with cell size regardless of the initial cell size chosen. This must be qualified within reason, of course, as an initial cell size of one square mile may yield little information on spatial distribution of specific communities, as many communities could be located in that area.

Section 3.2

The Test of Changing the Percent of Classification Similarity of Input Maps on the Calculation of Interspersion.

Procedure: An initial cover type map containing five cover types was chosen as a base map. This map was then altered by changing the cover type designation in randomly chosen cells until the percent of cells which had been changed corresponded to the desired percent decrease in similarity between the base and the test map. Test maps which were 95, 90, 85, 80, 75 and 70 percent similar to the base map (in cover type designation) were generated in this manner.

The chi-square test of homogeneity was then used to test the null hypothesis that changing the percent similarity of the input data does not change the resultant interspersion for the area (Fienburg 1980).

Results and Discussion: The results indicate significant differences between almost all of the maps (Table 3.2A).

Thus, the only cases in which the null hypothesis was not rejected included the tests between the maps which were 85 and 80 percent similar to the base map, and between the maps which were 80 and 75 percent similar to the base map as the p-value in both cases was $.1>p>.05$. These two were, therefore, only marginal acceptances. The adjusted interspersion indices show that as percent similarity of the input maps decreases, interspersion over the entire area increases (Table 3.2B).

This general increase in interspersion with a decrease in percent similarity of the input data may be attributed to the way in which the

Table 3.2A. The p-value obtained from the tests of classification similarity on the calculation of interspersion.

	Base	95	90	85	80	75	70
Base	-	< .005	< .005	< .005	< .005	<.005	<.005
95		-	< .005	< .005	< .005	<.005	<.005
90			-	< .005	< .005	<.005	<.005
85				-	.1>p>.05	<.005	<.005
80					-	.1>p>.05	<.005
75						-	<.005
70							-

Table 3.2B. Adjusted Interspersion Indices resulting from Differences in Percent Similarity of the Input Data.

Map (Percent Similar to Base)	Adjusted Interspersion Index
Base	1.52
95	1.59
90	1.75
85	1.86
80	1.97
75	2.06
70	2.21

initial map was changed to yield the test maps. The assignment of different cover types was done randomly over the entire map. This was done to objectively simulate errors in cover type assignment by a digital information source such as Landsat. However, it is generally observed that satellite imagery misclassifies information in a systematic rather than in a random manner. This means that with real satellite imagery, there is a general tendancy to misclassify some communities and not others, i.e., unequal accuracy among classes. In this simulation, each cell, regardless of its community designation, had an equal probability of being misclassified compared to every other cell. This may be expected to increase interspersion as cells which are located within homogeneous stands would automatically be classified as high when their cover type is changed.

Section 3.3

The Tests of Changing the Number of Cover Types in the Input Data on the Resultant Calculation of Interspersion

Procedure: A map with ten cover types (coded 0 through 9) was generated from a table of random numbers. The number of cover types was then systematically reduced by changing the highest digit to zero. Thus, test maps which contained 9, 8, 7, 6, 5, 4, 3, 2, and 1 cover type(s) were generated. This procedure corresponds to the recommendations of Heinen et al. (1981) that cover types which do not represent important habitat components for the species in question may be all collapsed into one category, designated as "other." At each step in the collapsing procedure, the calculation of interspersion was

Table 3.3A. The adjusted Interspersion Indices Resulting from Changing the Number of Cover Type

Number of Cover Types on Map	Adjusted Interspersion Index
10	2.81
9	2.57
8	2.32
7	2.10
6	1.84
5	1.59
4	1.40
3	1.19
2	1.05
1	1.00

repeated. Chi-square tests of homogeneity on the proportion of cells classed in the three intervals of interspersion were then completed between pairs of all the resultant interspersion maps.

Results and Discussion: The null hypothesis that changing the number of cover types on the input data does not change the resultant interspersion over an area was rejected in all cases ($p<<.005$). The adjusted interspersion index decreases as the number of cover types decreases (Table 3.3A).

The trend displayed in Table 3.3A is expected because as the number of cover types is decreased, the probability that a cell is surrounded by cells of different cover types is also decreased. One may further expect the trend to be more extreme using real cover type information which is non-random in distribution. In that case, the probability that a cell is next to another cell dominated by the same cover type is greater (hence lower interspersion) than it is using artificial data generated randomly. The collapsing of categories on real cover type data may be expected to create large homogeneous areas resulting in low interspersion.

Section 3.4

The Test of Changing Cell Shape on the Calculation of Interspersion

Procedure: Three grid cell systems were drawn on clear acetate. These included (1) square, (2) hexagonal, and (3) triangular cells. In each case, the cells covered an area of one square inch. Each piece of acetate was overlaid on a map containing five cover types, and the predominant cover type was coded into each cell. Interspersion was then calculated manually for each cell (see Appendces I and II).

Chi-square tests of homogeneity were used to test the null hypothesis that changing the cell shape does not change the calculation of interspersion within an area.

Results and Discussion: The adjusted index obtained from the grids for each cell shape is presented in Table 3.4A.

Thus, the grids with square and triangular cells produce similar interspersion values over the entire area, while the grid with hexagonal cells resulted in lower interspersion. The chi-square test results indicate that interspersion calculated from hexagonal cells is significantly different from that calculated from either square or triangular cells. Square and triangular cells tested against each other produce no significant difference (Table 3.4B).

The observed differences in the calculation of interspersion using cells of different shapes may be the result of the spatial packing of the cells. Using both square and triangular cells, there are potential cover type changes at each corner, and these are counted in the calculation of interspersion (see Appendices I and II). Using hexagonal cells, however, each cell is completely enclosed on each side by the side of another hexagon (Appendix·II). There is, therefore, no possible cover type change at the corner of the cell.

Table 3.4A. Adjusted Interspersion Index Values for Three Grids Containing Differently Shaped Cells

Cell Shape on Grid	Adjusted Interspersion Index
Square	2.45
Hexagonal	2.12
Triangular	2.45

Table 3.4B. The p-Values Obtained from the Tests of Cell Shape on the Calculation of Intespersion.

	Square Cells	Hexagonal Cells	Triangular Cells
Square Cells		p<.0005	.6>p>.5
Hexagonal Cells			p<.0005
Triangular Cells			

In the case of square and triangular cells, cover type differences at the corners are considered equally important as those at the sides of the cells in calculating interspersion. Using square cells, there is one potential cover type change at each corner (Appendix I), and using triangular cells, there are three potential cover type changes at each corner (Appendix II). The counting of corner cover type changes as interspersed edges may artificially increase the interspersion calculation over the entire area.

A chi-square test of homogeneity was then performed on the initial number of cells classed into each cover type using square, hexagonal, and triangular cells. The null hypothesis that changing cell shape does not affect the cover type designation within the cells was not rejected (.95>p>.9). The observed differences in interspersion may have been a direct result of the cell shape and not an indirect result of cover type designations differing between cell shapes.

Section 3.5

The Tests of Changing Weighting Factors of Edge Combinations in the Input Data on the Resultant Juxtaposition and Spatial Diversity Calculations

Procedure: The weighting factors used in the calculation of juxtaposition may be assigned any number between 0.00 and 1.00 and the index itself ranges between 0.00 and 1.00 (see Appendix I). This range is again divided into thirds as follows:

1. 0.00-0.33 - low juxtaposition
2. 0.34-0.67 - medium juxtaposition

3. 0.68-1.00 - high juxtaposition

The values above, therefore, represent threshold values. If, for example, all weighting factors are assigned between 0.00 and 0.33, all the cells would be classed as low juxtaposition. This section is designed to assess the percentage of weighting factors which when increased over the threshold values result in a significant difference in juxtaposition and spatial diversity over the entire area. Spatial diversity is again a function of both interspersion and juxtaposition, and the relative importance values of each index (σ_A and α_A, respectively) were held constant at 0.5 in the calculation of spatial diversity for these tests (see Appendix I).

There are two thresholds to consider for testing purposes. These include the thresholds between low and medium index values (0.33), and the threshold between medium and high index values (0.67). The input map used to generate base maps contained five cover types. The proportion of cells classed as each cover type was approximately equal on the input map. Base maps of juxtaposition and interspersion were generated by assigning all weighting factors below the threshold value in each case. Thus, all the weighting factors were assigned a value of 0.2 to generate a base map to test between the low and medium threshold, and a value of 0.5 to generate a base map to test between the medium and high threshold. There were a total of five cover types designated on the input data resulting in a total of 15 possible edge weighting factors, 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 values to generate test maps. The test maps include the increase of one, two, three, five, and seven weighting factors out of the 15 possible weighting factors. Thus, a total of five test maps was generated for each of the two thresh old tests. In the case of the low to medium threshold test, the designated number of weighting factors was changed from 0.2 to 0.4, and in the case of the medium to high threshold test, these were changed from 0.5 to 0.7.

The chi-square test of homogeneity was then used to determine how many weighting factors could be changed before a significant increase in juxtaposition or spatial diversity is observed.

Results and Discussion: Table 3.5A is a summary of the chi-square and p-values obtained from the low to medium threshold test for juxtaposition and spatial diversity.

In each case, the test map is compared to a base map generated by assigning all weighting factors a value of 0.2. The results generally indicate that as more weighting factors are increased above the threshold value, the chi-square results are higher, thus, tending more toward rejection of the null hypothesis. This trend is less dramatic for spatial diversity than for juxtaposition. This is the result of interspersion being rated of equal importance as juxtaposition (both σ_A and $\alpha_A = 0.5$) in the calculation of spatial diversity. Interspersion, held constant in each of these tests, has a dampening effect on the spatial diversity calculations.

Table 3.5A. Chi-Square Results from the Low to Medium Threshold Tests for Juxtaposition and Spatial Diversity.

Test	No. Weights	Juxtaposition			Spatial Diversity		
Map	Changed	Chi-square	p-Value	Decision	Chi-square	p-Value	Decision
1	1	2.004	$.25>p>.1$	Fail to Reject	.2045	$.75>p>.5$	Fail to Reject
2	2	2.004	$.25>p>.1$	Fail to Reject	.2045	$.75>p>.5$	Fail to Reject
3	2	71.1	$p<.005$	Reject	.658	$.5>p>.25$	Fail to Reject
4	3	19.4	$p<.005$	Reject	.0885	$.9>p>.75$	Fail to Reject
5	4	89.5	$p<.005$	Reject	.2.34	$.25>p>.1$	Fail to Reject
6	7	162.1	$p<.005$	Reject	12.97	$<.005$	Reject

There are some problems with this testing procedure. Note that there were two test maps generated by changing two weighting factors. In one of them (map 2), the null hypothesis was not rejected, while the other (map 3) lead to the rejection of the null hypothesis. This is the result of the specific edge weighting factors which were changed. In the generation of map 2, the weighting factors for two non-similar cover types were increased. In the case of map 3, the weighting factors for one similar and one non-similar edge type were increased. Due to the non-random distribution of cover types on the original map, each cell has a greater probability of being next to a cell dominated by the same cover type than by any of the four other cover types. Thus, when cells dominated by the same cover type are given higher weighting factors, this tends to greatly increase juxtaposition for the area regardless of how many weighting factors are changed. This can also be seen in the adjusted index values (Table 3.5B), which are higher for map 3 (with only two weighting factors raised) than for map 4 (with three weighting factors raised).

The low to medium threshold test was repeated using input data which was derived randomly. This again had five cover types. There is again a general trend toward increasing chi-square values as more cover types are increased above the threshold value (Table 3.5C).

In this case, test maps 1 and 3 produced identical juxtaposition and spatial diversity totals as the base map, thus yielding a chi-square of 0.0. Test map 3 was again produced by assigning the higher weighting factors to the adjacency of one similar and one non-similar

Table 3.5B. Adjusted Juxtaposition and Spatial Diversity Indices for the Low to Medium Threshold Test

Map	No. Weights Changed	Adjusted Index	
		Juxtaposition	Spatial Diversity
Base	0	1.00	1.26
1	1	1.01	1.26
2	2	1.01	1.26
3	2	1.14	1.28
4	3	1.04	1.27
5	4	1.18	1.31
6	7	1.30	1.31

Table 3.5C. Chi-square Results from the Low to Medium Threshold Tests for Juxtaposition and Spatial Diversity from Random Input Data.

Test Map	No. Weights Changed	Juxtaposition			Spatial Diversity		
		Chi-square	p-Value	Decision	Chi-square	p-Value	Decision
1	1	0.0	1.0	Fail to Reject	0.0	1.0	Fail to Reject
2	2	8.64	$<.005$	Reject	2.02	$.5>p>.25$	Fail to Reject
3	2	0.0	1.0	Fail to Reject	0.0	1.0	Fail to Reject
4	3	1.001	$.5>p>.25$	Fail to Reject	.004	$.95>p>.9$	Fail to Reject
5	4	8.64	$p<.005$	Reject	.016	$.9>p>.75$	Fail to Reject
6	7	29.86	$p<.005$	Reject	3.02	$.25>p>.1$	Fail to Reject

cover type combination. The input cover type information was the cause of the differing results in this case as compared to the previous low to medium threshold test. Because the input was randomly generated, no cell has a greater probability of being located next to any other cell dominated by the same cover type. Thus, test map 3 would not be expected to inflate the test statistic as it did in the previous case. This expectation is generally met in the chi-square results (Table 3.5C). In this case, test map 3 has a lower chi-square statistic than test map 2. This probably represents an anomaly of the data as that particular result is not expected.

The results of the medium to high threshold test are reported in Table 3.5D.

The input for the medium to high threshold test was the same as that used for the first low to medium test. Test map 3 was again generated by assigning the higher weighting factors (0.7 in this case) to the adjacency of one similar and one non-similar cover type combination. This inflated the test statistic. The general trend of greater differences as more weighting factors are increased above the threshold value is observed in the medium to high threshold test.

The results of all the threshold tests presented here depend highly on the original input data. Because of this, there are no conclusions which can be drawn concerning an absolute number or percentage of weighting factors which when changed will yield significant differences in juxtaposition and spatial diversity. The general trends observed here are as follows:

Table 3.5D. Chi-square Results and p-Values for the Medium to High Threshold Tests for Juxtaposition and Spatial Diversity.

Test Map	No. Weights Changed	Juxtaposition			Spatial Diversity		
		Chi-square	p-Value	Decision	Chi-square	p-Value	Decision
1	1	.002	$> .9$	Fail to Reject	2.02	$.25 > p > .1$	Fail to Reject
2	2	.001	$> .9$	Fail to Reject	2.006	$.25 > p > .1$	Fail to Reject
3	2	38.54	$< .005$	Reject	10.04	$< .01$	Reject
4	3	8.07	$< .005$	Reject	10.16	$< .01$	Reject
5	4	52.8	$< .005$	Reject	9.9	$< .005$	Reject
6	7	97.2	$< .005$	Reject	23.97	$< .005$	Reject

1. As more weighting factors are changed, the test statistics are generally higher, and, concomitantly, the p-values are generally lower.
2. The test results for spatial diversity do not change as rapidly as those for juxtaposition, since the former also depends on interspersion (which remains constant).

Factors which lead to differing results include:

1. The heterogeneity of the cover types on the original input.
2. The percentage of area classed in each cover type category.

Summary

The results of this sensativity analysis indicate that in some cases rather small changes in the input data lead to significant changes in interspersion, juxtaposition, and/or spatial diversity. This is particularly true in changing classification accuracy and the level of classification on the computation of interspersion. It is also true in the changing of weighting factors on the computation of juxtaposition and spatial diversity provided these are raised or lowered above or below the threshold levels between categories of index values (low, medium, and high).

There are various problems inherent in the simulations of changes in respective parameters. These were discussed concomitantly with the respective testing procedures. In general, the main differences result from the initial spatial arrangement of cover types. In this respect, specific results may vary somewhat between areas due to differences in factors such as the initial number of cover types, and the average areas dominated by certain cover types in relation to the cell size used in the technique. The general trends observed in each test may be found to hold true regardless of the study area. These general trends were discussed for each test, and their findings are of greater importance for wide-scale use of a system such as this than are some of the specific thresholds which result from a particular area. Thus, for example, an increase in cell size which approaches the average land area dominated by one cover type would be expected to increase the calculation of interspersion (see Section 3.1). The amount of increase which results in a significant difference in interspersion, however, is dependant on the average area dominated by one cover type, which may differ from region to region. Thus, the general trend is expected to hold while specific thresholds (in this case the percent increase in the area of the cell) may differ for different land units.

This study determined that both cell size and shape affect the calculation of interspersion. The system was developed mainly for rapid regional habitat evaluation using cover type information generated by satellite imagery. It is with this type of information where this habitat evaluation has the greatest utility as the data is already in a cellular format conducive to computer manipulation. However, in satellite inventories, both the size and shape of the cells are largely determined by the system. Since both parametes affect the index values, this represents a limitation of the input data of which potential users must be made aware.

The system proposed by Mead et al. (1981) and tested here may prove useful in assessing the impacts of managerial decisions on habitat within a large area through computer simulation. It may also be implemented manually for small areas. By altering weighing factors and/or collapsing categories, the same input data may be used repeatedly for different animals with different habitat requirements (Heinen et al. 1981). Thus, this system has great potential for a variety of uses provided that specific parameters are accounted for and the various limitations are known by potential users.

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APPENDIX I

The Calculation of Interspersion, Juxtaposition, and Spatial Diversity Using Square Cells

Interspersion

2	3	1
2	1	1
3	3	1

* Is = 5

The center cell has 5 adjacent cells with dissimilar cover types. The value of interspersion is, therefore, 5.

Juxtaposition

2	3	1
2	1	1
3	3	1

Edge type	Quantity	Quality	Total
1/2	3	.2	.6
2/3	5	.6	3.0
2/3	0	.4	0.0

Jx Index = 3.6

In the calculation of juxtaposition, diagonal edges count as 1, while vertical or horizontal edges count as 2. The quality value for each edge type must be determined for each species. This is then multiplied by the quantity to determine the totals, and the sum of the totals is the juxtaposition index for a particular species, and for that particular cell. The quality factor (weighting factor) may range between 0.0 and 1.0.

---

*The hatching indicates the cell for which the index is calculated.

Spatial Diversity

The spatial diversity index is a function of interspersion, juxtaposition and any number of exclusion factors.

$$Sd_A = [(\sigma_A \frac{Is}{8}) + (\alpha_A \frac{Jx}{12})] [1_A \times 2_A \times 3_A]$$

where: A - indicates the species in question.
σ - indicates the relative importance of interspersion to juxtaposition for that species.
α - indicates the relative importance of juxtaposition to interspersion for that species.

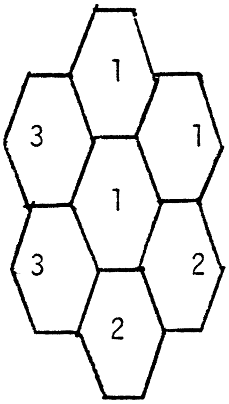
(σ and α may range from 0 to 1, but must sum to 1).
1_A, 2_A, 3_A indicate exclusion factors.

The exclusion factors may also range from 0 to 1, and these must be determined on a specific basis. Notice that in using square cells, the interspersion index is divided by 8, as there are 4 sides and 4 corners which represent possible changes in cover type. The juxtaposition index in this case is divided by 12 as there are 4 corners and 4 sides, and each of the latter is doubly weighted.

APPENDIX II

The Calculation of the Respective Indices Using Hexagonal and Triangular Cell Shapes

Hexagonal Cells



*

Interspersion

Is = 4

Juxtaposition

Edge Type	Quantity	Quality	Total
1/2	4	.2	0.8
1/3	4	.6	2.4
2/3	0	.4	0.0

Jx Index = 3.2

Spatial Diversity

$$S_D = [(\alpha_A \frac{Is}{6}) + (\sigma_A \frac{Jx}{12})] [1_A \times 2_A \times 3_A]$$

Notice that when using hexagonal cells, no corner cover types are used. Thus, in calculating the spatial diversity index, interspersion is divided by 6, and juxtaposition is divided by 12, as sides are again doubly weighted.

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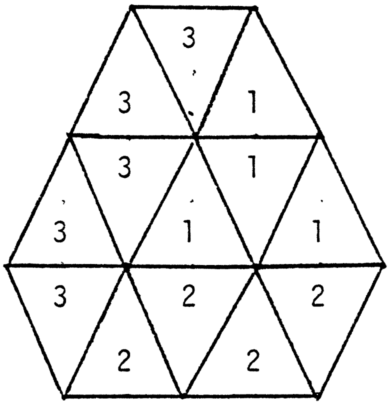
*The hatching indicates the cell for which the index is calculated.



Triangular Cells

Is = 9

Jx

Edge Type	Quantity	Quality	Total
1/2	5	.2	1.0
1/3	6	.6	3.6
2/3	0.0	.4	0.0

Jx Index = 4.6

Spatial Diversity

$$S_D = [(\sigma_A \frac{Is}{12}) + (\alpha_A \frac{Jx}{15})] [1_A \times 2_A \times 3_A]$$

Using triangular cell shapes, the problem becomes more complex as at each corner there are 3 possible changes in cover types along with the 3 possible changes at the 3 sides. Thus, in calculating spatial diversity, the interspersion index is divided by 12, and the juxtaposition index is divided by 15. The latter is again the result of diagonal edges counting as 1 (for a total of 9 diagonal edges, or corner edges) and the edges along sides counting as 2, for a total of (2 x 3) + 9 = 15 possible cover type changes in calculating juxtaposition.

CHAPTER 2

A Technique to Measure Juxtaposition, Interspersion, and Spatial Diversity from Cover Type Maps

Introduction

Leopold (1933) was among the first to recognize the importance of habitat heterogeneity for wildlife by stating that game abundance should increase in situations where various types of food and cover come together. The occurrence of different habitat types within a relatively small area affects wildlife abundance as animals must be able to meet daily and seasonal requirements within restricted spacial arrangements. This is the context in which Leopold defined the term "edge effect."

Wildlife managers, resource conservationists, extension personnel and others are often called upon to evaluate landscapes in terms of their potential to support wildlife populations. Spacial diversity is an important factor and must be considered along with qualitative and quantitative measurements of habitats. Since time and other resources may be limited, the manager needs a rapid and simplified technique for measuring habitat diversity on landscapes of varying sizes and types that can be an aid in arriving at management decisions. A simplified technique can be especially useful in educating land owners to the importance of spatial diversity in managing for wildlife.

A technique which uses measurements of interspersion and juxtaposition as components of a spatial diversity index was described by Mead et al. (1981) and Heinen et al. (1981). The purpose of this paper is to describe a manual implementation of this system and demonstrate how it can be used by wildlife managers and others to evaluate habitat potential.

Definitions

Interspersion is defined by Giles (1978) as the "intermixing of units of different habitat types." Juxtaposition is defined by Giles (1978) as a "measure of the adjacency or proximity of year-around habitat requirements to a site being analyzed for a particular species."

Methods and Procedures

The steps outlining the procedure for measuring interspersion, juxtaposition and spatial diversity are as follows:

1. Identify biologically meaningful cover types encompassing critical habitat components for the wildlife populations under management consideration. Cover types which are not critical can be grouped under a miscellaneous category.
2. Acquire maps, aerial photographs, or any other source of geographic information on which critical cover types can be identified.
3. Using the available sources of geographic information delineate the critical cover types. Critical cover types may be identified directly on aerial photographs or cover maps.

4. A grid is superimposed on the cover type map or on the aerial photograph. Symbols or letters representing the predominant cover types are placed in each cell on the grid. The choice of optimal cell size must take into consideration factors such as home range size and patchiness of landscape.
5. Calculate interspersion.
6. Calculate juxtaposition.
7. Calculate spatial diversity.

The Calculation of Indices for Interspersion and Juxtaposition

Interspersion is calculated for each cell by counting the total number of cells surrounding a centroid cell which contain a different cover type category than the centroid cell. There are eight cells surrounding any centroid cell in a grid. The total number of cells with different cover types is divided by eight to allow the index to range between 0 and 1.

An Example Calculation of Interspersion

A	B	B
B	A	A
A	C	C

$$I_s = 5/8 = 0.625$$

where 5 = total number of cover type changes

8 = total possible number of cover type changes

and the letters A, B, and C represent different cover type categories.

All combinations of edge types around the centroid cell are indentified. A numerical rating is given each edge type by assigning a value of one to diagonal edges and a value of 2 to verticle or horizontal edges. Relative weighting factors ranging from 0 to 1 are assigned each edge type which represent the quality of different community junctions. The quality factor is multiplied by the numerical rating of each edge type to give a total value for each edge type. All these values are totaled and divided by 12 to allow the index for each centroid cell to range from 0.0 to 1.0.

<u>An Example Calculation of Juxtaposition</u>

A	B	B
B	A	A
A	C	C

Edge Type	Quantity	Quality	Total
A/A	4	0.20	0.80
A/B	5	0.50	2.50
A/C	3	0.60	1.80
		Jx =	5.10

Index value = 5.10/12.00 = 0.43

Although the adjacency of two cells containing the same cover type does not represent a true edge, it may be given a weighting factor for the juxtaposition index if large stands of that type are important for the species under consideration.

Spatial Diversity

The spatial diversity (Sd_A) index described by Mead is as follows:

$$Sd_A = [(\sigma_A I_s) + (\alpha_A J_x)][1_A][2_A][3_A]$$

where

A = indicates a particular species

σ_A = indicates the relative importance of interspersion

α_A = indicates the relative importance of juxtaposition

(σ_A and α_A may range from 0 to 1 and must sum to 1.0)

1_A, 2_A, 3_A = indicate exclusion factors, which may range between 0 and 1.0

Any number of exclusion factors may be used depending on the area and species under consideration. An exclusion factor can be defined as any habitat component with a positive or negative impact on a particular species. An example of an exclusion factor with a postive impact may be the requirement of water within 1 mile. If it is present, 1_A may be given the value of 1.0 and thus does not affect the index. If it is absent, a value of 0.0 may be assigned, thus driving the Sd_A index for that parcel of land to zero. An exclusion factor with a negative impact may be the presence of anything which impairs the habitat suitability of the area for the species in question. An example may be oil derrick. If it is present, 1_A may be assigned a value of 0.0, thus driving the index to zero.

The numbers assigned for exclusion factors may range between 0 and 1, thus giving the Sd_A index more power.

Management Application

The headquarters of the Virginia Coast Reserve, owned and operated by the Nature conservancy and located near Nassawodox, Virginia was chosen as the demonstration study area for three reasons:

1. Recent (September, 1980), large scale (1:3,900) infrared aerial photography was available.
2. A comprehensive management plan for the area was recently completed (Anderson and Hennessey, 1981).
3. The area is ecologically diverse, containing a mosaic of mixed woodlots, agricultural fields, and salt marsh.

An aerial photo mosaic was constructed from the color infrared photographs. A cover type map was drawn on acetate by overlaying the photo mosaic (Figure 1). Eight cover type categories were designated (Table I). A grid cell system with cells measuring 6.45 cm 2 (one square inch) was then laid over the cover type map. Each cell thus represented 2.7278 ha on the ground at the designated photo scale (1:3,900). There was a total of 220 cells (a matrix of 11 by 20) in which indices for interspersion, juxtaposition, and spatial diversity were calculated. A total of 600.1 ha was included in the study area.

A digit representing the predominant cover type was then placed in each cell. Each cover type may thus be expressed by the frequency of occurrence within the study area on a cellular basis. Notice that using this criteria, cover type category number 7 (hedgerows) has a 0% frequency of occurrence. This is due to the predominance rule used in type mapping. The hedgerows were in all cases too thin to dominate a

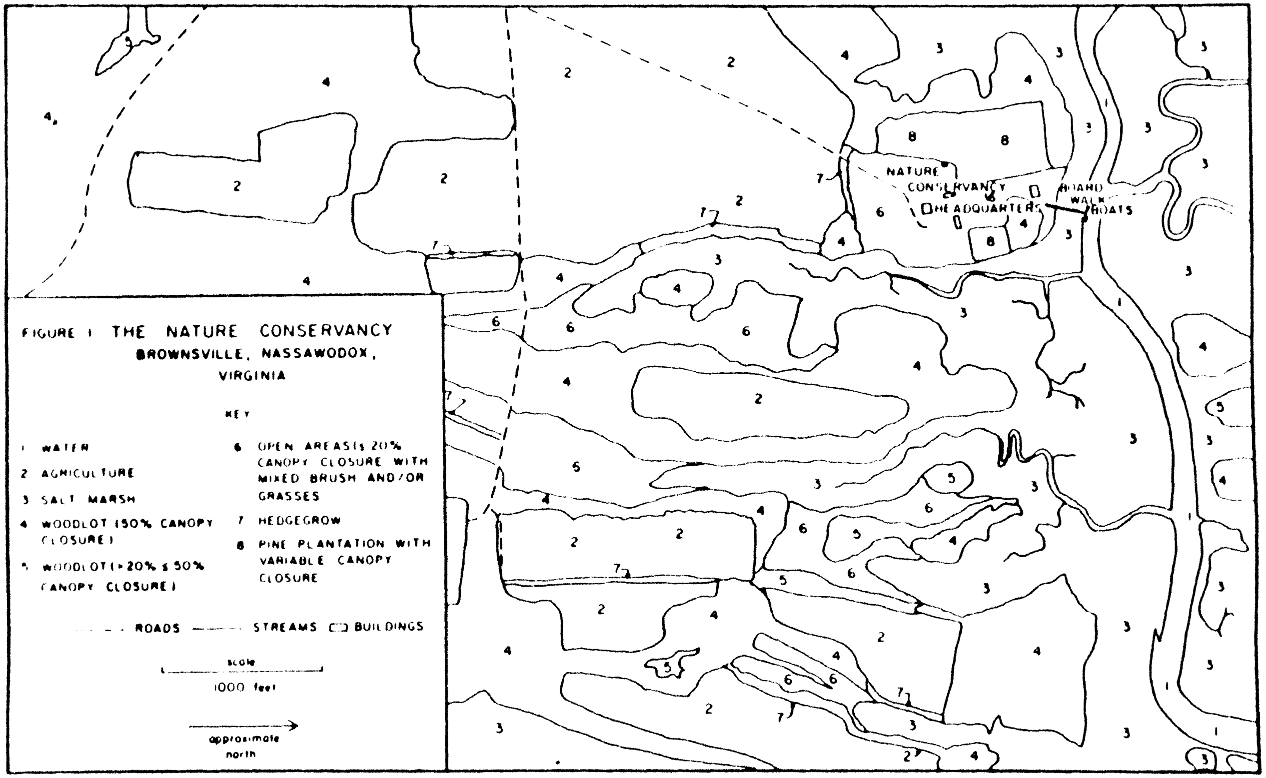


FIGURE 1 THE NATURE CONSERVANCY BROWNSVILLE, NASSAWODOX, VIRGINIA

Table I. The Cover Type Designations and Their Respective Frequencies of Occurrence on the Grid

Number	Description	Number of Cells	Frequency of Occurrence
1	Water	1	.5%
2	Agricultural Areas	67	30.5%
3	Salt Marsh	45	20.4%
4	Woodlot >50% canopy closure	73	33.1%
5	Woodlot >20% canopy closure ≤50% canopy closure	4	1.8%
6	Open Areas ≤20% canopy closure	25	11.4%
7	Hedgerows	0	0.0%
8	Pine Plantations	5	2.3%
	Total	220	100.0%

cell this size. If hedgerows are known to be important for the species in question, this situation may be easily remedied by assigning another category, such as agricultural areas containing hedgerows, thus reflecting this importance.

Edge weighting factors used in the calculation of juxtaposition were arbitrarily assigned for demonstrative purposes (Table II). Index values for interspersion, juxtaposition and spatial diversity were calculated for each grid cell. The values were grouped into three intervals representing areas of low (0.00-0.33), medium (0.34-0.67), and high (0.68-1.00) values for interspersion, juxtaposition and spatial diversity. These ranges are represented by the digits 1 (low), 2 (medium), and 3 (high) on the final grid (see Figures 2, 3, and 4). The total area in each interval for each index is presented in Table III. Since the management objective of the Virginia Coast Reserve is to maximize species diversity, consideration can be given toward increasing the percent of land with a high interspersion index by altering agricultural and forestry practices.

Discussion

The use of the system described here is dependent on the management objectives, and should not be considered unless the objectives are well defined. There are a few major advantages inherent in this system such as the relative ease and low cost of implementation. Due to the simplicity of the calculations, general office help could be used to do hand calculations if data sets are

Table II. The Edge Weighting Factors Assigned for the *Calculation of Juxtaposition and Spatial Diversity

		COVER TYPE II							
		1	2	3	4	5	6	7	8
COVER TYPE I	1	0.0	0.5	0.4	0.2	0.7	0.6	0.0	0.5
	2		0.1	0.3	0.5	0.6	0.3	0.8	0.7
	3			0.4	0.6	0.7	0.5	0.8	0.5
	4				0.8	0.5	0.7	0.0	0.0
	5					0.6	0.7	0.0	0.4
	6						0.3	0.4	0.7
	7							0.0	0.0
	8								0.3

*The lower half of the matrix is identical to the upper half and was thus not written (i.e., 2, 7 = 7, 2 - 0.8).

```
12222231111123322211
33322211111122222211
12222111222222233211
11112223333222222311
13322223333322221112
12332222332232121111
22222222232232331111
22222232233333321112
11111222223333321111
12222222222232323111
33333222222332222211
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Fig. 2. Interspersion

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33333221111112222221
22221111111112222221
33321111111112222221
33333112222222222221
32233332222223322221
33222233311123332221
33233222221123222221
11122232222222222221
11111121111222222221
11111222112321222221
22222233222221133221
```

Fig. 3. Juxtaposition

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22222231111122222211
22222111111112222211
22221111111122223211
22222223322222222321
23322223222222222121
22332233322222222111
22222222232232232111
11222232222222321111
11111222122333321111
11111222122222223211
33333222222331222211
```

Fig. 4. Spatial Diversity

Table III. The Frequencies of Occurrence for Areas of Low, Medium, and High Interspersion, Juxtaposition, and Spatial Diversity.

Interval Number	Designation	Number of Cells in that Interval	Frequency of Occurrence	Number of Hectares
		Interspersion		
1	Low (0.00-0.33)	60	27.3%	163.7
2	Medium (0.34-6.67)	109	49.5%	297.3
3	High (0.68-1.00)	51	23.2%	139.1
	Total	220	100.0%	600.1 ha
		Juxtaposition		
1	Low	65	29.6%	177.3
2	Medium	116	52.7%	316.4
3	High	39	17.7%	106.4
	Total	220	100.0%	600.1 ha
		Spatial Diversity		
1	Low	63	28.6%	171.9
2	Medium	127	57.7%	346.4
3	High	30	13.7%	81.8
	Total	220	100.0%	600.1 ha

large. Systems such as this are also easily programable into microcomputers if these are available, thus minimizing the time investment involved. One major advantage of this system is its versatility. As previously stated, we may use exclusion factors depending on the presence of or distance to important habitat components such as water, or detrimental factors such as some human activities. For organisms which require large homogeneous areas, hence low interspersion, the system can be appropriate by simply using large weighting factors for the juxtaposition of cells dominated by the preferred cover type. Juxtaposition may then be given a large importance value in the spatial diversity index with respect to interspersion.

One may wish to consider only an area's ability to support a variety of species, or species complex. In some cases, time and monetary constraints may preclude the repetative implementation of this system for all the species of interest which may occur in an area. In cases such as this, the interspersion index alone may provide the manager with a general feel for habitat diversity in an area.

The information obtained from the indices may be used in various ways. The final product consists of a grid cell system with numbers or characters designating areas of low, medium, or high values for interspersion, juxtaposition or spatial diversity. These areas may be easily located on the ground by overlaying the grid system onto the original type map. If a computerized system is used, a programmer can easily adjust the output so it may be registered to a map of any common scale such as a 7 1/2" U.S.G.S. 1:24,000 quad sheet. Thus the manager has at his disposal information on the location of areas which may represent good or poor habitat for the species or species complex in question.

This information may be used for a variety of purposes. Population census, for example, could be improved by stratifying habitat according to whether it represents a potential for supporting the organism of concern. The information may also be used to aid in decisions such as the placement of clearcuts or other treatments. These may be more optimally placed in areas of low index values if an increase in interspersion is desirable for one or more game species.

The appropriateness of the input data is probably the major limitation of the system described here. Extremely detailed cover type maps for species-specific analysis may prove inappropriate as many of the categories may be unimportant for a particular species. One way to circumvent this problem and preclude the need to re-map areas for each additional species is to collapse categories from a detailed map in an appropriate manner. This can be accomplished by including all non-important categories into a category designated as "other" (Heinen et al., 1981). In this manner the original (detailed) data base may be used for a variety of species by simply collapsing categories appropriately for each species.

Appropriate use of this system in choosing cover type designations, cell sizes, and weighting factors rests on educated resource managers. There are no simple criteria to follow in making these choices and the information obtained is necessarily subjective. It is not designed to be a detailed habitat analysis system, rather it is a system designed to expediently and economically provide information which may prove to be useful in general management-decision making. More detailed analysis systems relying on extensive ground surveys are needed in situations such as habitat designation for endangered species or problems in pest control.

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CHAPTER 3

Simulating the Effects of Clearcuts on Deer Habitat in the San Juan National Forest, Colorado

Introduction

The Resources Planning Act of 1974 requires that periodic assessment of all renewable resources including wildlife habitat be conducted on all federal lands (Hirsch et al., 1979). Legislation such as this has inspired a great deal of research aimed at devising more effective and expedient methods of analyzing habitat. It also imposes restrictions on federal agencies whose major objective may be to manage forests for timber production. These activities must now be legally conducted with regard to imposed secondary objectives such as providing suitable wildlife habitat or recreational opportunities (Federal Register 1979).

Much recent work has been devoted to the development and application of multiple-use planning models in forestry (Leuschner et al., 1975). These models are designed to estimate the effects of managerial decisions, such as harvesting timber, on a variety of other potential benefits (including recreational opportunities or wildlife production) in the area. Such models have the advantage of allowing managerial decision to be based on some knowledge of the potential outcome of the many alternatives. Particularly important are linear programming models used for timber harvest scheduling (Field et al., 1980). A wildlife habitat analysis system which is readily adapted to computer implementation, such as the one used here, can aid managers in multiple objective decision-making.

The purpose of this study was to test the effects (by simulation) of various clearcutting treatments on the wildlife habitat potential in an area. The wildlife habitat analysis system described by Mead et al. (1981) is used to assess these impacts on the habitat of mule deer (*Odocoileus hemionus*) for this demonstration.

DESCRIPTION OF THE HABITAT ANALYSIS SYSTEM

The habitat analysis system described by Mead involves the calculation of interspersion, juxtaposition, and spatial diversity.

CALCULATION OF THE INDICES

Interspersion

Interspersion was calculated for each cell on the study area by counting the total number of cells with a different cover type surrounding the centroid cell and dividing this value by 8 (as there are at most 8 possible cover type changes around any cell). This constrains the index to values between 0.0 and 1.0.

An Example Calculation of Interspersion

B	A	A
A	A	C
B	C	C

Is = 5/8 = 0.625

where A, B, and C represent different cover types.

Juxtaposition

Juxtaposition was calculated by summing the number of edges of a particular type surrounding a centroid cell. This is repeated for each edge combination. The total in each case is multiplied by a qualitative weighting factor representing the relative importance of each edge type. These weighting factors may range between 0.0 and 1.0 but they need not sum to one. This sum is then divided by 12 to constrain the index to values between 0.0 and 1.0. Horizontal or vertical edges count as two while diagonal edges count as one.

An Example Calculation of Juxtaposition

B	A	A
A	A	C
B	C	C

Edge Type	Number	Weighting Factor	Total
A/A	5	.3	1.5
A/B	2	.8	1.6
A/C	5	.2	1.0
		Jx =	$\frac{4.1}{12} = .342$

Spatial Diversity

This index is calculated by the following expression:

$$SD = [(\alpha_a \cdot Is) + (\sigma_a \cdot Jx)]$$

where:

a represents species of interest

α_a represents the relative importance of interspersion

σ_a represents the relative importance of juxtaposition

Using the previously described example:

$$SD = [(.5 \cdot 0.625) + (.5 \cdot 0.342)] = 0.4835$$

In this case, interspersion and juxtaposition are considered equally important, so both α_a and σ_a assume a value of 0.5.

Output

The program which calculates each index generates a grid cell system corresponding to that on the original digital input. Each grid cell is thus given a value (ranging between 0.0 and 1.0) for juxtaposition, interspersion, and spatial diversity. For the purposes of this demonstration, the range is divided into thirds to represent areas of low (0.00 - 0.33), medium (0.34 - 0.67), and high (0.68 - 1.00) values for each index. These are represented by the integers 1, 2, and 3, respectively.

These indices are species-specific in that the assignment of relative juxtaposition weighting factors represents the importance of various edge types for a particular species. This system could be used to assess changes in habitat resulting from forestry practices for any organism provided that its habitat requirements are well known in the area of interest. Since the relative importance of specific edge types may change from region to region for widespread organisms such as deer, these indices are site- as well as species-specific. The indices are calculated on a grid cell basis and are readily adapted to computerized systems. They may thus be easily incorporated into more comprehensive multiple use planning schemes. One of the major advantages of this system is its flexibility.

STUDY AREA AND DATA

The data for this study were derived from a Landsat MSS image of the Rampart Hills Quadrange, San Juan National Forest, Colorado. Each grid cell on this image represented approximately three acres on the ground. The northwest section of this quadrangle, totalling 1800 acres (600 pixels), was considered for this demonstration The original 19 cover types designated on the area were collapsed into seven categories. These include willow, grass, conifer, shrub, oak, aspen, and other. Those categories present on the original imagery which were not considered important habitat components for deer were all included in the category designated as "other".

The specific weighting factors chosen for the importance of various edge types for deer were derived from recommendations of Forest Service personnel (Cook, 1981, personal comm.) (Table 1).

Table 1. Juxtaposition Weighting Factors for the Collapsed Categories

	Willow	Grass	Conifer	Shrub	Oak	Aspen	Other
Willow	0.00	0.75	0.50	0.25	0.125	0.00	0.00
Grass		0.00	0.00	0.00	0.00	0.05	0.00
Conifer			0.00	0.00	0.00	0.025	0.00
Shrub				0.00	0.00	0.00	0.00
Oak					0.00	0.00	0.00
Aspen						0.00	0.00
Other							0.00

SIMULATION OF CLEARCUTS

This simulation was conducted by first assuming that the managerial objective was to cut 432 acres of timber of any type within the 1800 acre study area. This number of acres cut was chosen for the purposes of this demonstration as it is easily divisible by four to decrease clearcut size. These clearcuts could be various shapes and sizes, so long as a total of 432 acres, or 144 cells were affected. Each clearcut prescription was simulated by changing the cells affected by the cutting operation from their original forest cover type designation to a designation representing grasslands. The implicit assumption made was that following clearcutting, the major floral component in the area would be grasses and forbs.

After each clearcut was simulated, calculations for interspersion, juxtaposition, and spatial diversity were repeated. Total cell counts for high, medium, and low index values for each treatment and the control were then tallied and compared.

The treatments applied to the area included 3 different size categories for each of two different shapes of clearcuts (Table 2).

Treatments 1 and 2 consisted of 1 432 acre clearcut. Although this represents an unrealistically large clearcut, it is considered valid for the sake of comparison. Treatments 3 and 4 consisted of 4 clearcuts, each totalling 108 acres (36 cells). Treatments 5 and 6 consisted of 16 27 acre clearcuts. Treatments 1, 3, and 5 were simulated using square clearcuts and treatments 2, 4, and 6 were simulated using rectangular clearcuts. This method thus allows assessment of both size and shape of the clearcuts on the resultant indices over the entire area.

Table 2. Description of Treatment

Treatment Number	Number of Cuts in Area	Shape of Cuts	Number of Cells Per Clearcut	
1	1	Square	144	(Large)
2	1	Rectangle	144	
3	4	Square	36	(Medium)
4	4	Rectangle	36	
5	16	Square	9	(Small)
6	16	Rectangle	9	

RESULTS

The results indicate an effect from both size and shape of the clearcut prescriptions on the interspersion index for the area. As the size of the clearcut was decreased, the number of cells classed as low also decreased. Conversely, the number of cells classed as either medium or high interspersion increased with decreased clearcut size. For the same sized clearcuts, rectangular clearcuts yielded more medium and high values and less low values of interspersion than did square clearcuts (Table 3).

The adjusted interspersion index for the whole area for each treatment was calculated with the following expression:

ADJUSTED I_s INDEX = 1 · (# Cells classed as low interspersion) +
2 · (# Cells classed as medium interspersion) +
3 · (# Cells classed as high interspersion).

The adjusted index allowed for the relative comparison of overall index values for the entire area under each treatment. Placing these values in a 2 x 3 matrix illustrated the effect of both the size and the shape of the clearcut treatment (Table 4).

An adjusted interspersion index of 1127 was calculated using no treatment. This index increased over the entire area as clearcut sizes decreased and changed in shape from square to rectangular.

The juxtaposition index values for each treatment and the control were consistently low throughout the entire area. There is, therefore, no difference between any of the treatments for juxta-

Table 3. Interspersion Total for the Area by Treatment

		No Treatment	Treatment					
			1	2	3	4	5	6
Low	# Cells*	205	267	247	212	181	162	136
Medium	# Cells	263	238	250	262	292	316	317
High	# Cells	132	95	103	126	127	122	147

Total # of Pixels = 600

Total # of Acres = 1800

* # Acres = 3 x # Pixels

Table 4. Adjusted Interspersion Index for the 6 Treatments

Clearcut Size Clearcut Shape	Large	Medium	Small	Total by Shape
Square	1028	1114	1160	3302
Rectangle	1056	1146	1211	3414
Total by Size	2084	2260	2371	6715

position. This is a result of the weighting factors assigned (Table 1) and will be discussed elsewhere (see Discussion). Since the juxtaposition values are all low, and since juxtaposition was equally weighted with interspersion in the calculation of spatial diversity (both α_a and $\sigma_a = 0.5$), the spatial diversity values are lower than are the interspersion values. For any treatment, there are far more cells classed as having low spatial diversity than low interspersion (Table 5). There are no cells having high spatial diversity values using any treatment.

Despite the generally lower spatial diversity values in comparison to those obtained from the interspersion calculations, the adjusted totals for spatial diversity for the area showed similar effects of clearcut size and shape (Table 6). Spatial diversity over the entire area increased as the size of the clearcuts decreased, and as the shape of the clearcuts changed from square to rectangular.

DISCUSSION

The results of this simulation indicated that smaller clearcuts with shapes that tend to increase perimeter generally created an increase in interspersion and spatial diversity (as defined by Mead). Similar results would also be expected for juxtaposition, as the grassland community resulting from clearcuts is an important habitat component for deer. A comparison between treatments is not possible for the juxtaposition index as the entire area for each treatment yields low values. This is a result of the weighting factors used to calculate this index (Table 2).

Table 5. Spatial Diversity Total for the Area by Treatment

		No Treatment	Treatment 1	2	3	4	5	6
Low	# Cells	464	501	497	473	473	477	452
Medium	# Cells	136	99	103	103	127	123	148
High	# Cells	0	0	0	0	0	0	0

Table 6. Adjusted Spatial Diversity Index for the 6 Treatments and 1 Control.

Clearcut Size / Clearcut Shape	Large	Medium	Small	Total by Shape
Square	699	727	723	2149
Rectangle	703	727	748	2178
Total by Size	1402	1454	1471	4327

No Treatment 736

The weighting factors in descending order include willow with grass, conifer, shrub, and oak, respectively. There are no cells within the study area predominated by willow. This does not necessarily indicate that no willow is located in the area; rather, it indicates that willow was not aggregated enough to show up as a distinct class in any sampling units on the Landsat imagery. This represents a limitation of the input data but in no way negates the results obtained in this study. An effect of both clearcut size and shape is observed for both spatial diversity and interspersion. That trends in the adjusted spatial diversity index are less dramatic than those in the interspersion index is merely a result of the low juxtaposition.

The index values for the study area (no treatment) were higher than those obtained from treatments 1 through 3 for interspersion and treatments 1 through 4 for spatial diversity. This indicated that the area was initially composed of a diverse mixture of cover types, and the large clearcuts imposed by treatments 1 through 4 tended to decrease this mixture. In large homogeneous woodlots, clearcutting operations may be expected to increase interspersion regardless of the size of the cut. Juxtaposition would increase only if there are relatively large weighting factors assigned for the adjacencies of the forested and grassland communities which resulted from the clearcut. Spatial diversity could increase or decrease depending on the relative importance values assigned for interspersion (α_a) and juxtaposition (σ_a).

The clearcutting treatments were placed evenly and systematically throughout the entire area for this demonstration. The results of such a technique may differ somewhat if cuts are preferentially placed in one section of an area vs. another. This would depend on the homogeneity and the category of cover types in one section as opposed to another and is thus a result of the area in question. When this is taken into account, treatments may be simulated in such a way as to increase the index values for certain species depending on initial management goals.

SUMMARY AND CONCLUSIONS

This study demonstrated the use of simulating clearcutting prescriptions to assess the impact on wildlife habitat. Such simulation procedures allow managerial decisions to be based on an estimated outcome of any option available, and may be used to meet multiple use objectives imposed by recent legislation. The results indicated that as clearcut sizes decrease and assume shapes which increase the perimeter there is a trend toward better habitat for deer. The habitat analysis system described by Mead et al. (1981) and used in this demonstration has great potential as a submodel in more comprehensive planning models. It is easily adaptive to computer analysis and can be used for many species in an area with minor modifications in cover type designations and weighting factors.

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SITE AND SPECIES SPECIFIC WILDLIFE HABITAT ASSESSMENT

by

Joel Thomas Heinen

(Abstract)

This document contains three manuscripts, each forming a separate chapter. The first chapter is a sensativity analysis, conducted on a wildlife habitat analysis system previously described. This was designed to mathematically test the effects of changing various parameters used in the system on the calculation of specific indices that this system measures. Chapters 2 and 3 represent specific applications of the proposed habitat analysis system. Each has been submitted to appropriate professional journals. All three chapters are self-contained.