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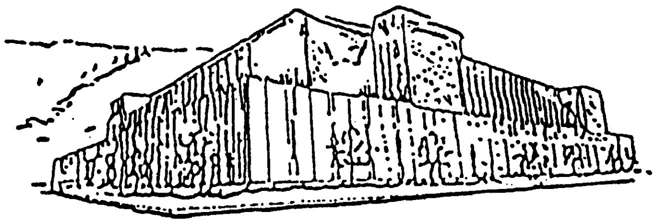

THE EFFECT OF PATCH RESOLUTION AND RASTER CELL SIZE ON SELECTED LANDSCAPE METRICS APPLIED AT LUBRECHT EXPERIMENTAL FOREST

by

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The Effect of Patch Resolution and Raster Cell Size on Selected Landscape Metrics
Applied at Lubrecht Experimental Forest (98 pp.)

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Landscape ecology and ecosystem management concerns present new challenges to land use planning. Emphasis on studying larger landscapes and relating the effects of landscape pattern to ecological processes across many scales requires new analytic techniques. This study used a landscape spatial analysis program, FRAGSTATS, to quantify landscape configuration, composition, and diversity, using different combinations of patch resolution and raster cell size for one analysis area, to examine the impact of these changes.

Scale variation was addressed by using two levels of patch resolution (Cover Type and Cover Type/Pattern) and five sizes of raster cells (10, 30, 50, 100, 200 meter cells) resulting in ten different interpretations for each landscape metric. Twenty metrics were selected for analysis from the FRAGSTATS program output and were grouped.

All twenty metrics were sensitive to changes in either patch resolution, raster cell size, or both. Different levels of patch resolution had significant effects on how patches are aggregated as the raster cell size is increased. Raster cell sensitivity became evident at the 50 to 100 meter cell size; some of the metrics displayed large variations at the 200 meter cell size.

The use of these spatial analysis methods and the proper scale of analysis needs to be matched with the problems being addressed in any specific study. Computer memory, amount of available program run time, and the level of knowledge about the area are important factors in designing any analysis. The landscape scale and choice of metrics must be relevant to the questions being asked and relate to the issues driving land management decisions.

ACKNOWLEDGMENTS

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I am especially grateful to Dr. Robert Pfister, committee chairman, for his enthusiasm, encouragement, and support for this study in all it's phases. This study was funded by the Mission-Oriented Research Program, School of Forestry, University of Montana, Missoula, MT.

I am also indebted to my wife, Christine Paige for her continual support and encouragement during my pursuit of this M.Sc. degree.

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CHAPTER 1: INTRODUCTION

The emergence of landscape ecology and ecosystem management are substantially changing the way managers approach land use planning. Increasing pressure on flora, fauna and ecosystems due to competing resource uses demands new types of analysis to resolve conflicting interests.

Landscape pattern analysis quantifies the composition and configuration of an area. It is useful to help discern patterns that affect ecological processes, as well as processes that affect landscape pattern. The landscape mosaic, in both fine and coarse scales, can have profound effects on the presence or absence of flora and fauna.

A number of landscape level studies have been undertaken in recent years (i.e. Columbia River Basin Project; Elkhorn Mountain Analysis; Augusta Project (all USDA-Forest Service)) which addressed different scales and levels of patch resolution. Relating the overlapping areas of these projects to one another can be difficult due to the differing scales used in the analysis. This study was designed to determine how selected landscape metrics respond using one analysis area defined by two different levels of patch resolution and five different levels of raster cell size. Turner et. al. (1989a) examined this same question, but used only a few metrics. Computer technology has developed to the point that landscape analysis programs are readily available (e.g. FRAGSTATS, r.le, DISPLAY), which compute many different metrics. This type of analysis evolved coincidentally with the development and general use of Geographic Information Systems. This study examines twenty different landscape metrics that are computed through the FRAGSTATS Spatial Analysis program.

McGarigal and Marks (1994) divide the suite of metrics available in the FRAGSTATS analysis program into two general groups of landscape metrics: composition and configuration. Composition metrics describe the amount and presence of patch types within the landscape, but gives no sense of the spatial arrangement of the patches. Configuration metrics provide a measure of the spatial arrangement of the patches on the landscape. However, some of the metrics they placed in the configuration group are not spatially explicit. This seems to warrant a third group of metrics called the "general" group in this study.

The twenty metrics selected for analysis in this study are listed in Table 1. These twenty metrics were selected for analysis since they are the most meaningful in describing landscape patterns for management applications.

Table 1. Landscape Metrics Selected for Analysis

Shannon's Diversity Index	Mean Shape Index	Number of Patches
Simpson's Diversity Index	Landscape Shape Index	Mean Patch Size
Modified Simpson's Diversity Index	Area-Weighted Mean Shape Index	Total Edge
Patch Richness	Double Log Fractal Dimension	Total Area
Shannon's Evenness Index	Area-Weighted Mean Patch Fractal Dimension	
Simpson's Evenness Index	Mean Nearest-Neighbor Distance	
Modified Simpson's Evenness Index	Contagion Index	
Largest Patch Index	Interspersion/Juxtaposition Index	

Two different levels of patch resolution were used (Cover Type/Pattern landscape and Cover Type landscape), which provide a fine and coarse scale version of the analysis area. Raster cells in five different sizes were chosen to examine the effect raster cell size has on the behavior of the metrics, both within the same patch resolution, and between the two levels of patch resolution. Table 2 illustrates the 10 combinations of scenes analyzed.

Table 2. Combinations of Patch Resolution and Raster Cell Sizes Analyzed

Raster Cell Size	Cover Type/Pattern Landscape	Cover Type Landscape
10	Fine scale patch/Fine scale raster	Coarse scale patch/fine scale raster
30 50 110	↓	↓
200	Fine scale patch/Coarse scale raster	Coarse scale patch/Coarse scale raster

CHAPTER 2: LITERATURE REVIEW

Landscape ecology focuses on broad spatial scales, the spatial patterns of the landscape and interactions between the landscape units (Turner 1989; Wiens 1992). The three main characteristics in landscape ecology are structure, function, and change. Structure is the spatial pattern of landscape elements; function is the interactions among the spatial elements (i.e. energy and species flows); change is the alteration in the structure and function of the mosaic over time (Forman and Godron 1986).

A variety of ecological and land management questions now being asked requires studying larger areas and understanding spatial pattern and process relationships (Turner 1990; Swanson et.al. 1990; Harris 1984). Spatial patterns can influence nutrient and energy flows, ecological processes, and dispersal spread patterns of biotic and abiotic factors. The analysis of landscapes is also necessary to determine if an increase in diversity at the local level is not adversely affecting diversity at the landscape level (Martin 1992).

Analysis of landscape patterns at different spatial scales has recently become feasible with the development of Geographic Information Systems and methods to measure landscape pattern. This has led to a rush to apply this technology to management questions, often without knowledge of the problems associated with this new technology and analysis methods. This makes it critical to understand the implications of analyzing a landscape at different scales. Since a landscape which appears heterogeneous at one scale may appear homogenous at another, this apparent hetero- or homogeneity can have dramatic effects on interpretations of pattern and process. This makes spatial scale inherent in definitions of landscape heterogeneity and diversity (Meentemeyer and Box

1987).

Defining scale for either grain or extent can have important consequences. Forman (1995) has defined scale as: "Spatial proportion, the ratio of distance on a map to actual length; also the level or degree of spatial resolution perceived or considered. (Fine scale refers to pattern in a small area, where the difference between map size and actual size is relatively small, whereas broad or coarse scale refers to a large area, where the difference is great.) Forman (1995) defines grain as the "coarseness in texture of an area, as determined by the size of patches recognized. (Fine grain has mostly small patches and coarse grain has mainly large patches.)"

The spatial pattern of land cover is important in relation to mapping scale. As scale decreases (e.g. going from a 1:5,000 to a 1:10,000 scale map) scattered cover types will be eliminated from a map at a faster rate than clumped types. However, this information is not lost at a steady rate with decreasing resolution (Turner, et.al. 1990), probably due to the spatial configuration and grain size of the landscape. This means that the level of map generalization (scale in relation to the relative heterogeneity of the land cover types) has an effect on predictions of habitat and species diversity (Stoms 1992).

The size of raster cells within a GIS can have significant impacts on landscape analysis metrics. This is especially true when polygons developed from aerial photography are digitized, and then rasterized for other types of analysis, as was done with this study. The smaller the raster cell used, the closer it will approximate the vector polygon boundary as originally defined on the aerial photo, and the more real it will look to the human eye. However, small raster cell sizes result in larger computer files which can quickly fill computer storage space and greatly increase program run times (Turner et.al. 1989, Turner 1990, Hart 1994, Tobalske 1995).

At this time it is uncertain how the effects of topography and human activity affect the behavior of spatial pattern metrics (Gustafson and Parker 1992), although Turner, et.al. (1989a) have shown fractal dimension to be correlated with the degree of human influence on a landscape as measured with Landsat imagery using seven land cover types.

The typical indices used in analysis of spatial patterns measure diversity, dominance, and contagion (O'Neill et.al. 1988; Turner 1989a, 1990). Turner et.al. (1989a) define these measures as follows:

Diversity (H)
$$H = -\sum_{k=1}^{m} (P_k)\log(P_k)$$

where P_k is the proportion of the landscape in cover type k, and m is the number of land cover types observed. The larger the value of H, the more diverse the landscape.

Dominance (D)
$$D = H_{\max} + \sum_{k=1}^{m} (P_k)\log(P_k)$$

Dominance is calculated as the deviation from the maximum possible diversity; and $H_{\max} = \log(m)$, the maximum diversity when all land uses are present in equal proportions.

Contagion (C)
$$C = K_{\max} + \sum_{i=1}^{m} \sum_{j=1}^{m} (Q_{i,j}) \log (Q_{i,j})$$

Contagion measures the adjacency of the land cover types. The index is calculated from an adjacency matrix, Q , in which $Q_{i,j}$ is the proportion of [raster] cells of type I that are adjacent (diagonals are excluded) to cells of type j, where $K_{\max} = 2m \log (m)$ and is the absolute value of the summation of $(Q_{i,j}) \log (Q_{i,j})$ when all possible adjacencies between land cover types occur with equal probabilities. $K_{\max}$ normalizes landscapes with differing values of m and causes C to be zero when $m = 1$ or all possible adjacencies occur with equal probability. When $m >= 2$, large values of C will indicate a landscape with a clumped pattern of land cover types (Turner 1989).

Another index commonly used is the fractal dimension, which measures patch shape complexity (Mandelbrot 1983; O'Neill, et.al. 1988; Cullinan and Thomas 1992). Milne (1988) used fractals to quantify complex patterns of patch perimeters and areas and patch diversity within landscape mosaics. Fractals are based on similarity dimensions (self-similarity) which "..is predicted when the effects of processes or mechanisms at fine scales are propagated to broad scales." (Milne 1988). Fractal dimension is calculated by the double log fractal dimension:

$$\mathrm{DLFD} = \frac{2 \quad (N \sum \sum \ln p_{ij}^{2}) - (\sum \sum \ln p_{ij})^{2}}{((N \sum \sum (\ln p_{ij} * \ln a_{ij})) - ((\sum \sum \ln p_{ij})(\sum \sum \ln a_{ij})}$$

Turner, et.al. (1989a) specifically examined the effects of changing the grain (resolution) and the extent (total area) of landscape data on observed spatial patterns and indices. However, the method of aggregation used in Turner, et.al. (1989a) only simulated cases in which the data on the land cover is of coarse resolution (each pixel represented 4.0 hectares; Turner et.al. 1989a). This study by Turner found that both the dominance and contagion indices decreased as grain size increased. They conclude that while "..it may be possible to identify simple relationships between landscape parameters measured at different scales, the exact relationship varies across landscapes and does not permit extrapolation from one region to another."

Fractal dimension estimates appear to capture the gross features of landscape pattern (i.e. from aerial photographs), but are not consistent when based on ground measurements (Cullinan and Thomas 1992). This may be due to differences in how edges are measured at different scales and with different methods. For example, a patch boundary delineated via satellite imagery and the same patch boundary delineated by a ground traverse, would probably have different patch edges when examined at a fine scale.

Other types of metrics for spatial pattern analysis are used to describe landscapes. These include measures such as nearest-neighbor distances, core area, patch richness, mean patch size, and others.

CHAPTER 3: STUDY OBJECTIVES

The objective of this study was to examine the behavior of selected landscape indices under the combination of two levels of patch resolution and five raster cell sizes for landscape analysis. Using two different levels of patch resolution (fine and coarse scale) of the same analysis area may show how the selected metrics are affected by patch size (landscape extent is held constant). Changing the raster cell size modifies the effective analytical shape of the patches. Figures 1-10 (pp. 11-20) demonstrate the effects that patch resolution and raster cell changes introduce upon the same analysis area. This may give an indication of which metrics are affected by raster cell size. The metrics were compared individually, by intermediate groups (i.e. Area, Diversity) and by overall groups (composition, configuration, or general) (see Tables 1 and 3, pp. 3 and 29).

Based on literature findings and experience, nine statements were hypothesized:

1) Area metrics are expected to remain the same across scales.
2) Total edge is expected to decrease as raster cell size increases.
3) Diversity indices should remain stable until a patch type is eliminated.
4) Shape indices should indicate simpler shapes at larger raster cell sizes.
5) Number of patches should decrease as raster cell size increases.
6) Mean Patch Size should increase as raster cell size increases.
7) Mean Nearest-Neighbor Distance would be expected to increase as raster cell size increases.
8) Contagion should decrease as raster cell size increases.
9) Interspersion/Juxtaposition should decrease as raster cell size increases.

Figure 1 Cover Type/Pattern Landscape

10 Meter Raster Cell Size

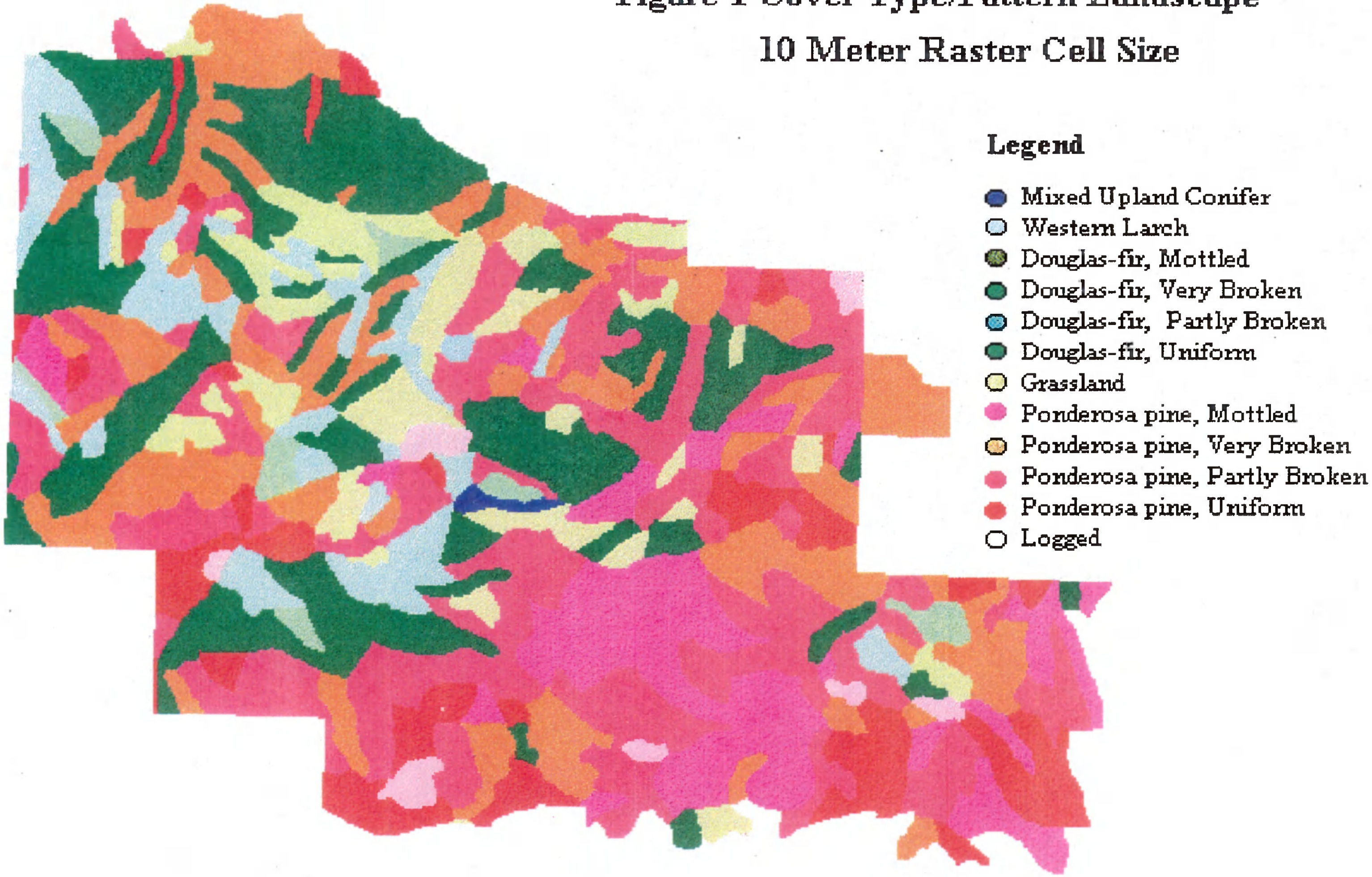


Figure 2 Cover Type/Pattern Landscape
30 Meter Raster Cell Size

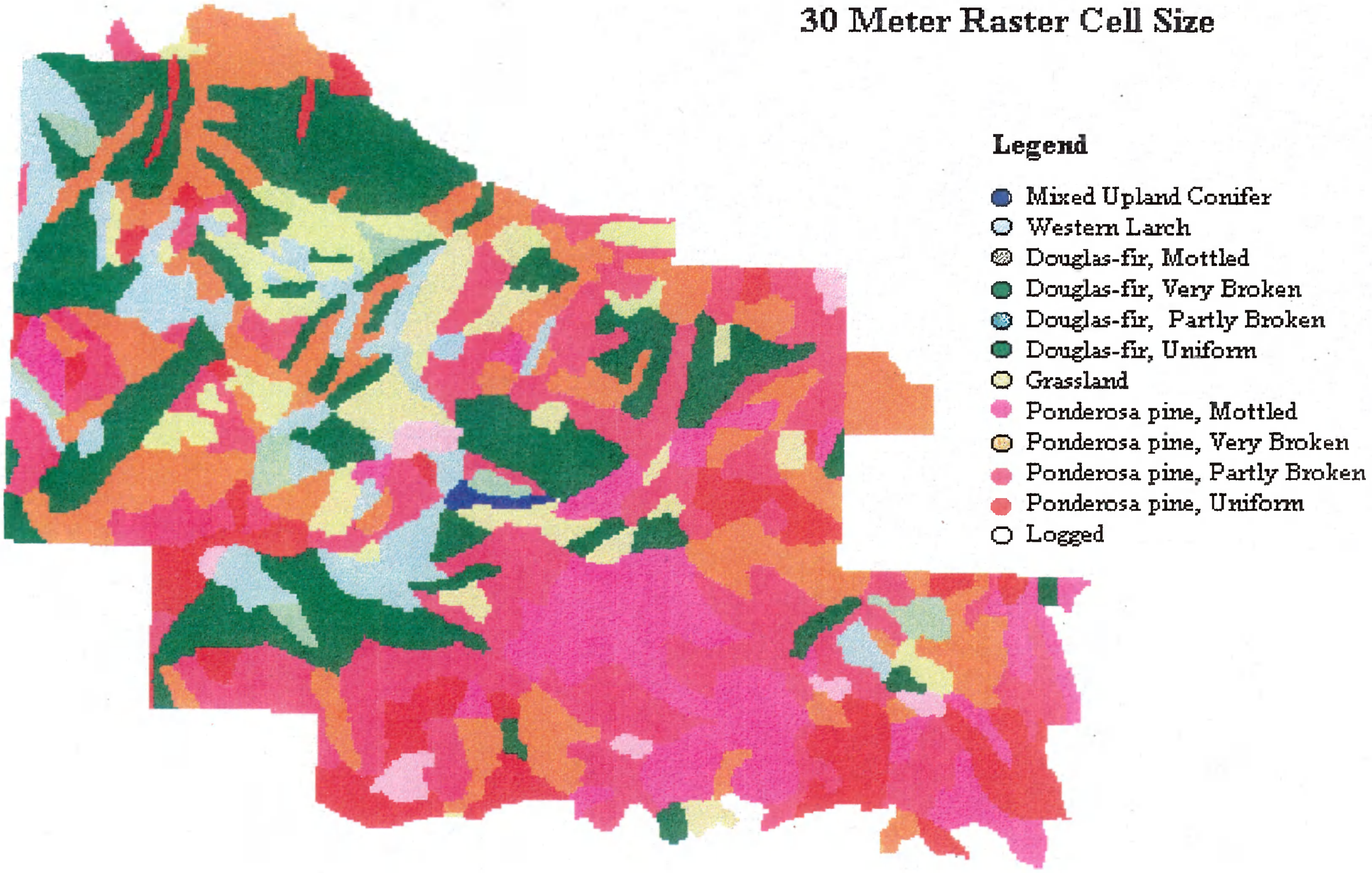


Figure 3 Cover Type/Pattern Landscape
50 Meter Raster Cell

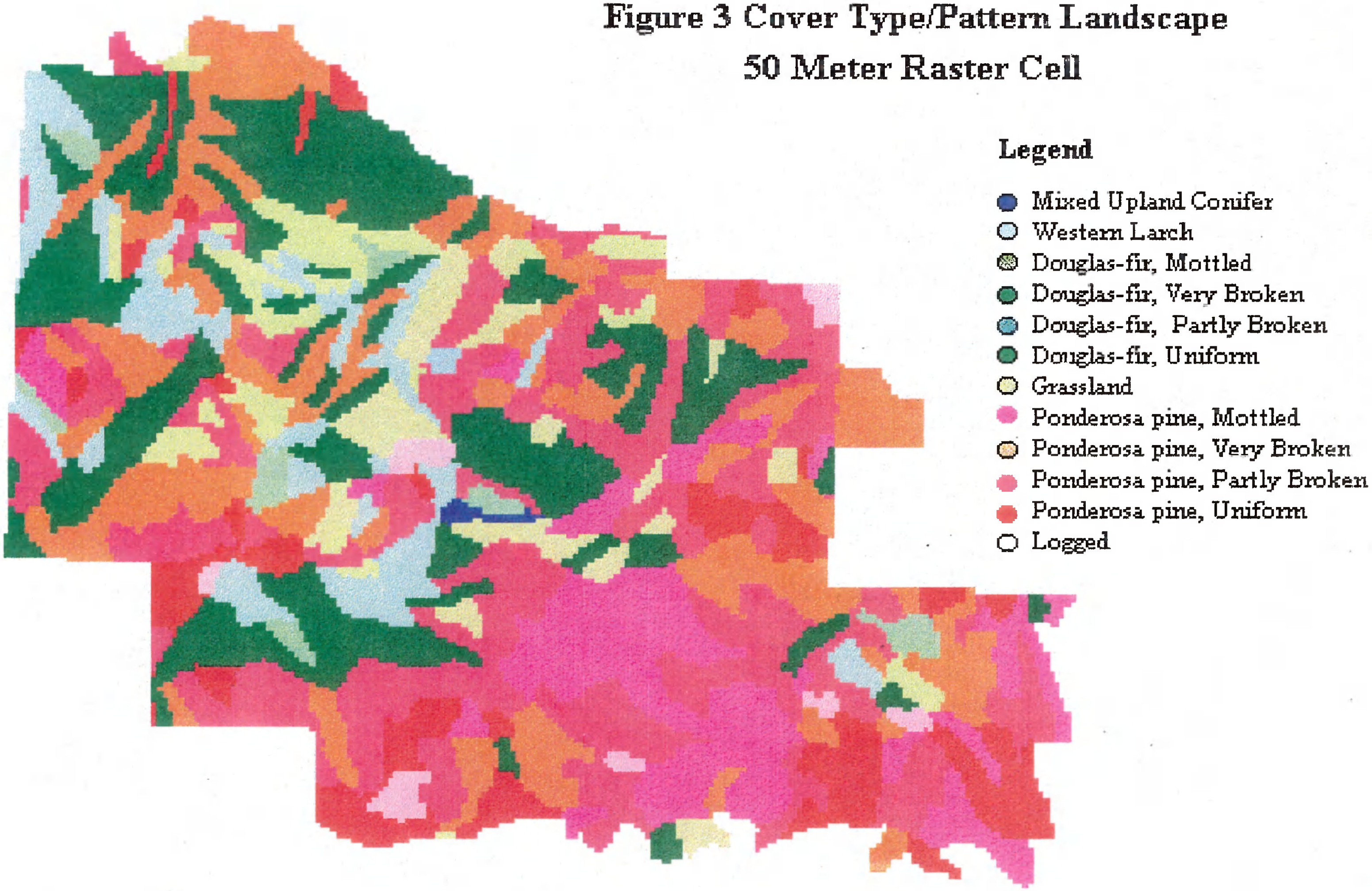


Figure 4 Cover Type/Pattern Landscape
100 Meter Raster Cell

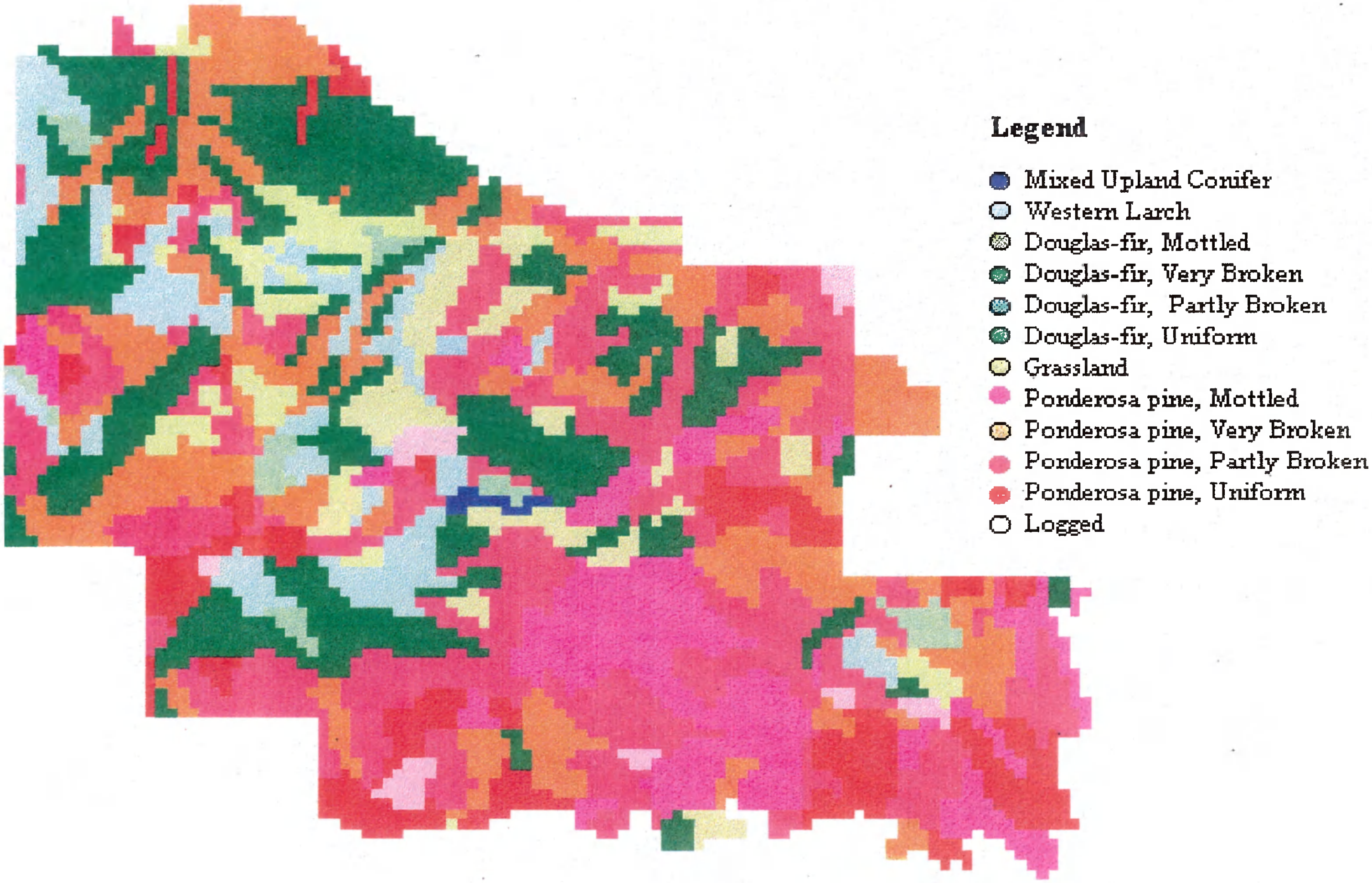


Figure 5 CoverType/Pattern Landscape
200 Meter Raster Cell

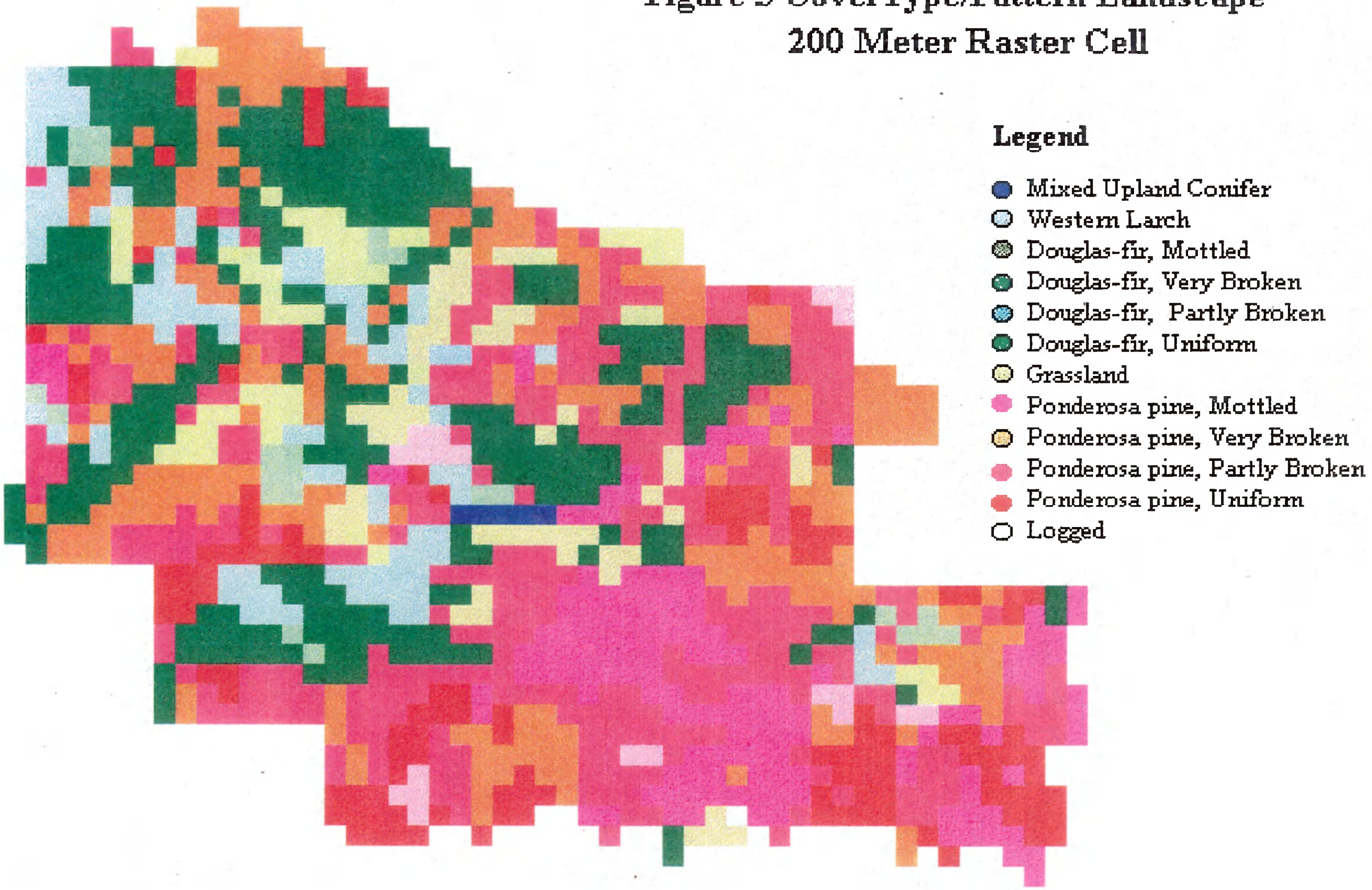


Figure 6 Cover Type Landscape
10 Meter Raster Cell

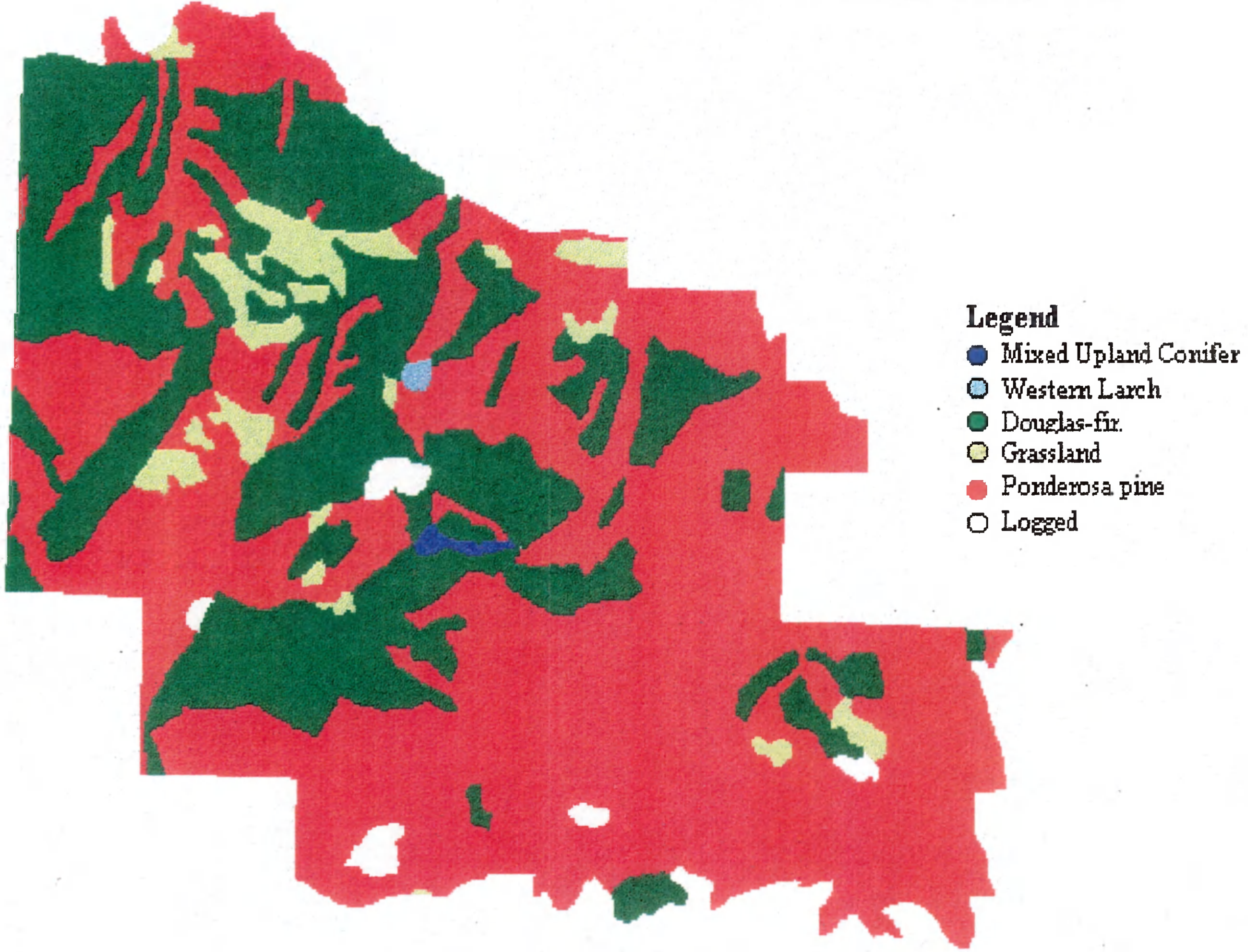


Figure 7 Cover Type Landscape
30 Meter Raster Cell

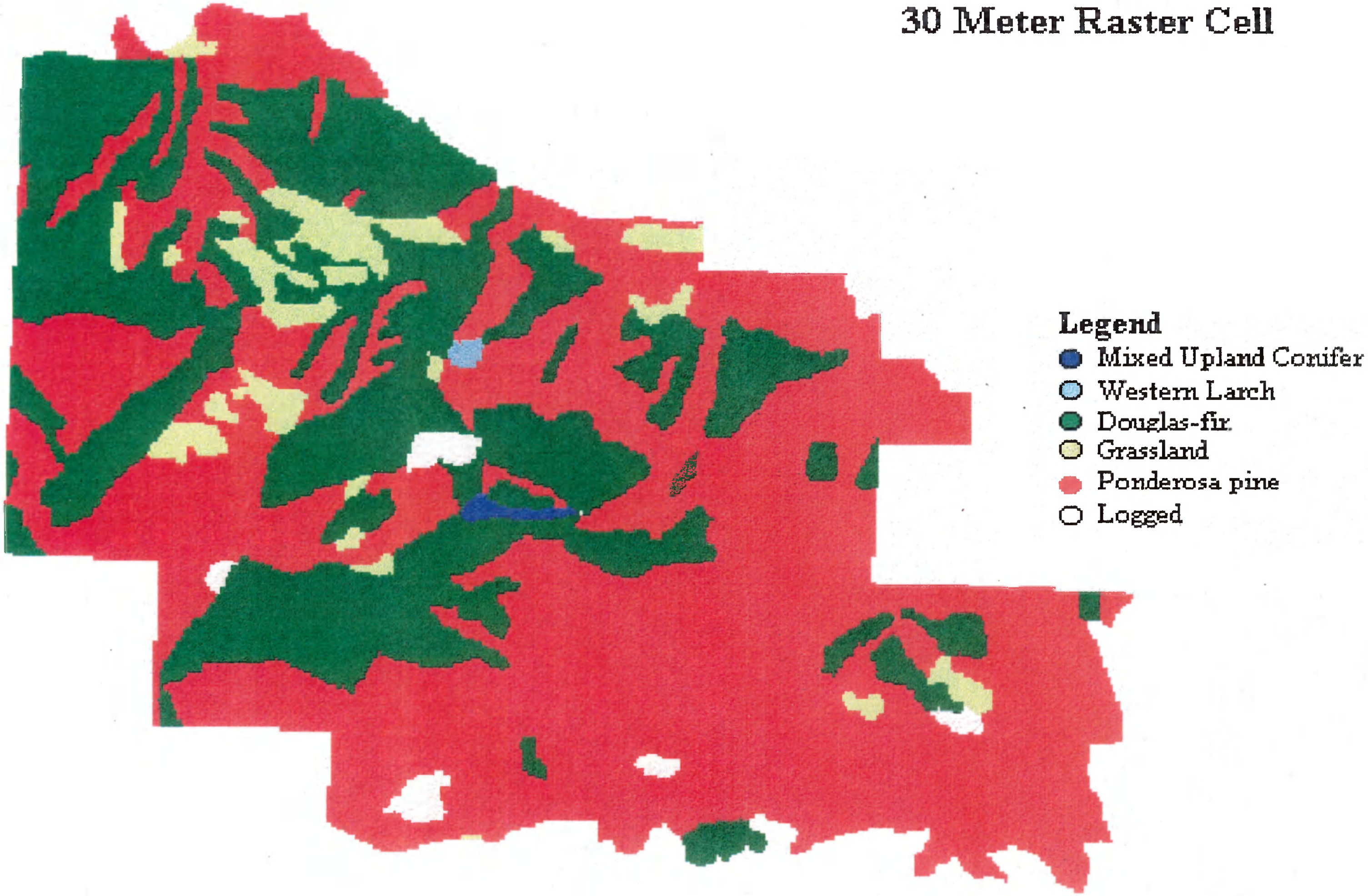


Figure 8 Cover Type Landscape
50 Meter Raster Cell

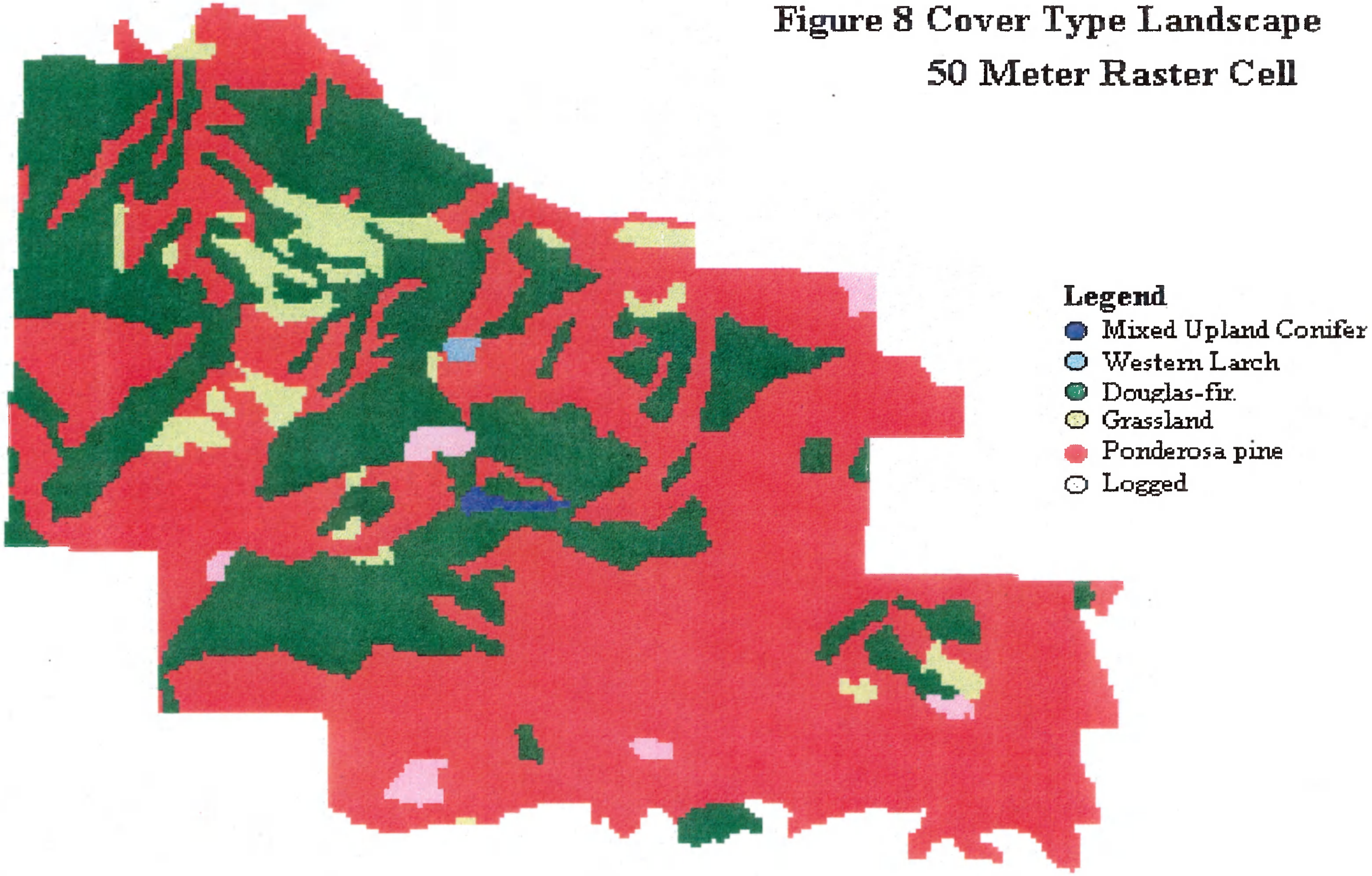


Figure 9 Cover Type Landscape
100 Meter Raster Cell

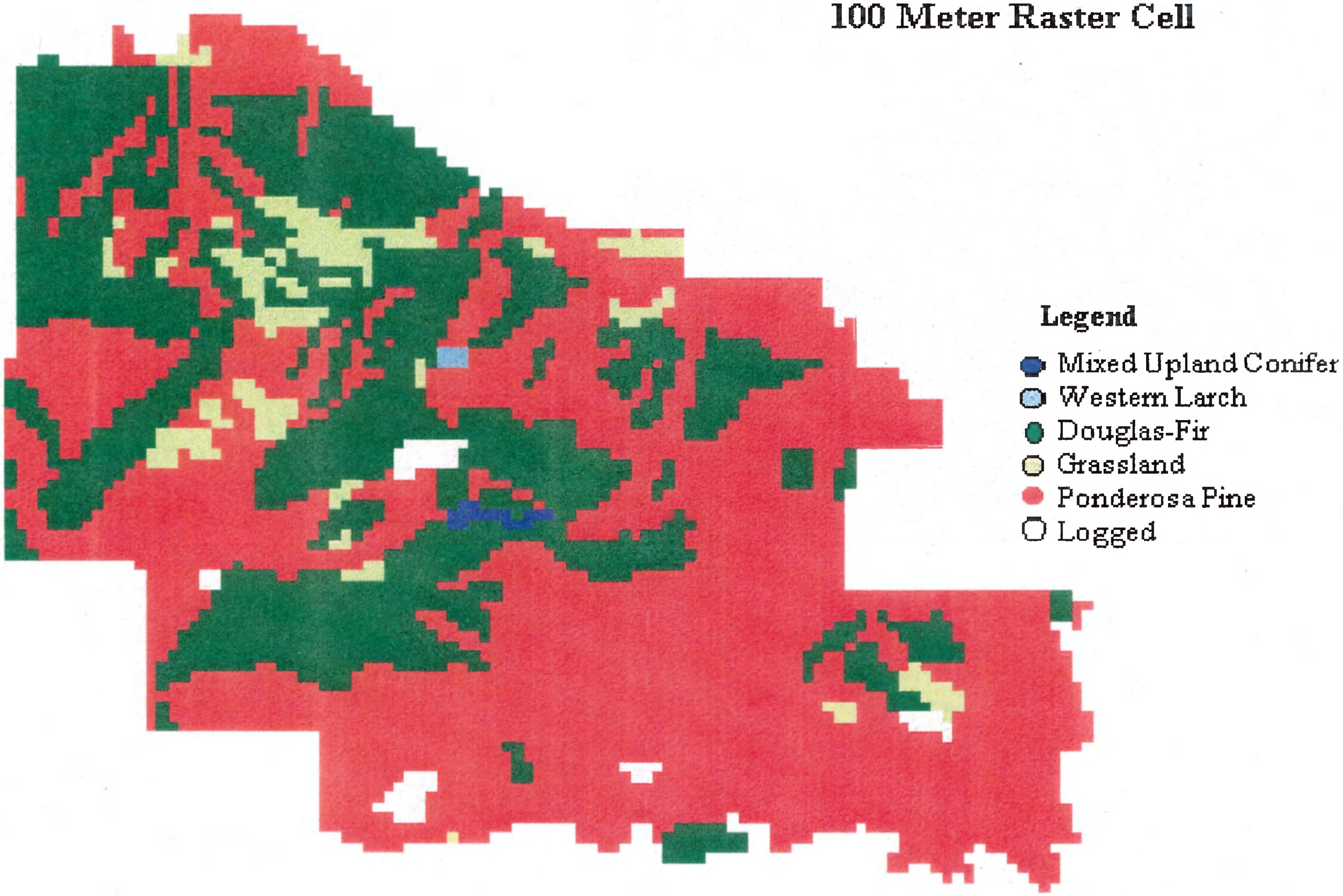
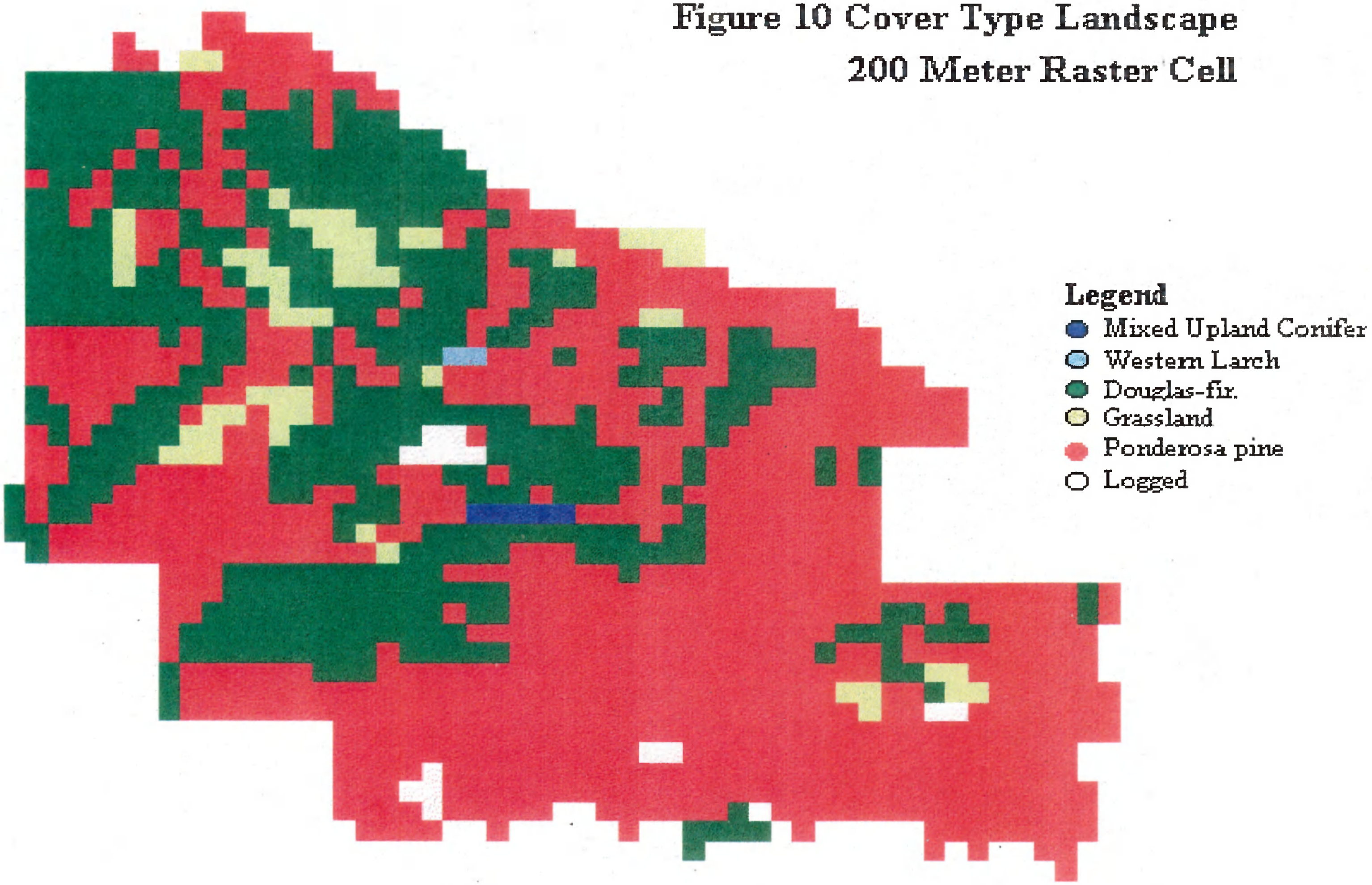


Figure 10 Cover Type Landscape
200 Meter Raster Cell



CHAPTER 4: METHODS

A. Study Design

To examine the combined effect of patch resolution and raster cell size on landscape metrics, I started with fine-grained patches (Figure 1-5) which were aggregated into coarse-grained patches (Figure 6-10) by merging adjacent patches of similar vegetation cover types. This provided two levels of patch resolution for the same analysis area (landscape extent was held constant).

These two levels of patch resolution were rasterized using 10 meter cells, which were then subsampled to produce the 30, 50 100, and 200 meter raster cell analysis levels (using the bilinear method). This produced ten different versions of the same landscape, each of which was analyzed using the FRAGSTATS 2.0 Spatial Pattern Analysis Program (McGarigal and Marks 1994). (See Table 2 for a matrix description of the 10 landscapes analyzed.)

B. Study Area

Lubrecht Experimental Forest, a 28,000 acre research forest operated by the University of Montana School of Forestry, is located approximately 35 miles northeast of Missoula, MT. The forest is considered to be typical of the mid-elevation coniferous forests of west-central Montana. The area is influenced by both the moister maritime climate of the western Continental Divide regime while laying close enough to the Divide to have a significant influence by the drier continental climate of the east side of the Divide (Steele 1964).

The main study area covered about 12,000 acres of the northwestern part of the Forest. It is bounded by Highway 200 on the south and east, the Blackfoot River on the north, and the Lubrecht Forest administrative boundary on the west. The study area is bisected by one main ridge trending northwest to southeast, with the two most prominent aspects being generally south and north. The area is moderately mountainous with Morrison Peak the high point at 5600' on the west boundary and the low point being where the Blackfoot River leaves the forest in it's northwest corner at 3600'.

The majority of the study area supports primarily forest vegetation, with the major exception being natural grass covered slopes that tend to have a south-southwesterly aspect and bedrock laying close to the surface. The principal tree species are: Douglas-fir (Pseudotsuga menziesii), western larch (Larix occidentalis), ponderosa pine (Pinus ponderosa), plus occasional lodgepole pine (Pinus contorta) and subalpine fir (Abies lasiocarpa). The grassy slopes consist mainly of native grasses such as Idaho fescue (Festuca idahoensis), rough fescue (Festuca scabrella), bluebunch wheatgrass (Agropyron spicatum) and some exotic grasses.

The coniferous part of the study area consists of second growth forest, with some older overstory trees left from logging conducted in the early decades of this century (Cauvin 1961, Steele 1964). Some other small areas of logging (10-100 acres) have been carried out in the recent past and are classified in this study as logged sites with no dominant overstory trees.

C. Database

The geographic database and map layers for the Lubrecht Experimental Forest reside in a Geographic Information System (PAMAP GIS), which is located in the School of Forestry GIS Lab at the University of Montana. The base layer from which all maps and images were generated are the Martin Forest Land Units (FLUs) which are discussed below.

Martin delineated his FLUs, to represent areas of similar vegetation and landform. Recorded photo interpretation (PI) variables for each polygon consisted of five landform characteristics, five vegetation characteristics and one combination variable (Martin, et.al. 1983). The vegetation PI variables are: Pattern; Overstory Texture; Crown Canopy Coverage; Average Overstory Height; and Average Overstory Crown Size. The land related PI variables are: Average Elevation; Contour Curvature; Aspect; Slope Angle; and Slope Position. The combination variable is listed as "Land and Overstory Modifiers".

These are some of the traditional attributes used to delineate forest stands, are visible on high altitude photography, and are usable for resource analysis (Martin, et.al. 1983). The combination variable is a land or overstory modifier that indicates the amount of disturbance or observable variation from a "normal" undisturbed stand. Some examples of modifiers are logging, rocky surfaces, mass failures, wetlands, etc. Compositional forest cover type is a derived variable based on a combination of ground truthing, statistical analysis of PI variables and photointerpretation. The minimum mapping unit (MMU) size was ten acres.

High altitude, quad centered, black and white air photos at a scale of 1:76,000 were used in the photo interpretation analysis. This type of photo is designed to cover the area within a 7.5 minute USGS quad map in a single frame.

A timber type map developed by Dennis Cauvin (Cauvin 1961) was also digitized to provide an additional PAMAP GIS vector layer of existing timber types. These stands were mapped at eight inches to the mile (1:7920) and were compiled from timber inventory points and checked with aerial photos. No accuracy estimates were made for this mapping.

The use of Martin's polygons in combination with Cauvin's polygons was originally intended to provide three levels of resolution. The original Martin polygons were to have formed the middle level and these mid-level polygons were to be aggregated to form the coarsest level of spatial resolution. This aggregation was to be accomplished by clumping adjacent homogenous stands based on photo-interpreted vegetation related variables. The finest level of resolution would have subdivided Martin's polygons based on Cauvin's estimate of compositional cover type differences. This would have resulted in a nested hierarchical set of three levels of land classification which could then be used to evaluate the relative effects of resolution changes in the behavior of the metrics.

D. Spatial Analysis Programs

The original intent in this study was to simply calculate selected metrics as listed in Turner's 1989 review paper (the original selected indices were to be: relative richness, relative evenness, diversity, dominance, fractal dimension, and contagion). However, programs which were designed to compute these metrics, plus others, became available and were examined for use in this study. Three analysis programs were eventually evaluated for their use in this study.

1. DISPLAY

DISPLAY is an interactive analysis tool used primarily for evaluating landscape scenes. Analysis consists of computing spatial statistics as well as three fractal analyses (perimeter-Area, Grid, and Number-Diameter) (Flather, unpublished ms. and software). Images proved to be difficult to import into this program, due to the DISPLAY program only accepting a certain type of image file not supported by the PAMAP system. Eventually a FoxPro program written by Mike Sweet solved this problem, but the number and type of metrics proved to be very limited. The required preparation time for different images, combined with the limited number of metrics available in DISPLAY led to the search for other analysis programs.

2. r.le Program

A second program, "r.le" which is a contributed program in GRASS 4.1 GIS was then examined in order to compare the metrics across different types of programs and their ease of use with the data available for this study. However, since the program runs on a workstation (it was originally written for a Sun Sparcstation) this program was not feasible to use, since a workstation was not available at the time of this study.

3. FRAGSTATS Program

The third program to be evaluated which became available after the study was underway is the FRAGSTATS program (McGarigal and Marks 1994). It is written for both workstation and PC platforms. There is extensive documentation for the program and it appears to have many more users than either of the other programs. The program calculates a large number of metrics and the user has more flexibility in choosing parameters than is available in DISPLAY. In addition, the program accepts many different image formats making it easier to analyze scenes exported from different GIS or ERDAS file type software packages (as integer GIS files).

When a new version of FRAGSTATS was released in late 1994 (FRAGSTATS 2.0), I decided to use it for all the analysis reported here.

E. Computer Preparation of Databases and Images for Analysis

The base map for Lubrecht Experimental Forest is located in the GIS Laboratory in the School of Forestry at the University of Montana. It resides in a PAMAP GIS file with a FoxPro database manager. The Morrison Peak unit was defined and cut out of the main data files. This simplified and speeded up the management and handling of the geographic data. Once the unit was defined, the surface layers were developed from polygonal covers. To clean up these layers required removing all unnecessary line elements and the related database information.

Vegetative land cover types were assigned to each raster cell for analysis (e.g. a Ponderosa pine cover type will be a "3" theme value in the GIS surface layer).

F. Cauvin Timber Type Maps/ Martin Land Unit Patch Characterization

These maps were drawn on paper (section by section) in 1961. Attempts to digitize the stand boundaries and attempted overlay of the section lines from the Lubrecht basemap over Cauvin's section lines, showed little correlation between the section lines and the error was in more than one direction. Attempted rubber sheeting in the PAMAP program was not successful. The error remained between six to ten percent which was considered unacceptable for this study (Zuuring per. comm.).

The problem in trying to successfully overlay the Cauvin and Martin maps was probably due to the paper base maps of Cauvin's which experienced shrinking and swelling over time and leads to map error due to this unstable media (Zuuring per. comm.).

After rejecting the use of Cauvin's type maps for this study, it was decided to define the patches from Martin's Land Unit vegetative characteristics only (removing the topographic or land form breaks if the vegetative characteristics did not change). The finest level of resolution is the cover type and pattern (CTP). These represent aggregation of all adjacent polygons having the same vegetation-related variable (pattern such as mottled, uniform, broken, etc.). The second level of resolution is an aggregation of all adjacent polygons having the same cover type (CT) (i.e. Ponderosa pine, Douglas-fir, etc.).

Personal field familiarity with the Martin Land Units was gained during previous employment as a forester at Lubrecht Experimental Forest and during field observations in the course of this study.

G. Vector to Raster Conversion

The two sets of polygons (CT and CTP) were converted to a 10 meter raster cell base. Previous studies (Turner 1989, Hart 1994, Tobalske 1995) have illustrated that the finer the raster cell size, the better will be the representation of a vector delineation such as polygons defined from aerial photography.

The CT and CTP landscapes were analyzed at five different raster cell sizes by resampling the 10 meter surface layer in PAMAP up to 30, 50 , 100, and 200 meter raster cell resolutions. Using these sizes gives a minimum raster cell size of 10 meters and a minimum possible patch size of ten acres (based on Martin's minimum mapping unit).

The next step was to copy these surface layers into an ERDAS GIS file format for use in the FRAGSTATS program.

H. Landscape Metrics

The metrics listed below were chosen from the FRAGSTATS 2.0 output of the two different PAMAP vegetation cover layers of the study area. They are listed under groups that measured a similar characteristic (Table 3).

Table 3. Landscape Metrics Analyzed, Categorized by Group

Composition	Configuration	General
Shannon's Diversity Index	Mean Shape Index	Number of Patches
Simpson's Diversity Index	Landscape Shape Index	Mean Patch Size
Modified Simpson's Diversity Index	Area-Weighted Mean Shape Index	Total Edge
Patch Richness	Double Log Fractal Dimension	Total Area
Shannon's Evenness Index	Area-Weighted Mean Patch Fractal Dimension	
Simpson's Evenness Index	Mean Nearest-Neighbor Distance	
Modified Simpson's Evenness Index	Contagion Index	
Largest Patch Index	Interspersion/Juxtaposition Index	

CHAPTER 5: RESULTS

The metrics are grouped according to the type of measurement each represents (i.e. Area, Patch Density, Shape, etc.). Following the explanation of each index is a display of the variation of the index over raster cell size, and comments about the results.

Area Metrics

Total Landscape Area (TA): This defines the extent of the landscape. TA is measured in absolute hectares for the entire landscape.

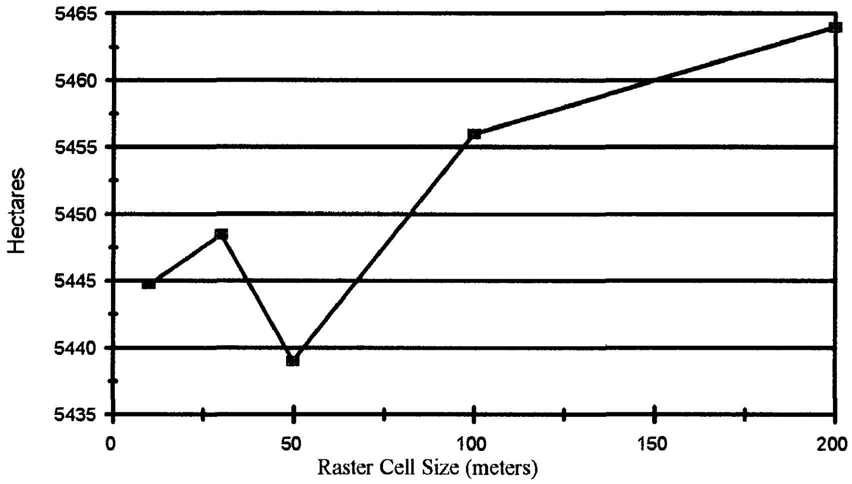


Figure 11. Total Landscape Area by Raster Cell Size for both the Cover Type/Pattern and Cover Type landscapes.

Results: The Cover Type/Pattern and Cover Type landscapes have the same TA, but the TA changes for each raster cell size. The lowest area is 5439 ha and the highest area is 5464 ha, a difference of 25 hectares. After the 50 meter raster cell size, the total area increases as the raster cell size increases.

Interpretation: This is an artifact due to the raster data type for calculating areas. Due to the method of interpolation in PAMAP, the number of raster cells will change for each size depending on if the next raster cell is in or out. If the centroid of the raster cell is included, this will add the area of the whole raster cell into the landscape calculations. Thus, interpreting area with a raster display is subject to some error.

Largest Patch Index (LPI): Quantifies the percentage of the landscape area occupied by the largest patch type. The higher the percentage, the less "fragmented" the landscape can be considered to be. For example, the Cover Type landscape at the 200 meter raster cell level has almost 60% of the total area taken up by one patch type.

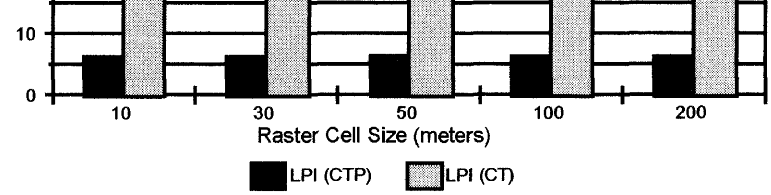


Figure 12. Largest Patch Index for Cover Type/Pattern and Cover Type landscapes. The area dominated by a single patch in the Cover Type landscape increased markedly at the 200 meter cell size.

Results: LPI increased markedly in the 100 and 200 meter raster cell sizes in the Cover Type landscape. In contrast, the LPI for the Cover Type /Pattern landscape showed essentially no change. LPI was approximately 8-9 times greater for the Cover Type landscape than for the Cover Type/Pattern landscape.

Interpretation: The lack of change in the Cover Type/Pattern index indicates that the fine grained nature of the landscape mosaic, even at a 200 meter raster cell size, keeps the proportional area at a relatively even percentage of the landscape. The coarser grain of the Cover Types allows a larger raster cell size to start to aggregate similar cover types, particularly starting at the 100 meter level. In this case, the level of land classification has a great influence on the behavior of the index across a range of raster cell sizes, but only once a raster cell size of between 50 and 100 meters is reached.

Patch Density and Size Metrics

Number of Patches (NP): This metric falls into the general group, as it does not have a strict spatial interpretation. NP can be very useful if it describes a particular habitat type or ecosystem type that is of particular interest. NP can also give an idea of the susceptibility of the landscape to the propagation of disturbances across it. For example, a landscape with few patches may be more susceptible to a disturbance than one with many different patch types.

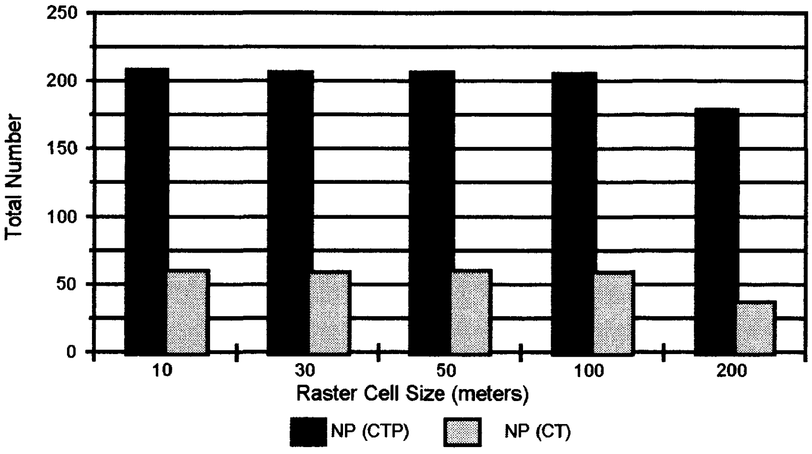


Figure 13. Number of Patches for Cover Type/Pattern and Cover Type landscapes. This index decreases for both landscapes as raster cell size increases.

Results: As expected the number of patches is greater for the Cover Type/Pattern landscape. Neither landscape shows an appreciable drop in the total number of patches until the 200 meter raster cell size is reached. The Cover Type/Pattern landscape drops from 208 to 179 patches, while the Cover Type landscape drops in patch number from 60 to 37.

Interpretation: With the number of patches dropping so much at the Cover Type level, this could have a significant influence on the estimation of how an ecosystem process or a disturbance could propagate across the landscape. (See Figures 6 thru 10 for an example of how the polygons "block up" in the Cover Type landscape as the raster cell size changes.)

Mean Patch Size (MPS): This measure is potentially useful for interpreting the fragmentation of a landscape. MPS is constrained by the grain and extent of the landscape, since if the minimum grain size is 10 meters, it will not have patches less than 10 meters square. Therefore, it is not possible to deal with questions that relate to processes or organisms that relate to patch sizes less than this minimum size. It is probably best to interpret this measure in conjunction with the number of patches and the variability in patch size.

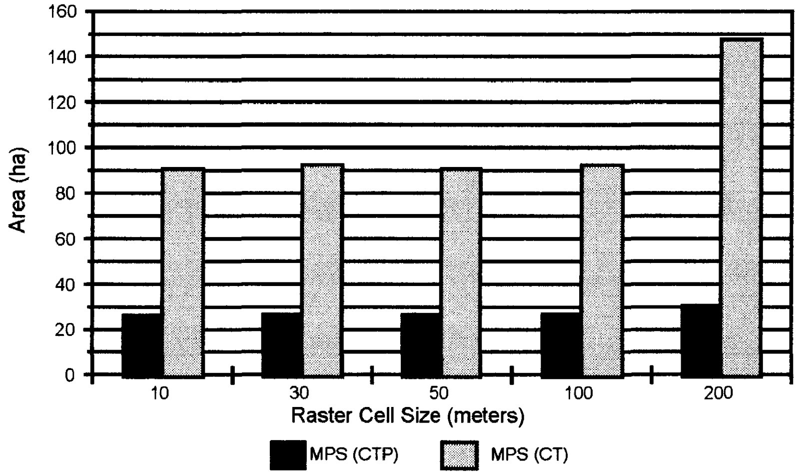


Figure 14. Mean Patch Size for Cover Type/Pattern and Cover Type landscapes. MPS shows a significant increase in the Cover Type landscape at the 200 meter cell size.

Results: Neither Cover Type/Pattern or Cover Type levels show much variation until the 200 meter raster cell sizes. Cover Type/Pattern changes from 26.18 to 30.53 ha; Cover Type from 90.75 to 147.68 ha. The change from 100 to 200 meter cell size accounts for nearly all of the total variation in patch size for each landscape.

Interpretation: For these particular landscapes, the spatial distribution of the patches is such that increasing the raster cell size does not aggregate patches together until a threshold between 100 and 200 meters is reached. These changes appear to be dependent on the spatial arrangement of the polygons. (Refer to Figures 6 to 10 for an example of polygon blocking.)

Edge Metrics

Total Edge (TE): This index is important to many ecological and biological phenomena (i.e. wildlife effects; wind throw; light penetration, etc.). Edge effects, like most of these metrics, needs to be interpreted in relation to the specific problem being addressed. The amount of edge is directly influenced by the resolution of the image. This is especially true in the raster format where the stair step effect of the raster elements "creates" more edge than in the vector format.

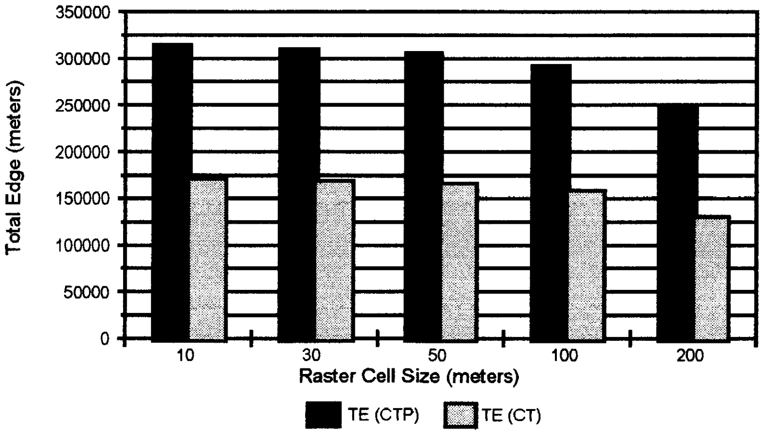


Figure 15. Total Edge for Cover Type/Pattern and Cover Type landscapes. Total edge declines with increasing raster cell size for both landscapes.

Results: Total edge (perimeter) shows a steady downward trend as raster cell size increases. This was consistent in both the Cover Type/Pattern and Cover Type landscapes. The total edge was reduced from 314,340m to 248,000m for the Cover Type/Pattern landscape and 170,790m to 130,600m for the Cover Type landscape.

Interpretation: Comparisons need to be made between similar geographic data format type (raster and vector), but TE does seem to be a measure that has some predictability. These results are as expected, that as the raster cell size increases, the amount of total edge will decrease.

Shape Metrics

Landscape Shape Index (LSI): Measures the perimeter-to-area ratio of the whole landscape. (Identical to Patton's 1975 index for habitat diversity.) This index quantifies the amount of edge present in a landscape relative to what would be present in a landscape of the same size but with a simple geometric shape and no internal edge (McGarigal and Marks 1994).

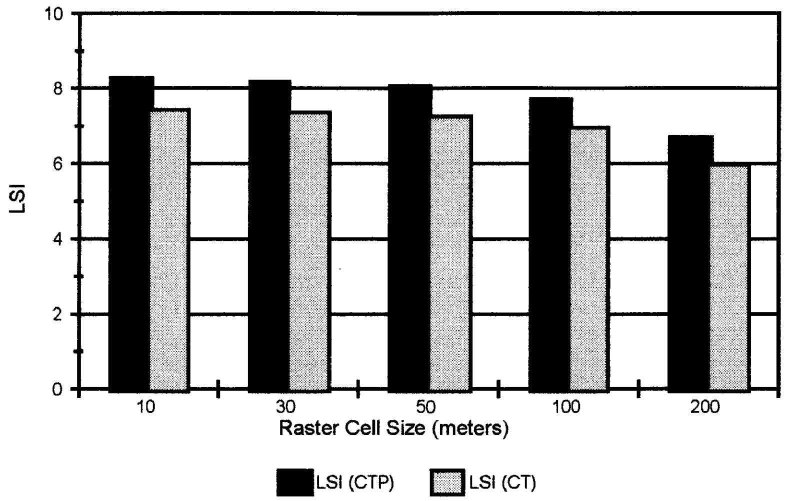


Figure 16. Landscape Shape Index for the Cover Type/Pattern and Cover Type landscapes. LSI decreases for both landscapes.

Results: There is a steady downward trend for both Cover Type/Pattern and Cover Type landscapes. The total change for the Cover Type/Pattern LSI was from 8.28 to 6.70 and 7.43 to 5.96 for the Cover Type LSI. The trend was consistent across the different raster cell sizes.

Interpretation: Due to the raster format that forms a blocky image, this index is one that shows a consistent trend in relation to raster cell size. As raster cell size increases and forms a blockier raster image the shape index becomes progressively smaller, thus indicating a "simpler", more geometric landscape.

Mean Shape Index (MSI): This index measures the average perimeter-to-area ratio for all the patches contained in the landscape image (also computed with a square standard for the raster format version). This index is most appropriate in landscapes that are not dominated by large patches of one type or another.

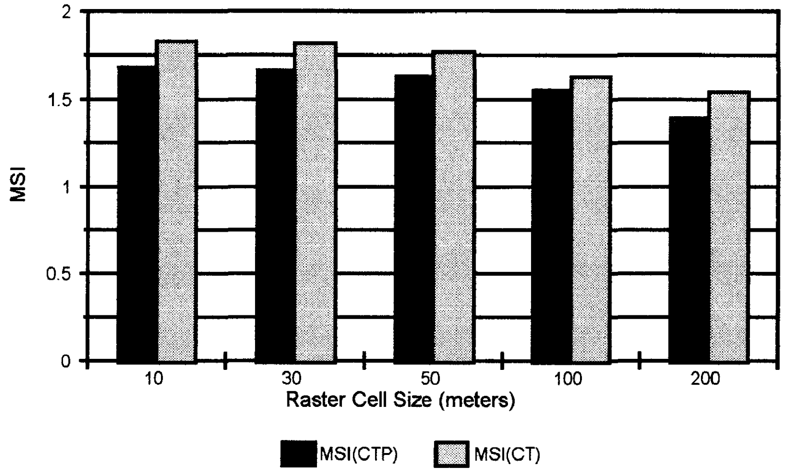


Figure 17. Mean Shape Index for Cover Type/Pattern and Cover Type landscapes. This index decreases for both landscapes across the range of raster cell sizes.

Results: The MSI for the Cover Type/Pattern landscape shows the biggest change over the range of raster cell sizes, from 1.68 to 1.39, while the Cover Type landscape changes from 1.83 to 1.54. The result for the Cover Type landscape is probably due to the landscape being dominated by a single patch type. It is interesting that the mean shape index is strikingly lower for the Cover Type/Pattern landscape. This indicates that the smaller Cover Type/Pattern polygons are simpler in shape than the larger polygons of the Cover Type landscape. In this case, the index is probably a good measure for the Cover Type/Pattern landscape since the Largest Patch Index for that landscape is 6%. However, MSI is probably not appropriate for the Cover Type landscape since the Largest Patch Index for this image is between 45% and 59% (McGarigal and Marks 1994). Increasing values of MI generally indicate more complex shapes.

Interpretation: Since the mean shape index uses all the patches in a landscape, it is necessary to interpret this index in conjunction with other metrics. When examined in conjunction with Total Edge, it shows that increasing the raster cell size decreases Total Edge and the Number of Patches as Mean Shape Index also drops, indicating a "simpler" more geometric, landscape.

Area-Weighted Mean Shape Index (AWMSI): This index weights the patches according to their size (larger patches are weighted more heavily than smaller patches). For this study, AWMSI is probably the more appropriate index for the Cover Type landscape.

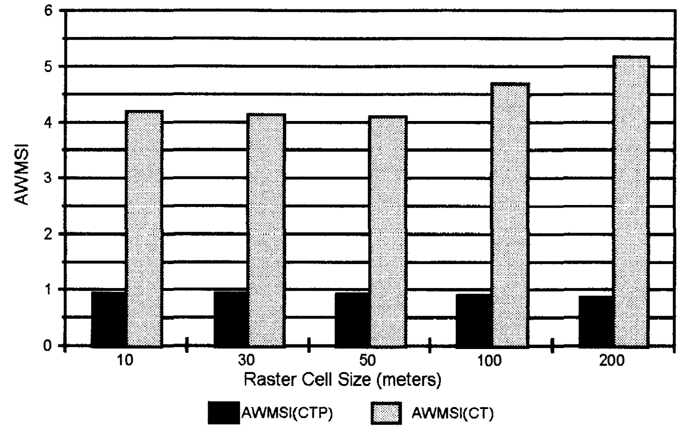


Figure 18. Area-Weighted Mean Shape Index for the Cover Type/Pattern and Cover Type landscapes. The index increases for the Cover Type landscape and decreases for the Cover Type/Pattern landscape.

Results: For the Cover Type landscape, AWMSI increased from 4.19 to 5.17 across the range of raster cell sizes. The index showed little change from the 10 to 50 meter raster cell sizes, but then increased at the 100 and 200 meter levels unlike any of the other shape indices. This demonstrates that the increasing raster cell size with broad levels of land cover classification causes aggregation of polygons which will increase the size of the largest patches (increasing the Largest Patch Index). This is seen in Figure 10 as the landscape becomes increasingly blocky with an increase in raster cell size. For the CTP landscape, the AWMSI shows little change across all cell sizes (0.93 to 0.86), but the index is much lower than the CT.

Interpretation: Since this index is most appropriate for landscapes dominated by large patches, the assumption is made that the behavior of the index for the Cover Type landscape is the best result to look at. The small change in the 10 to 50 meter range can be probably be considered minimal. The large change seen in the 100 and 200 meter sizes can be attributed to the aggregation of patches into larger polygons (the number of patches decreases from 50 to 37). This results in a sharp increase in the index as the landscape becomes dominated by fewer, larger patches.

Double log fractal dimension (DLFD): At the landscape level, DLFD is calculated with a perimeter-to-area relationship using the entire landscape mosaic. Fractal dimensions normally range from 1.0 (the dimension of a line) to 2.0 (increasingly plane-filling) as a polygon becomes increasingly more complex.

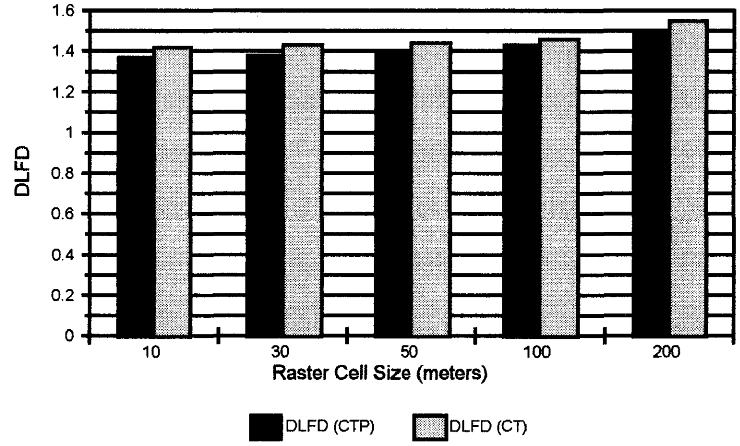


Figure 19. Double Log Fractal Dimension for Cover Type/pattern and Cover Type landscapes. This index increases the same relative amount for both landscapes.

Results: The DLFD for both the Cover Type/Pattern and Cover Type landscapes shows increasing complexity as the raster cell size increases. Increasing the raster cell size, increases the fractal dimension, indicating an increasing complexity of shape.

Interpretation: The seemingly inconsistent results of this index, where it appears that the complexity is increasing with an increase in raster cell size is probably due to the landscape boundary becoming blockier, although the amount of edge is decreasing. By comparing the landscape images (Figures 1 through 5) it becomes apparent that the outside boundary edge of the landscape is becoming more "shape-filling" and complex, than at the 10 meter resolution.

Area-Weighted Mean Patch Fractal Dimension (AWMPFD): Patches are again weighted by size, with the biggest patches receiving the most weight in the calculations.

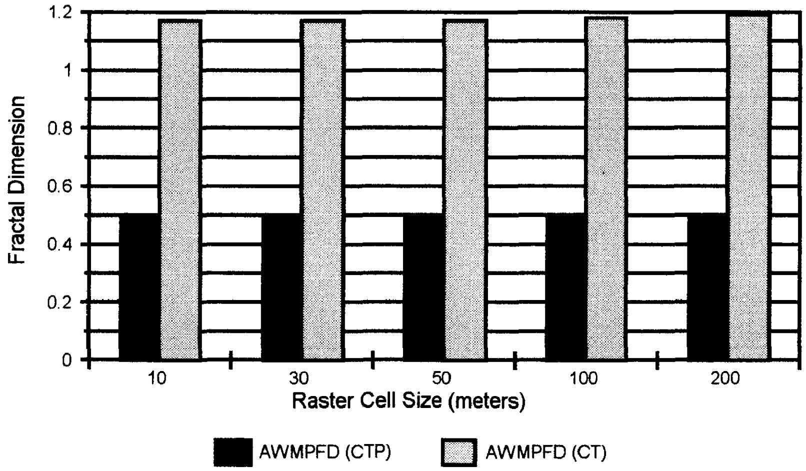


Figure 20. Area-Weighted Mean Patch Fractal Dimension for Cover Type/Pattern and Cover Type landscapes. This index changes for the Cover Type landscape only.

Results: For the Cover Type landscape the index varied very slightly, from 1.17 to 1.19 over the 10 to 200 meter raster cell size. The Cover Type/Pattern landscape changed from 1.40 to 0.50 which may be a spurious result since 1.0 is considered to be the dimension for a line.

Interpretation: The slight variation in the index for Cover Types may suggest a tendency for the larger raster cell sizes to transform into shapes that are more complex than squares. The Cover Type/Pattern value of 0.50 may be a spurious result since the index is not supposed to go below 1.0 (see page 88). Attempts to explain the apparent anomalies have been unsuccessful.

Nearest-Neighbor Metrics

Mean Nearest-Neighbor Distance (MNN): This is computed only for those patches that have neighbors, which is all of the patches in the two analyzed landscapes. It is based on the distance from a patch to the nearest neighboring patch of the same type by it's nearest edge to nearest edge distance. Rare patch types present in the study area require careful interpretation of this index. Both of the study landscapes contain rare types, but the number of other patch types gives a sufficient sample for this index to work well. This index is relevant to questions of disturbance propagation, dispersal, or population viability analysis.

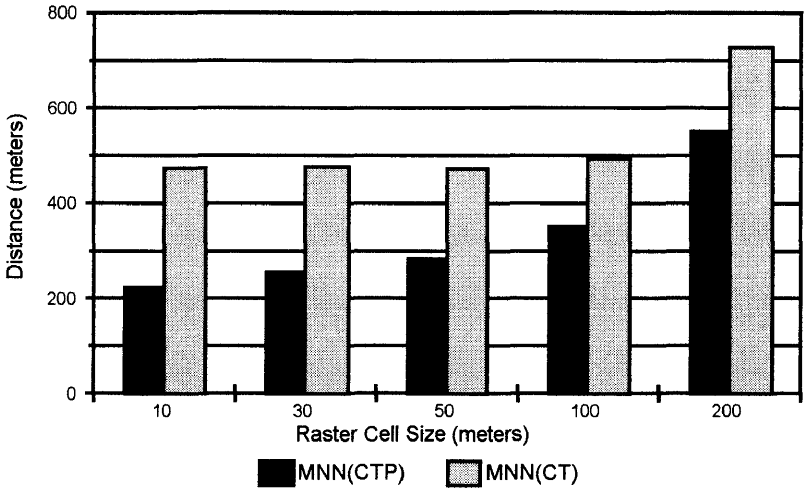


Figure 21. Mean Nearest-Neighbor Distance for Cover Type/Pattern and Cover Type landscapes. As expected this metric is greater for the Cover Type landscape.

Results: As expected, the Cover Type/Pattern MNN distance is much lower (nearly half) of the Cover Type landscape distance. The 200 meter Cover Type/Pattern landscape is 247% of the 10 meter size (223.1 m to 550.2m). The change across the raster cell spread in the Cover Type landscape shows a 153% change (474.3m to 727.0m).

Interpretation: This difference between CT and CTP is not surprising since the Cover Type landscape already is an aggregated version of the Cover Type/Pattern landscape. Therefore, the distances should be greater and the change should not be as large. The larger distances in the Cover Type landscape demonstrate the relatively greater isolation of the patches when this coarser level of land classification is used, compared to the Cover Type/Pattern landscape.

Diversity Metrics

Shannon's Diversity Index (SHDI): All of the diversity indices use two components for calculations--richness and evenness. Richness is the number of patch types present; evenness is the distribution of area between all of the different patch types. Shannon's index is more sensitive to richness than evenness. As a result of this, it is influenced more by the presence of rare types. It represents the amount of information contained in the individual patches. (The information theory indices, such as SHDI, are based on the premise that diversity, or information in a natural system can be measured in a similar way to the information contained in a code or message (Magurran 1988)). The value of the Shannon index is usually between 1.5 and 3.5.

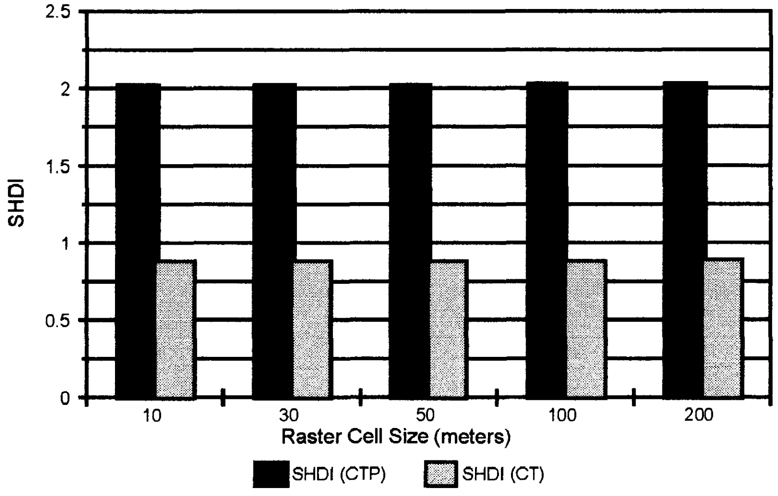


Figure 22. Shannon's Diversity Index for Cover Type/Pattern and Cover Type landscapes. This index is constant at all raster cell sizes for both landscapes.

Results: Neither landscape shows much variation in this index over the range of raster cell sizes analyzed. The Cover Type/Pattern landscape measure changes varies from 2.02 to 2.03, while the Cover Type landscape changes from 0.88 to 0.89. This indicates that the CTP landscape diversity is approximately two and a half times greater than the Cover Type landscape.

Interpretation: This index simply confirms what would be expected about these two differing levels of land classification-the one with greater resolution conveys greater information (due to the fine-grain) about the area in question.

Simpson's Diversity Index (SIDI): Simpson's index is less sensitive to rare types on the landscape and is more intuitive to interpret than Shannon's (McGarigal and Marks 1994). The Simpson index is the probability that any types selected at random would be different types. So the higher the value the greater the possibility that two randomly selected patches would be different. As this index approaches 1.0, the observed diversity approaches perfect evenness. The Simpson's index is in that group of heterogeneity indices known as the dominance measures since they are more concerned with the abundances of the most common species, rather than with species richness (Magurran 1988).

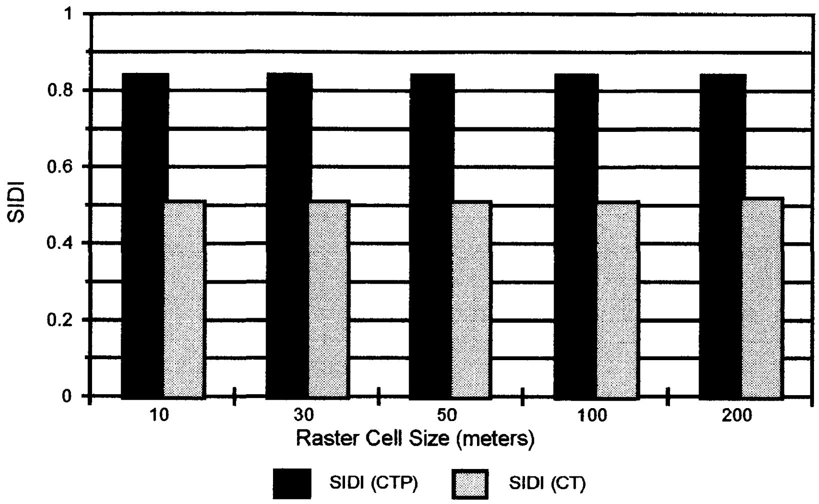


Figure 23. Simpson's Diversity Index for Cover Type/Pattern and Cover Type landscapes. This index is essentially constant over all raster cell sizes for both landscapes.

Results: The index for the Cover Type/Pattern landscape shows no change over the range of raster cell sizes. The Cover Type landscape has virtually no change in probability, going from 0.51 for the 10-100 meter raster cell sizes, to 0.52 at the 200 meter raster cell level. The Cover Type/Pattern landscape appears to be much closer to perfect evenness at 0.84 than the Cover Type landscape at 0.51, which is an expected result.

Interpretation: While the number of patches decreases for both landscapes as the raster cell size increases, the probabilities of randomly choosing different patch types within the landscape is not affected. The Cover Type/Pattern landscape being closer to perfect evenness than the Cover Type landscape is a result of the smaller polygon size in the Cover Type/Pattern landscape leading to a greater number of polygons so that the probability of choosing different types at random remains high.

Patch Richness (PR): This is the number of patch types present. Patch richness often correlates well with species richness since many organisms are associated with a single patch type.

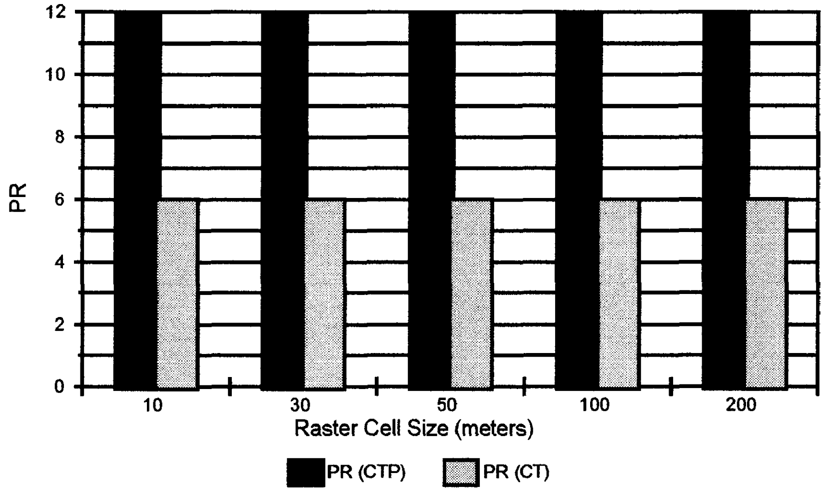


Figure 24. Patch Richness for Cover Type/pattern and Cover Type landscapes. This metric does not change for either landscape across the range of raster cell sizes.

Results: The patch richness remained the same for both landscapes over the range of raster cell sizes (12 for Cover Type/Pattern; 6 for Cover Type).

Interpretation: Since the smallest type on both landscapes remained in the landscape through all the raster cell size changes, the number of patch types was unchanged. (I was interested at what raster cell size patch types would start dropping out and resampled the 10 meter image up to 300, 400, and 500 meter raster cells. At the 400 meter raster cell size, the single Western Larch and single Mixed Upland Conifer patches were eliminated.)

This "dropping out" of patches is also dependent on the size of the individual patch in relation to the rest of the landscape. A single, large patch, while it may be rare in abundance, may remain in the landscape and even come to dominate it at a larger raster cell size. This again points out that many of these metrics need to be interpreted in relation to one another, and the landscape as a whole.

Modified Simpson's Diversity Index (MSIDI): This modified version transforms the index into one that is similar to Shannon's diversity index. This modification eliminates the intuitive interpretation of Simpson's index as a probability (McGarigal and Marks 1994). This index is modified by taking the natural log of the sum instead of 1 minus the sum as in the unmodified version.

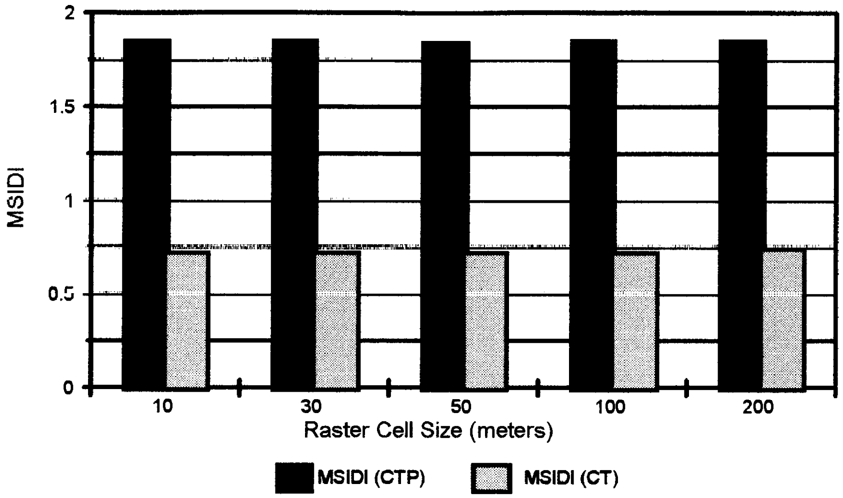


Figure 25. Modified Simpson's Diversity Index for Cover Type/Pattern and Cover Type landscapes. This index does not show any significant changes across all the raster cell sizes for both landscapes.

Results: The difference between the two landscapes is due to the change in patch richness. It is interesting to note that although the Patch Richness for the Cover Type/Pattern landscape is twice as great as the Cover Type landscape (12 and 6 respectively), the Cover Type/Pattern metric is greater than twice the Cover Type metric.

Interpretation: MSIDI eliminates the sensitivity to rare patch types, and when compared to the other two indices, shows approximately the same low level of variation.

Shannon's Evenness Index (SHEI): Evenness measures the distribution of area among patch types. Evenness is used in FRAGSTATS instead of dominance since larger values are associated with greater diversity. As the evenness index approaches 1.0, the observed diversity approaches perfect evenness. Evenness is strongly influenced by richness. McGarigal and Marks (1994) define evenness indices this way: "Evenness is expressed as the observed level of diversity divided by the maximum possible diversity for a given patch richness".

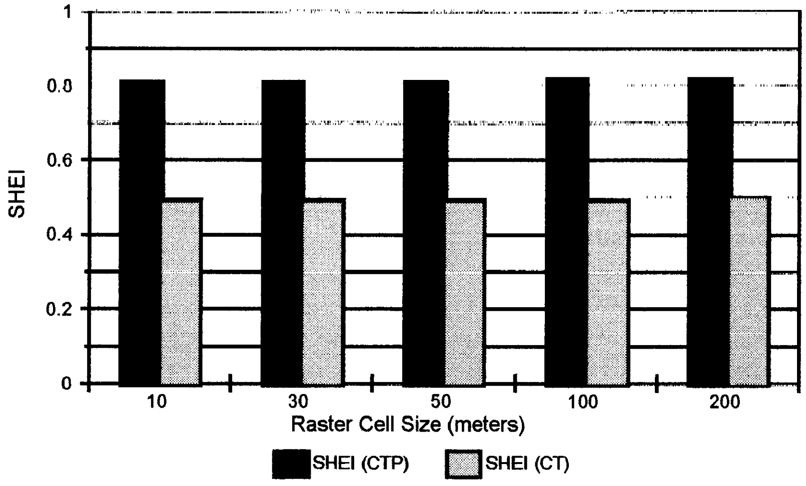


Figure 26. Shannon's Evenness Index for Cover Type/pattern and Cover Type landscapes. This index remains unchanged across all raster cell sizes.

Results: These show that the Cover Type/Pattern landscape is much closer to perfect evenness than the Cover Type landscape. Little change was shown across the range of raster cell sizes.

Interpretation: This index shows that the Cover Type/Pattern landscape has a higher level of evenness than the Cover Type landscape. Breaking the larger polygons down into a finer level of pattern types results in a landscape with more evenly distributed land cover types.

Simpson's Evenness Index (SIEI): Like the Shannon's index, this is the complement to Simpson's diversity index. Evenness is the observed level of diversity divided by the maximum possible diversity for a given patch richness. As the evenness index approaches 1.0 the observed diversity approaches perfect evenness. This metric is less influenced by rare patch types.

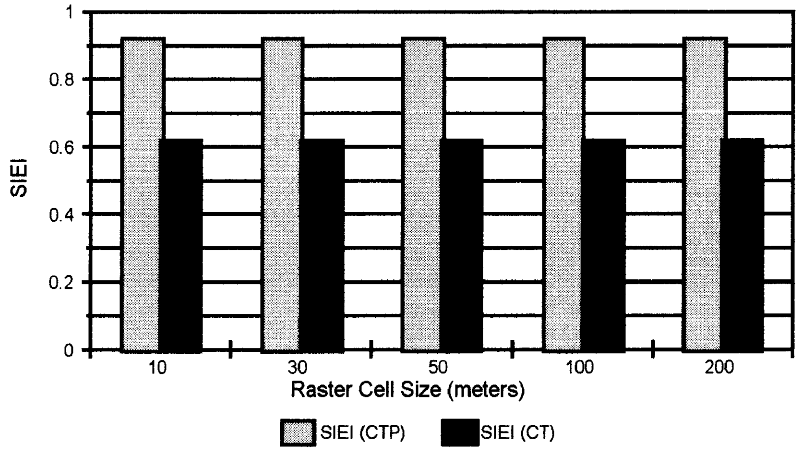


Figure 27. Simpson's Evenness Index for Cover Type/Pattern and Cover Type landscapes. This index remains invariant across the cell sizes, but is different between the two landscapes.

Results: This index shows that the Cover Type/Pattern landscape approaches a high level of evenness (0.92 for the range of raster cell sizes, compared to 0.81 to 0.82 for the SHEI). The Cover Type landscape shows an increase in this index as compared to the Shannon index, from 0.49 to 0.62 across the range of raster cell sizes.

Interpretation: Since this index is less sensitive to the occurrence of rare patch types (two out of six in the Cover Type landscape; two out of twelve in the Cover Type/Pattern landscape) it would be expected that the results for this index to be more consistent than Shannon's index.

Modified Simpson's Evenness Index (MSIEI): The evenness indices isolate the evenness part of diversity by controlling for the contribution of richness to the diversity index. This index ranges between 0 and 1, when there is only 1 patch, and close to 0 when the areal distribution between patch types is very uneven. The index will equal 1 when the areal distribution among patch types is equal.

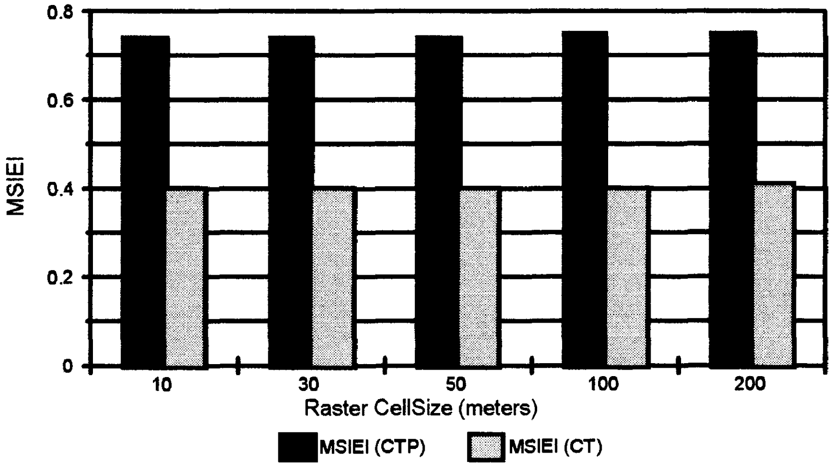


Figure 28. Modified Simpson's Evenness Index for Cover Type/Pattern and Cover Type landscapes. This index shows a very slight increase across raster cell sizes for both landscapes.

Results: Compared to the Simpson's index, this modified version shows a rather sharp decline in the measured evenness. While the unmodified version shows 92% evenness, the modified version shows only 74% evenness across the landscape.

Interpretation: The modified version does not show any appreciable difference from the unmodified version for these particular landscapes.

Contagion Metrics

Contagion Index (CONTAG): This particular index is applicable only to raster images and is based on raster cell adjacencies and not patch adjacencies. Contagion metrics in landscapes with highly aggregated, contiguous patches will show high levels of contagion because the proportion of total cell adjacencies which have like adjacencies is very large.

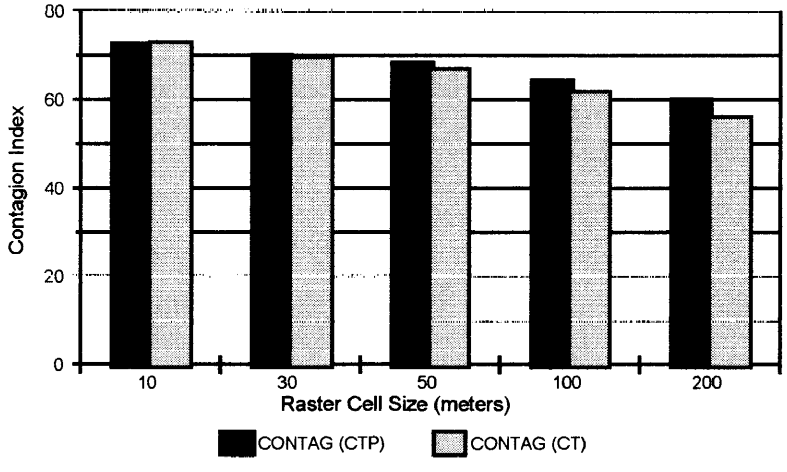


Figure 29. Contagion Index for Cover Type/Pattern and Cover Type landscapes. Both landscapes show a decreasing trend in this index as the raster cell size increases.

Results: The Cover Type/Pattern landscape shows a smaller drop in this index than does the Cover Type landscape. Cover Type/Pattern measures range from 72.65 to 60.09 for the 10 meter to 200 meter raster cell sizes. Cover Type varies from 72.97 to 56.02 for the 10-200 meter pixel range.

Interpretation: These results indicate that even though the Cover Type/Pattern landscape has many more polygons, it retains a higher level of contagion, that is, it has a greater number of individual raster cells that are adjacent to a similar cell type. Conversely, even though the Cover Type landscape has more highly aggregated polygons than the Cover Type/Pattern landscape, it has a lower level of contagion. This is an unexpected result.

Interspersion/Juxtaposition Index (IJI): In contrast with the contagion index, this index is based on adjacency with all other patch types. This index measures the degree to which patch types are interspersed; higher values are those landscapes in which the patch types are well interspersed.

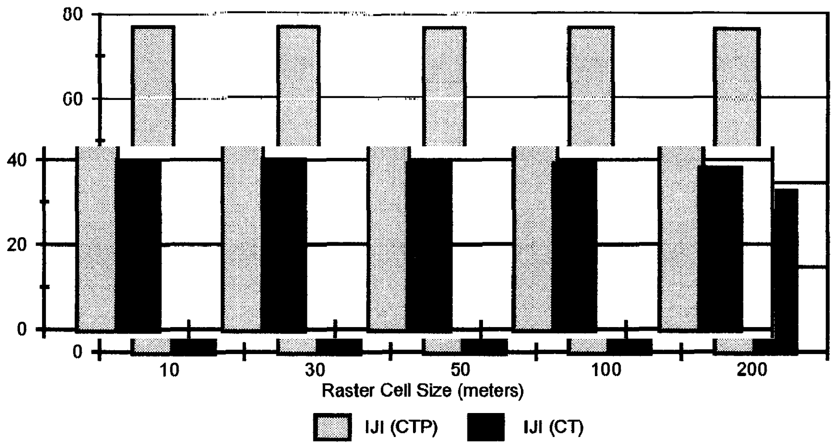


Figure 30. Interspersion/Juxtaposition Index for Cover Type/Pattern and Cover Type landscapes. This index is nearly invariant for the CTP landscape, while the CT landscape shows a slight decrease as the raster cell size increases.

Results: These results closely match expectations. The Cover Type/Pattern landscape shows a high value which indicates that the patch types are well interspersed. The Cover Type landscape has values which are lower by nearly half, indicating that the patches here are not as well dispersed.

Interpretation: The index changes very little in either landscape via raster cell size, but the difference in the two land cover classifications is quite large. This is a good example of how ascertaining the proper level of "perception" of habitat for flora or fauna is very important for describing the proper level of land classification.

Relativized Graphs

The following figures compare the metrics when they are relativized to 1.0 at the 10 meter raster cell size for the three general groups (Composition, Configuration, General). Relativized numbers are used to enhance the display of changes in the metrics response to raster cell size and patch resolution .

Both diversity and evenness indices showed almost no change across the range of raster cell sizes (see Figures 31 and 32).. The noticeable changes are in the 100 or 200 meter raster cell sizes. This is probably related to the change in the proportion of land types that occur at these larger raster cell sizes, due to patch aggregation and overall patch configuration changes (see Figures 1-10).

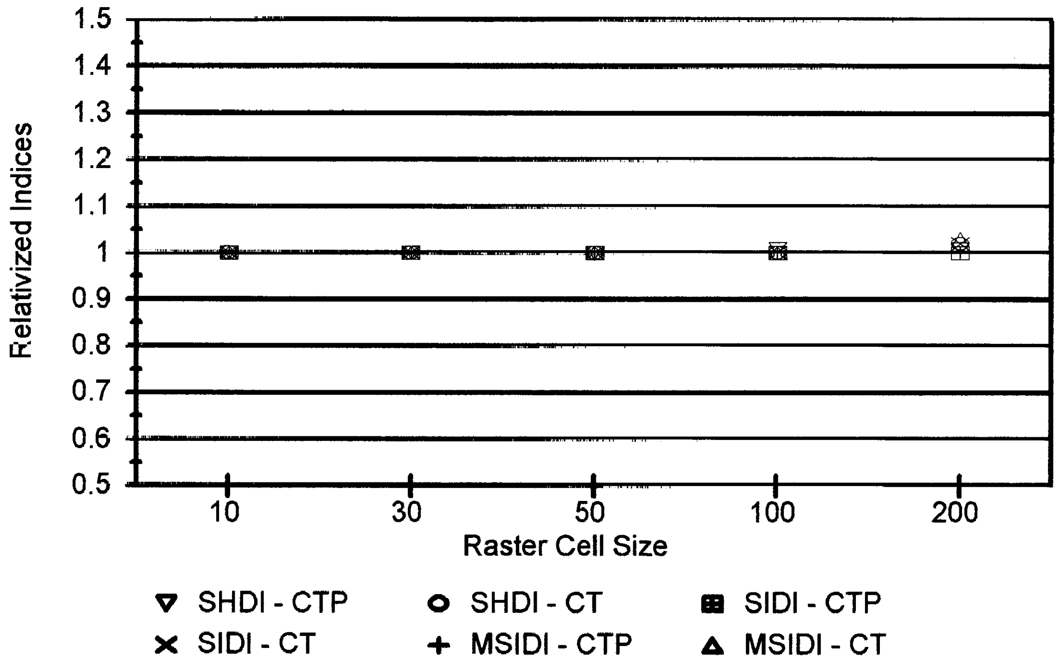


Figure 31. Composition group, Diversity Indices. Relativized to 1.0 at the 10 meter raster cell size. The response of the diversity indices is nearly invariant across the range of raster cell sizes. A slight increase is noted at the 200 meter raster cell size.

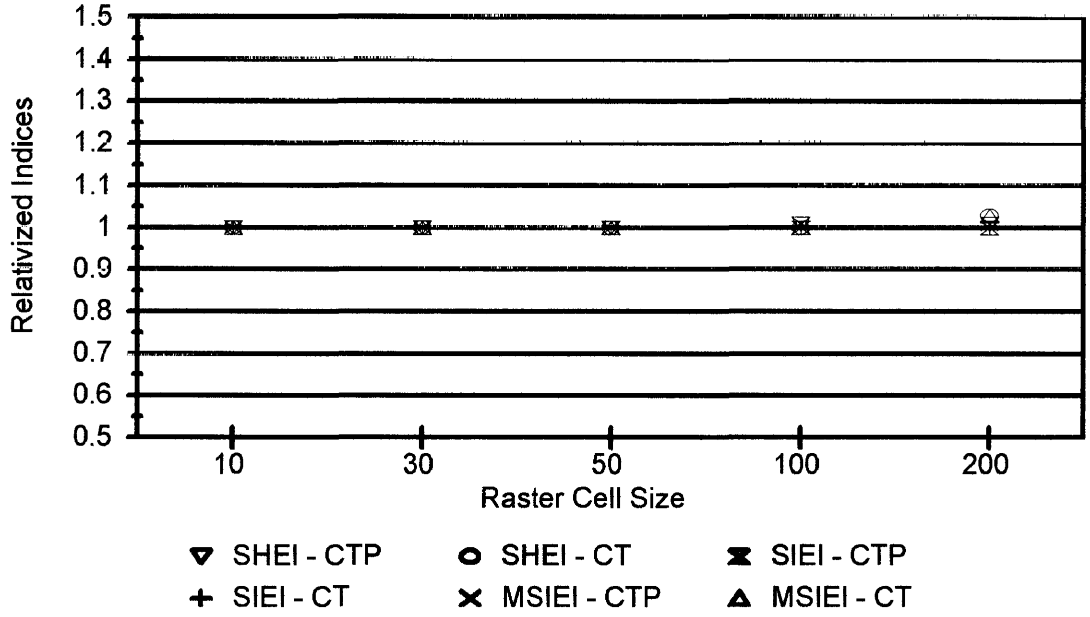


Figure 32. Composition Group, Evenness indices. Relativized to 1.0 at the 10 meter raster cell size. The evenness indices are nearly invariant across the range of raster cell sizes. A slight increase is noted at the 200 meter raster cell size.

The shape indices, as a group, display a sharp change at the 100 meter raster cell size (Figure 33). Most of the indices decrease at the 100 to 200 meter cell size except for the AWMSI index in the CT landscape, which increases. The AWMSI index in the CTP landscape does not show nearly as strong a decrease as the other shape indices.

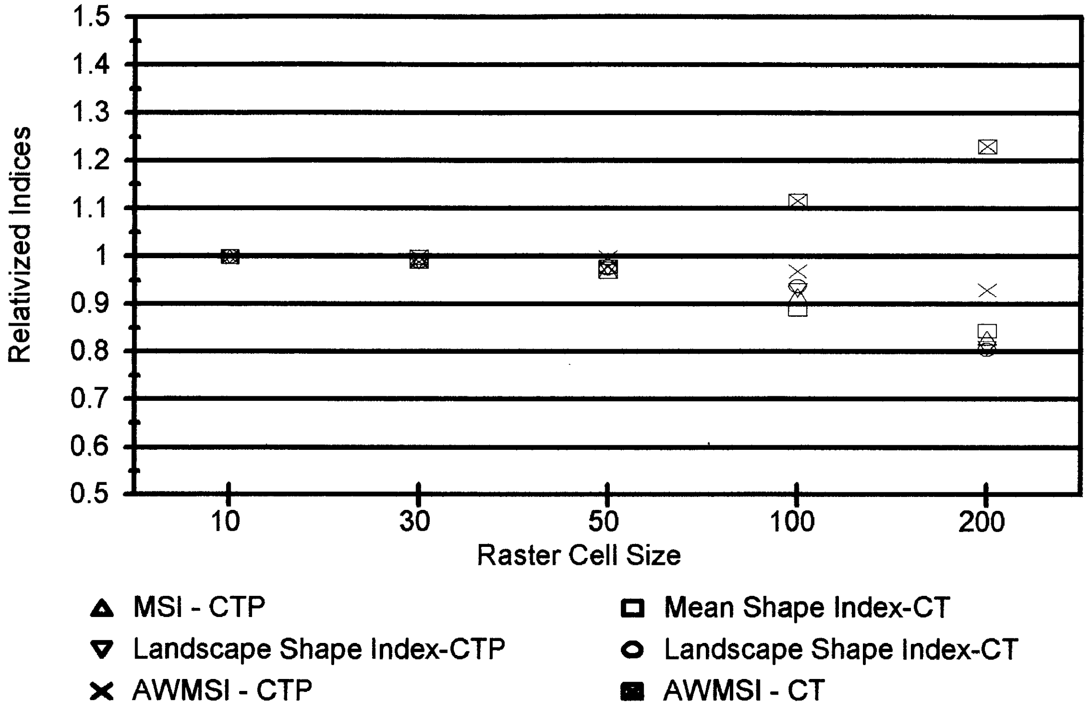


Figure 33. Configuration group, Shape indices. Relativized to 1.0 at the 10 meter raster cell size. The shape indices as a group are seen to have a two-way response at the 100 meter raster cell size. The AWMSI-CT index increases, while all the other indices decrease.

Two of the fractal dimension indices increased a small amount with increasing raster cell size (Figure 34). The AWMPFD index does not show any change. The DLFD index shows a slight increase at the 50 meter raster cell size and increases steadily to the 200 meter raster cell size.

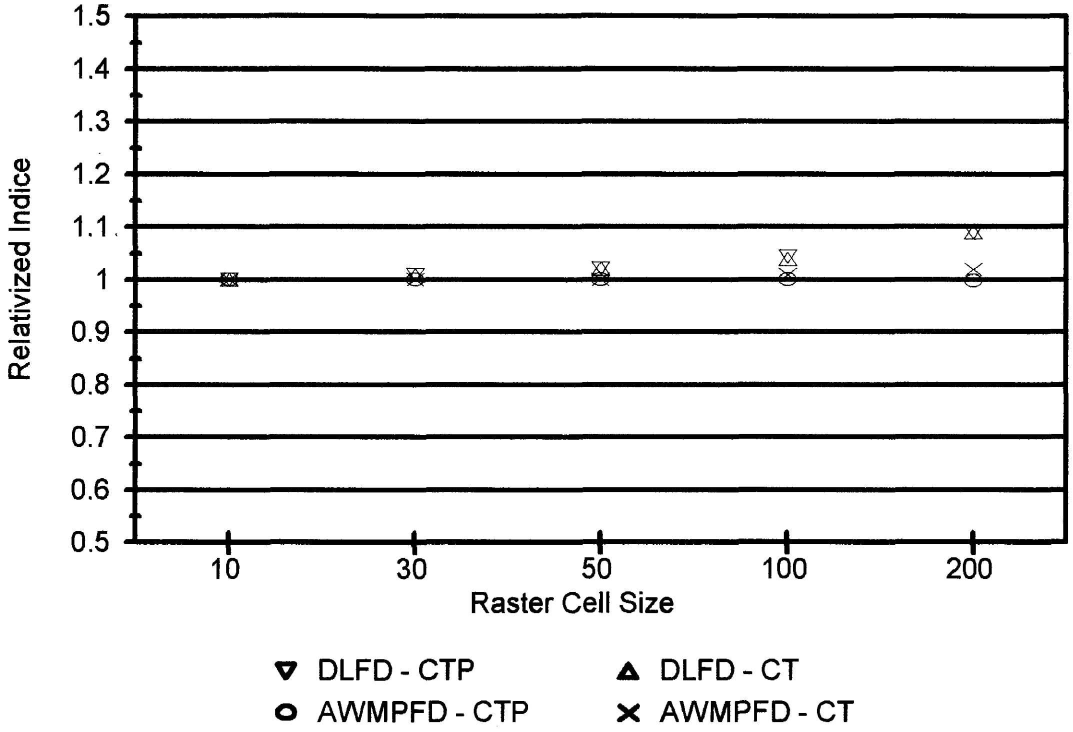


Figure 34. Configuration group, Fractal dimension indices. Relativized to 1.0 at the 10 meter raster cell size. These indices display an increase at the 50 meter raster cell size, which becomes very evident at the 200 meter raster cell size, except for the AWMPFD for both landscapes.

The Contagion and Interspersion/Juxtaposition indices display variable responses (Figure 35). The Contagion index noticeably decreases at the 30 meter raster cell size, and then decreases steadily to the 200 meter raster cell size. This is in contrast to the other metrics which generally do not show any affect until the 50 or 100 meter cell size. The Interspersion/Juxtaposition index is nearly unchanged across the range of raster cell sizes and between the two landscapes.

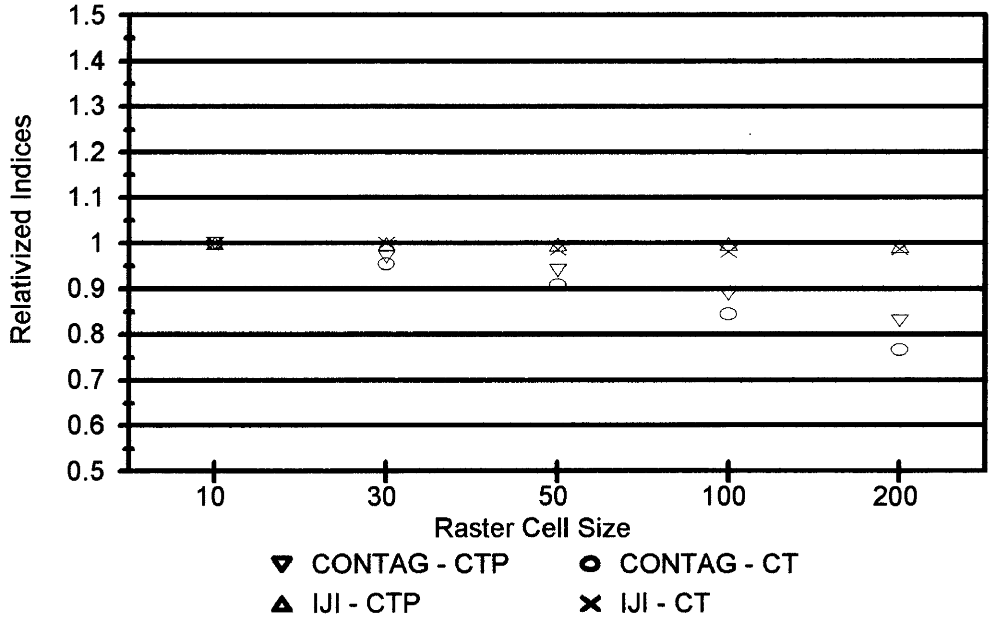


Figure 35. Configuration group, Contagion indices. Relativized to 1.0 at the 10 meter raster cell size. The Contagion index has a noticeable decrease starting at the 30 meter raster cell size for both landscapes. This trend continues across the range of raster cell sizes. IJI is nearly invariant for both landscapes across the range of raster cell sizes.

The general metrics group showed significant changes at the 100 meter raster cell size (Figure 36). The 200 meter raster cell size shows a large difference among the indices. In 200 meter raster cells, Mean Patch Size for the CT landscape has a large increase, while the CTP landscape shows a slight increase. The other indices decrease at the 200 meter cell size. The NP index for the CT landscape shows the greatest decrease, which mirrors the increase in Mean Patch Size (larger patch size equals less patches as like patches aggregate).

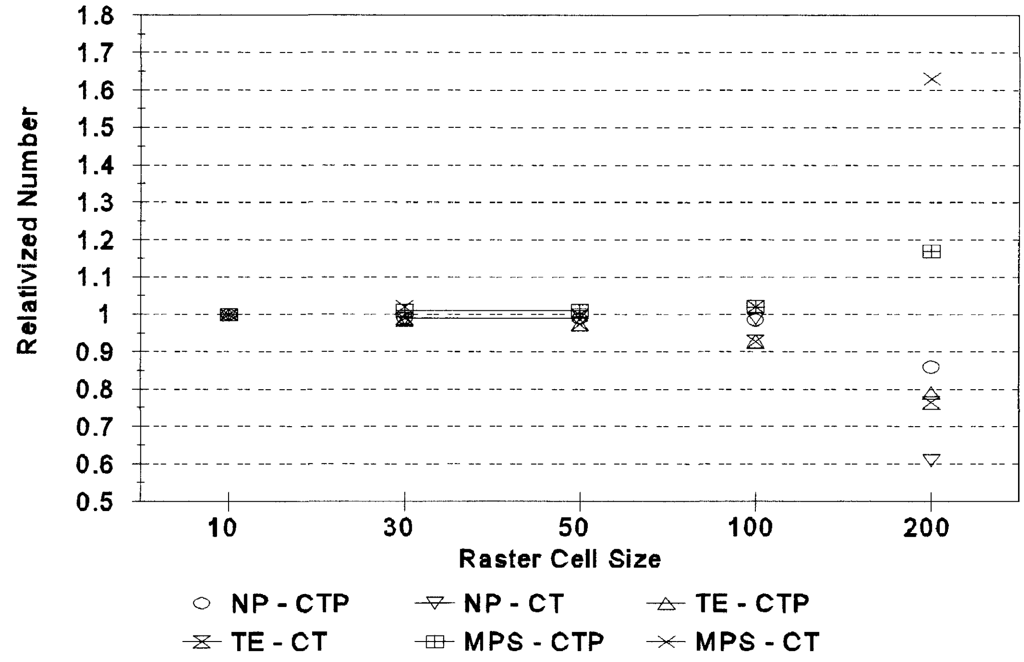


Figure 36. General Group Metrics. Relativized to 1.0 at the 10 meter raster cell size. The general group of metrics displays a decrease in most metrics at the 100 meter raster cell size. At the 200 meter raster cell size, the indices show a large deviation, with MPS showing an increase for both landscapes, while the other indices decrease.

CHAPTER 6: DISCUSSION

Summary of Individual Metrics and Groups

Figures 11 through 30 illustrate the behavior of individual metrics across the 10 - 200 meter range of raster cell sizes and for the two levels of patch resolution tested. These 20 metrics are summarized in Table 4 (page 62) by their type of response, groupings and by landscape (CTP or CT). In general, most metrics demonstrate fidelity to Composition, while they do not show any fidelity to the other groups (Configuration or General) as raster cell size changes.

Table 4. Response of Metrics by Group, across 10 to 200 meter Raster Cell Size

Groups	Variable Response	Slight or No Change	Increase	Decrease
Configuration				
Shape Indices	AWMSI - CT			MSI - CTP, CT AWMSI - CTP LSI - CTP, CT
Fractal Dim.		AWMPFD - CTP	AWMPFD - CT DLFD - CTP, CT	
Others		IJI - CTP, CT	MNND - CTP, CT	CONTAG - CTP, CT
Composition				
Diversity		SHDI - CTP , CT SIDI - CTP, CT MSIDI - CTP, CT PR - CTP, CT		
Evenness		SHEI - CTP, CT SIEI-CTP, CT MSIEI - CTP, CT		
Others	LPI - CTP		LPI - CT	
General	TA - CTP, CT	MPS - CTP	MPS - CT	NP - CTP, CT TE - CTP, CT

Sixteen of the metrics show similar responses to changes in raster cell size for both levels of patch resolution (CTP and CT in Table 4). Exceptions to this are AWMSI, AWMPFD, MPS and LPI which responded differently depending upon patch resolution.

The Largest Patch (LPI) and Mean Patch Size (MPS) metrics increase for the Cover Type landscape as raster cell size increases, but show only a slight increase for the Cover Type/Pattern landscape. The reason for this lack of response in the CTP landscape is that even at the 200 meter raster cell size, enough patches of similar types were not able to combine to form larger patches.

The two area-weighted indices (AWMPFD and AWMSI) displayed different responses due to the differences in mean patch size between the two landscapes. The CTP landscape did not have the large increase in patch size that the CTP landscape did, which meant that the area-weighted indices would not change for the CTP landscape.

The diversity and evenness indices (SHDI, SIDI, MSIDI, SHEI, SIEI, MSIEI) show no significant change as raster cell size increased. The metrics do show differences between the two levels of patch resolution however. The lack of change across raster cells results from the Patch Richness metric remaining the same for each landscape for all five raster sizes (12 for CTP and 6 for CT). I was interested at what raster cell size patch richness would start to decrease. Each landscape lost one patch type (Western Larch), at the 400 meter raster cell size. This is dependent on the spatial configuration of patch types, size of patches and the size of raster cell. Rare types with small areal extent would be expected to be lost quickly if other patch types are large and the raster cell size exceeded the size of the rare patch type.

Fractal dimension indices showed variable responses. The AWMPFD index is nearly invariant across the range of raster cell sizes for both landscapes, although the CT landscape did show a slightly greater increase than the CTP landscape. The DLFD index, on the other hand, increases at the 50 meter raster cell size and continues to increase for both landscapes through the 200 meter raster cell size. This indicates greater shape complexity (at the patch level, but for the landscape as whole) as the raster cell size increases.

The Contagion index starts to decrease at the 30 meter raster cell size, and continues this decrease out to the 200 meter raster cell size. This decrease means that the distribution of adjacencies among the raster cells (within each unique patch type) is increasingly uneven as the raster cell size increases. The Contagion index reacts strongly to raster cell size, since this index directly measures the adjacencies of like raster cells. So smaller, more numerous raster cells within the same patch type means greater contagion.

The Interspersion/Juxtaposition index indicates that the patch types in the CTP landscape are more adjacent to each other than the CT landscape (higher numbers equal greater adjacency. IJI is not greatly affected by the raster cell size, which contrasts with the Contagion index. IJI gives a measure of patch type adjacency, which gives an idea of the relative interspersion of patch types across the landscape (higher values equal better interspersion).

The shape (MSI, LSI, AWMSI) and general group indices (NP, TE, MPS) displayed the most significant changes across raster cell sizes (see Figures 33 and 36). MSI gives the average perimeter-to-area ratio for all patches in the landscape. The CTP landscape has a smaller MSI than the CT landscape due to the smaller patch size. The Landscape Shape index measures the perimeter-to-area ratio of the landscape as a whole. As expected, the CTP landscape index is higher, since more edge is present. AWMSI shows the largest difference between landscapes, as expected, since the CT landscape is dominated by one patch type (ponderosa pine).

The NP index decreases for both landscapes as like patch types aggregate at larger raster cell sizes. Total edge decreases as raster cell size increases due to higher perimeter-to-area ratios. This reflects an expected difference between landscapes, since the CT landscape is composed of larger patches. MPS increases most dramatically for the CT landscape and much less so for the CTP landscape. MPS shows a significant response to the change from the 100 to 200 meter raster cell size. Most of these metrics deviate at the 100 meter raster cell size and demonstrate large differences at the 200 meter raster cell size.

Many of the metrics tested are "stable" up to the 50 meter raster cell size (the Contagion index is the exception). Beyond the 50 meter cell size, most metrics develop greater variation, with large changes becoming apparent at the 200 meter raster cell size (i.e. MPS, NP, TE, MSI, LSI, AWMSI). The main reason for this "instability" is probably due to the increasing dominance of one patch type in the CT landscape as cell size increases, which does not occur in the CTP landscape.

Diversity Indices

The results of the diversity indices (Shannon and Simpson) need some interpretation. These indices were originally applied to measuring diversity at the species level. The Shannon index (classified as one of the information statistic indices) assumes that the individuals are randomly sampled from an effectively infinite population. It also assumes that all species are represented in the sample (Magurran 1988). The Simpson index (one of the dominance measures), is weighted toward the abundances of the most common species rather than species richness (Magurran 1988).

These indices are commonly used in landscape ecology studies, but it has rarely been made clear that the focus is switched from species diversity to vegetation type diversity in these studies. If these diversity indices are to be valid, this change in perspective from species to landscape vegetation types would need to meet the same assumptions: an effectively infinite population and representation of all species (or vegetation types) in the sample. However, the presence of all patch types can be dependent on the size of the minimum mapping unit used in developing the landscape. The smaller, "rarer" types may be lost as unit size increases, which would violate the assumption and give a false estimate of diversity. This information on size of mapping units, assumptions about the presence/absence of all land types and the purpose of the analysis are all important metadata that should be included with the dataset and subsequent analysis.

Further, once "types" are defined for a landscape, diversity among these types cannot be equated with the alpha, beta, or gamma diversity levels, unless the total species floristic data base is analyzed. It is only possible to infer that high patch type diversity would provide high habitat diversity. Technically then, it is only possible in this case to measure the landscape diversity in reference to patch types (Kimmins 1992).

Nine statements were hypothesized in the study objectives and the following conclusions can be drawn:

1) Area metrics did remain the same across patch resolutions, but did vary by raster cell size. This variation across the raster cell sizes is due to the process used in PAMAP to resample the 10 meter raster cells into the 30, 50, 100, and 200 meter raster cells.

2) Total edge did decrease as the raster cell size increased.

3) Diversity indices did remain the same. They would be expected to change when a patch type was eliminated, which did occur at the 400 meter raster cell size (which was not tested in this study).

4) The shape indices all decreased which indicates simpler shapes, except for the Area-Weighted Mean Shape Index (Cover Type landscape) which increased. This increase may be due to the initial size and configuration of the landscape itself.

5) Number of patches for both patch resolutions did decrease.

6) Mean patch size did increase as raster cell size increased, with the Cover Type landscape showing the largest increase.

7) Mean Nearest-Neighbor distance actually increased for both levels of patch resolution. This is probably due to the patch configuration of this landscape and due to some aggregation of patches.

8) Contagion did decrease as the raster cell size increased.

9) Interspersion/Juxtaposition did not vary appreciably. This indicates that the patches are not well dispersed in the landscape.

CHAPTER 7: CONCLUSIONS

The results of this study confirm that the level of patch resolution (land classification) and raster cell size have strong effects on the behavior of certain landscape metrics. Total Area was the only metric that varied between raster cell sizes and not between landscape patch resolution, in contrast to the other metrics. Thus, all metrics show sensitivity to raster cell size, patch resolution or both.

The metrics themselves need to be carefully evaluated as to their relevance to the analysis being conducted. Some guidelines developed from this study for conducting landscape analysis are listed below:

1. Raster cell sizes should not be mixed when comparing alternative landscapes, or between analysis elements. This may require some compromise of the size of analysis area, the size of raster cells, and how much computer storage space is available.

2. Ecological processes operate across a variety of scales, which means they need to be examined at the appropriate scale. Thus, it is important to conduct landscape analysis at the scale(s) that is suitable for a specific landscape, and the ecological process being studied. An example would be comparing the boundary of a large fire (coarse scale), with the fire intensity mosaic within the large fire (fine scale).

This guideline also holds true for analysis of wildlife habitat relationships. Since different species have different habitat requirements during their life history, it may be important to identify the scale that captures the essential attributes necessary for the species survival at the appropriate scale. If fine scale units are aggregated into a coarser scale picture, one must recognize that some of the data may be lost or obscured.

This loss of features at a coarser patch resolution can lead to an underprediction of species occurrence when their presence is based on vegetative relationships. Conversely, the use of fine patch resolution delineating many different types of plant communities can surpass the knowledge that is available for predicting the presence/absence of wildlife species (Edwards, et.al. 1996).

McGarigal and McComb (1995) document some of the problems encountered in a landscape analysis for a number of bird species. One relevant point made is that patchiness can occur at many scales, and that the level of patch classification and "...various metrics of configuration could change dramatically and unpredictably." Perhaps more importantly, McGarigal and McComb found that bird species which exhibited strong patch level associations did not show the same relationship when habitat was examined at the coarser landscape level.

The definition of patch types is highly dependent on who, where, and why the patches are being delineated. For example, timber stand polygons may have very little correlation with polygons that are defined for elk security, flammulated owls, or rare plants. This means that analysis of landscape pattern must be carried out for a specific landscape and that the landscape must be scale-defined for one or more of the critical elements of concern.

In short, the landscape must be relevant to the question(s) being asked, and, in turn, must be related to the questions driving the analysis of, or alternatives to land management.

APPENDIX 1: MARTINS FOREST TYPES

The landform characteristics consist of elevation, aspect, slope angle, slope position, and contour curvature. Martin feels that the use of topographic characteristics helps identify more permanent units on the ground rather than using vegetative cover and that topographic features often demonstrate sharper boundaries than vegetation types.

Vegetation characteristics used were pattern, texture, canopy coverage, overstory height, and crown size. These are some of the traditional criteria used to delineate forest stands, are visible on high altitude photography, and are usable for resource analysis (Martin, et.al. 1983). He states that units delineated from overstory characteristics have little permanence and that overstory conditions are difficult to use to predict future conditions. The combination variable is a land or overstory modifier that indicates the amount of disturbance or observable variation from a "normal" undisturbed stand. Some examples of modifiers are logging, rocky surfaces, mass failures, wetlands, etc.

High altitude, quad centered air photos at a scale of 1:76,000 were used in the photo interpretation analysis. This type of photo is designed to cover the area within a 7.5 minute USGS quad map in a single frame. The final results used six forest types with the following accuracy when verified with ground plots:

Predicted Type		Accuracy
1.	Ponderosa pine	71 %
2.	Douglas-fir	89 %
3.	Mixed upland conifer	47 %

4.	Mixed bottomland conifers	78 %
5.	Lodgepole pine	84 %
6.	Mixed hardwoods	50 %
Overall average		75 %

APPENDIX 2: FRAGSTATS 2.0 OUTPUT COMPARISONS

Metric Landscape

Total Area		CTP	CT
	10	5444.75	5444.75
	30	5448.51	5448.51
	50	5439.00	5439.00
	100	5456.00	5456.00
	200	5464.00	5464.00

Largest Patch Index		CTP	CT
	10	6.23	45.17
	30	6.25	45.17
	50	6.27	45.14
	100	6.18	53.52
	200	6.22	59.81

Number of Patches		CTP	CT
	10	208	60
	30	206	59
	50	206	60
	100	205	59
	200	179	37

Mean Patch Size		CTP	CT
	10	26.18	90.75
	30	26.45	92.35
	50	26.40	90.65
	100	26.61	92.47
	200	30.53	147.68

Total Edge		CTP	CT
	10	314340.0	170790.0
	30	309780.0	168570.0

50	305900.0	166200.0
100	292000.0	158700.0
200	248000.0	130600.0

Landscape Shape Index	CTP	CT
10	8.28	7.43
30	8.18	7.35
50	8.07	7.25
100	7.73	6.96
200	6.70	5.96

Mean Shape Index	CTP	CT
10	1.68	1.83
30	1.66	1.82
50	1.63	1.77
100	1.55	1.63
200	1.39	1.54

Area-Weighted Mean Shape Index	CTP	CT
10	0.93	4.19
30	0.93	4.14
50	0.92	4.10
100	0.90	4.68
200	0.86	5.17

Double Log Fractal Dimension	CTP	CT
10	1.37	1.42
30	1.38	1.43
50	1.40	1.44
100	1.43	1.46
200	1.49	1.55

Area-Weighted MPFD	CTP	CT
10	0.50	1.17
30	0.50	1.17

50	0.50	1.17
100	0.50	1.18
200	0.49	1.19

Mean Nearest-Neighbor Distance	CTP	CT
10	223.1	474.3
30	255.9	476.9
50	282.9	472.3
100	350.4	493.0
200	550.2	727.0

Shannon's Diversity Index	CTP	CT
10	2.02	0.88
30	2.02	0.88
50	2.02	0.88
100	2.03	0.88
200	2.03	0.89

Simpson's Diversity Index	CTP	CT
10	0.84	0.51
30	0.84	0.51
50	0.84	0.51
100	0.84	0.51
200	0.84	0.52

Modified Simpson's Diversity Index	CTP	CT
10	1.85	0.72
30	1.85	0.72
50	1.84	0.72
100	1.85	0.72
200	1.85	0.74

Patch Richness	CTP	CT
10	12	6
30	12	6

	50	12	6
	100	12	6
	200	12	6

Shannon's Evenness Index		CTP	CT
	10	0.81	0.49
	30	0.81	0.49
	50	0.81	0.49
	100	0.82	0.49
	200	0.82	0.50

Simpson's Evenness Index		CTP	CT
	10	0.92	0.62
	30	0.92	0.62
	50	0.92	0.62
	100	0.92	0.62
	200	0.92	0.62

Modified Simpson's Evenness Index		CTP	CT
	10	0.74	0.40
	30	0.74	0.40
	50	0.74	0.40
	100	0.75	0.40
	200	0.75	0.41

Interspersion/Juxtaposition Index		CTP	CT
	10	76.80	39.87
	30	76.79	40.00
	50	76.62	39.38
	100	76.72	39.18
	200	76.36	38.35

Contagion Index		CTP	CT
	10	72.65	72.97
	30	70.20	69.51

50	68.31	66.84
100	64.40	61.74
200	60.09	56.02

APPENDIX 3:

Definition and Description of FRAGSTATS metrics (adapted McGarigal and Marks 1994)

Notations used:

Subscripts

$i = 1, \ldots, m$ or m' patch types (classes)

$j = 1, \ldots, n$ patches

$k = 1, \ldots, m$ or m' patch types (classes)

$s = 1, \ldots, n$ patches, within specified neighborhood

Symbols

A = Total landscape area (m^2)

a_{ij} = area (m^2) of patch ij

a_{ijs} = area (m^2) of patch ijs within specified neighborhood (m) of patch ij

p_{ij} = perimeter (m) patch ij

p_{ijk} = length (m) of patch ij adjacent to patch type (class) k

E = total length (m) of edge in landscape; includes landscape boundary and background edge segments if the user decodes to treat boundary and background as edge; otherwise, only boundary segments representing true edge are included.

E' = total length (m) of edge in landscape; includes entire landscape boundary and background edge segments regardless of whether they represent true edge

e_{ik}= total length (m) of edge in landscape between patch types (classes) i and k; includes landscape boundary segments representing true edge only involving patch type i

e'_{ik}= total length (m) of edge in landscape between patch types (classes) i and k; includes all landscape and boundary edge segments involving patch type i, regardless of whether they represent true edge.

e''_{ik}= total length (m) of edge in landscape between patch types (classes) i and k; includes the entire landscape boundary and background edge segments

N = total number of patches in the landscape, excluding any background patches

N' = total number of patches in the landscape that have nearest neighbors

$n = n_i$= number of patches in the landscape that have nearest neighbors

$n' = n'_i$= number of patches in the landscape of patch type (class) i that have nearest neighbors

m = number of patch types (classes) present in the landscape, excluding the landscape border, if present

m' = number of patch types (classes) present in the landscape, including the landscape border, if present

m_{max}= maximum number of patch types (classes) present in a landscape

h_{ij} = distance (m) from patch ij to nearest neighboring patch of the same type (class), based on edge-to-edge distance

g_{ik}= number of adjacencies (joins) between pixels of patch types (classes) i and k

P_i = proportion of the landscape occupied by patch type (class) i

Landscape Metrics

Total Area

$$TA = A(1/10{,}000)$$

Units: Hectares

Range: $TA > 0$ without limit

Description: TA equals the total area (m^2) of the landscape, divided by 10,000 (to convert to hectares). TA excludes the area of any background patches within the landscape.

Largest Patch Index

$$LPI = \max_{j=1}^{n}(a_{ij}) / A\ (100)$$

Units: Percent

Range: $0 < LPI <= 100$

LPI approaches 0 when the largest patch in the landscape is increasingly small. LPI= 100 when the entire landscape consists of a single patch

Description: LPI equals the area (m^2) of the largest patch in the landscape divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage)

Number of Patches

$NP = N$

Units: None

Range: NP >=1, without limit

Description: NP equals the number of patches in the landscape. Note NP does not include any background patches within the landscape or patches in the landscape border

Mean Patch Size

$MPS = A / N (1 / 10,000)$

Units: Hectares

Range: $MPS > 0$, without limit

Description: MPS equals the total landscape area (m^2), divided by the total number of patches, divided by 10,00 (to convert to hectares)

Total Edge

$TE = E$

Units: Meters

Range: $TE >= 0$, without limit. $TE = 0$ when there is no edge in the landscape; that is, when the entire landscape and landscape border, if present, consists of a single patch and the user specifies that none of the landscape boundary and background be treated as edge.

Description: TE equals the sum of the lengths (m) of all edge segments in the landscape. If a landscape border is present, TE includes landscape boundary segments representing true edge only.

Landscape Shape Index

$LSI = 0.25\ E' / \sqrt{A}$

Units: None

Range: $LSI >= 1$, without limit. $LSI = 1$ when the landscape consists of a single square patch; LSI increases without limit as landscape shape becomes more irregular and/or as the length of edge within the landscape increases

Description: LSI equals the sum of the landscape boundary (regardless of whether it represents true edge or not) and all edge segments (m) within the landscape boundary (including those bordering background), divided by the square root of the total landscape area (m^2), adjusted by a constant for a square standard

Mean Shape Index

$$MSI = \sum_{i=1}^{m}\sum_{j=1}^{n} 0.25p_{ij} / \sqrt{a_{ij}}) / N$$

Units: None

Range: MSI >= 1, without limit

MSI=1 when all patches in the landscape are square; MSI increases without limit as the patch shape becomes more irregular

Description: MSI equals the sum of the patch perimeter (m) divided by the square root of patch area (m^2) for each patch in the landscape, adjusted by a constant to adjust for a square standard, divided by the number of patches (NP)

Area-Weighted Mean Shape Index

$$AWMSI = \sum_{i=1}^{m}\sum_{j=1}^{n} ((.25p_{ij} / \sqrt{a_{ij}})(a_{ij} / A))$$

Units:	None
Range:	AWMSI >=1, without limit. AWMSI=1 when all patches in the landscape are square; AWMSI increases without limit as the patch shapes become more irregular
Description:	AWMSI equals the sum, across all patches, of each patch perimeter (m) divided by the square root of patch area (m^2), adjusted by a constant to adjust for a square standard, multiplied by the patch area (m^2) divided by total landscape area

Double Log Fractal Dimension

$$DLFD = \frac{2\,(N \sum \sum \ln p_{ij}^2) - (\sum \sum \ln p_{ij})^2}{((N \sum \sum (\ln p_{ij} * \ln a_{ij})) - ((\sum \sum \ln p_{ij})(\sum \sum \ln a_{ij}))}$$

Units:	None
Range:	1 <= DLFD <= 2. A fractal dimension greater than 1 for a 2-dimensional landscape mosaic indicates a departure from a euclidean geometry (i.e. an increase in patch shape complexity). DLFD approaches 1 for shapes with very simple perimeters such

as circles or squares, and approaches 2 for shapes with highly convoluted, plane-filling perimeters. DLFD employs regression techniques and is subject to small sample problems. Specifically, DLFD may greatly exceed the theoretical range in values when the number of patches is small (e.g. <10), and its use should be avoided in such cases.

Description: DLFD equals 2 divided by the slope of the regression line obtained by regressing the logarithm of patch area (m^2) against the logarithm of patch perimeter (m)

Area-Weighted Mean Patch Fractal Dimension

$$AWMPFD = \sum_{i=1}^{m}\sum_{j=1}^{n}((2\ln(.25p_{ij}) / \ln a_{ij})(a_{ij} / A))$$

Units: None

Range: 1<= AWMPFD <= 2. A fractal dimension greater than 1 for a 2-dimensional landscape mosaic indicates a departure from a Euclidean geometry (i.e. an increase in patch shape complexity). AWMPFD approaches 1 for shapes with very simple perimeters such as circles or squares, and approaches 2 for shapes with highly convoluted, plane-filling perimeters

Description: AWMPFD equals the sum, across all patches, of 2 times the logarithm of patch perimeter (m) divided by the logarithm of patch area (m^2), multiplied by the patch area (m^2) divided by total landscape area; the raster formula is adjusted to correct for the bias in perimeter

Mean Nearest-Neighbor Distance

$$MNN = \sum_{i=1}^{m} \sum_{j=1}^{n'} h_{ij} / N'$$

Units: Meters

Range: MNN > 0, without limit

Description: MNN equals the sum of the distance (m) to the nearest patch of the same type, based on nearest edge-to-edge distance, for each patch in the landscape with a neighbor, divided by the number of patches with a neighbor

Shannon's Diversity Index

$$SHDI = -\sum_{i=1}^{m}(P_i*\ln P_i)$$

Units: None

Range: SHDI >= 0, without limit. SHDI=0 when the landscape contains only one patch (i.e. no diversity). SHDI increases as the number of different patch types (i.e. patch richness, PR) increases and/or the proportional distribution of area among patch types becomes more equitable

Description: SHDI equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion

Simpson's Diversity Index

$$SIDI = 1-\sum_{i=1}^{m}P_i^2$$

Units: None

Range: 0 <= SIDI <1. SIDI = 0 when the landscape contains only 1 patch (i.e. no diversity). SIDI approaches 1 as the number of different patch types (i.e. patch richness, PR) increases and the proportional distribution of area among patch types becomes more equitable

Description: SIDI equals 1 minus the sum, across all patch types, of the proportional abundance of each patch type squared

Modified Simpson's Diversity Index

$$MSIDI = -\ln\sum_{i=1}^{m} P_i^2$$

Units: None

Range: MSIDI >= 0. MSIDI = 0 when the landscape contains only 1 patch (i.e. no diversity). MSIDI increases as the number of different patch types (i.e. patch richness, PR) increases and the proportional distribution of area among patch type becomes more equitable

Description: MSIDI equals minus the logarithm of the sum, across all patch types, of the proportional abundance of each patch type squared

Patch Richness

$$PR = m$$

Units: None

Range: PR >= 1, without limit

Description: PR equals the number of different patch types present within the landscape boundary

Shannon's Evenness Index

$$SHEI = -\sum_{i=1}^{m}(P_i * \ln P_i) / \ln(m)$$

Units:	None
Range:	0 <= SHEI <= 1. SHEI = 0 when the landscape contains only 1 patch (i.e. no diversity) and approaches 0 as the distribution of area among the different patch types becomes increasingly uneven (i.e. dominated by one type). SHEI = 1 when distribution of area among patch types is perfectly even. (i.e. proportional abundances are the same)
Description:	SHEI equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion, divided by the logarithm of the number of patch types

Simpson's Evenness Index

$$SIEI = 1-\sum_{i=1}^{m}P_i^2 / 1-(1 / m)$$

Units:	None
Range:	0 <= SIEI <= 1. SIEI = 0 when the landscape contains only one patch (i.e. no diversity) and approaches 0 s the distribution of area among the different patch types becomes increasingly uneven (i.e. dominated by 1 patch type). SIEI = 1 when distribution of area

among patch types is perfectly even (i.e. proportional abundance are the same)

Description: SIEI equals 1 minus the sum, across all patch types, of the proportional abundance of each patch type squared, divided by 1 minus 1 divided by the number of patch types

Modified Simpson's Evenness Index

$$MSIEI = -\ln\sum_{i=1}^{m} P_i^2 \;/\; \ln m$$

Units: None

Range: 0 <= MSIEI <= 1. MSIEI = 0 when the landscape contains only one patch (i.e. no diversity) and approaches 0 s the distribution of area among the different patch types becomes increasingly uneven (i.e. dominated by 1 patch type). SIEI = 1 when distribution of area among patch types is perfectly even (i.e. proportional abundance are the same)

Description: MSIEI equals minus the logarithm of the sum, across all patch types, of the proportional abundance of each patch type squared, divided by the logarithm of the number of patch types

Interspersion/Juxtaposition Index

$$IJI = -\sum_{i=1}^{m'}\sum_{k=i+1}^{m'}((e_{ik} / E) \circ \ln(e_{ik} / E)) / \ln(1/2[m'(m'-1)])*(100)$$

Units:	Percent
Range:	0 <IJI <= 100. IJI approaches 0 when the distribution of adjacencies among unique ;patch types becomes increasingly uneven. IJI = 100 when all patch types are equally adjacent to all other patch types (i.e. maximum interspersion and juxtaposition)
Description:	IJI equals minus the sum of the length (m) of each unique edge type divided by the total landscape edge (m) , multiplied by the logarithm of the same quantity, summed over each unique edge type; divided by the logarithm of the number of patch types times the number of patch types minus 1 divided by 2; multiplied by 100 (to convert to a percentage)

Contagion Index

$$Contag = (1 + \sum_{i=1}^{m}\sum_{k=1}^{m}((P_i)(g_{ik} / \sum_{k=1}^{m} g_{ik})) \circ (\ln(P_i)(g_{ik} / \sum_{k=1}^{m} g_{ik})) / 2\ln(m)*(100)$$

Units: Percent

Range: 0 < CONTAG <= 100. CONTAG approaches 0 when the distribution of adjacencies (at the level of individual cells) among unique patch types becomes increasingly uneven. CONTAG = 100 when all patch types are equally adjacent to all other patch types (i.e. maximum interspersion and juxtaposition).

Description: CONTAG equals minus the sum of the proportional abundance of of that patch type and all other patch types, multiplied by the logarithm of the same quantity, summed over each patch type; divided by 2 times the logarithm of the number of patch types.

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