GEOGRAPHIC INFORMATION SYSTEM MODEL RATING OLD-GROWTH STAND SIGNIFICANCE ON THE OLYMPIC NATIONAL FOREST

by

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ABSTRACT: With increased attention being focused on the remaining old-growth forest resource in the Pacific Northwest a way to ecologically rate forest stands is needed to assist the U.S. Forest Service in its management decisions. A Geographic Information System (GIS) model was developed to rate old-growth stands in a 49,500 acre study area on the Olympic National Forest. The model utilizes the vector based PC ArcInfo package and the raster based OSU Map Analysis Package (MAP).

The ecological rating was performed on individual sub-models which represent one specific ecologic criterion. Sub-model significance curves were used to rate the ecological value of the old-growth stands based on distance from the specific ecologic criteria. Five main ecological criteria were used: 1) core area, 2) spatial corridors, 3) riparian corridors network, 4) stand isolation, and 5) Northern Spotted Owl locations. In addition, the model also considers edge effect and the placement of Spotted Owl Habitat Areas (SOHA). The flexibility of the GIS model allows for the development of many different types of final map layers depending on the management criteria being addressed. The sub-models in this paper were combined to created a final map layer showing the initial rating of old-growth stands based on the above criteria. This final map can be used as a preliminary guide for the future placement of timber sales in areas with the least ecological impact on the old-growth ecosystem.

INTRODUCTION

Due to increased pressures on the forest resource in the Pacific Northwest, the criteria for spatial placement of timber sales on U.S. Forest Service land are being expanded. Each new clear-cut area will impact the forest ecosystem in many ways, and its spatial placement will determine the forest's potential wildlife habitat for many species. The results of past forest clearing and the potential consequences for further management activities have influenced the creation of new data sources and the enhancement of old sources. As new data are collected about the old-growth forest ecosystem a spatial management system becomes critical. This management system must be capable of incorporating many different types of data and relating these data over a regional scale. The introduction of Geographic Information Systems (GIS) to forest management brings the potential for the development of an advanced management system used to examine many possible criteria in a fast and efficient manner. A GIS is a digital system for the analysis and manipulation of a full range of geographical data, with possible additional systems for the output and display of the data manipulations (Tomlinson, 1987).

In the initial stages of GIS introduction to forest management, the system has been used for little more than automation of the cartographic process of updating forest inventory maps. However, as additional information is input into the system the ability to manipulate and analyze data as well as model potential management criteria becomes apparent. With multiple themes, a GIS database can provide simultaneous consideration of a number of possible parameters for the development of management decisions.

It is this ability to incorporate multiple themes into a final output that will be examined in this paper. Looking specifically at ecological parameters developed to rate old-growth forest stand significance, a GIS model will be developed to analyze potential placement of future timber sales. This model will aid Forest Service managers in locating areas of low ecological significance based on the input parameters, which can be further analyzed for the placement of sale units.

ECOLOGICAL CONSIDERATIONS

The definition of an old-growth forest stand has been hotly debated in recent years as increasing political pressure has been put on the Forest Service. The presently adopted definition of old-growth is based on the number of live trees, size of live trees, canopy condition, number of snags, and the amount of down logs in a stand (Franklin et al, 1986, Research Note PNW-447). Intensive management of old-growth forest in the Pacific Northwest has rapidly changed the structure and composition of the forest ecosystem. The dramatic reduction or elimination of old-growth stands beyond the age of commercial maturity represents a truncation of natural succession. The results of this forest management practice is a landscape dominated by relatively young and undeveloped forests. This managed landscape is ecologically inadequate to ensure long-term forest productivity and the survival of the full array of wildlife populations (Thomas, 1987).

The major structural differences occurring between a replanted young stand and an old-growth stand are large live trees, large standing dead snags, large fallen logs, and large amounts of woody debris deposited into area streams. The old-growth stand is often uneven in age, possesses many species of differing size classes of dominant and co-dominant tree species, and maintains a multi-layered canopy. A replanted stand is even aged with one or two tree species, one canopy layer, and few standing snags or down logs.

Plant and animal species composition changes dramatically after the harvesting of an old-growth stand. The species present before harvesting are adapted to an old-growth environment of small daily temperature ranges, moist climates, protective cover, and diverse structural characteristics. Species present after harvesting are more adapted to open environments with extreme daily temperature fluctuations, drier climatic conditions during the summer months, very little protective cover, and simplified structural characteristics (Harris, 1984). It has been estimated that simply the removal of standing dead snags and large fallen logs from managed young stands will cause the elimination of 29 percent of the wildlife species which were found in the preceding old-growth stand (Maser, 1988).

The functional characteristics of an old-growth stand are only beginning to be understood. It is evident, however, that an old-growth stand possesses the capability to retain and recycle nutrients, produce high quality water and fish habitat, and support specialized species of plants and animals. Even with these known functions we are rapidly eliminating a diverse old-growth ecosystem, and replacing it with a Christmas tree like plantation without understanding the full impact of our actions. The focus of current and future management decisions will be based on weighing the economic benefits of timber harvesting against the ecological significance of the remaining old-growth stands.

MANAGEMENT BACKGROUND - The federally controlled old-growth forests of the Pacific Northwest represent the last remaining 5 - 15% of a vast forested area once covering approximately 28 million acres from Southern British Columbia to Northern California extending down out of the Cascade Mountains to the Pacific Ocean (Harris, 1984). In recent years the management of these forests has become extremely controversial and complex as additional pressure is put on a finite resource. The amount of timber harvested on the federally controlled lands has increased dramatically over the last three decades as private lands in the region have become over-cut. On National Forest lands in the Pacific Northwest approximately 48,000 acres of virgin forest are being cleared annually; and on BLM lands, mostly in Oregon, an additional 22,000 acres are being cleared (Ervin, 1989).

As pressure to harvest timber on federal lands has increased, so have other competing management concerns. Uses such as recreation and wildlife preservation have, in part, been a catalyst for the creation of forest management regulations governing the way in which the Forest Service manages the forest. These regulations include the Multiple Use/Sustained Yield Act of 1960, and the National Forest Management Act of 1976; which place the Forest Service in charge of the protection, management, and development of national forest resources for timber, outdoor recreation, water, wildlife, and other forest purposes (Johnston, 1987). The Forest Service has also recently recognized the importance of old-growth forest for the first time on a national level by announcing a national policy on old-growth. In this policy two important management considerations are discussed; 1) reducing the fragmentation of old-growth forest, and 2) maintaining future options for significant old-growth forests by selectively locating timber sales (USFS Memo; Oct. 19, 1989). These management regulations along with public pressure have spurred the establishment of new data collection campaigns on the old-growth ecosystem. Now, because of the Forest Service's management regulations and additional concerns for the protection of the endangered Northern Spotted Owl (Strix occidentalis caurina), the need for a GIS to analyze and model ecologic criteria to help in forest management decisions becomes critical.

STUDY AREA - The study area used for the development of this GIS model is a 49,500 acre area in the Olympic National Forest known as the Matheny Block. It is situated on the western side of the Olympic Mountains just north of Quinault Lake in the Quinault Ranger District (Figure 1). The study area's climate is both marine and topographically influenced with a Koppen classification of Csb (Mediterranean Coastal). This climatic classification is generally mild in temperature with rainy winter months and cool dry summer months. The area is one of the wettest areas in the Pacific Northwest, receiving between 120 and 200 inches of precipitation a year. Most of this precipitation is generated by low pressure disturbances that originate in the winter low pressure cell found off the Aleutian islands. The elevation range in the study area is between 200 and 3200 feet with an approximate increase of 30 inches of precipitation for every gain of 1000 feet in elevation (Henderson, 1989).

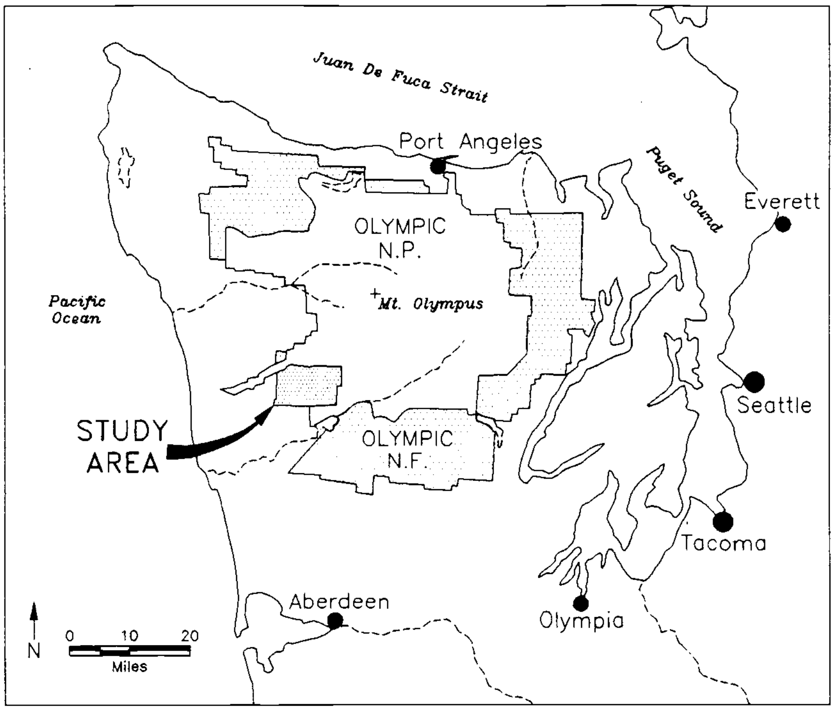

Figure 1. Olympic Peninsula and the study area.

The dominant climax tree species in the study area is Silver Fir and Western Hemlock, with the occurrence of old relict Douglas Fir intermixed (Henderson, 1989). Other species occurring in the area include Western Redcedar, Alaskan Yellowcedar, Mountain Hemlock and Pacific Yew. The major natural disturbance characteristic in the study area is wind-throw. Large storms generated in the South Pacific are pulled northward to the Washington coast by the northern jet stream, bringing hurricane force winds to the area. These winds have on numerous occasions created large amounts of forest blow-down in the study area.

The study area is assumed to be made up of two different types of forest stands. The old-growth stands are assumed to be virgin stands which have had no management activities performed on them, and the managed stands are assumed to be areas that in most cases have been clear-cut. The assumption that the virgin forest is also old-growth is necessary for the application of this model. The Forest Service is presently developing new old-growth maps of the area, however, they are not available at this time.

GIS AND DATA STRUCTURE CONSIDERATIONS

Before model development can begin the type of software package needs to be selected. On the National Forest level most forests are either in the process of obtaining a GIS or already have one in place. However, this model building process was limited to the PC environment with strict storage space limitations. The model building process in the PC environment is still widely variable with many types of software available. The major difference between most of these systems is the type of data structure used by the software, with the two basic ones being vector and raster.

Vector data structures are ways of coding line and area information in the form of units of data expressing magnitude, direction, and connectivity (Burrough, 1988). A raster based data structure contains all mapped spatial information in the form of regular grid cells. Each data structure has its advantages and disadvantages (Table 1). The capability of using both is the best possible way to insure model flexibility.

Because no single system with the capability to use both data structures was available, it was decided to use a "pseudo" link between the vector based PC ArcInfo Version 3.4D (ArcInfo) system and the raster based OSU Map Analysis Package (MAP) in order to incorporate both systems (Appendix A). However, it was soon evident that for the final modelling procedures the raster based MAP was much more suited to meet the design objectives and criteria than the vector based ArcInfo package. The raster based system is better suited to spatial overlays, changing of values, and is very fast in comparison to the vector based system. However, the vector based advantages of accurate geographic representation and graphical output capabilities are also used in the model.

TABLE 1. VECTOR VS. RASTER GIS

Vector methods

Advantages
- Good geometric representation of geographic data
- Compact data structure
- Accurate graphics
- Retrieval, updating & generalization of graphics and attributes

Disadvantages
- Spatial analysis sometimes very slow
- Complex data structures
- Combination of several vector polygon maps and raster maps creates difficulties
- Simulation is difficult because of different topological forms
- Display and plotting can be slow and expensive
- Spatial analysis and filtering within polygons are impossible

Raster methods

Advantages
- Simple data structures
- Spatial Analysis very fast
- The overlay and combination of mapped data with remotely sensed data is easy
- Various kinds of spatial analysis are easy
- Simulation is easy, each spatial unit has the same size and shape
- The technology is cheap and is being energetically developed

Disadvantages
- Volumes of graphic data
- The use of large cells to reduce data volumes means the quality of the data's geographic representation will be compromised which can create a serious loss of information
- Crude raster maps are considerable less beautiful than maps drawn with fine lines
- Projection transformation are time consuming unless special algorithms or hardware are used.

(Adapted from Burrough, 1988)

GIS MODELING

The notion of cartographic modelling has been a basic function of cartography for a very long time. A cartographic model is a set of map layers that are all registered with respect to a common coordinate system. A map layer is a flat drawing indicating the nature, the form, the relative position, and the size of selected conditions in a geographic area (Tomlin, 1990). An example of a cartographic model would be a regional atlas where multiple maps are created showing different pieces of information over the same geographic area.

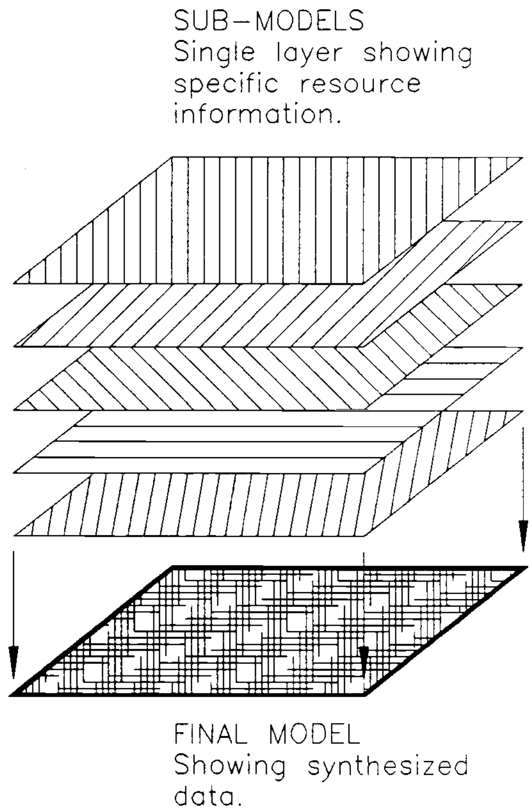

Figure 2. GIS modelling, showing overlay process.

As computer hardware has developed in the last two decades, many disciplines have attempted to develop a computer system that would store, retrieve, transform, and display spatial data for a particular set of purposes, or basically create a computerized cartographic model. These functions are the basis for a GIS. A GIS describes objects in terms of their position with respect to a known coordinate system, attributes which are unrelated to position, and spatial interrelations with each other (Burrough, 1988). A GIS model is the computerized function of overlaying multiple digital layers of resource information into a single output layer to aid in management decisions (Figure 2).

The ability of GIS to model management scenarios provides forest managers with a system designed to test a variety of management criteria quickly and efficiently. It is this ability to adapt to changing criteria that makes GIS a valuable tool to aid in forest management decisions. The development of a GIS model is based on the following three steps; 1) definition of design objectives, 2) inventory of existing resources, and 3) creation of the model's database (Johnston, 1987). Once the database has been created the different types of management scenarios can be applied to the data to produce various results.

DESIGN OBJECTIVES

Given the GIS's ability to analyze and combine resource data, a model can be developed to display significant facts about a data set and to use values a user may assign to those facts. Such techniques are synthetic in nature and attempt to synthesize information from data using a manager's judgment (Tomlin, 1990). The following model's overall objective is to synthesize old-growth ecological values given to individual map layers or subjects into a final layer, expressing areas of high and low old-growth ecological significance in the study area.

The model must incorporate the following design criteria:

1. The capability to incorporate existing Forest Service data.
2. Design flexibility in order to meet the needs of changing priorities and conditions.
3. Ability to be understood by all possible users.
4. Capability for rapid data analysis and spatial overlay techniques.

This model can then be used as a tool to identify possible areas of lower ecological significance and to aid in the placement of future timber sales in the study area. The initial development of the model will demonstrate its capabilities for applying ecological data to a landscape-wide setting. If the model is found successful, additional models can be developed incorporating other new ecological criteria for more effective representation of the old-growth forest ecosystem. The addition of data from other land owners on the Olympic Peninsula could also be incorporated in future models to generate a truly regional GIS model capable of addressing ecosystem-wide criteria used for management decisions.

INVENTORY OF EXISTING RESOURCES

The inventory of existing data is very important to minimize data input, and is the beginning of the model building process. The type of model input data is dependent on the desired management criteria and must be considered before the data processing begins. The model developed for this paper uses Forest Service data which fulfill possible ecological parameters, were available at the start of the model building process, and were capable of being transferred to the PC environment. A table showing the general model development process was created at this time to organize the different data types into a process that would eliminate duplication of map layers, and hopefully eliminate any backtracking for additional data (Table 2).

TABLE 2. INITIAL MODEL DATABASE DEVELOPMENT

LAYER	DEFINITION	PROCESSING
DB	District Boundary	Cookie cutting, area calculations and cartographic output.
Old	Old-Growth Layer	Cookie cutting, development of nearest neighbor distance, core analysis, edge effect and corridor identification.
AGE	Age Class of Stands	Area calculations, edge effect.
SOHA	Spotted Owl Habitat Area	Significance values from edge of SOHA.
IRA	Integrated Resource Analysis Areas	Final calculation for fragmentation index.
HYDRO	Stream classes 1-5	Riparian zone areas and corridor identification.
TRANS	Transportation Lay	Edge effect.
OWLS	Spotted Owl locations	Assigning significance to areas around center of activity.

The above map layers are data available from the first stages of GIS development on the Olympic National Forest. The full potential of GIS has not been realized on the Forest and will only be fulfilled with further time and data input. The map layers used in this model cannot fully represent all ecological values of old-growth in the study area, however, the model building process allows for the addition of new data as they are developed. It is important to note at this time that not all data being collected on old-growth are potentially useable in a GIS. The best data sources are those which have some type of spatial relationship and can be represented in an attribute file or grid cell structure.

MODEL CREATION

The creation of the model is broken down into the creation of individual map layers or sub-models which make up the individual data layers. These sub-models are assigned significance values and are combined to produce the final single layers showing the rating values based on the selected criteria (Figure 3). If the criteria are changed due to changes in management priorities or changes in basic data, the sub-models are changed to represent the new values and the model is again combined to produce the final rating layer. Weighting values can also be applied during the sub-model combination stage to show possible changes in significance based on different priorities.

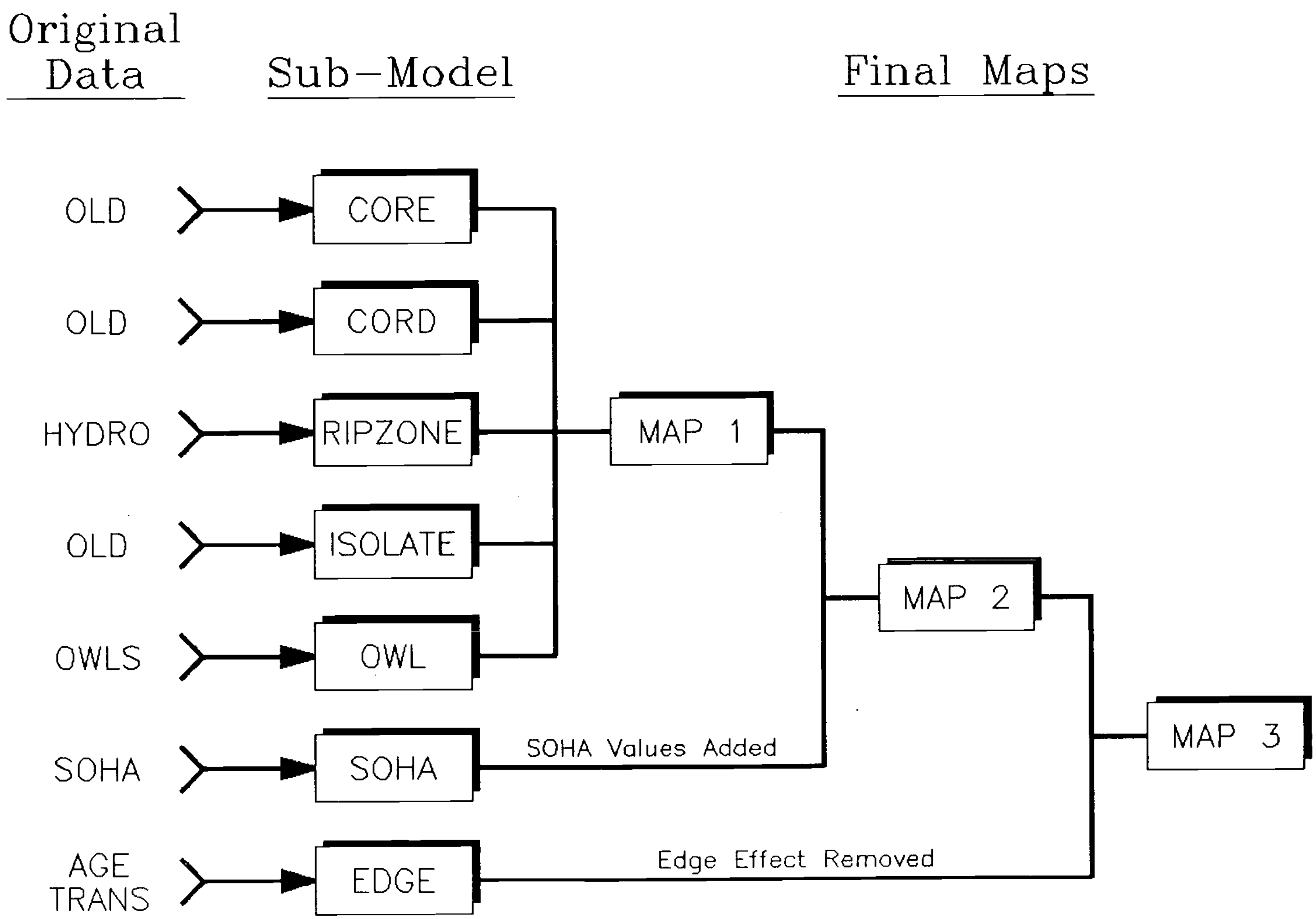

Figure 3. Organization of GIS model development.

SUB-MODEL CREATION - The following is a description of the sub-model development with all GIS functions being performed in MAP, unless otherwise stated. The use of **bold** lettering represents commands or functions used in the development of that particular sub-model.

CORE AREAS of old-growth stands represent areas that are the greatest distance from forest management activities. This sub-model is designed to determine the amount and quality of interior old-growth habitat. At present, the Forest Service uses a checkerboard system to harvest timber. This pattern represents a method of creating maximum edge effect which severely influences interior forest species (Franklin, 1987). The edge effect on the remaining old-growth forest after timber harvesting includes changes in temperature, relative humidity, light penetration, and increased potential for catastrophic blow-down. Biological responses include elevated tree mortality, an increase in sun tolerant species, and depression of bird populations due to increases in predation rates on interior species (Lovejoy, 1986; and Yahner, 1988). The type of edge found between an old-growth stand and the managed stand is dependent on many factors including slope, aspect, and abruptness of the edge. This sub-model identifies areas which have significant core characteristics based upon distance from the edge of the stand. The significance values assigned are represented by the curvilinear relationship as shown in figure 4. At this time the lack of a digital elevation model (DEM) eliminates the ability to look at slope and aspect as a factor in gauging the total edge effect. However, in the future the use of a DEM along with age class representation could improve the accuracy of this sub-model.

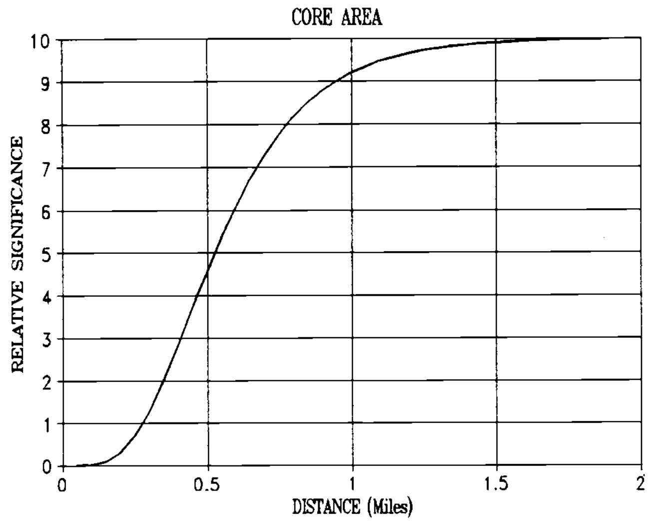

Figure 4. Significance curve for CORE sub-model (adapted from Henderson et al, 1990).

The original old-growth layer OLD was used as the starting layer which was mirrored or reversed to allow the spread command to create buffers inward into the core of the old-growth layer. These buffers were then renumbered into ten zones of significance representing distance from the stand's edge. The significance curve developed to rate this sub-model assumes a consistent edge effect around the old-growth and rates stands with depths under 0.2 miles as having no old-growth core significance, or made up entirely of edge characteristics (Henderson et al, 1990). This model rates interior core habitat and does not address the edge effect directly. The quantification of the edge effect on the forest landscape is addressed in the edge effect sub-model.

<u>CORRIDOR AREAS</u> represent important linkages between existing old-growth stands. Corridors represent possible pathways for interior species to travel from one geographic location to another without having to enter into openings or managed stand environments. There are four major types of corridors as outlined by Forman and Godron (1981). The line corridor is typically narrow and has species

characteristics of patch edges and includes such things as road sides, hedgerows, property boundaries, drainage ditches, and irrigation channels. Strip corridors are wider bands containing a patch interior environment which allows the movement of interior species. Stream corridors border waterways and vary in width according to the size of the stream. Stream corridors are very important in providing riparian zone characteristics such as the input of organic materials, large woody debris, temperature control, and erosion control (Waring, 1985). A stream network makes up the fourth group of corridors allowing for the linkage of a system of corridors over a large geographic region. There is overlap between the different corridor types. For example, a wide stream corridor has the ability to act as a strip corridor if there is sufficient interior habitat.

This sub-model examines the spatial links between large old-growth stands. The type of corridor was not considered, only the spatial linkage was important. This sub-model is developed to identify those old-growth stands in areas of heavy forest management activities which still link larger stands of old-growth and, if removed, would cause additional isolation of the forest ecosystem. The following sub-model on riparian zone corridors addresses possible stream and strip corridors in a network setting.

This sub-model involves an interpretive process of identifying areas of linkages aided by distance and reclassification commands in the GIS. The commands **spread** and **filter** were used to identify areas of possible linkage along with visual interpretation. Areas that were identified as spatial links were separated from the original old-growth layer in ArcInfo. ArcInfo's digitizing capabilities (ArcEdit) allowed for the creation of individual polygons around the identified links. These polygons were then **intersected** in ArcInfo, with the original old-growth layer OLD to act as a "cookie-cutter" to remove only corridor stands. These corridors were then transferred to MAP for the assignment of significance values.

The significance given to these corridors is not based on a curve showing different values of significance for a given distance, since most of these corridors are very thin and/or short. If a stand is identified as a corridor in this sub-model it is given a value of 10 or highly significant, since its removal would severely limit future movement pattern of species. This method of spatial corridor selection could be greatly enhanced by the input of field specialists.

RIPARIAN ZONES, the second type of corridor addressed in the model, are important linkages between existing old-growth stands. The riparian zone is utilized by more species of wildlife than any other type of habitat found in the Pacific Northwest (Harris, 1984). The most fundamental reason for this is that riparian ecosystems receive water, nutrients, and energy from surrounding upstream environments. The capability of coupling this rich ecosystem with sufficient expanses of old-growth to act as a strip corridor make the riparian zone an important corridor network over the entire landscape.

Present forest management practices on Forest Service lands only consider a 200 foot buffer zone around riparian zones. This buffer zone is subject to different management criteria depending on the stream's class and its local geography (USFS, Direct Communication). In this sub-model I propose the use of riparian zones along with a sufficient amount of surrounding old-growth to act as a corridor network. This

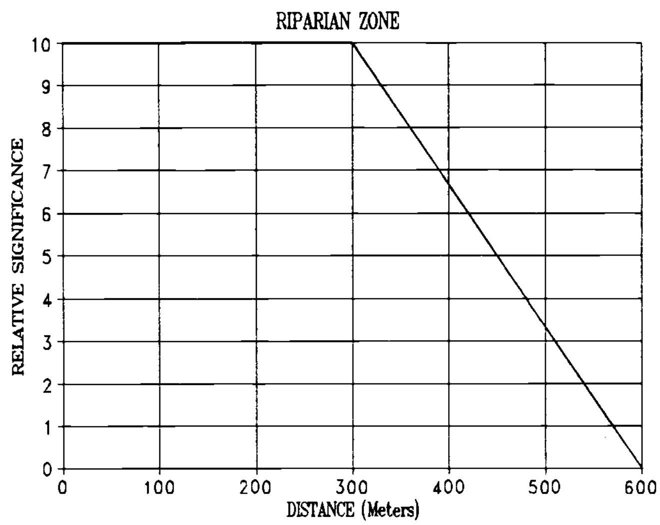

Figure 5. Significance curve for RIPZONE sub-model.

network of corridors is created from the HYDRO layer using class 4 and 5 streams.

If the network needs to be expanded or contracted the selection of the desired stream class is quick and easy. The significance values assigned range from 1 to 10 based on the distance from the stream (Figure 5). All old-growth within 300 meters of the stream is given a value of 10 or the highest significance with decreasing significance outward to a total of 600 meters on each side of the stream. These distances are based on the maximum edge effect identified through elevated predation rates of bird communities near edges (Andren, 1988; Lovejoy, 1986; Wilcove, 1989; and Yaher, 1988).

The buffering of the corridor area was done in ArcInfo in order to get a more accurate representation of the distances involved. The vector based system allows you to **buffer** outward a specific distance from the original HYDRO layer. The buffered file was then gridded using the **polygrid** command to allow for the transformation to the MAP package (Appendix A). If the original buffering was done using **spread** in MAP the original data would have been represented by a series of 80 meter grid cells with the buffering proceeding outward from there in 80 meter increments. After the file was transferred to MAP the buffer zones were then **renumbered** to represent the assigned significance values.

NEAREST NEIGHBOR DISTANCE is used to identify those old-growth stands that because of isolation are significant. Due to forest fragmentation from management activities some old-growth stands are isolated from other larger more continuous old-growth stands. The effects of this isolation are dependent on the size of the remnant stand and its distance from more contiguous old-growth stands. The size of the remnant stand and its shape will determine the stand's ability to compensate for the edge effect which has been created through the fragmentation process. A small stand of old-growth will be dominated entirely by edge characteristics with no interior habitat. This change in ecologic characteristic along with the dispersal barriers created by the stand's isolation will cause a decline in many interior species (Wilcove, 1989).

Although size and isolation of a remnant stand will decrease its significance value for many species, the distance from other old-growth stands will increase the stand's significance for other species. An isolated old-growth stand will act as an important source of wildlife refuge providing valuable resting, roosting, and feeding areas for birds and mammals which migrate over large distances (Henderson et al, 1990). The isolated stand will also act as an important source for seeding and supply diversity to the gene pool of the surrounding area.

The identification of these significant isolated old-growth stands is based on distance from other neighboring stands. Size was not considered since even a small

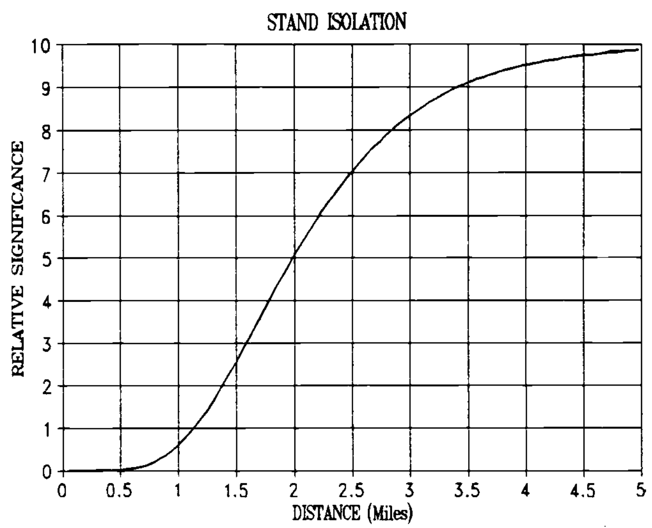

Figure 6. Significance curve for ISOLATE sub-model (adapted from Henderson et al, 1990).

remnant stand may have valuable characteristics. The original old-growth layer OLD was spread outward as a tool to measure distance. The buffered zones created are represented by different colors, and the distances between stands are easily definable based on the color of rings or buffered zones around isolated stands. The significance curve developed for this sub-model shows the values assigned based on the distance for other old-growth stands (Figure 6). In the study area it was found that only a few stands were isolated by more than a half mile, with no stands receiving a value over one. This shows significant isolation has yet to take place in the study area. However, other areas outside of the study area may have many possible stands showing high significance. This sub-model may have little effect on the initial model building process, however, the possibility exists to increase the sub-model's significance or weighting factor to enhance its value if desired.

Once the stands were identified in MAP as being isolated the individual stands or polygon ID's were identified in ArcInfo and **reselected.** The reselected ID's were then transferred back to MAP where they were **renumbered** to show the proper significance value based on the significance curve.

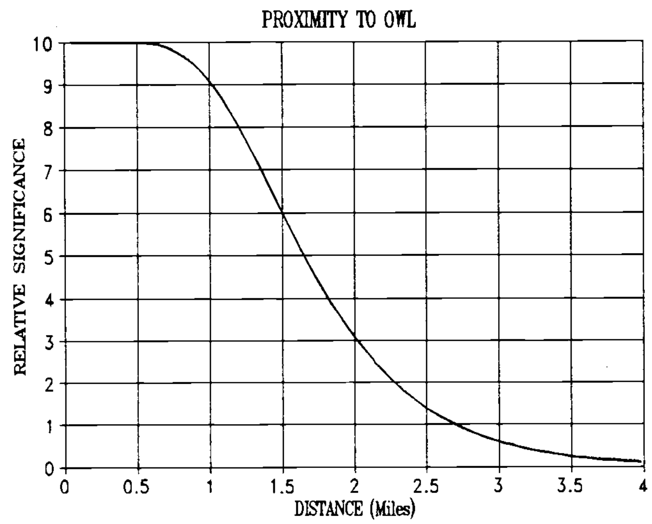

Figure 7. Significance curve for OWL sub-model (adapted from Henderson et al, 1990).

<u>OWL POINTS</u> are areas that represent centers of activity in areas of known northern spotted owls. These owl center points are based on data received from the Olympic National Forest and are plotted only to the nearest section. This generalization is a necessary fact due to the nature of the northern spotted owl controversy. Based on the northern spotted owl's preference for old-growth the significance of stands around the center of activity is very high, with decreasing significance as distance increases. The amount of old-growth needed around a center point for the spotted owl's survival has been hotly debated and, at least for the near future, will continue to be.

The significance curve developed for this sub-model (Figure 7) is based on Forest Service data for non-SOHA nesting pairs used in the February 1, 1990 report on the Evaluation of Ecological Significance (Henderson et al, 1990). The non-SOHA nesting pair designation means a pair outside of spotted owl habitat areas or protected areas. The rating system presented here is an initial starting point for this sub-model and will have to be adjusted as additional data and management criteria are implemented. This is easily accomplished in the GIS and is an ideal tool to show data such as these.

These owl points were digitized in ArcInfo (ArcEdit) into centers of old-growth stands in the section numbers provided by the Forest Service. The ability to attach many attribute values to these owl points makes the storage of these data in the vector based system much more flexible for future data compilation. For the sub-model development the owl points were **polygridded** in ArcInfo for the transformation to MAP. Once in MAP, the use of **spread** and **renumber** allowed the development of concentric zones of significance outward from the center of activity.

<u>SOHA LAYER</u> is based on the distance from the edge of an existing SOHA. This sub-model is based on management criteria that considers old-growth adjacent to the edge of a SOHA as being higher in significance than old-growth further away. However, the edge of the SOHA is a manmade boundary that is subject to change and adjustments. This sub-model shows how

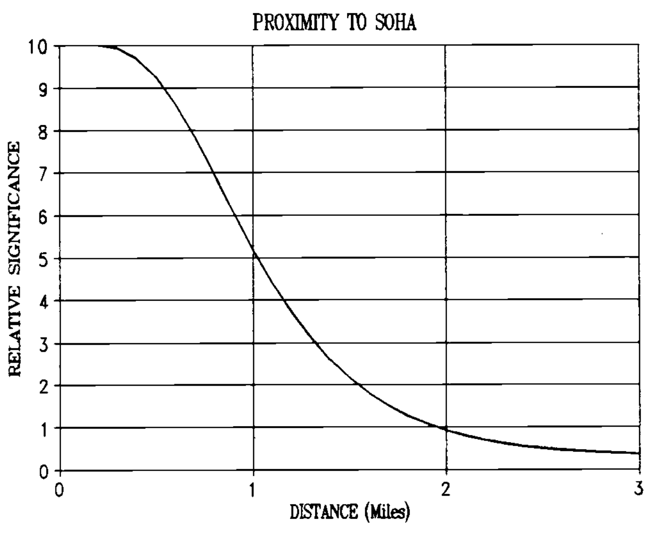

Figure 8. Significance curve for SOHA sub-model (adapted from Henderson et al, 1990).

management criteria and priorities can be added into an ecologic model to represent human priorities and conditions, and how it effects the overall output of the model.

The entire SOHA layer was transferred from ArcInfo to MAP using the **polygrid** command (Appendix A). Once in MAP the entire SOHA region was **spread** outward and **renumbered** based on the significance curve (Figure 8). This output layer represents an interesting test of how to assign values based on management criteria. Since the buffered zone originates outwards from the edge of the SOHA starting with a value of ten, what should the SOHA itself be assigned? If it is not assigned a value the area around the SOHA in the final model could have a higher value than the SOHA itself. If it is assigned a value of ten the area of the SOHA and the first buffered zone will be of the same significance, and the area of the SOHA will be increased with no increased significance given to the SOHA itself. For this sub-model I decided to give both the SOHA and the first buffered zone a value of ten, given the opportunity to add an additional value to the SOHA later.

The EDGE EFFECT sub-model was developed to quantify the amount and area of edge effect on the forest in the most accurate manner possible with the original data at hand. This is again a generalization of the factors involved in the complicated process of describing the type and amount of edge. However, I feel it is important to test ways of showing edge effect so a better understanding and a more accurate quantification can be made of the remaining interior old-growth ecosystem on National Forests. At this time the factors of edge effect and the exact amounts are not clearly defined for the study area. Because of this limited understanding the estimates of edge effect are conservative in this sub-model, based more strongly on light penetration and wind penetration than on predation rates which would most likely increase the distances tremendously.

Two original layers were used in this sub-model: the TRANS and AGE layers. First, the transportation layer was used to quantify the amount of edge created by the road network on the landscape. Each road through an old-growth stand creates some type of edge depending on the type of road and its geographic location. A well traveled road may have a greater edge effect than a small dirt logging road. However, the geographic situation of the road will determine the amount of ecosystem change based on light penetration, wind penetration and accumulation of edge species. Because of the wide range of possibilities given by many authors (Andren, 1988; Forman, 1981; Franklin, 1987; Lovejoy, 1986; Ripple, 1990; Wilcove, 1989; and Yahner, 1988) a generalized amount of 100 meters, or approximately two tree heights was used in this sub-model to represent edge along roadsides.

The second layer used to quantify edge was AGE, or the age class of stands. This layer was broken down by stand age in years; 1) 0-10, 2) 11-20, 3) 21-30, 4) 31-50, 5) 51-80, 6) 81-160, and 7) 160+. As a replanted stand grows, tree height increases and the edge effect decreases. A freshly cleared stand next to an old-growth stand will have a much greater edge effect than that created by a 30 year old stand (Lovejoy, 1986; and Klein, 1989). Based on this decreasing edge effect the groupings of age class in this layer were combined into three major classes which were assigned different edge effect distances:

1. 0-10 and 11-20 - Edge effect of 150 meters.
2. 21-30 and 31-50 - Edge effect of 100 meters.
3. 51-80 and 81-160 - Edge effect of 50 meters.

The buffering of this sub-model was done in ArcInfo using the **buffer** command. The TRANS layer was simply buffered a distance of 100 meters and then transferred to MAP. The AGE layer had to be **reselected** on the groupings of the age classes and then **buffered, unioned** and **dissolved** back together. The option of using this layer in both MAP and ArcInfo give the greatest flexibility to be both incorporated in the final model and to be used as an accurate quantification tool to estimate the total amount of edge effect on the forest.

MODEL CONSTRUCTION - The final construction of the ecologic rating model involves the process of merging the individual sub-models into a final model layer showing the rating of old-growth ecologic significance throughout the study area. This process involves the data analysis side of MAP using commands such as **add, cover, cross, divide, exponentiate, multiply and subtract,** with the selection of the command dependent on the desired output. For the initial model composition the **add** command is used to composite the sub-models into a final map layer. This process generates a new layer based on the sum of the corresponding values of the input layers (Figure 2).

The first map is a composition of the five basic ecologic sub-models with the human created boundary of the SOHA absent (Map 1, Appendix B). This map has a possible significance rating between 1 and 50 or the sum of the highest possible scores in each sub-model. I decided to leave the two corridor layers of CORD and RIPZONE separate to define any areas of both spatial and riparian zone corridors; however, the model could easily be changed and the two layers merged into one single rating scale from 1-10. After the sub-models were **added** together the map was **renumbered** to break the 50 possible scores down into manageable class intervals. It was decided to renumber the map by intervals of four which create eight separate class intervals since the highest pixel value was 32 (**describe** command). This renumbering process could be performed using any set of intervals based on assigned criteria. Intervals of four created the greatest number of intervals and was still graphically feasible.

The second map (Map 2, Appendix B) shows the effect of the SOHA sub-model being added to the model composition process. This sub-model uses a value of 10 for both the SOHA and the first buffer zone. The addition of this sub-model changes the possible significance values by **adding** an additional 10, making the range 1-60. Again, the model was **renumbered** by intervals of 4, resulting in 10 class intervals since the highest pixel value is now 40. A clear outline of the original SOHA area is shown in Map 2A (Appendix B).

The third map (Map 3, Appendix B) shows the removal of the edge effect sub-model from Map 2. The same rating system is used for the remaining old-growth, but the edge effect was removed using the **cover** command. This map demonstrates the tremendous versatility of the GIS. The area shown represents the remaining interior old-growth after the edge effect has been eliminated. The use of ArcInfo and its vector based data structure can give more in-depth information on the total area of edge effect on a stand by stand, or polygon by polygon basis.

ADDITIONAL MODELS - The methods and the flexibility of the model building process creates excellent possibilities for additional models. The development of different significance curves will influence the assignment of values to the buffered zones and the output of the model would be changed. Weighting factors can also adjust the significance by making one sub-model greater than the others. This can easily be done using commands in the Data Analysis section of MAP.

Possible changes to the existing model created for this paper include the increase in significance given to isolated stands in the nearest neighbor sub-model. Based on the existing significance curves the isolated stands are only slightly significant, receiving a value of one. These stands are located on the western and southwestern side of the study area (Map 1, Appendix B). By increasing the values of these isolated stands based on different curves, or by management design the stand's significance score could jump by one or two classes. This jump in significance can influence the decision to preserve or harvest these stands.

The use of man-made boundaries represents an added dimension to the model. These boundaries and the significance values assigned will tend to change more than the ecological criteria. The representation of the SOHA in the model can be looked at on the same level as the other ecologic criteria, or it can be assigned a different type of significance. For example, the SOHA itself can be assigned a value of 100 and composited with the other layers. This high value will demonstrate the management decision not to harvest timber inside the SOHA. If management priorities change and harvesting is allowed in the SOHA the value can be changed back to 10 in order to represent high significance on that sub-model, but possibly not high enough to eliminate stands in the SOHA from consideration (Map 2, Appendix B).

The output of useable data is also very important for the GIS system. The raster based MAP package will provide a user with data such as scale, values of assigned category, labels and number of cells contained in each category allowing for area calculations. In the ArcInfo package the areas and perimeters for individual polygons are easily defined. Using commands either in **tables** or **Dbase** (newest beta test of PC ArcInfo, version 3.4D) polygons with a specific value can be identified to calculate total area or total perimeter in a particular class. This type of information is very important when quantifying landscape or resource values.

In addition to simple quantification of landscape data the output from GIS can be used to perform other types of data analysis. One such analysis is the use of area and perimeter to identify fractal dimensions for the study of landscape fragmentation (Cola, 1989; Krummel, 1987; Lovejoy, 1982; Mandelbrot, 1977; and Ripple, 1990). The study of fragmentation has become critical in the placement of timber sales to limit the amount of additional isolation and edge created on the forest landscape. Using the perimeter-area method for calculating fractal dimensions the log(P) is regressed on the log(A) and D (fractal dimension) equals the slope of the regression line. The fractal dimension of a region can be calculated before the placement of sale units and then recalculated after their placement in the GIS model. This quick method of calculating before and after fractal dimensions estimates the fragmentation effect on the forest landscape, allowing forest managers the opportunity to quantify possible impacts on the landscape before they actually occur.

DISCUSSION

The final output maps are a synthesis of the sub-models showing the sum of pixel values which corresponded in the GIS composition process (Figure 2). These pixel values represent the total significance assigned by the sub-models to the old-growth layer. The values are relevant to the type of management criteria being addressed. For example, if the placement of a single timber sale is being examined, the area of consideration may be limited to the first interval class of 1-4. However, if an entire sale plan for a fiscal year needs to be examined, the number of class intervals used will grow until enough area is being considered to reach the targeted quota.

The first map (Map 1, Appendix B) created is the synthesis of the five main ecological sub-models (Figure 3). The areas of lowest values are represented by the cyan, blue and green, areas in the middle range being the yellow, orange and red values, and the highest values being the purple and brown areas. This model suggests that the cyan and blue areas have little ecologic significance based on the five criteria and should be looked at first for future management activities. It should be noted that the addition of one timber sale or clear-cut area may have dramatic effects on the area around it. For this reason the area of a sale unit can be eliminated from the original data and the model composition process again performed to identify possible changes in values of the surrounding stands before a second sale unit is selected.

In Map 1 notice the areas of extreme values. The largest area of low values is in the north center part of the study area. This area borders the State of Washington's Department of Natural Resource land (Figure 1) and may have an entirely different significance value if additional regional data are considered. This is also evident on the southeastern side of the map where the Olympic National Park borders the study area. These two examples draw attention to the need for a regional wide approach when considering ecological data for the use in management decisions which effect the entire ecosystem on the Olympic Peninsula.

The low values of significance running down the center of the study area in Map 1 are also possible candidates for the placement of timber sales. However, Map 2 and Map 2A show the placement of the SOHA over these areas of lower significance. This suggests another possible use for the model as a tool to spatially place future reserved areas in places of highest possible significance. The area of highest significance in the northeastern section of the study area would be a possible candidate for the placement or adjustment of future SOHA's. This ability to define areas of high significance becomes important as new management decisions and new data are collected about the northern spotted owl. It is very likely that in the near future the areas of the SOHA's will have to be increased dramatically throughout the Forest Service SOHA network. A model such as this can assist in the placement of future reserves to help ensure the survival of the species.

The production of Map 3 is designed to illustrate the extremely large effect of edge throughout the study area. The overall landscape of the study area is highly fragmented, however, there is not yet a tremendous amount of stand isolation. Yet, when examining the remaining stands, which are not influenced by edge, it becomes clear that the fragmentation on the landscape has eliminated most true interior habitat areas. The SOHA (Map 2A, Appendix B) is also added on this map showing the amount of area found inside the reserve which can be considered interior habitat.

There are many possible model combinations which can yield various results. The maps used in this paper are simply the initial platform from which many possible combinations can be analyzed to answer the "what if" questions. The output from the various models can also be used to calculate many pieces of important and useful data. Again, it is determined by the selected management criteria and the desired output needed to make the proper management decision.

CONCLUSION

The model building process as presented in this paper is the first step in the use of GIS modelling as a tool to aid in management decisions on a National Forest level. This model demonstrates the potential uses of GIS as a tool to incorporate many different types of spatial data which can be synthesized into a useful model to help guide management decisions. As additional data become available the use of GIS will move more and more from the cartographic management stages to the analysis and model building environment. This advanced area of processing is where the true capabilities of a GIS will be realized. The application of this powerful analysis tool to a regional model will yield fast and efficient ways to test management criteria in ways never before possible. There is no other technology that can offer forest managers the capability to store, retrieve, analyze, manage, and synthesize large databases. These capabilities become critical in the extremely complex and controversial domain of public forest management.

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APPENDICES

APPENDIX A

The data transfer used to produce the model in this paper is outlined in the following list of commands and functions. The original data from the U.S. Forest Service are in the form of Map Overlay and Statistical System (MOSS) export files. The importation of these files into PC ArcInfo is the stating point of this paper's model building process.

COMMANDS IN PC ARCINFO

MOSSARC [moss_export_file] [cover] {POLY / LINE / POINT}

This command in the PC ArcInfo Data Conversion kit converts MOSS export format files into an ArcInfo coverage. Even though a PAT file is created for the coverage in this command using the POLY option, it will require further processing using the ArcInfo Starter Kit command **BUILD** or **CLEAN** to create polygon topology.

POLYGRID [cover] {grid_file} {item} {lookup_table} {weight_table} {sml_file}

This command in the PC ArcInfo Data Conversion kit creates a grid file of one of the supported formats from the polygon feature of an ArcInfo coverage. The type of {grid_file} created by this command is base on a selection of option given by a series of prompts once the command has been implemented.

Prompt 1. Grid File Types
1 - Noncompressed ASCII (Note: used to transfer to MAP)
2 - Compressed ASCII

3 - ERDAS 8 bit
4 - ERDAS 16 bit
5 - EPPL7
6 - Grid Card Image

Enter the number of the grid file type to created:

Prompt 2. Lower Left Reference Coordinate (x,y):
Note: Enter the location of the lower left corner of the lower left cell of the grid that is being created. This same value should be used throughout all coverages that are being gridded.

Prompt 3. Cell Size (width,height):
Note: Enter the width and the height which a single grid cell should be. These dimensions must be given in coverage units. This same value should be used throughout all coverages that are being gridded.

Prompt 4. Grid Size (nrows,ncolumns):
Enter the number of rows (nrows) and the number of columns (ncolumns) that the grid should have. Neither of these dimensions can exceed 5000. These dimensions should be carefully calculate to consider all coverages that will be gridded. All the information in all sub-models must fit into the area of the designated grid.

The limitations of the MAP Analysis Package or any other software package that will import this gridded file needs to be considered at this time. The following is an example of the selections use to correctly transfer a coverage file from PC ArcInfo to MAP Analysis Package:

POLYGRID [DB] {DBGRID} {DATA}; @prompts - 1) Noncompressed ASCII, 2) 420184,5261439 (UTM coordinates), 3) 80,80 (cell size), 4) 175,255 (size of grid).

COMMANDS IN OSU MAP ANALYSIS PACKAGE

ARCTOMAP [name of input file] [layer name for use in database] [scale of grid cell]

This command is a stand-alone utility program which may be used to convert files in PC ArcInfo NAS (noncompressed ASCII) format into a format that can be read by the **GRID** or **READ** command in MAP. This command is executed by simply typing **ARCTOMAP** at the DOS prompt in the MAP sub-directory. The utility program will then prompt you to fill in the above information. After entering the name of the input file, you will be prompted for the name of the output file. The name of this file must have a ".DAT" extension if you wish to start a new database. Otherwise it may be any name up to 8 characters in length for use by the **READ** command into an existing database in MAP.

GRID [On <existing layer>] [For <new layer>]

This command is an all-purpose data entry format to explicitly fill each cell in a map layer. Entries are made at the row level; one entry operation assigns values to all of the cells in a given row. The information to be provided for a given row consists of a row number followed by a string of cell values. The order of the values in the input string determines the left-to-right order of the cell values in the row. Data may be entered from an ASCII file or directly from the keyboard. Grid may be used to create a new map layer from scratch or to edit an existing layer.

READ [from] [keyboard or filename]

This command allows NAS files created in ArcInfo **POLYGRID** to be read into a existing database in MAP. If a database does not exist use the ".DAT" extension when running **ARCTOMAP** to create a database. This command transfers control of MAP from the user to a DOS file containing ASCII characters. This file may contain any valid MAP commands and these commands, including the **PAUSE** command, will be executed in sequence. When adding data to an existing database or creating a file containing only commands, the first four lines in the file are always ignored, so entry of commands must begin on the fifth line. The first four lines are reserved for parameters used in creating a new database.

DUMP [existing layer] [for] [new layer]

This command writes a copy of the numeric values of a layer to a DOS file for transfer to ArcInfo. The output file is in PC ArcInfo noncompressed ASCII (NAS) format and contains the numeric values composing the layer. The file contains ASCII characters in FORTRAN 13I6 format in which the first line consists of text identifying the format type and the second line contains the beginning and ending row and column numbers.

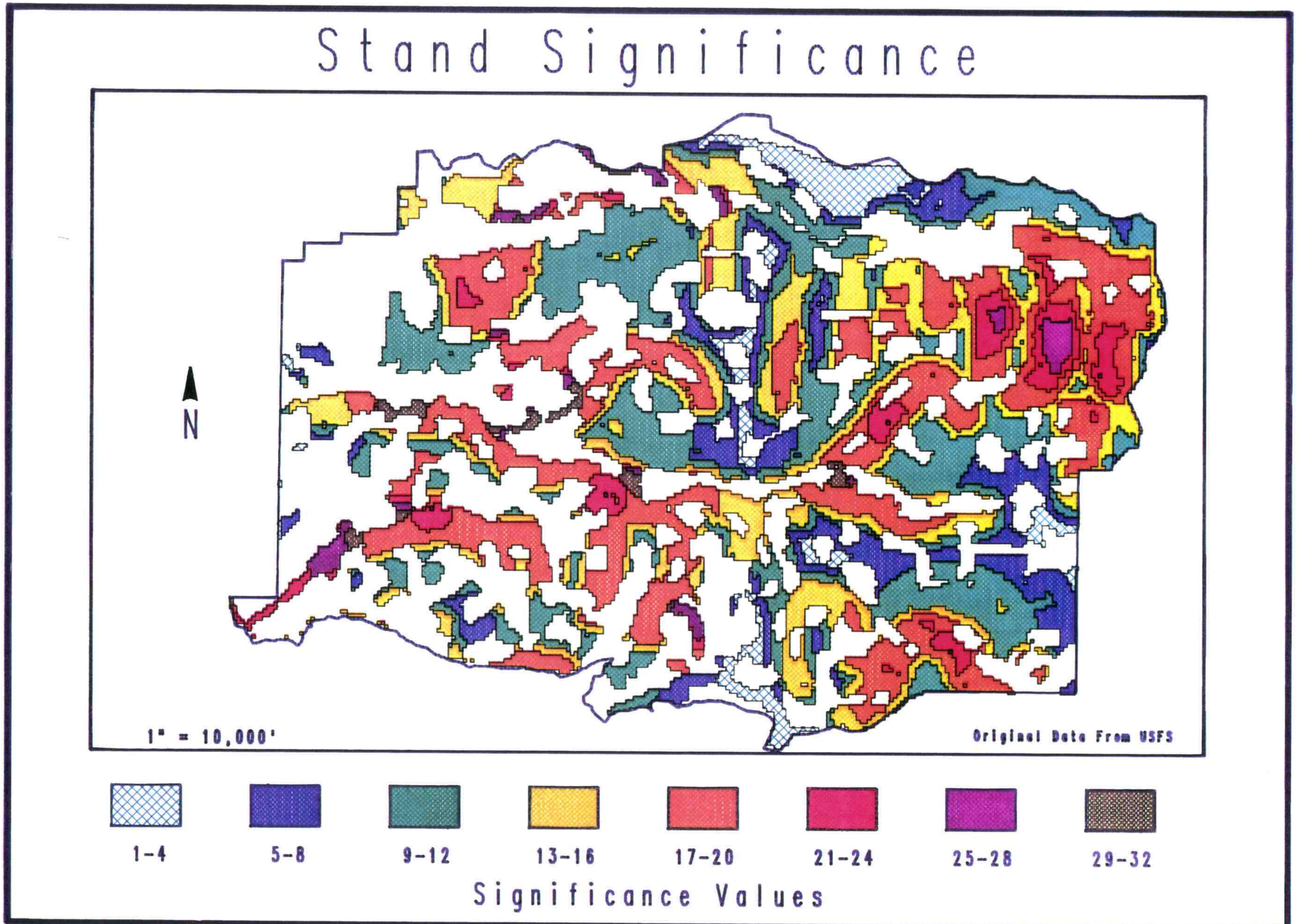
COMMAND FOR GOING BACK TO PC ARCINFO

GRIDPOLY [in_grid_file] [out_cover] [x_min] [y_min] [cell_width] [cell_height]

This Data Conversion Kit command converts the file created in MAP, using the **DUMP** command to an ArcInfo polygon coverage. You can use **GRIDDISP** to view the NAS file from MAP before this command is implemented. The same x,y coordinates and cell size used in the **POLYGRID** command should be used for this command. It is very important to note that grid files containing cell code values that are less than or equal to 0 will result in a polygon coverage with improperly coded polygons. This has to be considered in MAP before the **DUMP** command is used. **RENUMBER** (in MAP) can be used to change any 0 values to some other value that can be disregarded later in ArcInfo.

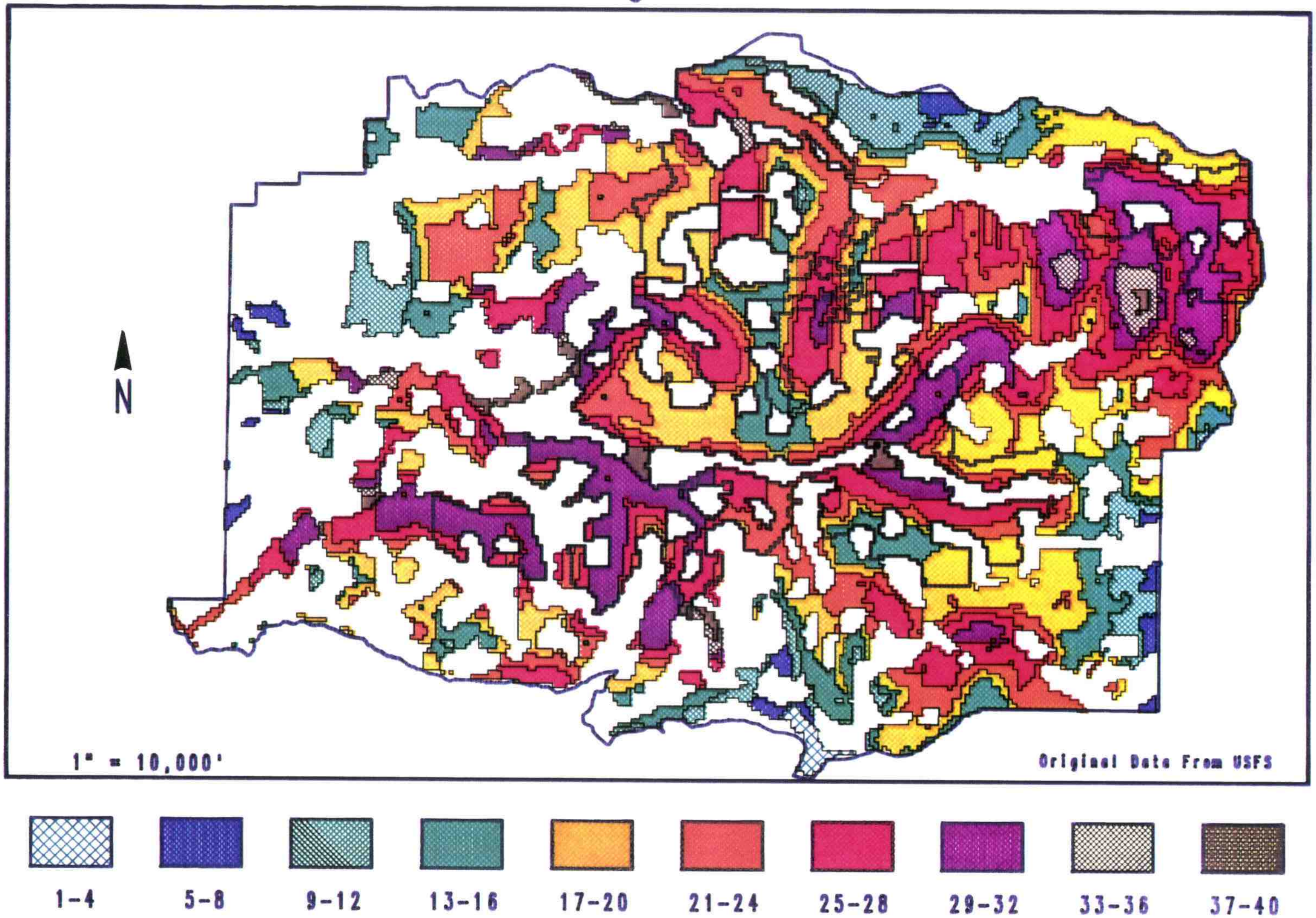
GRIDPOLY creates arcs from grid cell borders of [in_grid_file]. Contiguous grid cells having the same cell code value are grouped together to form polygons. In addition to the usual items, the PAT also contains an item named GRID_CODE. This item records the cell code values from the original grid file. The process of building the topology of a polygon coverage requires about 3 to 14 times the disk space needed to store it. Make sure sufficient disk space is available before running the command.

APPENDIX B


Stand Significance
N
1" = 10,000'
Original Data From USFS
1-4
5-8
9-12
13-16
17-20
21-24
25-28
29-32
Significance Values

MAP 1

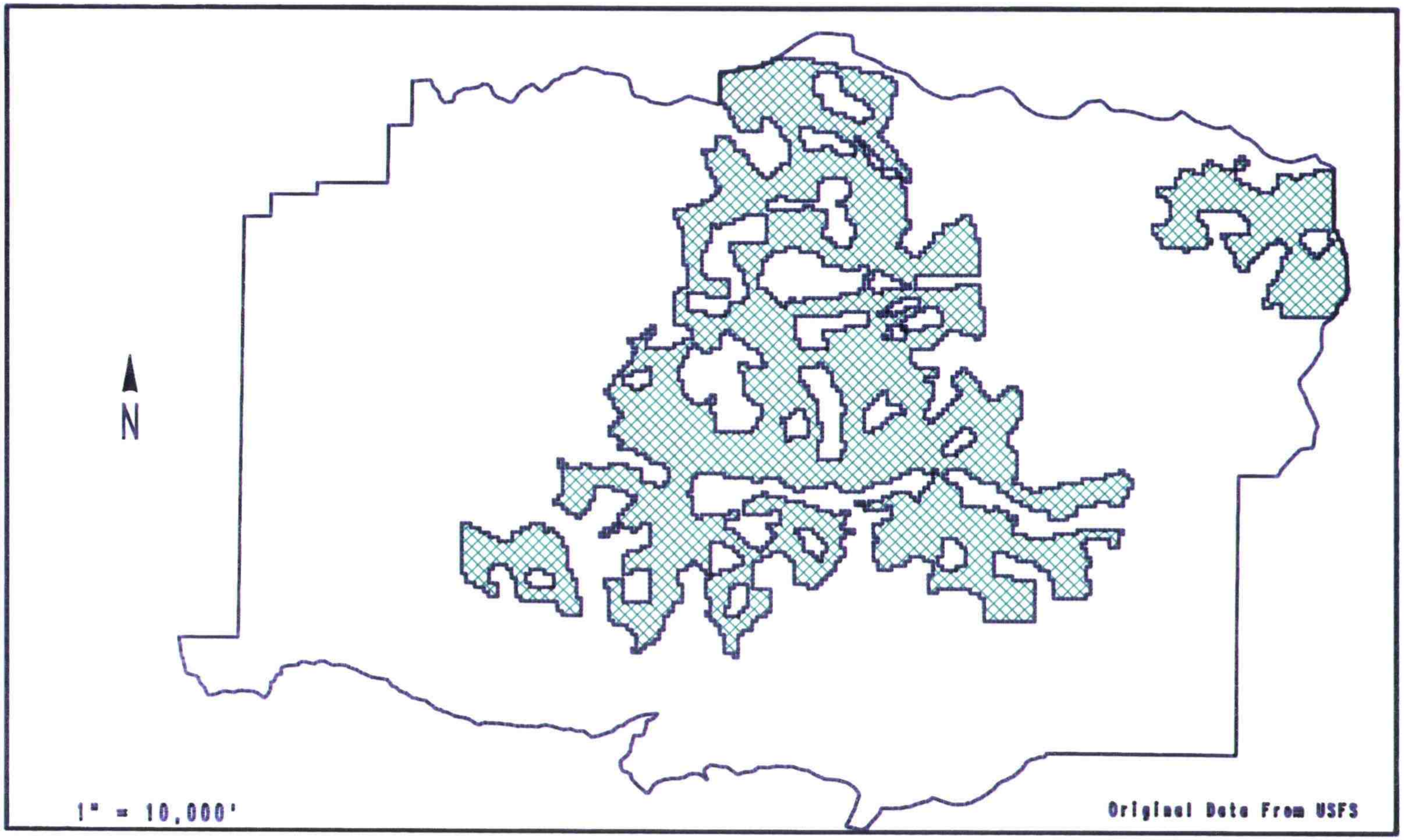
Stand Significance



Significance Values with SOHA

MAP 2

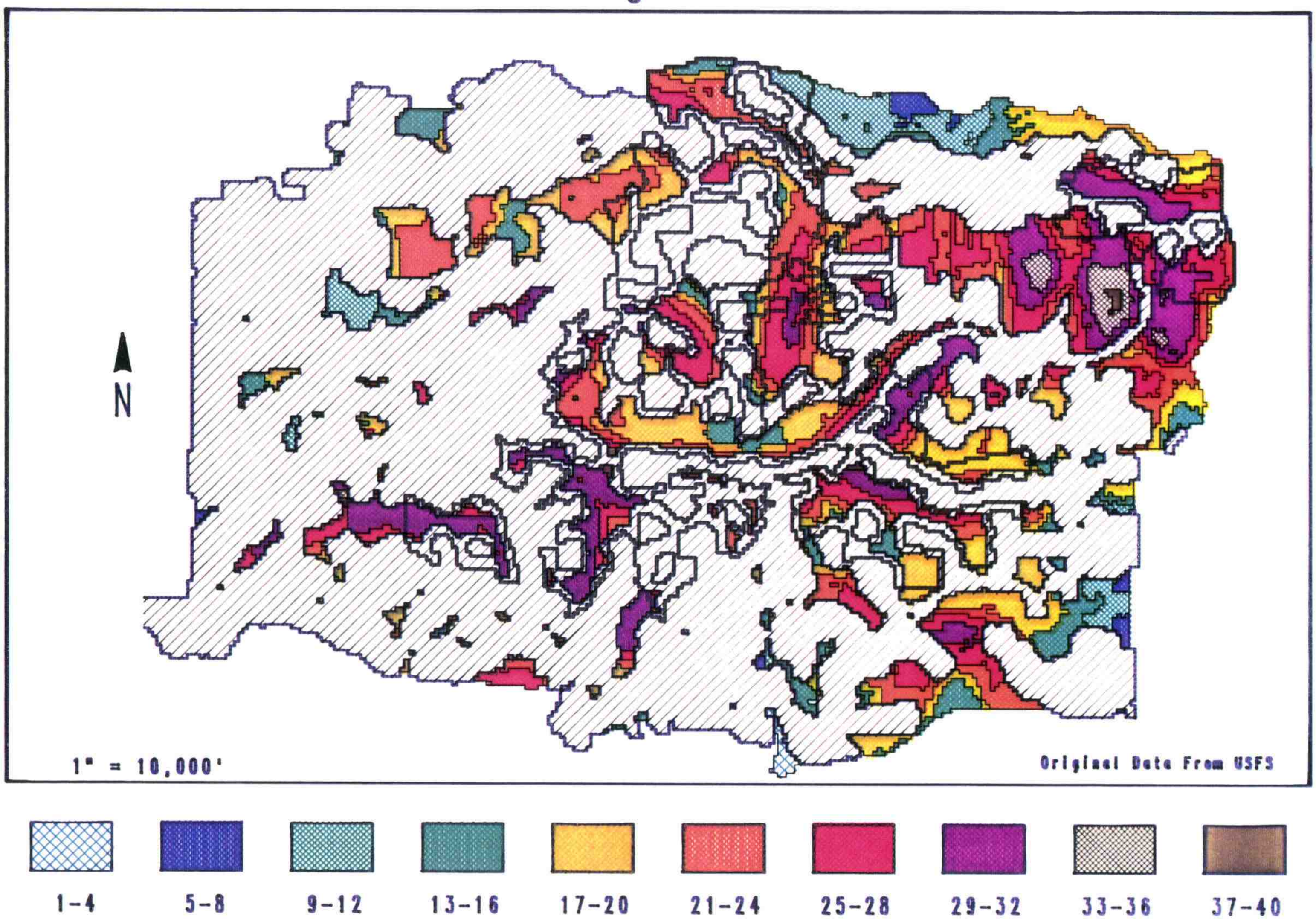
Location of SOHA



Location of SOHA as of Jan., 1990

MAP 2A

Stand Significance



Significance Values with SOHA - Edge Removed

MAP 3