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Applications in Forestry

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Introduction

Forests have been central in human history, providing materials and areas for human settlement and agriculture and raw materials for products such as lumber, pulp, chips, rubber, cork, fuel wood and charcoal. Now, other values are becoming increasingly important. For example, forests provide critical ecosystem services for climate, range and forage, wildlife habitat, biotic diversity, watershed protection and erosion control. Many forests throughout the world are fundamentally linked to the culture and survival of indigenous peoples.

As recognition of the multiple values of forests has grown, so have concerns for their disappearance (Brundtland Commission 1987). In many areas, tropical and temperate forests are being lost due to, for example, questionable land use practices and the harmful effects of atmospheric pollutants. As a result, more responsible management approaches are being demanded that can accommodate complex economic, ecological, and cultural needs. Examples include efforts to designate selected forest lands as national parks, wilderness areas, or biosphere reserves. Also, the continuing need for wood products has provided incentives for the development of plantations, afforestation projects, and agroforestry (an approach that yields both agricultural crops and wood products from the same area), particularly in the developing world.

Systematic forest management practices can be traced to the German states of the 16th century in response to concerns about overcutting. Each forest property was divided into sections for harvesting and regeneration. This planning required accurate maps, assessments of timber volume and knowledge of expected growth rates. Since then, many countries have adopted management approaches that rely on detailed maps of forest resources and predictions of harvest amounts and regeneration rates. Within the last two decades, computer technology has changed rapidly and, with the introduction of the personal computer, has generally become more accessible. During this time specific applications have been developed using this technology to describe and better understand the complex issues associated with forest management. Two of these applications are explored in this work – Geographic Information Systems (GIS) and Image Processing (IP), along with their role in forest management.

Definitions

A Geographic Information System is a computer-assisted system for the digital storage of maps, along with tabular data associated with map features, that permits the user to produce customized maps, perform specialized database queries, analyze complex relationships, apply models, and assist in decision making. In the context of forest management, Jordan and Erdle (1989, p. 288) describe some of the advantages of GIS as follows:

> ...forest management requires data that describe the present and future forest resource in terms of both conditions and geographic distribution. These spatial data typically consist of conventional inventory data that describe the physical condition of the forest's component stands and cover-type maps that define the geographic location of stands. It is for this reason, therefore, that forest management programs generate a great demand for computer-based, information –handling systems capable of accommodating both data types. GIS is an obvious choice for forestry because such systems are unique in providing that capability. Thus the forestry-GIS link is a logical one.

The role of GIS in modeling different management scenarios in space and over time is becoming increasingly important for actual management decisions.

An Image Processing System is designed for the computer-assisted enhancement and interpretation of remotely sensed imagery. With the advent of high resolution natural resource-oriented satellite systems in the early 1970's, Image Processing techniques were developed to convert raw3 imagery into classified maps. While the analytical procedures of an Image Processing System are not as extensive as those used in traditional visual interpretation, the consistency, precision, and speed of such a system can significantly aid the analyst in developing maps of such features as land cover, vegetation, and soils. Today, remote sensing and digital image processing represent an important resource for access to timely environmental data.

Many GIS software packages on the market offer both GIS and Image Processing capabilities within the same system. Therefore, in this document they will be treated together. Thus, when the term GIS is used, it is assumed that this includes the capabilities of Image Processing for data acquisition.

Role of the Workbook

This workbook explores the role of GIS in forest management. The purpose of this workbook is to provide foresters and other natural resource managers who have already had an introductory level course in GIS with the means to gain a strong appreciation for the application of GIS to forestry concerns. This workbook was conceived with the needs of UNITAR (United Nations Institute for Training and Research) training programmes as a guide. To this end, the first section of this workbook presents a review of forestry applications in GIS. It is not intended that this be an exhaustive inventory – only that it provide a broad overview to the role of GIS in modern forest management. Nor will it deal with the technical implementation of GIS. It has been assumed that the reader already has a broad familiarity with GIS.

Following the review paper, the workbook presents a set of exercises using the IDRISI Geographic Information System to illustrate several specific techniques and applications. IDRISI has been used because it provides an inexpensive and widely accessible tool for computer-assisted geographic analysis. However, the exercises can also be used with other systems. A

Given the objective of the UNITAR training programmes in natural resource and environmental management, a sincere effort was made to represent forest management issues, application s and research from around the world. While a range of examples is provided, some readers may feel that the content of the workbook emphasizes the efforts of forestry and GIS in the West. In part, this reflects the diffusion of GIS technology, with its early development and adoption in North America and Europe. Several letters in response to data inquiries attest that many organizations around the world are currently establishing systems for future use with forestry. As the technology continues to expand, future editions of this workbook should reflect the broader representation of applications that is elusive now.

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Exercises

The exercises progress from fundamental to more complex GIS analyses. The application of these tools to forestry was intended to be representative and diverse but not exhaustive. The exercises range widely in terms of geographic location and application.

The first three exercises deal primarily with the cornerstone GIS concepts of reclassification, overlay, and attribute query. Although all three utilize similar GIS concepts, they range in terms of complexity and forestry application. The first exercise uses data from Ontario, Canada and focuses on basic forestry management for stand leasing. The second exercise, also based in Canada, is oriented towards habitat analysis in a national park. And the third exercise, which uses the same basic tools as the previous two, concerns suitability analysis for eucalyptus stands in Africa. The amount of data manipulation, and therefore completion time, increase with each of these three exercises.

Exercises 4, 5, and 6 explore more advanced GIS topics. Exercise 4 examines the spread of the Gypsy Moth throughout northeastern North America, where it has severely damaged forest stands for several decades. The first part of the exercise examines the relationship between forest type and defoliation due to gypsy moth. The second part of the exercise uses regression analysis to determine the rate of spread of gypsy moth from its point of introduction. Exercise 5 uses data from a forest in the state of Ohio in the United States. It uses distance and cost analyses for studying timber stand harvest. Exercise 6 illustrates how basic GIS procedures can be used to perform complex analyses such as soil loss and deforestation measurement and modeling.

The final exercise in this workbook looks more closely at image processing and analysis using remotely sensed data. Exercise 7 uses satellite imagery and unsupervised classification techniques to identify deforestation in Rondonia, Brazil.

All of the exercises assume a basic working knowledge of raster based geographic information systems. The text is written specifically for use with the IDRISI GIS and Image Processing software package. However, every attempt is made to fully explain the procedures undertaken so you may be able to adapt the exercises for use with another raster system.

Revision Notes

May 1995

This volume was revised in June 1995 to be compatible for use with the IDRISI for Windows GIS software. The content of the volume is exactly the same as that of the previous version, except that specific instructions for operating the GIS in the exercises are given for IDRISI for Windows rather than IDRISI for DOS. In addition, minor editorial revisions have been made.

Mathilde Snel and Mahadevan Ramachandran, Revision Editors

June 1995

July 2000

This volume was revised in July 2000 to be compatible for use with the Idrisi32 GIS software and for distribution in electronic format. The content of the volume is quite similar to that of the previous version, except that specific references to IDRISI in the review paper were modified to reflect changes in Idrisi32 where appropriate, and instructions for operating the GIS in the exercises are given for Idrisi32. Some minor changes to the content of the exercises were also made. The editor would like to thank Jessica Cook and Nick Pieri for their invaluable assistance.

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This volume was revised in April 2005 to be compatible for use with the IDRISI Kilimanjaro GIS and Image Processing software and for distribution in electronic format. The content of the volume is exactly the same as that of the previous versions, except that specific instructions for the exercises are given for IDRISI Kilimanjaro rather than older versions. In addition, minor editorial revisions have been made.

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This volume was revised in April 2009 to be compatible for use with the IDRISI Taiga GIS and Image Processing software and for distribution in electronic format. The content of the volume is exactly the same as that of the previous versions, except that specific instructions for the exercises are given for IDRISI Taiga rather than older versions. In addition, minor editorial revisions have been made.

Applications of GIS in Forestry: A Review

Jean E. McKendry and J Ronald Eastman

Introduction

A review of forestry applications in GIS reveals an extensive range of activities. Geographic Information Systems for forest management may be characterized by two broad and related categories:

1. resource inventory and monitoring;

2. analysis, modeling, and forecasting to support decision making.

In fact, the development of a fully operational GIS for forest management will likely incorporate each activity as two distinct stages in its development (see Crain and MacDonald 1983, Jordan and Erdle 1990). For example, spatial data input, editing, and simple maps characterize the inventory and monitoring stage. In the modeling stage, overlays, reclassifications and suitability analyses are increasingly included as part of the decision making process. More sophisticated forecasts and "what if" simulations may then be used to assess management decisions before any changes or interventions are made on the ground. The boundaries between these activities, however, are not distinct. Monitoring, for example also includes an analytical component to assess change or the result of specific interventions.

With these two types of broad activities as a guide, this paper is organized into two parts – resource assessment (including inventory and monitoring) and resource management (including the full range of analysis and modeling concerning the evaluation and testing of specific interventions). In each part, general concepts are introduced and then specific examples are summarized.

Resource Assessment

Resource assessment activities include: 1) inventorying forest resources available for harvest, fuel, food, recreation, or conservation purposes, along with related data such as topography, soils, roads, and hydrology, 2) monitoring changes that occur to these resources over time, and 3) evaluating potential land productivity for forest types given certain biophysical and climatic factors. It is in forest resource assessment that other technologies related to GIS, remote sensing, and global positioning systems, make direct and substantial contributions.

Inventory

The acquisition of basic inventory data is fundamental to timber management as well as efforts to conserve certain forest ecosystems. Data include soil type, species type, size, class/stand structure, crown closure, density, and the boundaries of management units (e.g., stands). Once data are entered in a GIS, maps can be displayed showing general species distributions and the area of stands can be calculated (see, for example, Green and Congalton 1990). As the data are updated over time, changes in these distributions can be recorded and analyzed. More customized maps may be created to answer specific resource questions, such as a map that displays the locations of only stressed or diseased species. Creating maps that show the spatial relationships between harvestable tree species and other features such as mills, steep slopes, or even ecologically sensitive riparian areas are possible and useful to managers (Sheffield and Royer 1989).

Data collection techniques for forest inventories range from selecting sample plots for ground surveys to using topographic maps, remote sensing, and emerging global positioning systems (GPS). While a range of techniques is critical for comprehensive inventories, particularly ground surveys, remote sensing will be highlighted here.

Historically, remote sensing has been important in data collection activities and includes black and while, color and infrared aerial photography, radar, imaging spectrometers, laser altimetry, video imaging, and multispectral digital satellite imagery (Duggin et al. 1990, Leckie 1990). Integrating data from different types of remote sensors for forest inventory is strongly encouraged (Leysen and Goosens 1991, Leckie 1990). However, since the structure of satellite data (pixels) permits the input of these data directly into a GIS for processing, satellite remote sensing for inventory will be emphasized in the examples that remain.

Satellite imagery is available at varying spectral, spatial, and temporal resolutions and is useful to map broad forest types and to detect and delineate major forest changes over time (Leckie 1990). The primary sources and types of imagery available include Landsat Multispectral Scanner (MSS) imagery (80-meter resolution), Landsat Thematic Mapper (TM) imagery (30 meter resolution), SPOT panchromatic (10 meter resolution) and multispectral imagery (20 meter resolution), and NOAA Advanced Very High Resolution Radiometer (AVHRR) imagery (one kilometer resolution).

Satellite imagery provides several possibilities for inventorying. The United States Environmental Protection Agency (EPA) tested a method to identify xeric riparian (dry riverbed) habitats using Thematic Mapper imagery (Hewitt 1990). These riparian zones are important for plant and animal diversity and are more productive (amount of biomass) than bordering terrestrial habitats. They also serve as a permeable buffer between aquatic and terrestrial systems. Healthy riparian vegetation moderates sediments, nutrients, temperature, and bank erosion. Using three bands of TM imagery, the EPA focused on an area in eastern Washington State, USA. Sixteen distinct spectral classes were identified and then eventually aggregated to three classes indicating water, riparian, and non-riparian areas. Ground verification established a final accuracy of 81 percent. This approach potentially could be used to identify riparian areas that should remain undeveloped.

As deforestation in South and Central America, Malaysia and elsewhere has become a significant international concern (see Carneiro 1991, Lugo 1991, Brundtland Commission 1987 and world Resources Institute 1985 for discussions), inventories of tropical forests have become an urgent priority. The utility of satellite remote sensing to inventory large, sometimes remote areas proved itself early in the development of the technology. For example, in the 1970s, the Philippine government estimated that 57 percent of the national territory was covered by forests, mainly evergreen rainforests. However, a 1976 remote sensing survey revealed that forest cover was only 38 percent (Myers 1988).

To inventory the vast area of the tropics, a strategy using multiple satellite sensors has been suggested (Sader et al. 1990). Coarse resolution scanners with high temporal resolution are needed to reduce data volumes and increase the probability of cloud free data—a persistent problem in the tropics. With its 12-hour global coverage frequency (repeat cycle), NOAA satellite AVHRR sensor data provides this capability. High-resolution scanners, such as SPOT and TM with repeat cycles of around two weeks, are required to record spatial and spectral detail. Coarse resolution data may be used to stratify areas as the first step in a multi-stage sampling design. More detailed identification of forest parameters can then be made in specific locations at later stages with the higher resolution sensors. In fact, TM imagery has been used in several efforts to interpret the accuracy of and even calibrate AVHRR imagery (Stone et al. 1991, Cross et al. 1991, Teuber 1990, Iverson et al. 1989).

In addition to remote sensing, spatial positioning technologies have begun to influence surveying techniques and, thus, resource inventories. GPS (Global Positioning System) technology is based on a set of orbiting satellites (a total of 24), operated by the United States Department of Defense. They provide 24-hour, three-dimensional positional fixes with an accuracy of within tens of meters. With four or more satellites in view, a GPS receiver can interpret the carefully timed satellite signals to determine geometrically the latitude, longitude, and altitude at the operator's location.

GIS applications of GPS include georeferencing of satellite imagery and navigating to sample sites for ground truth (Lange and Stenberg 1990)—operations particularly relevant for forest inventories. As both the cost and weight of GPS receivers continue to decline, its greatest value will be as a real-time mapping tool to update GIS inventory data concerning specific forest management areas (Duggin et al. 1990). In remote tropical areas where base maps are lacking, GPS will provide an opportunity to establish ground control points to locate field plots and to rectify satellite imagery (Sader et al. 1990). On a cautionary note, GPS technology is not entirely trouble-free with respect to forest inventories. Receivers may not work well under forest canopies (Herrington, pers. Comm. 1992).

Monitoring

While an initial inventory of forest resources stored in a GIS is an important step, changes occur that need to be monitored and recorded. For example, silvicultural activities to manage timber involve complex and specific interventions to control stand structure, stand density, species composition, length of harvest rotation, and to maintain site quality. Other changes may result from sudden, discrete events or disturbances, such as massive deforestation or pestilence that initiate new development patterns in the affected areas.

Examples of how GIS is used to monitor changes resulting from large-scale deforestation and pests and pollution are explored in the following pages. Again, remote sensing technology makes important contributions.

Deforestation

Since deforestation is a continuing process, efforts to inventory and monitor changes are very closely related. There are many uncertainties about actual rates of deforestation (Sader et al. 1990), hence the need for accurate, up-to-date monitoring schemes. Techniques used to inventory these areas also can be applied in their systematic monitoring to create a time-series of data describing rates and magnitudes of deforestation.

In Rondonia Brazil, for example, Landsat MSS (1980) and TM (1986) imagery were used to define the area and deforestation rates for a study area of approximately 30,000 square kilometers (Stone et al. 1991). The researchers found that 3168 square kilometers (528 square km/year) of new clearing occurred between 1980 and 1986. Earlier research (Woodwell et al. 1987) had revealed a rate of clearing of 14 square km/year from 1972 - 1978 and 79 square km/year from 1978 - 1980.

Historical records have also been used in GIS to identify changes in forest cover. Between 1979 and 1984, a land resource inventory project was completed in the Jhikhu Khola watershed in Nepal (see Schreier et al. 1989). Land use information was digitized using 1:50,000 scale topographic maps as the base for information collected by surveying 1980. Land use data that had been divided into three broad categories in the original 1950 topographic map were also digitized. The area of each land use type was calculated in the GIS and then the two layers were subtracted. "Although somewhat crude, this information was found to be very useful in producing a land use change overview map" (Schreier et al. 1989). The thirty-year interval revealed that about 50 percent of the forestland has been lost to shrub and agriculture.

A second three-year project was initiated in 1988 to "examine processes relating to soil erosion, sediment transport, soil fertility changes and land use changes in a quantitative way" in the Jhikhu Khola watershed (Schmidt and Schreier 1991). Forest and agricultural land uses were mapped and digitized using 1:20,000 scale and aerial photographs taken in 1972 and 1989. Changes in the area of four land uses were calculated for each date: forest, grassland, irrigated agriculture and sloping terraces. In this case, using a larger scale and a different land cover scheme, the researchers found that the forest area had not decreased substantially (only 1 percent) during these 17 years.

Damage From Pollution and Pests

Gradual forest decline is another type of change that can be monitored. Vegetation is sensitive to stress factors associated with changes in moisture, temperature, as well as anthropogenic factors, such as air pollution, forest pests and disease. GIS together with remote sensing offers the means to monitor the magnitudes and rates of decline (Rock and Vogelmann 1989).

In Germany and Poland, forests have been dying gradually due to industrial air pollution (Landauer 1989, Zawila-Niedzwiecki 1989). In Germany, a three-year project was initiated in 1986 to establish methods to detect, classify, and map forest decline using a combination of Landsat MSS and airborne multi-spectral imagery. The researchers found that characteristic spectral signatures could be identified for different tree species (spruce, pine, and beech) depending on the degree of decline (Landauer 1989). Similarly, in Czechoslovakia, Trezzi (pers. comm. 1991) found that the extent of pollution-damaged forest stands near Liberec could easily be measured because of their distinctive contrast to undamaged areas.

In another example, Landsat TM data was used to assess and monitor damage in coniferous forests in the state of Vermont, USA (Rock and Vogelmann 1989). Researchers found that the most useful spectral reflectance data were TM4 (near-infrared) and TM5 (short-wave infrared). A ratio of TM5/TM4 was used to highlight the differences in spectral regions. Bank four displayed changes in canopy biomass and structure and Bank five indicated loss of foliage and changes in canopy moisture. The higher the ratio, the higher the damage that had occurred. Damage patterns suggested that factors associated with clouds and weather patterns from the west may influence forest decline. In a comparison of Landsat MSS data from 1973 and 1984, they also found a decrease in near-infrared reflectance for red spruce on west-facing slopes and for lower elevation hardwoods.

Pests and disease are another source of forest decline. A diversity of insects, fungi, bacteria, and viruses occur in forests and may be beneficial. More destructive pests may be controlled by natural enemies or an unfavorable environment. In the economics of timber harvesting, small losses due to pests and diseases are generally acceptable; losses that significantly affect timber production are not. Therefore, monitoring pest and disease infestations is a concern for private and national timber interests. GIS and remote sensing are becoming important tools to identify, monitor, and anticipate the spread of infestations. An example from Canada illustrates this application.

Since 1936, the Forest Insect and Disease Survey (FIDS) of Forestry Canada has annually collected and recorded data on forest pest conditions. The Pacific regional database includes 171,000 disease and 295,000 insect and parasite records with host and location information. Approximately 6,000 new records are added each year. Since 1986, the Pacific Forestry Centre (PFC) has used a GIS to store data from annual ground and aerial surveys and added data from historical maps.

With this information, the area of each pest's infestation is calculated annually for each forest region. Overlays of yearly defoliation maps then become quite useful to identify areas of greatest damage. These identifications can then assist managers in making decisions about salvage or treatment. Silvicultural planning efforts can benefit from the patterns revealed by long-term pest and disease occurrence records.

Defoliation also can be related to factors such as climate, forest types, ecozones, slope, and aspect and this analysis can be accomplished with a GIS. Van Sickle (1989) suggests that this provides a useful source of information for management:

Identification of the most susceptible areas and stand types focuses and improves monitoring techniques, provides a basis for risk assessment and identifies the probable need and frequency for direct control of infestations in future rotations. Information on the environmental requirements and limitations for outbreaks can improve predictions of where and when future outbreaks will occur and is basic to estimating damage which may be expected with climatic shifts because of atmospheric pollution or global warming effects.

Suitability and Productivity Assessment

Another factor in resource assessment includes efforts to identify biophysical and climatic factors suitable for the regeneration of tree species. This can be important for establishing tree plantations, for afforestation programs, for re-establishing endemic species following severe over-utilization and for timber harvesting. The information obtained from assessing the potential productivity of a site can be used to manage it for optimal harvest.

In one example, Booth (1990) describes a technique to identify and map locations satisfying up to six climatic criteria where plantation species could be cultivated. Three plantation species were used to demonstrate the technique: *Eucalyptus grandis, Eucalyptus tereticornis*, and *Pinus radiata*. The six climatic criteria were mean annual rainfall, rainfall regime, dry season length, mean maximum temperature of the hottest month, mean minimum temperature of the coldest month and mean annual temperature. This approach has been demonstrated at the global and continental scales (Booth 1989, 1990).

This technique may be used with afforestation projects at more local levels as suggested by the efforts of Schreier et al. (1989). As part of the land resource inventory in Nepal (1979-1984), data on land use, topography, land systems, and land capability were collected. Based on available climatic information and elevation data, the Jhikhu Khola watershed was divided into elevation, slope, and aspect categories. This was done to create physiographic subdivisions reflecting local micro-climatic conditions. (During the project, these classes were calibrated with climatic information collected in the field.) The locations of these combined elevation/slope/aspect categories were compared with crop and forest classes. The distribution of forests and crops was then compared with land capability ratings. Schreier et al. (1989, p. 181) explain the value of this approach:

These combined maps are of interest in afforestation programs that are initiated in many parts of Nepal to overcome chronic fuelwood and fodder deficits. Tree seedling survival is a serious problem. Heavy grazing, difficult climatic conditions and poor site and soil conditions are the main reasons for this difficulty. The elevation/slope/aspect map in combination with forest cover and capability can greatly assist in the afforestation program. It provides a crude basis for matching tree species with appropriate environments and new crops and cropping systems, such as fruit and vegetables with the most appropriate site conditions.

Resource Management

Collecting forest inventory data and monitoring changes are critical to forest management activities. Yet, a GIS can build on these activities by incorporating models to guide, for example, timber harvesting, silviculture and fire management activities, or predict fuel wood and other resource supplies. Other priorities, such as providing for wildlife habitat, ensuring recreation opportunities and minimizing visual impacts of harvesting, are also growing in importance.

In this section, examples of resource management applications in forestry will be described. Some applications deal with single management issues, such as timber production, while others illustrate how a mix of management concerns can be integrated through the use of GIS, such as timber production combined with habitat protection.

Timber Harvesting

Timber management focuses on efforts to provide a continuous supply of trees for economically optimal wood production. In the recent past, foresters have relied on wood supply models to guide planning for optimal harvests that typically ignore specific geographic locations (Jordan and Baskent 1991, Moore and Lockwood 1990, Reisinger et al. 1990, Reisinger 1989, Reisinger and Davis 1987). These simulations (WOSFOP, OWOSFOP, NORMAN, FEM, FORMAN, and FORPLAN), developed over the past 10 years, use an aspatial optimizing approach. Jordan and Baskent (1991, p. 150) describe the problem as follows:

While today's models are sufficient for defining and developing aspatial management design strategies for wood supply, they lack consideration of the geographic structure of forests and are insufficient for design of wildlife sensitive and operationally, i.e., economically, acceptable management.

GIS has now made it possible to incorporate spatial components into harvest planning and simulation models. In some cases, the modeling capabilities of a particular GIS may be used directly to aid decisions about timber harvesting; in other cases, an external model is linked to a GIS database. These models are typically called Decision Support Systems (DSS) or Spatial Decision Support Systems (SDSS). In any case, the analytical goals are quite similar, as several examples will illustrate.

Herrington and Koten (1988) assert that harvest planning requires knowledge of individual stand or compartment status and the geographical relationships between compartments. They developed a harvest model using a raster GIS to create a map showing the relative maximum potential stumpage (MPS – the market value of standing timber) for all compartments in a forest. Harvesting costs were derived from topography, forest type, soil classification, management compartments, roads, and streams. Total cost was based on cost to landing (road) and cost to mill. In their harvest model they:

1. cut all the merchantable trees in a compartment,

2. skidded the stems downhill to the nearest road,

3. transported saw logs to a sawmill, and

4. transported pulpwood to a pulpmill.

The model assumed that loading logs onto transport trucks had no cost and that skidding across streams and lakes was not permitted. Skidding cost also varied due to obstacles created by steep slopes. The market value of the timber was derived from compartment and forest type maps and based on volume. In their final MPS map, each grid cell had a value representing the price at the mill for all products minus the costs of harvesting the products on that grid cell, that is, profitability from the harvest.

Using regression models developed by McGreer (1974), Berry et al. (1980) evaluated timber loss due to felling breakage during harvesting for both tree pulling and conventional felling techniques. The independent variables used in the two regression models were topographic slope, tree diameter, tree height, amount of wood defect and tree volume. Each regression variable was treated as a separate map and multiplied by the corresponding regression coefficient derived from McGreer's models. The resulting weighted maps were summed to create predicted breakage maps for each technique. The researchers suggested that the analysis was useful to the harvest planning process in its potential to identify locations of potentially high breakage.

Jordan and Baskent (1991, p. 150) describe a spatial wood supply simulation model, GISFORMAN, which is linked to a GIS database. It forecasts in selected yearly increments (for instance, five-year period), "forest response to harvesting and silviculture of types, amounts, timings, and geographic locations". Management strategies can then be translated into very specific mapped schedules. Similarly, Moore and Lockwood (1990) developed a planning system known as the HSG Wood Supply Model that directly incorporates a GIS to assist in the design and evaluation of long-range timber harvest schedules.

In the HSG system, the fundamental GIS data layer is a forest stand inventory in which each stand is assigned attributes of the year of stand origin, site class (productivity of the site), area, relative stocking factor, and silvicultural treatment class. The model then repetitively adds a certain time interval (e.g., five years) to the stand origin date to produce a sequence of stand ages (e.g., over a 100-year interval). It then uses a look-up table to relate stand age, site class, and silviculture treatment class to estimate a yield factor. This is then multiplied by the stocking factor and area to produce an estimated yield. As Moore and Lockwood (1990) point out, although the yield table will most commonly describe merchantable volume development of a tree species, it could equally well describe such factors as wildlife habitat characteristics.

Through its progressive aging of the stand, the HSG model simulates the development of the forest on a stand-by-stand basis. At each stage, the effects of disturbances such as harvesting, silviculture treatment, and ecological succession are incorporated. For example, Moore and Lockwood (1990) give the illustration of a rule that results in the breakup of a 140 year old black spruce stand on a particular site class and its replacement through regeneration over 40 years. For harvesting, the model allows a variety of rule logics. One, for example, allows the model to evaluate the effects of a specific harvest quota. Stands are then numerically rated at each stage for their suitability for harvest and then selected to meet the quota. Similarly, the model incorporates the ability to select the most suitable stands for silviculture treatment (such as renewal treatments on harvested stands) based on a fixed budget.

The HSG model illustrates the potential utility of simulation models in GIS. At present, GIS is largely used for database development and the spatial representation of results during the run of the model. However, there is little to prevent it from incorporating specific spatial disturbance rules (such as economic factors of harvesting related to distance, terrain characteristics and the like). Simulation models are still fairly rare in GIS, but the potential that the technology offers for the evaluation and assessment of varying management scenarios is enormous.

Fuel Wood Supplies

The availability of fuel wood supplies for local use is an important forest management issue in many parts of the world. GIS can contribute to assessments of fuel wood supply and demand and offers the potential to predict future needs. Several examples illustrate this type of approach.

As part of the land resource mapping project in Nepal, fuel wood sufficiency for the 75 districts in the country was evaluated and mapped using GIS. This was part of a larger resource overview for national land use planning that also included food and fodder resources (Schreier et al. 1990). Fuel wood production was estimated using yield data for each forest type included in the inventory: shrub, grassland, and four forest maturity classes. To calculate fuel wood supplies, the yields were multiplied by area data for each land use category. To calculate fuel wood demand, estimates for each district were supplied by the domestic energy model of the Water and Energy Secretariat. Surplus and deficit figures were calculated and each district was assigned a surplus, sufficiency, or deficit rating. Figures for 1981 were based on the resource survey. Figures for the year 2000 were calculated based on an unchanging resource base and two changing variables, increases in population and livestock. The fuel wood assessment was also combined with the fodder and food assessments to create an overall evaluation of resource poverty.

The calculations for the future were not actual predictions but a test to examine the model's response to population and livestock growth. The researchers suggested that the projection maps could be used to direct attention to districts that will likely experience severe resource deficits. Also, GIS capabilities could be used to develop:

> ...deficit elimination scenarios. If we assume current growth and consumption rates, the model can calculate what changes in key variables would be required to eliminate the deficits in each critical district.... To eliminate such deficits, we can calculate by how much we would have to increase the tree biomass production or how much we would have to enlarge the area of tree planting (Schreier et al. 1991).

In a similar example, Olsson (1986) used a GIS to examine the balance between supply and demand for fuel wood. Using Landsat MSS imagery, Olsson first used the infrared and red image bands to produce a vegetation biomass map (there are several procedures for doing this, the simplest of which simply divides the infrared reflectance for each pixel by the red reflectance). Using ground-truth data he then scaled the data to yield a map of woody biomass supply. He then took a map of village locations and populations, along with an interpolation rule based on the gravity model (a potential model) to create a population surface. Based on field studies, he then assigned to each person a demand for fuel wood. This was then compared to the woody biomass supply map through a procedure that had individual pixels simulate the action of humans gathering wood in a radial pattern from their homes, with full competition for resources. He then specified a maximum distance that an individual could walk with their required wood and produced a final map illustrating areas of surplus, areas in balance, and areas of deficit.[1]

Fire Management

The effect of fire on forest resources is another important management concern. Management activities include fire prevention, wildlife control, prescribed burning, and post-fire recovery actions. The modeling capabilities of GIS have been quite effective in this context. Forest fire managers have used GIS for fuel mapping, weather condition mapping, and fire danger rating (Holder et al. 1990). Several examples illustrate a range of fire applications.

At Cuyamaca Rancho State Park in California, USA, GIS has been used to guide prescribed burning. After decades of wildfire suppression in the park, fuel loads had dramatically increased, chaparral had replaced other vegetation, biotic diversity had decreased and exotic grasses dominated the park's grasslands (Wells and McKinsey 1991). Beginning in 1970, fire was reintroduced into the park's ecology.

The key to managing prescribed burning activities was the ability to anticipate fire behavior after ignition. Fire behavior models have been developed from fuel models to predict the fire intensity based on factors such as slope, elevation, site exposure, wind speed, relative humidity, cloud cover, temperature, and live and dead fuel moisture. These models are not spatial, however, and are typically used to predict fire behavior for a fairly large area. To increase the sensitivity of the fire behavior models to spatial variability within the park, fire behavior models were fun with a raster-based GIS. With input layers stored in the GIS, its mathematical modeling capabilities, along with selected lookup tables, were then used to implement several fuel and fire intensity models. By comparing the predicted fire behavior with actual burn conditions, Wells and McKinsey (1991) concluded that the GIS implementation of fire behavior models was useful in locating potential control areas, planning ignition patterns, and accommodating sensitive areas that would be adversely affected by high fire intensities.

In a different study, Chou (1990) describes an effort to construct a probability model of fire occurrence based on logistic regression. The goal was to develop a map showing areas of extremely high fire danger. Alternative management strategies could then be developed to reduce overall fire danger. The study area was in the San Jacinto Ranger District of the

San Bernadino National Forest, California, USA. The independent variables included environmental and human factors: temperature, precipitation, vegetation, transportation and structures (building or campgrounds). Vegetation was converted to fire potential weights based on fuel models. Fire potential and a second variable measuring "neighborhood effect" (a polygon surrounded by adjacent polygons with a high fire danger would have a higher probability of burning than one that was not) were found to be statistically significant. The resulting regression coefficients were used to create a map showing probabilities of fire occurrence.

In a third example, a pilot project in Canada linked a fire growth model with a GIS (Holder et al. 1990) to evaluate its potential to minimize the costs of controlling and managing forest fires. The researchers described a two part demonstration in which, 1) only a GIS was used and 2) a forest growth model was combined with a GIS.

In the first part, data for fuel types, weather parameters and lightening strikes from the North Central Fire Region in Ontario, Canada were entered into a GIS. Canadian Forest Fire Weather Index codes and indices related to weather observations were calculated as well as Fire Behavior Prediction System-defined Rate of Spread (ROS) conditions. A map showing the density of lightening strikes over a one-day period was generated from a data set of almost 6500 points. In a two-part analysis, the distribution of ROS conditions was first compared with forest fire fuel types. Then a map containing airport locations was added to the database, distance buffers were created based on 15 minute flying intervals and this buffer map was matched with the ROS map to identify potential hazard zones that did not have adequate coverage by air.

In the second part of the demonstration, a subset of the North Central Fire Region was used. Digital terrain data and forest fire fuel types were moved from the GIS to fire growth modeling software. Data on wind speed and direction as well as Fire Fuel Moisture Codes were added to the model. Several fires were ignited and their growth modeled. When the model was halted, the result was moved back into the GIS. The burns were classified into intervals, areas were calculated and the results compared, using cross-tabulations, with forest types to identify the effect of the fire over time.

In a final example, GIS was used to analyze environmental impacts resulting from a fire and to develop management strategies to deal with the impacts. Scher (1990) describes a devastating wildfire that occurred in the Lowman Ranger District of the Boise National Forest in Idaho, USA where over 46,000 acres burned. Managers were concerned about the effects of the fire on streamside vegetation and corresponding erosion problems. The effects of accelerated sedimentation on stream channel stability and fish habitat were a related concern.

Data collection included a survey of post-fire vegetation that was divided into four density classes and four burn intensity classes: high, moderate, low, and no burn. Data on aspect, slope, and stream classes also were used and buffers were generated for each stream class to identify riparian management zones. Examples of the analysis included a comparison of burn intensity with stream management zones. This provided information on the location of areas deficient in riparian vegetation. A comparison of conifer density classes with stream management zones helped identify riparian areas deficient in woody debris that traps sediment and contributes to quality fish habitat. A comparison of slopes with burn intensity led to the identification of areas where the potential for post-fire erosion was high. This information guided the development of recovery plans for the post-fire situation.

Multiple Resource Management

Most of the studies presented so far have emphasized single management concerns. However, contemporary forest management should incorporate non-timber values and multiple resource concerns. In some situations, sites to be protected for non-timber uses are defined before a harvest supply model is implemented (Dippon and Cadwell 1991). In other cases, issues of visual quality or habitat requirements are integrated as constraints in overall harvest plans (Johnston 1987). This clearly involves a more complex analysis.

Fortunately, the ability of GIS to simulate ecological, social, and economic changes lends important support to multi-resource management (Levinsohn and Brown 1991, Behan 1990). The following discussion, then, provides some examples of the emerging potential of GIS in multi-objective resource management situations.

In one broad category of multi-objective applications non-timber issues are directly incorporated into timber management planning. Duinker et al. (1991), for example, are developing habitat simulations for moose and marten in Ontario, Canada. They argue that integrating timber and wildlife needs will not occur without GIS-based habitat supply analyses. They plan to follow five criteria in their research:

1. the habitat model must rely on easily obtained data describing landscape vegetation patterns,

2. it should incorporate the dynamic evolution of forests on a stand by stand basis, including the stands that have been harvested and those left alone,

3. it should be able to accept the input of forest management interventions, forecast habitat response and generate alternative timber strategies if necessary,

4. the model should consider that wildlife species often have home ranges that include many forest stands and range in spatial patterns that are difficult to predict, and

5. finally, the model should deal with the link between food sources and proximity to cover, important for many species.

In an example from Tasmania, conflicts between land preservation and timber management were the focus. Blakesley (1990) described an effort by the Forestry Commission to balance timber and non-timber uses of the Southern Forests, a strip of land about 20 kilometers wide and 85 kilometers long. This area supplied timber to sawmills, a newsprint mill, a pulp mill and two export woodchip plants. Yet conservationists also wanted to preserve the tall, old growth eucalyptus forests and existing wilderness qualities in the area.

The Forestry Commission, responsible for managing state forests, acquired a GIS in 1982 and began work on a new Forest Management Plan for the southern Forests. Wood and non-wood uses were evaluated. The unit of analysis was the basic logging unit or *coupe* and areas already developed for wood production were removed from further analysis. Each of the coupes was assigned a wood and a non-wood value derived from a specific set of criteria. Based on these values, different boundary options between timber and non-timber areas were presented to managers. The managers selected a "limit to logging line" for the Southern Forests that was then made available for public comment. During this planning process, the GIS was also valuable in expanding the boundaries of the Tasmanian Wilderness World Heritage Site nomination to include areas in the Southern Forests.

In a third example, ecologically based forest planning was the goal in a project undertaken in Vermont, USA to examine competing land uses. For the Mad River Valley, a forest site index (based on the average height of trees at a site at a given age) and soil erosion estimates were combined to produce land suitability classes of resource protection, forest management, multiple-use, and trade-off (Hendrix and Price 1986). Using data layers that included soils, land use, elevation, slope, aspect, roads, and water course, the project considered forest productivity, soil erosion potential, and management opportunities and constraints.

Forest productivity was used as an indicator of ecological conditions. It was estimated by using previously computed regression equations that incorporated site index as the dependent variable and topography, altitude, and soil series groups as the independent variables.

Soil erosion was used as an indicator of a site's sensitivity to disruption. Sites with high erosion potential required protection or special management techniques. Soils were divided by their soil erodibility factors, or K-Factor estimates, a variable used in the Universal Soil Loss Equation (USLE) developed by the US Department of Agriculture. K-Factor and slope categories were combined in a matrix and empirically assigned a rank (very low to very high) corresponding to their erosion potential.

To identify management options, the productivity and erosion potential maps were compared. The resulting combinations and the judgement of managers produced the following options: lands with high erosion potential were classified as resource protection areas, lands with low erosion potential and high site index were classified as forest management areas and sites with low erosion potential and low site index were considered a trade-off. Sites in the forest management category were further refined by relating these areas to existing land uses, elevation, and access to roads. A map was created showing only the forest management sites that were in forest cover, below 2500 feet in elevation and within one kilometer of existing roads.

For a final example, a study described by Johnston (1987) provides a much broader perspective on the problems of multi-resource planning. For a project in the Kedgewick River Area of Edmunston, New Brunswick, Canada a series of natural resource models were developed to test a variety of management priorities (Johnston 1987). Although timber management was an important objective for the Fraser Timber company, the models were designed to be flexible, running management scenarios (submodels) that could completely exclude timber production and economics to focus on visual quality, landscape ecology, potential natural vegetation, fire management, wind management, or any combination of objectives.

In the first step of the project, managers were asked to define the design objectives of the study, those actions that would or would not be allowed in the area. This guided the creation of the database. The database included base maps for deer-yards, topography, soils, deposits, many different species of trees, windthrow affected areas, crown closure, forest codes, development stage, waterways, and roads.

With the database complete, suitability maps were produced from each submodel using a raster GIS. For example, a visual quality submodel produced a map where each cell contained a suitability rating for its visual quality. Then, a decision was made about the percent of lands that would be allocated to different uses given the objectives of the management plan. In this project, five land uses were considered and assigned the following proportional areal coverages: logging (45 percent), ecology (35 percent), visual quality (10 percent), controlling fire (5 percent), and reducing windthrow (5 percent). As the model was run, cells with the highest weight on each suitability map were selected for placement on the output map until the total number of cells selected in each category matched the original percentage. If any cells were assigned two or more land uses in the result, the conflict would be resolved by iteratively choosing the land use for which the cell was most suited while adjusting other assignments to keep as close to the final proportion as possible.

The procedure highlighted, however, the fact that most GIS software systems do not have automated procedures for the optimum allocation of land to meet multiple objectives. Despite this, Johnston (1987) felt that use of this technology allowed the manager to examine different management scenarios in a manner that would be difficult without a GIS.

Conclusions

The range of applications reviewed in this paper is clear testament to the significant value of forests and the potential of GIS to aid in their management. Despite the diversity of applications, however, a number of broad conclusions can be reached about the role of GIS in forestry:

1. GIS applications can strongly benefit from remote sensing and image processing technologies. Forests are complex assemblages of species that lend themselves well to broad-level inventory through remote sensing. However, the need for strong ground-truth remains paramount and it is likely that satellite positioning systems (such as GPS) will play an important role in augmenting traditional forest survey activities.

2. Forests are a dynamic resource, affected by many concurrent ecological processes and direct management interventions. Simulation modeling has been applied in forestry to a degree that is substantially higher than in many other disciplines. Simulation or *process* modeling is one of the more challenging areas of GIS applications and it is likely that this activity will increase as the research and tools to support this kind of application become more prevalent.

3. It is clear that throughout the world, forests are subject to many demands. As a result, many forest management problems have the nature of multi-objective planning procedures. Unfortunately, GIS is not well developed for multi-objective planning. Stronger tools are necessary for the analytical resolution of conflicting suitabilities and choices in resource allocation.

In a sense, forestry applications embody the full scope of GIS technology. Thus its study provides an excellent overview of the state of the technology and its potential as a management tool for natural resource concerns.

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Exercise 1: General Forest Management and GIS — Locating Optimal Harvest Areas

This introductory exercise consists of an application of GIS to forest management and involves some of the most common procedures used in GIS. In the exercise, you will be identifying areas suitable for leasing to timber companies for timber harvesting. You will prepare a final image showing the stands appropriate for leasing, each with a unique identifier, the road network in the area, and an informative legend.

This exercise was originally developed by Len Gaydos at the University of California at Santa Barbara. It was published and distributed, along with the data, by the National Center for Geographic Information and Analysis (Dodson, 1991) and has been adapted for this workbook.

The data for this exercise covers an area centered on Maple Mountain, located in the Timiskaming District of Ontario, Canada. The area is approximately 70 kilometers east-west by 30 kilometers north-south. The images have a resolution of 350 meters, meaning that the pixels are 350 meters long on each side.

Using the data provided, you will locate areas suitable for harvest leasing, based on the following criteria:

Only White Pine is to be harvested.

Leases cannot be granted for areas less than 1000 meters from a water body.

Leases cannot be granted for areas less than 1000 hectares in size.

Leases can only be granted for areas meeting all three criteria. Each area thus identified will be assigned a unique identification code as an identifier to be used for leasing purposes.

You have been provided with three images: FOREST, SHORELINE, and ROADS. Based only on these three images, you will be creating many additional images using a variety of commands. The output image from one operation often serves as the input image to the next. It's a good idea to view each new image immediately after you create it, in order to verify that the result is what you expect. Early detection of a simple mistake can save you from having to repeat an entire sequence of steps.

a) To aid you in this process, open the User Preferences dialog under the File menu. Click on the Revert to Defaults button near the bottom of the dialog. This will turn on the automatic display of module output with legend and title options.

b) Before performing any operations, we need to set the Working Folder. First, under the File menu, select IDRISI Explorer. Then select it's Projects tab. This tab allows you to set the project environment of your file folders. Make sure that the Editor pane is open at the bottom of the form. If you right-click anywhere in the Projects form, you can select to show the Editor. The Editor pane shows the Working and Resource folders. Choose to either create a new project or edit the existing project to include the folder holding the data for this exercise, (e.g., \UNITAR\Forestry\Data\Exer1). Please note that this folder must be listed in the Editor pane as either the main Working folder or one of the Resource folders. Click on the Files tab in IDRISI Explorer to see the list of files for this exercise.

c) Now we will view the image FOREST. To do so, select DISPLAY Launcher from the Display menu. Keep the raster layer option, then either click on the browse button at the right side of the file input box or double-click in the input box to bring up the pick list of filenames. Choose the file FOREST and then choose the default Qualitative palette. Click OK.

This data is qualitative, since different values in the image indicate a difference of character (e.g., White Pine versus Jack

Pine). In this exercise, you will be working with this type of data as well as quantitative data, in which different values indicate differences in quantity (e.g., elevation). In general, you will want to view qualitative data with the Qualitative palette and quantitative data with the Quantitative (Standard IDRISI) palette. Qualitative palettes emphasize contrast between values while quantitative palettes blend colors smoothly from one value to the next. The auto-display feature will choose a palette for the display based on a set of decision rules. At times, these rules lead to a wrong palette choice and the auto-displayed image will appear as all black or illogical. When this happens during the exercises, choose Layer Properties from Composer and select the proper palette.

1. *What type of palette, quantitative or qualitative, would be most useful in viewing the following types of data?*

   a. elevation   b. landuse categories

   c. administrative districts   d. age of forest stands

d) With the image still displayed on the screen, click on the Cursor Inquiry Mode icon (the one with the question mark and arrow) to activate the cursor. Cross hairs willl replace the cursor on the screen and the column and row position, as well as the X and Y position of the cursor will be shown at the bottom of the screen. To check the data value of any pixel, press the left mouse button once. The z-value will be displayed on the image next to the pixel selected. Move the mouse across the screen and click on the left mouse button at various points to check the z-values. Note that the z-values correspond to the forest categories indicated in the legend. (White Pine corresponds to a z-value of 1 and Jack Pine corresponds to a z-value of 2.) You may explore the position and z-values of any image in this way throughout the exercises. When you are done, close the image.

e) Before proceeding to identify suitable leasing sites, you will need some information about the data files. From the IDRISI Explorer Files tab, select the file FOREST. If the Metadata pane is not in view at the bottom of the form, right-click anywhere in IDRISI Explorer and check that Metadata is selected. Next, scroll through Metadata and double-click on the Categories option. This will open the Categories form. Record the legend categories below. Do the same for the SHORELINE image.

FOREST

Category 1:

Category 2:

Category 3:

SHORELINE

Category 1:

Category 2:

In order to isolate those areas that meet the specified criteria, you will use the standard practice of creating and combining Boolean images. A Boolean image has only two values, usually 1 and 0. The 1s represent the areas that meet the stated criteria, while the 0s represent areas that do not meet the criteria. This is sometimes referred to as a “mask” because the Boolean image is used to “mask out” the desired areas on more complex images. You will create a Boolean image for each criterion, then combine these to produce a final image in which only areas meeting all three criteria are shown.

Locations meeting the first criterion, that only White Pine should be harvested, can be identified by creating a Boolean image in which the pixels representing White Pine have the value 1 and all other pixels have the value 0. There are two IDRISI modules that may be used in creating Boolean images, RECLASS and ASSIGN. Both are found in the GIS Analysis/Database Query menu. The use of each will be illustrated in this exercise.

f) Use the module RECLASS under the GIS Analysis/Database Query menu with FOREST as the input image to create an output image called WHITEPINE. Use the default user-defined classification type. Assign a new value of 1 to all values ranging from 1 to those just less than 2 (this changes the value of the White Pine category to 1). On the second row, assign a new value of 0 to all values ranging from 2 to just less than 4. Note that in the last case, it was necessary to enter an integer value greater than 3 because of the "just less than" wording of RECLASS. In Output Documentation, enter a title for the new image, such as "Boolean Image of White Pine," and "Boolean" for the units. Click OK. You will be expected to fill in titles and new value units without a reminder for the remainder of the exercises in this workbook. Click OK again.

WHITEPINE should automatically display. Verify that you have created a Boolean image in which the White Pine areas have value 1 and the rest of the image has value 0. You may want to look at FOREST again to recall where the White Pine areas are located.

The second criterion states that leases cannot be granted for areas less than 1000 meters from a water body. Several steps are involved in creating a Boolean image that identifies areas satisfying this criterion. You will first create a Boolean image of the water bodies in which water has the value 1 and everything else has the value 0. Then you will create an image that represents distances from the water bodies. Finally, you will reclass the distance image to make the Boolean image for this criterion.

g) This time use ASSIGN from the GIS Analysis/Database Query menu instead of RECLASS to create the Boolean image. ASSIGN uses an attribute values file to assign new values to all values. You create the attribute values file by using the Edit command in the Data Entry menu. This brings up the IDRISI Text Editor.

An attribute values file consists of two columns of numbers separated by one or more spaces. The numbers in the first column are the values that are currently in the image. The numbers in the second column are the new values you would like to assign to the old value. Any old value that does not appear in the attribute values file is automatically assigned the new value 0.

h) In Edit, type the following single line into the edit box:

2 1

This attribute values file requires only one line since with ASSIGN, any values that are not specified in the values file (e.g., the old value of 1) are automatically assigned new values of 0. Click on Save As under the Edit File menu, enter WATER as the new filename, and save as an attribute values file (*.avl). Click Save. A values file information box will appear—choose integer as the data type. Click OK and close.

ASSIGN uses an attribute values file along with a feature definition image to create a new image. The feature definition image contains the old values that you want to change. In this case, SHORELINE is the feature definition image. ASSIGN will create a new image that is exactly like SHORELINE, except every pixel that has the value 2 in SHORELINE will have the value 1 in the resulting image. All the pixels in SHORELINE having values other than 2 will be assigned 0 in the new image.

i) Run the module ASSIGN specifying SHORELINE as the feature definition image, WATER as the output image, and WATER as the attribute values file. Note that the new file can be named WATER without affecting the attribute values file WATER because each will have a different extension. In IDRISI, image files have the extension .RST, while attribute values files have the extension .AVL.

2. Which operation, RECLASS or ASSIGN, was the easiest? What factors would you consider in determining which operation to use?

Now that you have an image in which water is isolated, you must create an image showing buffer zones around the water bodies. This could be done with a combination of DISTANCE and RECLASS, or with a single step using the module

BUFFER. We will use the latter method.

Before you run BUFFER, think about the desired result. The criterion states that we are to consider suitable only those areas 1000 meters or more from water bodies. In Boolean suitability analysis, areas that meet the criteria are assigned the value 1 while areas that don't meet the criteria are assigned the value 0.

3. What values should be assigned to:

The water bodies:_____

The areas from 0-1000 meters from water bodies:_____

The areas greater than 1000 meters from water bodies:_____

j) Run BUFFER from the GIS Analysis/Distance Operators menu. Enter WATER as the feature image and give 1000 as the buffer width. Enter the answers to the question above for the Target Area, Buffer Zone and Non-Buffer Zone respectively. Call the output image WATERBUFFER.

The next task is to combine the first two criteria to produce a Boolean image of the areas that are both White Pine *and* are at least 1000 meters from water. To combine these images you will use the fundamental GIS operation "overlay". In general, an overlay involves any of a set of mathematical logical operations that are performed between two raster images. These operations include the basic math operations of addition, subtraction, multiplication, and division, and the logical expressions of *AND* and *OR*. Each pixel in an image produced by an overlay is the result of the requested operation being performed on the corresponding pixels of the two input images.

In this case, we are interested in the logical AND (i.e., intersection) of the two Boolean images. This is achieved with the overlay multiply operation. As you can see from the following table, the only areas to be assigned the value 1 in the output image are those that have the value 1 in both input images

.

Input Image 1	Multiply (*)	Input Image 2	=	Output Image
1		1		1
1		0		0
0		1		0
0		0		0

k) In IDRISI, the overlay operation is carried out by the module OVERLAY. Run OVERLAY from the GIS Analysis/Database Query menu. Select the multiply option (First*Second) to multiply WHITEPINE and WATERBUFFER. Call the output image PINE-BUFF.

The third criterion states that leases cannot be granted for areas less than 1000 hectares in size. Creating the Boolean image that identifies areas meeting this criterion also involves a number of steps. At present, the suitable stands identified in PINE-BUFF all have the same value. If you do an area calculation on this image, you will find the total area of suitable stands (and the unsuitable areas) rather than the areas for each individual suitable stand. So, before calculating areas, you must assign each contiguous stand of PINE-BUFF a unique value.

This is accomplished using the module GROUP from the Analysis/Context Operators menu. GROUP goes through an image and assigns the same identifier to all the pixels in each cluster that have the same value and are touching each other. You have the option of determining if pixels touching only at their corners (diagonal links) should be considered as belonging to the same group.

l) Run the module GROUP from the GIS Analysis/Context Operators menu with PINE-BUFF as the input image and select to include diagonals. Name the output image GROUPS. Click OK. Scroll down the entire legend.

4. *How many groups were identified? What value does the background have in GROUPS?*

m) Now you are ready to calculate the area of each group. Run AREA from the GIS Analysis/Database Query menu with the image GROUPS. Choose image for output format and calculate the area in hectares. Call the output image AREA1. AREA assigns each cell a value equal to the area of the group to which it belongs.

The image display is not what you might expect because AREA calculated the area of the background groups as well as the areas of the groups of interest. The area of the large background group is so high compared to that of the individual groups, the pixels of the large group are displayed with the highest palette color, while those of all other groups are assigned the lowest palette color. Small groups of the background will also have an area recorded. Before continuing, you must remove all these background values by setting them back to 0.

5. *Which image should you overlay with AREA1 to set the background values to 0? Which overlay operation should you use?*

n) Carry out the OVERLAY operation indicated by your answers to the questions above. Name the result of the overlay operation AREA2.

You have now isolated only the groups that meet the white pine and water buffer criteria. The remaining step is to exclude groups that are smaller than 1000 hectares. To do so, first click on Layer Properties in Composer for AREA2 to find the minimum and maximum values.

Minimum: Maximum:

o) Use RECLASS on AREA2 to create an output image called LARGESTANDS. Choose the user-defined classification system and assign a value of 0 to all values less than 1000 and a new value of 1 to all values greater than or equal to 1000. You will need to use the minimum and maximum values you recorded above. Again, make sure that the upper limit for the new value of 1 *includes* the maximum value you recorded above.

6. *What error would have resulted if we had made a Boolean image by reclassifying AREA1, keeping all the groups that had areas greater than 1000 hectares?*

Now that LARGESTANDS shows all the areas that are suitable for leasing according to our three criteria, you are ready to prepare the final map. Each area satisfying the three criteria will now be assigned a unique identification code to be used for leasing purposes.

p) Use GROUP on LARGESTANDS to create an output image called LEASE. Choose to include diagonal links.

7. *What is the purpose of this step?*

8. *How many areas have been identified as suitable for leasing?*

The final image should include the leasing information as well as the road network in the area and it should have legends for both the lease areas and the roads attached.

q) First fix the lease area image legend by adding category captions. You can do this with IDRISI Explorer's Metadata pane to update the documentation file for LEASE. For each of the areas in LEASE, add a legend category for the area. The captions for these categories can be anything you want, such as "Lease ID 1," "Stand No. 1," etc. Enter a caption for each code. Remember that the image also includes a background area with value 0 that is not suitable for leasing. Give code 0 an appropriate caption as well. Make sure you save the changes in Metadata. Now display LEASE with the Qualitative palette.

r) Open DISPLAY Launcher, choose the vector layer option and enter the filename ROADS. Choose the Outline Black symbol file. These are the roads in the study area. You will overlay these on top of the LEASE image. Note, however, that if you use the black symbol file, in areas where the raster image is black, the roads won't show up. If you use the white symbol file, the roads will show up on the image, but the symbol won't show up in the legend (because of the white page background). Make a new symbol file that can be used to display the roads prominently on the image and will show up in the legend.

To do this, open Symbol Workshop from its toolbar icon (third from the left) or from the Display menu. Under its File menu, choose New and indicate a line symbol file. Give the name ROADS. The road features in the ROADS file all have the code 1, so the only symbol you need to modify is symbol 1. Change the color of symbol 1 (this is the second symbol box – the first is symbol 0) to one that will show up prominently on top of the colors of the LEASE image. You may also wish to change the thickness of the line to 2 points. When you are finished, save the file and close Symbol Workshop.

s) Now close everything that is open on the screen except for the LEASE display. Choose Add Layer on Composer and add the layer ROADS using the user-defined ROADS symbol file. Add the legend for the roads layer by clicking Map Properties on Composer. The first line already contains information about the legend for LEASE. In the second line, choose to make the legend visible, then select the layer ROADS from the list and click OK. The Roads legend appears off to the right. To move it to the side, double click on the legend and drag it below the other legend.

9. Outline the steps you would follow to add the following fourth criterion to the analysis: No lease should be granted to areas that are more than 500 meters from an existing road.

This exercise has demonstrated the utility of the GIS operations of reclassification and overlay for basic forestry management. These tools are the building blocks of more complex GIS analyses and will be used again several times in later exercises with different forestry applications.

References

Dodson, R., ed. (1991) NCGIA GIS Laboratory Exercises: Volume 1, Santa Barbara: National Center for Geographic Information & Analysis, University of California at Santa Barbara.

Exercise 2: Habitat Analysis in Kootenay National Park, British Columbia, Canada

Kootenay National Park is the setting for this exercise focusing on forests as ecological habitats. The park is located in the province of British Columbia, Canada. Two rivers, the Vermilion and the Kootenay, cross through its valleys and intersect in the southern half of the park. Kootenay is in the heart of the Rocky Mountains, with glaciers crowning some of its peaks. Highway Route 93 passes through the park from the southwestern edge near Radium Hot Springs and follows the rivers to the northeastern edge of the park where it enters Banff and Jasper National Parks of Alberta Province. Data for this exercise was acquired from the disk library of the Canadian Cartographic Association Automation Interest Group.

This exercise introduces you to several GIS tools used for the most fundamental of analytical operations—the attribute query. You will be asked to examine the available data in order to answer some basic questions about the physical character, flora, and fauna of Kootenay National Park. While the data set is not meant to be seen as a complete and sufficient database for analyzing ecological relationships in the park, it is more than adequate to introduce the concepts of attribute query and to demonstrate the power of GIS in analyzing relationships among multiple layers of data.

The data set for the park includes information about elevation, vegetative cover, eco-regions, and population densities of several animals in the summer and winter in the park. With this data, your task is to provide the requested information, answer the given questions, and create the requested images for the following five items.

Information Requests:

A. Write a description of Kootenay National Park based on the information available to you, excluding information about animal densities.

B. Are the eco-regions described by the file ECOREG merely based on elevation? Describe any associations you can find between eco-regions and forest cover types in the data set.

C. Choose moose, deer, or coyote and describe the high to very high (combined) density winter habitat of this animal in terms of elevation, eco-region, and vegetative cover type. In addition to your written description, provide an outline of the GIS steps you took in gathering the information.

D. Describe the general distribution of the high to very high (combined) density classes of all six animals in winter in relation to each other. Do not consider variables of elevation, vegetative cover, or eco-region. Produce an image of the park showing, per pixel, which groups of animal species are supported at high or very high densities in the winter.

E. Choose bighorn sheep, elk, *or* mountain goat and describe the differences, if any, between the species' summer and winter habitats. Consider all density levels. Finally, produce a single image showing, for the chosen species, areas of high or very high density in 1) summer, 2) winter, and 3) both seasons. In the same image, also show those areas that do not support a high or very high density of the species as the fourth category.

While the exercise will take you through many of these procedures in a step-by-step fashion, there is considerable opportunity for creativity and further exploration on your own. Do not feel limited to the steps outlined. You are encouraged to pursue other questions and procedures according to your personal interest.

a) Before performing any operations, make sure the main Working folder is set correctly in IDRISI Explorer to the folder including the data for this exercise (e.g., \UNITAR\Forestry\Data\Exer2).

b) Now use Metadata in IDRISI Explorer to examine the filenames and titles in the data set.

   1. *What is the resolution of the data? What reference units are being used?*

c) Take a few minutes to display some of the files in the data. Be sure to select an appropriate palette for each file (the Default Quantitative palette for quantitative data and the Default Qualitative palette for qualitative data). In contrast to the data set used in Exercise 1, the shape of the study area here is not rectangular and therefore does not fill the image. Because of this, you will need to be particularly aware of excluding the background from analysis since the zero values of the background do not represent data values, but merely fill in space.

Begin with Information Request A and address each of the remaining Information Requests in order.

Information Request A: Write a description of Kootenay National Park based on the information available to you *excluding* information about animal densities.

To provide the requested information, you will examine the images of vegetative cover, eco-regions, and elevation and then write the information into a narrative form. You must first decide what kind of information is of interest. For example, is it sufficient to list all the categories of vegetation types, or would it be better to discuss the relative dominance of each category in the park? What is it about elevation that is interesting?

You must decide what pieces of information to extract from the data set to allow you to write an interesting description of Kootenay National Park. The following is an example:

GENERAL

What is the total area of the park?

ELEVATION

What is the spatial arrangement of mountains and valleys? What are the maximum, minimum and average elevations?

VEGETATIVE COVER

What categories of vegetative cover are present? Which categories cover the most area? Is there anything interesting about the spatial distribution of these categories?

ECO-REGIONS

What eco-regions are present? What percent of the park is covered by each eco-region?

You will use several basic GIS tools to find the answers to these questions. There is often more than one way to find an answer. In this section, you will be exposed to several different methods.

As you saw in Exercise 1, the module AREA may be used to calculate areas in a raster image. It reports the area covered by each value in the image. To find the total area of the park, you could run AREA on any of the raster images in the data set, and then sum the areas given for all the categories, excluding the background. Another approach is to make a Boolean image of the park by reclassifying any of the images so that the park has a value 1 and the background has a value 0. Then run AREA on this image. The result will yield values for the areas of the background and of the park, so no additional calculation will be necessary.

d) Use the latter approach and call the Boolean image PARKMASK. (Refer to the discussion preceding step f in Exercise 1 if you don't remember how to make Boolean masks.) Then run AREA with PARKMASK. Ask for tabular output and the result to be calculated in square kilometers.

   2. What is the area of Kootenay National Park in square kilometers?

e) Now display the elevation file, ELEV, using the Quantitative Palette.

3. *Describe the arrangement of the mountains and valleys in the park. For example, are the mountains found mostly in the northern part of the park? Are there many deep valleys or only a few? Where are the lowest and highest elevations found? (Note: the images in this data set are registered so that the top of the screen is north.)*

f) To find the maximum, minimum, and mean elevations, you will need to use a method other than visual analysis. As you saw in Exercise 1, Metadata can provide you with important information about an image. Pick ELEV from the IDRISI Explorer Files list.

4. *What are the minimum and maximum values shown? What does the value given for the minimum represent? Is there any way to find the mean elevation from the information presented by Metadata?*

g) Another way to glean information from a dataset is by displaying a histogram. With IDRISI, this is accomplished with the module HISTO. Run HISTO from its toolbar icon or from the GIS Analysis/Database Query menu. Give ELEV as the input image and accept all the defaults. HISTO will calculate and display a graphic histogram of the elevation data. The number of pixels having a given value determines the height of each bar in the histogram.

5. *What data value has the highest peak (most pixels)? What does it represent?*

Clearly the background values dominate the histogram of the image, making it difficult to see any variation among the actual elevation values. Also, in the summary statistics presented, the background values are also included. Thus, the mean reported is not the mean elevation value but rather the mean of the elevation values and all the background zero value pixels. This number is therefore not what you want to report as the mean elevation of the park.

h) To produce a more meaningful histogram and the mean value you want, from the graphic HISTO display, alter the minumum (from) value to 1 and the class width values to 4, then click on Update. This will exclude the background values of 0 from the histogram and from the calculation of the summary mean statistic.

6. *From looking at the histogram, what is your estimate of the lowest elevation value in the image (or, at approximately what value does the x axis start)? What is the mean value reported?*

You still need to find the true minimum elevation value for the park. A different form of histogram can help you find this.

i) Run HISTO again, setting the class width to 4, minimum value to 1, and choosing the option to produce a numeric histogram. When the histogram displays on the screen, look for the column labeled “Frequency.” This indicates how many pixels fall in the range between the “Lower Limit” and the “Upper Limit.” Find the first class that has a frequency greater than 0 pixels.

7. *What is the minimum elevation in the park? How many pixels have this elevation?*

You should be able to continue now on your own using DISPLAY Launcher, Metadata, AREA, and HISTO to answer the remaining questions about vegetative cover and eco-regions. Be certain to exclude the background from your calculations.

8. *For each of the remaining questions, record the answer and list the GIS commands and specific IDRISI modules you used to find it.*

VEGCOVER

Categories:

Categories covering the largest areas:

Spatial distribution of vegetation types:

ECO-REGIONS

Categories:

Percent covered by each eco-region:

Finally, satisfy Information Request A by writing a description of Kootenay National Park using the data you have assembled and any other information from the data set you would like to add.

j) Close any windows you currently have opened.

Information Request B: Are the eco-regions described by the file ECOREG merely based on elevation? Describe any associations you can find between eco-regions and vegetative cover types in the data set.

Unlike the first request that asked for information about each image individually, the second request asks you to discuss the relationships between images. Here you will be introduced to two additional tools for attribute query. EXTRACT allows summary statistics to be calculated for specific regions identified in a feature definition file. CROSSTAB allows you to overlay two images and see all the resulting combinations of the categories for each cell in either a table or an image or both.

EXTRACT can be used to determine whether the eco-regions are simply derived from elevation. If it were true that the eco-regions were determined solely by elevation, you would expect each eco-region to span a different range of elevation with little or no overlap between the elevations of the various eco-regions.

k) Test this by running EXTRACT from the GIS Analysis/Database Query menu. Give ECOREG as the feature definition file and ELEV as the file to be processed. Choose to calculate all summary types and have the result written as a tabular output. The resulting table lists the category numbers of ECOREG and the corresponding minimum, maximum, mean, standard deviation, etc. for the corresponding values of ELEV.

9. Are the eco-regions based solely upon elevations? Explain, giving specific examples and elevation values you found using EXTRACT.

10. Now that you are familiar with EXTRACT, outline the steps you could take to find the minimum and mean elevations of the park using EXTRACT rather than HISTO. What type of image would be necessary for the feature definition file?

To answer the second part of information request B about the association between eco-regions and vegetative cover, you will use the GIS operations of cross-classification and cross-tabulation. Cross-classification produces an image in which the new categories represent the places where a category from the first image and a category from the second image overlap. That is, it creates an image that represents all possible combinations of the logical *AND* of the two input images. Cross-tabulation produces a table showing the number of pixels falling into each new category. Cross-classification and cross-tabulation in IDRISI are accomplished with the module CROSSTAB.

CROSSTAB creates a new image or table in which each combination of the original categories becomes a unique category. For example, all the pixels that are category 1 in the first image *AND* category 1 in the second image will be assigned a new value in the resulting image, while all the pixels that are category 1 in the first image but category 2 in the second image will be assigned a different value. The new values are much like the numbers assigned by GROUP and have no analytical value other than as class identifiers.

l) Run the module CROSSTAB from the GIS Analysis/Database Query menu with ECOREG as the first image and VEGCOVER as the second image. Choose to create a cross-classification image. Call the resulting output image CROSS.

The key to interpreting the CROSS image is the legend. The legend caption tells you which value in the first image overlays which value in the second image to form the new class. For example, the legend caption 1|2 indicates ECOREG class 1 overlays with VEGCOVER class 2.

11. *How many classes resulted from the cross-classification? Describe the relationship between eco-regions and vegetative cover types in light of the information in the cross-classification image.*

Your answer to questions 9 and 11 satisfy the demands of Information Request B. With what you have learned, you should be able to address Information Request C on your own.

Information Request C: Choose moose, deer, *or* coyote and describe the high to very high (combined) density winter habitat of this animal in terms of elevation, eco-region, and vegetative cover type. In addition to your written description, provide an outline of the GIS steps you took in gathering the information.

12. *Write up your response to information request C. Be sure to include the name of the animal chosen, descriptions of relationships you found and an outline of the GIS procedures used.*

Information Request D: Describe the general distribution of the high to very high (combined) density classes of all six animals in winter in relation to each other. Do not consider variables of elevation, vegetative cover, or eco-region. Produce an image of the park showing, per pixel, which groups of animal species are supported at high or very high densities in the winter.

m) Since this query is only concerned with the high and very high density classes, the first step is to create Boolean masks for each of the animals in which the areas of high and very high winter density have the value 1 and everything else has the value 0. (You do not want to maintain the distinction between high and very high categories for this query. Both should be reclassified to the new value 1.) Use RECLASS or Edit/ASSIGN and give the masks the following names: ELKHIGH, MOOSEHIGH, DEERHIGH, COYOTEHIGH, SHEEPHIGH, and GOATHIGH.

n) Display all the images but elect not to display the legends to save display space. Then move the images so you can view them simultaneously. If you need to reduce the size of the images, 1) double-click on the image to activate it for moving and sizing. 2) Place your cursor over the lower-right corner of the image until the cursor becomes a double arrow. 3) Drag the image corner to the desired position. 4) Click in the map window outside the image. 5) Drag the map window border in as well.

13. *Which animals have similar high density winter distributions? Which animal is not found in the northern part of the park in high densities in the winter? List any other observations you have about the general distributions shown in these images.*

The second part of Information Request D asks you to create an image showing which groups of animals are found at high or very high densities in the winter. You have already seen how cross-classification works. It could certainly be used in this situation, but keeping track of what the categories mean through each successive cross-classification of image pairs might be tedious. OVERLAY is another possible tool for this problem.

14. *Would overlaying the layers with multiplication produce the desired result? What is the difficulty presented if the six mask images are simply added together with OVERLAY?*

This problem can be overcome by assigning each mask a value such that when all the images are added together, any of the values in the final image can only be the sum of one set of original values. For example, if the images were assigned the values 1, 2, 4, 8, 16 and 32 (with 0 as the background value in all six images) then when the images were added, a pixel with the value 7 could only be the result of 1+2+4 and a pixel with the value 40 could only be the result of 8+32.

You could create new mask images, each with the appropriate value, then sum them through a series of OVERLAY operations. However, IDRISI provides a utility called Image Calculator that will allow you to create the output image in one step. Each mask image will be multiplied by its assigned value. This will change the values of the areas with high densities

(1's in the mask image), but will leave the 0 values unchanged. These will then be summed. Use the following assignments for each animal:

Species	Value
ELK	1
MOOSE	2
DEER	4
COYOTE	8
SHEEP	16
GOAT	32

o) Open Image Calculator from its toolbar icon or from the GIS Analysis/Mathematical Operators menu. You will be creating a Mathematical Expression. Enter FINALSUM as the output filename. In the Expression to Process input box, enter the following expression. Note that you can use the Insert Image button to choose filenames from the pick list and automatically include the square brackets. The equation will be too long to see it all in the input box. You can move around in the input box by clicking into it, then using the home, end, left and right arrow keys.

FINALSUM = [ELKHIGH]+([MOOSEHIGH]*2)+([DEERHIGH]*4)+

([COYOTEHIGH]*8)+([SHEEPHIGH]*16)+([GOATHIGH]*32)

p) Choose Layer Properties on Composer and change the palette used to display FINALSUM to be QUAL. The image FINALSUM holds all the information necessary for creating the requested image. (If a legend does not appear, right-click on the image to bring up Map Properties. Click on the Legends tab, select Visible for the first legend and choose FINALSUM from the drop-down list of layers.)

15. What is the highest value in FINALSUM? What would be the value of a pixel having all 6 animals at a high density during winter?

q) Obviously not all the possible combinations of animals are present in FINALSUM. Run HISTO and create a numeric histogram of FINALSUM so that you may see exactly which values are present in the final image. Keep all the default settings. In the resulting numeric histogram, the large number of 0 value pixels represents background areas as well as those areas that have no high-density animal populations. Look for all the values that have frequencies higher than 0.

16. List the values present in FINALSUM and for each value, list the animals that must be present to give this value.

r) To finish the requested image, you will add a meaningful title and legend. Use Metadata for the image file FINALSUM. In the File title field, enter "Species Found in High Densities in Winter." Then double-click on the Categories option and enter each of the values that are present in the image (excluding 0) as codes with the animal names as the captions. Save the file changes.

s) Close any windows you currently have open. Now display FINALSUM again, using the Qualitative palette and a legend. This is the image required for Information Request D.

You should now have all the tools you need to provide the description and create the image for information request E on your own.

Information Request E: Choose bighorn sheep, elk, *or* mountain goat and describe the differences, if any, between the species' summer and winter habitats. Consider all density levels. Finally, produce a single image showing, for the chosen species, areas of high or very high density in 1) summer, 2) winter, and 3) both seasons. In the same image, also show those areas that do not support a high or very high density of the species as the fourth category.

17. *Write the requested description and provide an outline of the steps you took in creating the final image for request E.*

This exercise has introduced you to several important GIS tools for attribute query. The tools you have used in this and the first exercise are basic to most GIS analyses and will be used again in the remaining exercises.

Exercise 3: Mapping Suitable Locations for Reforestation — Eucalyptus in Africa

Deforestation and the depletion of forest resources can have very adverse effects on humans, wildlife, and entire ecosystems. When forest resources are lost, it becomes more difficult for humans to supply their fuel needs, erosion and flooding can become more severe, and the climate of an area may be altered.

Afforestation efforts around the world have met with varying degrees of success. Many factors must be considered when planning a reforestation project if it is to be successful a species or group of species must be selected that will suit the needs of the people in the area. These species must also be suited to the physical conditions of the area, such as temperature, rainfall, slope, aspect, and soil depth and type.

There are generally two ways to approach this question. The first is to ask: "Given what we know about the environmental and social conditions in a particular location, which tree species are most suitable for reforestation efforts?" The second is to ask: "Given what is known about a particular species, where would it be expected to grow well?" In this exercise you will take the second approach and use GIS to determine where in Africa the climatic conditions are suitable for the planting of the tree species *Eucalyptus grandis.*

With the data available, you will be able to examine only climatic factors, so your result will be only a partial suitability analysis. The use of this particular species has been criticized by some development professionals because of its high water and nutrient use and because it may not meet the needs of local people. A more complete suitability analysis would need to account for long-term environmental effects and the needs of the resident populations. This exercise is an adaptation of an exercise included in *Global Change Database Project, Pilot Project for Africa Workbook* (Eastman et al. 1990).

Eucalyptus grandis, or *E. grandis*, is used in forestry projects in many locations around the world. Scientists have observed the conditions under which *E. grandis* grows and have found that the species thrives under the following climatic conditions:

Mean annual rainfall	700-2500 mm
Rainfall regime	summer or uniform
Max. monthly mean temp.	31 C° (or lower)
Min. monthly mean temp.	-1 C° (or higher)
Mean annual temp.	14-22 C°

The final product of your suitability analysis will be a map of Africa showing the areas that meet all of these conditions. The data for this exercise is from the *Global Change Database Project, Pilot Project for Africa Data Set* (Kineman et al. 1990). The images cover the entire African continent and the resolution of the data is quite coarse. Each pixel is 5 minutes of latitude by 5 minutes of longitude. Because of this, the area covered by each pixel varies with distance from the equator since the length of 5 minutes of longitude is different at various latitudes (see Figure 1).

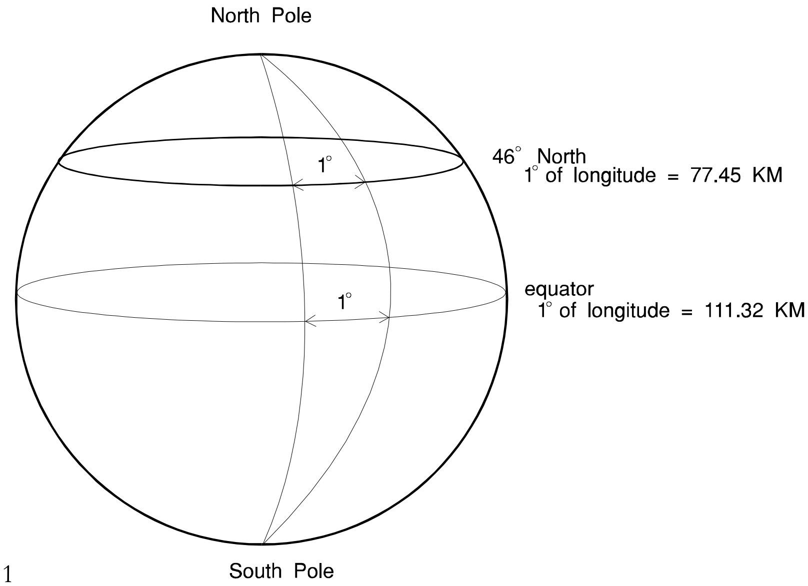

Figure 1

a) Before performing any operations, make sure the main Working folder is set correctly in IDRISI Explorer to the folder including data for this exercise (e.g., \UNITAR\Forestry\Data\Exer3).

b) Use Metadata to find the maximum and minimum data values and the value unit of measurement for each file and record these.

Climatic Factor	Image	Max.	Min.	Value Units
Mean Annual Rainfall	ANNPREC			
Max. Monthly Mean Temp.	MAXHOT			
Min. Monthly Mean Temp.	MINCOLD			
Mean Annual Temp.	ANNTEMP			
Rainfall Regime	(to be created)			

With the coarse resolution of the data for this exercise, local variations that might be important in an actual suitability analysis will not be seen. You will be defining very broad areas as suitable or non-suitable, realizing that there are local variations that will not be accounted for, but that would need to be considered before beginning any local project.

There is no image for the Rainfall Regime factor, so the first task will be to create it. A "rainfall regime" indicates when, during the course of the year, an area receives rain. There is a considerable difference, for example, between a place that receives its total annual rainfall in a few months during the summer and another place that gets small but frequent showers throughout the year, even if the total annual precipitation for both places is exactly the same.

There are many ways to characterize rainfall regimes. A very simple way is to assign all areas to one of three regimes: summer, winter, and uniform. A place is said to have a summer rainfall regime when a summer rainfall is at least 30 percent greater than winter rainfall. Likewise, a winter rainfall regime is one in which winter rainfall is at least 30 percent greater than summer rainfall. If neither of these conditions applies, the place is assumed to have a uniform rainfall regime. This way of classifying rainfall regimes yields information about the relationship between rainfall and temperature. A summer rainfall regime, for example, indicates that more of the annual precipitation falls when the temperatures are higher.

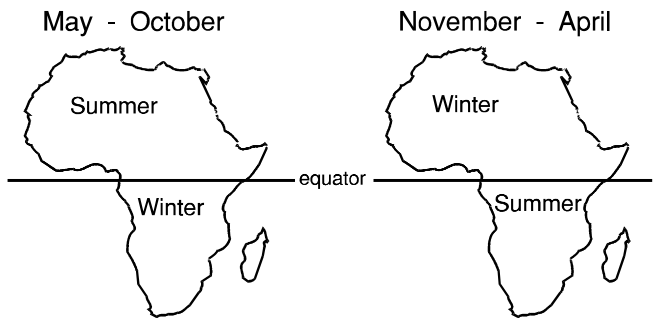

Figure 2

You must create a map that identifies these three categories of rainfall regimes for Africa. First, it is necessary to define what is meant by the terms "summer" and "winter". If summer is understood to be the warm part of the year and winter to be the cold, then we know that south of the equator, winter is approximately May through October and summer is roughly November through April. North of the equator the opposite is true. Since the equator runs through Africa, you will need to be careful about what is called summer and winter in this exercise (see Figure 2).

1. *The rainfall regimes map will be made from monthly rainfall images. Before continuing, review the definitions given for summer, winter, and uniform rainfall regimes. Then try to outline the procedure necessary to make this image.*

The first step is to make an image showing the total rainfall from May though October. To do this, you will add the separate monthly images together. The monthly precipitation images are named JANPREC, FEBPREC, etc.

c) The addition of several images in IDRISI is most easily accomplished with Image Calculator. (This will yield in one step the same result as performing several OVERLAY addition operations.) Open Image Calculator and enter MAYOCTPREC as the output image. In the Expression to Process input box, enter the following equation. Note that you may use the Insert Image button to choose files from the pick list. This will automatically enter the necessary brackets around the filenames.

[MAYPREC]+[JUNPREC]+[JULPREC]+[AUGPREC]+[SEPPREC]+[OCTPREC]

Click Process Expression.

MAYOCTPREC is the sum of the monthly precipitation values for May through October. If necessary, increase the size of your image by clicking on the Maximize Display of Layer Frame icon on the tool bar. It would be nice to know where the country boundaries lie, even though they are not important to the actual suitability analysis. There are three vector files in the database that can be used as vector overlays with the images: COASTS, COUNTRY, and LAKES.

d) With MAYOCTPREC displayed on the screen with the Quantitative palette, choose Add Layer on Composer to overlay the vector file COASTS with the user-defined symbol file COASTS. Use the Add Layer option again to overlay COUNTRY with the COUNTRY user-defined symbol file. Then overlay the vector file LAKES using the LAKES user-defined symbol file. (These outline files can be overlaid on any image in this data set. Use them at any time during this exercise when you wish to get an idea of where things are.)

2. *Summer precipitation is highest in what parts of Africa? What is the maximum value in MAYOCTPREC?*

You will now create a similar image for November through April. This time, rather than using Image Calculator, you will create a macro file. A macro file is simply a listing of commands and their parameters to be performed in sequence. Macros are useful for automating tedious processes and processes that should be run several times with few variations.

e) In IDRISI, the Help System contains information about running each module in a macro. Open the Help System by choosing Contents under the Help Menu. Click on the Index tab and choose OVERLAY. Then click on the Macro Command link. Note the macro command format. The module name is followed by a space, then the letter x, then another space. The rest of the parameters are separated by asterisks. The Help System box may be sized as needed by dragging the edges. You may also choose to Keep Help on Top from the Help System Options menu.

To create the macro file, open the Edit module. Type the following commands into the new file, one on each line (Edit is not case-sensitive so you may type commands in upper or lower case):

OVERLAY x 1*NOVPREC*DECPREC*TEMP1

OVERLAY x 1*TEMP1*JANPREC*TEMP2

OVERLAY x 1*TEMP2*FEBPREC*TEMP1

OVERLAY x 1*TEMP1*MARPREC*TEMP2

OVERLAY x 1*TEMP2*APRPREC*NOVAPRPREC

Note that the temporary files, TEMP1 and TEMP2 are necessary because OVERLAY only works with two images at a time.

When finished, select Save As from Edit's File menu. From the drop-down list of file types choose Macro File (.iml) and give the filename ADDER. Close Edit.

f) To run the macro, select Run Macro from the File menu. Choose ADDER.iml. Leave the input parameters box empty. Click on Run Macro.

Watch as the macro file is executed. If there are any mistakes, you will hear a beep and see an error message. If there were no errors, skip to the next question. If there was an error message, use Edit again, opening ADDER.iml. Correct any mistakes in the file and resave. Run the macro file again and repeat this process until the macro file runs without error.

3. Did it take you longer to make MAYOCTPREC or NOVAPRPREC? If you were summing 30 images instead of six, which method would you use? What if you wanted to sum only three images? And what if you needed to repeat the process several times with different images?

4. Display NOVAPRPREC with the Quantitative palette (autodisplay is disabled for macro processing). Where is rainfall highest and lowest? How does this image compare to MAYOCTPREC?

Now that you have these two images, you are a step closer to determining the rainfall regimes. According to the definitions of summer, winter, and uniform rainfall regimes stated earlier, you need to find the relationship between summer and winter rainfall. In other words, a certain amount of rain in the summer or winter does not determine which rainfall regime a pixel belongs to. Rather, it is the *ratio* of rain falling in summer to that falling in winter that determines the rainfall regime of each pixel. To make this image you must divide the two seasonal rainfall images.

Before dividing, another issue must be addressed. Use Metadata to look at the minimum values in MAYOCTPREC and NOVAPRPREC. Both should have minimum values of zero. Since dividing by zero is mathematically undefined, there are several methods available in OVERLAY to handle this problem. For this exercise we will simply remove the zeros by adding a small number, such as 1, to all the values. This won't change the values significantly—only 1 mm of precipitation over 6 months—but it will solve the division by zero problem.

Zero values in the numerator do not pose a problem mathematically, but they will lead to a loss of information about the comparison between the summer and winter rainfall of a pixel. Since zero divided by any number is zero, a pixel that has zero precipitation in summer and 400 mm in winter, or another with 1000 mm in winter, will both have the value zero in the resulting image. By adding 1 to the numerator, you will be able to make this distinction between 1/4000 (0.0025) and 1/1000 (0.001).

g) To add, subtract, multiply, divide or exponentiate all the pixels in an image by a single number, you can use the command SCALAR. Run the module SCALAR from the GIS Analysis/Mathematical Operators menu and add a scalar value of 1 to MAYOCTPREC. Call the resulting output image MAYOCT1. Do the same with NOVAPRPREC to create NOVAPR1.

h) Now perform the division. Use OVERLAY with the First image/Second image option to divide MAYOCT1 by NOVAPR1 and call the result RATIO. Look at RATIO. You might want to enlarge the image. Use Cursor Inquiry Mode to examine the values of several pixels.

You didn't make a mistake! The image should be mostly black, with some colored areas in the Sahara Desert. The values in RATIO are so much higher in these areas, when the palette is stretched between the lowest and highest values (i.e., autoscaled) the high values are assigned to almost all the colors while the low values are all assigned to the lowest color—black.

5. *Why do these colored areas have such high values? (Hint: Use Cursor Inquiry Mode to find the row and column of one of the pixels with a high value in RATIO. Then find the values of the same pixel in MAYOCT1 and NOVAPR1.)*

6. *Think carefully about how RATIO was created, then match each of the following questions with answer A, B, or C:*

What do values greater than 1 represent in the Northern Hemisphere? In the Southern Hemisphere?

What do values less than 1 represent in the Northern Hemisphere? In the Southern Hemisphere?

What do values equal to 1 represent in the Northern Hemisphere? In the Southern Hemisphere?

A) Summer Precipitation is greater than Winter Precipitation

B) Winter Precipitation is greater than Summer Precipitation

C) Summer and Winter Precipitation are equal

Remember, however, that the definition of rainfall regime is not concerned only with whether the winter rainfall is higher than summer, for example, but whether one is at least *30 percent* higher than the other.

When you divided MAYOCT1 by NOVAPR1 in the Northern Hemisphere, you divided summer by winter. Therefore, for the Northern Hemisphere all old values that are greater than 1.30 will be considered a summer rainfall regime (1+30%=1.30). Using the same reasoning, since a winter rainfall regime is defined as winter rainfall exceeding summer rainfall by at least 30 percent, all values in the Northern Hemisphere that are less than 0.77 will be considered a winter rainfall regime (1/1.30=0.77). All values that are between 1.30 and 0.77 will be considered a uniform rainfall regime.

7. *What will be the case in the Southern Hemisphere? Fill in the chart for the values in RATIO.*

Northern HemisphereSouthern Hemisphere

Summer = > 1.30

Winter = < 0.77

Uniform = 0.77 < z < 1.30

The above chart points out another problem. You need to have a map in which all the summer regime pixels have the same value. The problem is that summer regime pixels in the northern part of the image have one range of values while those in the southern part have another range of values. If you reclass pixels in the Northern Hemisphere that are summer regime, the winter regime pixels in the Southern Hemisphere will also be reclassified to the same value!

There is more than one way to address this problem. You could cut the image in half along the equator, reclass the halves separately then join them back together. You could make a copy of the image and blank out the northern half on one image, the southern half on the other image, reclass them separately, then rejoin them with an overlay operation. You could also make a new image to multiply with the old image that would result in changing the values in one half of the image.

You may use any method you like. Instruction will be given here for the last method described. You will create an image in which the Northern Hemisphere all has the value 1 and the Southern Hemisphere all has the value –1, then you will multiply this image with the RATIO image.

8. What will happen to the values in the Northern Hemisphere? The Southern Hemisphere? Would this method be appropriate if RATIO had positive and negative values in both hemispheres?

i) You will first need to create an image with the same dimensions as the other images in this data set. To do this, use the module INITIAL from the Data Entry menu. INITIAL creates an image according to your specifications, in which all the pixels have the same initial value. Run INITIAL to make the output image CHANGER. Choose to create an integer output data type, give it the initial value 1 and choose to copy parameters from any image in the data set. This image is used to define the number of rows and columns, and the reference system information. (The result of INITIAL does not autodisplay. You may display CHANGER if you wish.)

At this point, CHANGER has the value 1 in every pixel. Now you must change the Southern Hemisphere to have the value –1 in all its pixels. Before you can change the Southern Hemisphere, however, you need to know where it is. You will need to find out between which rows the equator lies.

j) Display any of the images in the dataset, then add the layers COASTS, COUNTRY, and LAKES with their respective user-defined symbol files. Move the cursor over the image from north to south, keeping an eye on the Y coordinates reported at the bottom of the screen. The Y coordinate is the latitude. In these images, latitude north of the equator is positive while that south of the equator is negative. Once you have an idea of where the equator lies, zoom in very closely on the image using the zoom window tool. The keyboard arrow keys or your mouse may also be used to zoom and pan in the image. Try to determine which rows are in the northern hemisphere and which are in the Southern Hemisphere (you cannot split a row).

9. The equator passes (approximately) between which two rows in the image?

k) To change the value of the pixels in the Southern Hemisphere to –1, use UPDATE from the Data Entry menu with the input image CHANGER. The first row is the row you identified just below the equator. The last row is the bottom row of the image, number 437. The first column is number 0 and the last is 479 (row and column numbering begins with 0). Enter –1 as the new value to be placed in these cells. Click OK. Now look at CHANGER. Use Cursor Inquiry Mode to confirm that the pixels in the Northern Hemisphere have the value 1 and those in the Southern Hemisphere have the value –1.

Multiply CHANGER and RATIO using OVERLAY and the multiply option (First*Second). Call the resulting image NSRATIO. Use Metadata to see the maximum and minimum values of NSRATIO.

10. What are the maximum and minimum values of NSRATIO? A Southern Hemisphere pixel with value 0.77 in RATIO has what new value in NSRATIO? A Northern Hemisphere pixel with a value of 0.77 in RATIO has what value in NSRATIO?

Now you are ready to reclass NSRATIO into three classes: summer, winter, and uniform rain regimes. Give these classes the following new values in the resulting image:

Winter Rainfall Regime = 1

Uniform Rainfall Regime = 2

Summer Rainfall Regime = 3

11. *Think about how you created NSRATIO and fill in the following table:*

Northern Hemisphere	New Value	Old Value Range
Winter	1	
Uniform	2	
Summer	3	
Southern Hemisphere		
Winter	1	
Uniform	2	
Summer	3	

l) Reclass NSRATIO using the above table as your guide and the RECLASS command. Name the resulting image REGIMES. This is the final rainfall regime map.

12. *What can you say about the distribution of summer, winter, and uniform rainfall regimes in Africa?*

13. *What do you notice along the equator? What causes this? Can you think of a way to produce REGIMES without having this occur?*

Now that you have supplied the missing image in the climatic criteria list, you are ready to continue with the *E. grandis* suitability analysis. For each of the five images, you need to make a new image showing where the conditions for that particular climatic factor are suitable for *E. grandis*. You will be reclassifying the images into Boolean images, or masks, in which the suitable areas all have the value 1 and the unsuitable areas have the value zero.

m) Consult the table at the beginning of this exercise for the minimum and maximum values, units, and the range of suitabilities for the five climatic variables. Now fill in this information for rainfall regime and create Boolean images for each of the five images using RECLASS. Note that the suitable ranges for the three temperature images are given in degree C while the value units of the temperature images are in tenths of degrees C. (You need to multiply the suitable range numbers by 10 and use these new values when reclassifying.)

Call the resulting images SUIT-ANNPR, SUIT-REGIMES, SUIT-MAXHOT, SUIT-MINCOLD, and SUIT-ANNTEMP. Check each result visually and with Metadata to make sure the images are Boolean.

n) You now have five separate images, each showing where one climatic factor is suitable for *E. grandis*. You must now identify the places where *all five* factors are suitable. To do this, use whichever method you find easier, Image Calculator, OVERLAY, or a macro file. Name the resulting image SUITABLE. If necessary, display SUITABLE with the Qualitative palette, or change the autodisplayed image to use the QUAL256 palette. This is the final product of your analysis—an image showing all the areas in which all five of the specified criteria are suitable for the growth of *E. grandis*. Overlay the vector files COASTS and COUNTRY with their corresponding user-defined symbol files.

14. *How did you create SUITABLE?*

15. *How would you describe the distribution of the suitable areas? Are the suitable pixels spread out or grouped together?*

Why do you think this is the case?

16. *How could you create an image showing the number of criteria suitable for each pixel?*

References

Eastman, R., J. Kineman, R. Dodson, M. Livingston, and N. Azimi (1990) Global Change Database Project: Pilot Project for Africa Workbook. Worcester, Massachusetts: Clark University.

Kineman, J., S. Boyle, A. Mealey, M. Ohrenschall, J. Colby, and S. Della Mana (1990) Global Change Database Project: Pilot Project for Africa Data Set. Boulder, Colorado: U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Exercise 4: Gypsy Moth Defoliation of Forests in Northeastern North America

The gypsy moth (*Lymantria dispar (L.)*), a destructive forest pest, was accidentally introduced from France to North America by an amateur entomologist in 1868 or 1869. The primary point of introduction was Medford, (a suburb of Boston) Massachusetts, U.S.A. Despite many attempts at eradication, the moth has spread throughout most of northeastern North America. There was a second introduction in Michigan that continues to spread and there have been several isolated infestations in the western United States and Canada.

The sporadic defoliation caused by outbreaks of gypsy moths can lead to substantial ecological and economic damage, including tree mortality. In addition, the large number of caterpillars associated with an outbreak is a general nuisance to people living in the area.

In this exercise, we will examine two aspects of the gypsy moth problem. Part A makes use of three decades of yearly defoliation data for the state of Massachusetts, along with a forest type map, to determine if there are any particular tree species associations that are more susceptible to gypsy moth defoliation. Part B examines the rate at which the gypsy moth spread through northeastern North America from the point of introduction. This exercise closely follows procedures used by Liebhold et al. (1992a and 1992b).

Part A: Susceptibility to Gypsy Moth Defoliation

a) Before performing any operations make sure the main Working folder is set correctly in IDRISI Explorer to the folder including the data for this exercise (e.g., \UNITAR\Forestry\Data\Exer4).

b) Use Metadata to examine the files in this dataset. You will find a series of yearly images for Massachusetts that show where defoliation occurred during the period 1961-1990. (There are no images for 1966 and 1988 because there was no defoliation in those years.) These images are named MA61DEF, MA62DEF, etc. and were transferred to digital format from aerial sketch maps. For more information about how this data was gathered and transferred to a GIS format, see Liebhold and Elkintong (1989). You will also find a file named FOREST, which shows the different forest types in the state.

c) The images for this exercise have 2-kilometer resolution. Take a few moments to display some of the images. Use the Qualitative palette to make it easier to distinguish the defoliated areas. With an image displayed on the screen, use the cursor to locate Medford, Massachusetts at column 188, row 26 (the column, row position of the cursor is displayed at the bottom of the screen).

The first thing you need to calculate is the total number of times over the three-decade period that each pixel in the image has experienced defoliation. To calculate this, you will sum all of the yearly images in the MA61DEF series. In the previous exercise you used both Image Calculator and OVERLAY in a macro file to sum groups of images. You may use either of these methods with the 28 input images here as well. However, when all input images are Boolean, a third method is available to accomplish this using the module COUNT.

d) Before running COUNT, you will save time by first creating a raster image group file that lists all 28 input filenames. You can do this in IDRISI Explorer from the files tab. Create a raster group file of all the images from MA61DEF to MA90DEF, 28 input images. Save the raster group file as MADEF.

e) Now run COUNT from the GIS Analysis/Statistics menu. Click on Insert Layer Group and choose the raster group file you made above, MADEF. This will enter all 28 images into the COUNT dialog. Give MAFREQ as the output image name. The output image of COUNT contains the frequency probabilities (i.e., the sum divided by the number of input images) per pixel.

f) To change MAFREQ from frequencies per pixel to the sum per pixel, simply multiply by 28. Do this using

Image Calculator or SCALAR. Call the resulting image MASUMDEF.

The MASUMDEF image is a summation of all the years of defoliation — the value of an area represents the number of years that it has been defoliated. Check the defoliation values in the image by using Cursor Inquiry Mode.

Obviously there are areas that have often been defoliated and others that have never been defoliated. Is this pattern random, or are there variables that can explain it? The first variable we will test is forest type. While gypsy moths are known to eat many different tree species, they may have a preference for certain species.

MASUMDEF shows the sum of years of defoliation *per pixel*. Now you must find the average sum of years of defoliation *per forest type*. To find this, you will use the EXTRACT module. As you saw in Exercise 2, EXTRACT uses a feature definition file that defines areas, then it calculates the requested summary statistics from a second file for those defined areas. In this case, the forest type map, FOREST, is the feature definition file. The average value of MASUMDEF for each forest type is what you want to have calculated.

g) Display the image FOREST with the Qualitative palette. Note the forest type categories.

Run EXTRACT, using FOREST as the feature definition file and MASUMDEF as the image to be processed. Choose average as the type of summary procedure and choose the tabular output type. For each class in FOREST, EXTRACT reports the average of all the corresponding pixels in MASUMDEF.

Examine the table. Does one type of forest stand out as being more susceptible to defoliation?

1. List the forest categories in order from least to most likely to be deforested by gypsy moths. Include the average value and the legend captions for each category.

Your list shows that the non-forest class (8) experienced more defoliation than three other classes (7,2,1). This obviously should not be the case, but when using very generalized data, such as this, results may not be as expected. The next step, if you were actually doing the study, would be to check the accuracy of the forest type map.

2. Finally, think of some other variables that might affect the susceptibility of an area to defoliation. How would you go about testing the relationships? What data would you need?

Liebhold et al. (1992a) have studied the effects of elevation, along with forest type, on defoliation in Pennsylvania. They found that oak-pine forests were generally the most susceptible. They also found that forests of pitch pine, oak-pine, and oak-hickory were less susceptible to defoliation at elevations below 200 meters.

Information like this is very useful for planning containment and eradication efforts and for predicting which currently uninfested regions are at greatest risk. Knowledge of preferred habitat combined with information about how the gypsy moth spreads is useful in long-range planning in currently uninfested areas. The next part of this exercise illustrates how Leibhold et al. (1992b) used GIS to characterize the rate and direction of the spread of the gypsy moth.

Part B: Gypsy Moth Invasion!

The gypsy moth spreads rather slowly, compared to other such pests and this is probably due to its biology. The female gypsy moth in North America can't fly, so dispersal occurs mainly by wind. When larvae hatch, they crawl out on branch twigs, spin down on silk threads, and are then blown away. Transportation by humans or animals of various life stages of the moth may also contribute to the spread of the pests.

In this part of the exercise, you will study the diffusion rate of the gypsy moth from its point of introduction in Medford, Massachusetts throughout the northeastern United States and southeastern Canada using historical records of infestation collected by the US Department of Agriculture and Agricultural Canada. You are specifically interested in looking at the relationship between an area's first year of infestation and its distance from Medford.

In this study, the smallest unit of analysis is the county in the United States and the Census District in Canada. This means that all the pixels within a unit have exactly the same value. (In cases in which a county or district was extremely large, it was systematically divided into pieces approximately the size of the surrounding units.)

h) Display the image UNITS of the counties and districts with the Qualitative palette. Note that Michigan has been masked out, since the source of its infestation was not Medford, Massachusetts, but a separate introduction in Michigan itself. Also note that this study area is much larger than that of the first part of this exercise. Use Metadata with UNITS to see the dimensions of the pixels in this and all the files that will be used in this section of the exercise.

3. What is the resolution of this data set?

Yearly images of infestation beginning in 1900 and ending in 1990 were summed using the same procedure used to create MASUMDEF used in the first part of this exercise. Note that this is infestation data, not defoliation data as you used in part A. Once an area has been infested, it remains so, whether or not defoliation is evident. The final summed image is included in your data set and is called YEARSUM.

i) Display YEARSUM with the Quantitative palette and with the 256 Equal Interval autoscaling option. Use Cursor Inquiry Mode to check some of the values. Verify that the counties with the highest number of years of infestation are nearest to Massachusetts. Also note that there are some areas that have never been infested (that is, where z=0).

In order to determine the rate at which the gypsy moth spread, you first must create an image showing the year of initial infestation experienced by each unit, rather than the total years infested.

There are several steps required to create this image. First, you must think of a way to manipulate the image so that pixels will have the value of the *year of infestation* rather than the *number of years infested*. For example, a pixel with the value 5 in YEARSUM, meaning it has been infested for 5 years, should have the value 86. (Since all the years are in the 1900's, you may ignore the "19" of the year.)

An easy way to create the desired image is to use Image Calculator to subtract 91 from YEARSUM and multiply the result by –1. Use the following equation with Image Calculator and call the resulting image YEAR.

YEAR = ([YEARSUM] – 91)*-1

4. What will be the new value of the pixel containing Medford? What will be the value of a pixel that has never been infested?

j) View YEAR with the Quantitative palette and autoscaling. Use Cursor Inquiry Mode to help identify values in the image.

The image is still not quite correct. Counties and districts that have never been infested (as well as the ocean!) have the value 91, meaning that they would have been infested in 1991, yet there is no data for 1991. You don't want to include this invalid information in the analysis; therefore you must turn all of these values into 0's. It would be easy to do this with a simple reclass, but you will need to remove these never-infested areas from other images as well. Instead of reclassifying, make and use a Boolean mask.

k) This mask should have the value 0 where there has never been an infestation and the value 1 everywhere else. Make the mask from YEARSUM. Reclass YEARSUM so that all the old values from 1 to just less than 92 are assigned the value 1 and name the result MASK.

l) Now use the mask to create an image of the first year of infestation in which never-infested areas have the value 0. OVERLAY, using the multiply option, MASK and YEAR. Name the output image YEARMASK.

m) Next, you need an image that shows the distance from the point of introduction to each county or district. This has already been created for you (using the IDRISI module DISTANCE) and is named DISTANCE. Again, you must use your mask image to mask out parts of DISTANCE that correspond to those areas that have never been infested. Use OVERLAY to multiply MASK and DISTANCE and call the output image DISTANCE-MASK.

n) Finally, you will also be using UNITS, so you must mask the corresponding uninfested counties or districts out of that map. Run OVERLAY as before with MASK and UNITS and call the output image UNITSMASK.

The goal of the study is to determine the rate of spread of gypsy moth and to do this, you will use regression analysis. Since rate is the ratio of distance divided by time, you must gather two pieces of information for each county or district—its distance from Medford and its year of first infestation. You will then run a regression using these two variables to find the relationship between them.

5. *You have a choice between comparing the entire images, pixel by pixel, or using only one value for each variable per county or district. Why should you choose the latter?*

o) To create files of the single value for distance and year for each unit to be used in the regression, use the IDRISI command EXTRACT. You will do this twice, once for DISTANCEMASK and once for YEARMASK. Both times use UNITSMASK as the feature definition file, values file as the output type and minimum as the desired summary. Name the resulting values files DISTANCEMASK and YEARMASK. These files won't overwrite the image files DISTANCEMASK and YEARMASK because they have a different extension. Image files have .rst extensions while values files have .avl extensions.

Examine the values files YEARMASK and DISTANCEMASK using Edit. The first column in each file is the identifier of the county or district. The second column is the minimum value of all the pixels in DISTANCE-MASK (or YEARMASK) belonging to that county or district.

6. *The first line in both files is 0 0. What do these represent?*

p) This information should not be included in the subsequent analysis. In other words, you want to leave out the zeros. The easiest way to do this is to remove the first line of each values file. To do this, run Edit, choose File/Open, Attribute Values File as the file type and then choose the file YEARMASK. Delete the first line, then choose File/Save. Do the same with DISTANCEMASK.

Now that you have assembled the necessary data and have it in the correct format you are ready to examine the relationship between the earliest year of infestation in a county or district and its distance from Medford, Massachusetts. In particular, you want to find the rate of diffusion of the gypsy moth. You will be running a regression in which the first year of infestation is the independent variable and the distance from Medford is the dependent variable. This means that a county's or district's distance from Medford is a function of the year in which it was originally infested. (A county infested in 1950 is likely to be further away from Medford than a county infested in 1920.)

An example using a regression equation that includes units of measure may help to clarify this. Remember, you're interested in rate of diffusion. Rate is represented as distance divided by time. The generic equation is therefore:

distance = constant + (rate * time)

In this study, distance (DISTANCEMASK) is measured in kilometers and time (YEARMASK) is measured in years. The rate, therefore, will be in kilometers per year. (The constant has no unit of measurement.)

q) Run REGRESS from the GIS Analysis/Statistics menu and specify the attribute values file option. Give YEAR-MASK as the independent variable and DISTANCEMASK as the dependent variable. Click OK. When the display appears, study it, then click off the Show Regression Line option and look carefully at the distribution of the points. The coefficient of determination is rather low and indicates that the single linear regression line does not fit the points very well.

Each point on the resulting display represents a county or district. The value along the horizontal scale is for the independent variable, YEARMASK and that along the vertical scale is for the dependent variable, DISTANCEMASK.

Notice that the scatterplot of the points shows that the diffusion rate has not been constant over the data period. In fact, fitting a single linear regression line to such a non-linear data set is not very useful. It would be much more useful to divide the data into segments, with each segment having a roughly linear scatterplot of points.

Liebhold et al. (1992b) divided the data into three sections; 1900-1915, 1916-1965, and 1966-1989, then found the diffusion rate for each period using regression. (Liebhold's analysis did not include the data for 1990. You should include it, however, in the third time period, 1966-1990.)

The values files for the three regressions are included in your data set. The background values of 0 have already been taken out. The files are named YEAR1, YEAR2, and YEAR3, corresponding to the three time periods above. Similarly, the distance files are named DISTANCE1, DISTANCE2, and DISTANCE3.

r) Run REGRESS with each pair of attribute values files using the year as the independent variable and the corresponding distance as the dependent variable.

> 7. *Record the three equations. In which time period was the diffusion rate the fastest? Slowest? Remember the equation is in the form:*

distance = constant + (rate * time)

Liebhold et al. (1992b) propose several hypotheses to explain the variable speed of the expansion of the Gypsy Moth. The lower diffusion rate of the 1916-1965 period may have been due to a vigorous containment and eradication program that began in 1912 and was largely abandoned in 1965. It is also possible that the forests infested in 1965 and after provided a more suitable habitat for the Gypsy Moth, allowing for faster diffusion. There may have also been an increase in the rate of transfer of live Gypsy Moths in their various life stages by humans in the later period.

In addition, the researchers noted a pronounced difference in the most recent period between the rates of diffusion in regions where the winter temperatures are quite cold and in those with more moderate winter temperatures. They suggest that the lower diffusion rate at lower temperatures may be due to overwintering egg masses being killed off at a higher rate.

> 8. *Describe the steps you would use to predict the year of first infestation for a currently uninfested area assuming the rate of diffusion for the most recent time period remains constant and that no outside variables, such as temperature are involved.*

The exercise illustrates the study of the dispersal of an introduced species over space and time. With necessary modifications, however, their methodology could be applied to the study of the diffusion of disease, information, or any number of other subjects.

We would like to thank Dr. Andrew Liebhold of the Northeastern Forest Experiment Station in Morgantown, West Virginia for his generous contribution of the data set used with this exercise.

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Exercise 5: Forest Management—Getting the Trees to the Mill

In this exercise you will examine a procedure for assessing the economics of timber harvesting. The methodology has been adapted from Berry and Sailor (1981) and involves the division of a forest tract into management zones based on logical collection units (road segments) and the costs of *skidding* (or *yarding*) timber to the nearest road. Subsequent analyses will then look at the economic potential of these zones by examining the cost of hauling wood from the road collection point to the mill and the volumes of various forest cover types within transportation zones defined by the combined costs of hauling and skidding.

a) Before performing any operations, make sure the main Working folder is set correctly in IDRISI Explorer to the folder including the data for this exercise (e.g.,\UNITAR\Forestry\Data\Exer5). Also open User Preferences under the File menu and click the Revert to Defaults button, then OK, to ensure that the automatic display parameters are set properly.

b) Display the image named FORTYPE with the Qualitative palette.

For the purposes of this exercise, assume that the study area is a forest tract leased to a commercial timber company.[1] This image shows the various forest types within the forest tract. Note that the irregular boundary marks the edge of the leased land. The area is 4.5 kilometers east-west by 4 kilometers north-south, and the images have a 10 meter resolution.

The forest tract is served by a series of existing roads. These roads are divided into a series of segments for management purposes. Segments start and end at road intersections. In addition, some of the longer roads are divided into segments at prominent landmarks.

c) Display the image named ROADSEGS with the user-defined palette named ROADSEGS.

These road segments serve as basic collection units for the gathering of timber that has been skidded to the road. It is reasonable, therefore to consider them as the basis for developing management zones. These zones will be called *timbersheds* (by analogy to the concept of watersheds) since they include all areas for which the cost is cheapest to skid timber to that segment.

In Part A you will define the timbersheds (there will be one timbershed for each road segment). Then in Part B you will use these as the basis for determining the costs of hauling timber from each segment back to the mill (the image named MILL shows the position of this facility). You will also analyze the volumes of wood of various types within transportation zones defined by the combinations of timbershed hauling and skidding costs.

Part A: Defining the Timbersheds

To create the timbersheds, you will first need to assess the costs of skidding the timber to the nearest road. Distance from the road is the main factor in determining cost. However, a second factor of considerable importance is terrain since it is more costly to skid timber over slopes than over flat areas.

d) To get an idea of the topography of this area, display the image ELEV with the Quantitative palette. This is a digital elevation model for the area.

In earlier exercises you used the module DISTANCE to calculate the distance from features. In this exercise you are interested not only in the distance from the roads but also in the relative costs of moving over different terrain. This combina-

1. The study area is actually the Athens Unit of Wayne National Forest in southern Ohio. Some of the files have been simplified or altered and a file containing a fictitious lumber mill has been created for the purposes of this exercise. The data set, therefore, should be used in the context of demonstration only and not as an accurate representation of the study area.

tion is known as *cost distance* and is calculated in IDRISI by the module COST.

The primary input to COST is a *friction surface* that can account for the various impediments and resistances to movement. A friction surface indicates the relative difficulty of moving through each pixel relative to some base cost. For example, if you were making a friction image for walking, you might decide that walking over paved surfaces can be considered as the base cost (measured in any units you wish—monetary, time, effort expended, etc.). If you were to determine that it is two and a half times as difficult to walk on loose sand, pixels representing areas covered with loose sand would be assigned a friction value of 2.5. Any real number value may be used. Values greater than 1 represent frictions, value equal to 1 represent identical costs to the base cost and values between 0 and 1 represent accelerations (these are not normally used in a friction surface).

Frictions do not prevent movement; they simply make it more difficult (or costly) to move. They are thus *relative barriers*. On the other hand, if you were to decide that it is impossible to move across a particular area, then that area would be an *absolute barrier*. In the walking example, an absolute barrier might be a lake or private land that is closed to pedestrians.

The COST module in IDRISI provides a choice of two algorithms. The faster of the two, COSTPUSH, only recognizes relative barriers and thus requires that absolute barriers be specified as very high (i.e., impossibly high) relative barriers. The other, COSTGROW, uses a special value of –1 to designate true absolute barriers. It is slower than the COSTPUSH algorithm, but has the ability to recognize true barriers to movement and to calculate cost distances along complex linear networks. Both will be used in this exercise.

With regards to skidding logs, it will be assumed that slopes between 0-5 percent represent the base friction cost of 1 and any slopes greater than 75 percent (about 36 degrees) represent an extremely high (nearly impossible) barrier. The following table summarizes the friction values.

SLOPE RANGE	FRICTION
0-5%	1
5-15%	2
15-35%	3
35-75%	500

Your first step will be to create an image of slopes. Slope gradient, measured in percent, is defined as the change in Y (change in elevation) divided by the change in X (change in horizontal extent) multiplied by 100 (to convert to percent) in the direction of maximum slope change. In IDRISI this can be calculated by using the SURFACE module with the digital elevation model.

e) Run SURFACE from the GIS Analysis/Context Operators menu. Choose to calculate slope, then enter ELEV as the input file and SLOPE as the output file. Choose to have slopes calculated in percent (i.e., slope gradients). In viewing the image, note that there are some broad areas that are fairly flat (low slope gradient) and other very steep areas. (Note that the output of SURFACE is automatically displayed using the Quantitative palette.

f) Use HISTO to examine the range of gradients in the slope image using a class width of 1. A value of 100 percent represents a slope of 45 degrees (equal change in height for any distance traveled). Note that none of the slopes exceed 75 percent and therefore none can be considered as an absolute barrier.[2]

g) You are now ready to reclassify SLOPE to create a friction image that reflects the friction values in the table. Run RECLASS with SLOPE, assigning new values according to the friction table above. Name the resulting

2. If you wish to experiment with the effects of an absolute barrier, try repeating this exercise after the first run with a new set of frictions that introduce an absolute barrier at some lower gradient. The cutoff of 75% was chosen for the procedure outline above partly because it produces a cost surface that can be readily visualized using DISPLAY Launcher without any further contrast manipulation.

image SKIDFRICTION.

Now that you have the friction surface associated with timber skidding, you must calculate the cost of skidding the trees across the friction surface to the road. The resulting cost-distance surface includes elements of friction and distance to the road and can be calculated using the module COST.

h) Run COST from the GIS Analysis/Distance Operators menu and choose the default Cost push algorithm. Indicate that you wish to use the file named ROADSEGS as the source feature image (costs build up as you move away from the road) and SKIDFRICTION as the friction image. Enter SKIDCOST as the output image name. When COST finishes, examine SKIDCOST and use Cursor Inquiry Mode to query several cell values.

The values in this image represent cost distances in *base cost cell equivalents*. For example, if a cell has a value of 34.82,this means that it costs 34.82 times the base cost to get to this location from the nearest source feature (a road in this case). If you knew the base cost in monetary units, you could convert this relative cost image into a monetary cost image by multiplying by the base cost This could be done in IDRISI by using Image Calculator or SCALAR.

For the purpose of developing timbersheds, it is not necessary to know the monetary costs of skidding. Only the relative costs are required, which is exactly what SKIDCOST represents. There will be a separate timbershed for each road segment and each timbershed will include all areas that are closer (in cost terms) to that segment than any other. To delineate these timbersheds, you will use the IDRISI module ALLOCATE.

i) ALLOCATE is a procedure that assigns each cell in the output image to the feature to which it is closest. It thus requires two images, one of the distances to a set of features (in this case, the cost distance surface named SKIDCOST) and a second of the features in question, referred to as the target image (in this case, the road segments). Run ALLOCATE from the GIS Analysis/Distance Operators menu and supply these parameters to produce a new image named TIMBERSHED. When ALLOCATE has finished and TIMBERSHED displays, change the display to use the user-defined palette TIMBERSHED by selecting it from the Composer/Layer Properties dialog box.

Part B: Analysis Using the Timbersheds

Now that you have defined the timbersheds as basic management units, there are a variety of analyses that can be undertaken, including the following four:

evaluating the haul costs of transporting wood to the mill

defining access zones within the timbersheds

creating combined haul/access transportation zones

calculating wood volumes within these haul/access transportation zones

Evaluating the Timbersheds for Haul Costs

To evaluate the costs of transporting timber from the collection segment to the mill, you will again create a friction surface to use with COST. This time the cost depends on both the distance from the mill and the quality of the road. Secondary roads, for example, cost one and a half times as much, and tertiary roads cost twice as much to haul over than do primary roads because of the slower speeds required and wear and tear on the trucks.

j) Information about the road type of each road segment is contained in an attribute values file named ROADTYPE. To examine the data file, open Edit, choose File/Open, and select the Attribute Values file type. Click on ROADTYPE and Open. This file gives the road type of each segment. Notice that the file has two columns. The left column contains road segment identifiers that match the values in the image ROADSEGS. The right column contains a road type code. Close Edit. If asked, do not save any changes you may have made inadvertently.

k) To create a map of road types, you can use ASSIGN along with this values file. Run ASSIGN and specify ROADSEGS as the name of the feature definition image and ROADTYPE as the name of the attribute values file containing the assignments. Then type ROADTYPE again as the name of the new output image to create. The result will be a new image of the roads in which the values indicate the road type rather than the segment number.

l) You can now reclassify the ROADTYPE image to create a map of frictions associated with hauling timber over the roads. Here you will need to create a true absolute barrier since the trucks cannot drive off the road. You will use Edit and ASSIGN to create this new friction surface. First, open Edit. Set all pixels which are off the road networks (zeros in ROADTYPE) to be absolute barriers (value –1) and those of road types 1, 2, and 3 to have frictions of 1, 1.5 and 2 respectively. Your values file should look like this:

```
0  -1
1  1
1  1.5
3  2
```

Once this values file is complete, save it. Select Attribute Values File type, enter ROADFRICTION as the new filename and click Save. When asked about the data type to be used, indicate Real, since the frictions you are using include non-integer values. Close Edit.

Run ASSIGN using ROADTYPE as the feature definition image to create ROADFRICTION. The values file is also called ROADFRICTION. Use Cursor Inquiry Mode to explore the data values in the resulting image and verify that values off the roads are –1. If necessary, zoom in using the zoom window tool, keyboard page down/ page up keys or the arrow buttons on Composer.

m) Now determine the costs of traveling along this road network from the mill using these frictions as relative and absolute barriers. The absolute barriers will restrict the cost calculations to the roads while the relative frictions will incorporate the costs of traveling along those roads[3]. To calculate the costs, run COST again, but this time use the Cost grow algorithm. The Cost grow algorithm is better suited to network cost analyses and will also allow you to incorporate true absolute barriers (although at a cost in processing speed). Specify MILL as the source feature image and select to use the friction surface ROADFRICTION. Name the output image HAULCOST. Check to see that the output type will be in cost distances and that the maximum growth distance is infinite (these should be the defaults). This operation may take a while.

Look at HAULCOST. This image shows the relative cost of hauling wood along the road network to the mill. Again, if you had information about the monetary costs of transporting timber, you could now create a monetary cost image from the relative cost image by using SCALAR.

The next step will be to characterize the costs associated with hauling wood from each timbershed to the mill. To do this, you will evaluate the average cost of hauling from each timbershed. The module you will use to do this is EXTRACT.

n) Run EXTRACT and specify ROADSEGS as the feature definition image and HAULCOST as the image to be processed. Elect to produce a values file named AVGSEGCOST based on evaluating the average cost within each segment. Be sure to use average as the summary type.

o) Use Edit to examine the AVGSEGCOST attribute values file. For each road segment (id's 1-35 as in the ROAD-

3. Slopes also affect trucking costs. As an optional exercise after completing this one, consider adding the friction effects of slope to those of road type and recalculate the cost distance.

SEGS image), the average cost of hauling timber to the mill is recorded. Since each road segment is associated with a single timbershed, you may create an image showing the average hauling costs for each timbershed. Use ASSIGN with TIMBERSHED as the feature definition file and AVGSEGCOST as the attribute values file to produce the new output image SHEDCOST. This image indicates, for each timbershed, the cost of hauling timber to the mill, once it has been moved to the road.

p) For broader management purposes, you may now divide the timbersheds into a higher-level grouping of haul zones. Use RECLASS, this time with the Equal Intervals option to reclassify SHEDCOST into 4 classes to produce a new image called HAULZONE. Reset the minimum and maximum to 0 and 1000 respectively, choose to use 4 classes and use all other defaults. This will produce an image in which timbersheds are classified into 4 zones, each representing an average haul cost-distance of 2.5 kilometers further from the mill.

Defining Access Zones

Since you know for each cell within each timbershed the relative cost associated with skidding timber to the nearest road (SKIDCOST), you can now subdivide the timbersheds into zones of accessibility. In this case only two zones will be produced: areas within 0.5 kilometers cost-distance equivalent of the road segment (that are relatively easy to access) and those further than 0.5 kilometers. This can be produced in two steps.

q) First, use RECLASS to reclassify SKIDCOST into an image named SKIDZONE based on assigning a new value of 1 to those cells with skid cost values from 0-50 and a new value of 2 to those from 50-9999. Examine the result.

1. *Why was the value 50 used to indicate the cutoff threshold of 0.5 kilometers?*

r) Now run the module CROSSTAB to cross-classify TIMBERSHED (first image) with SKIDZONE (second image) to produce the output image TIMBERZONE. Change the TIMBERZONE display to use the user-defined TIMBERZONE palette. You will need to use the scroll bar in the legend to see all the categories.

2. *Notice how the first 35 categories in this cross-classification show the most economically viable areas (with respect to skidding—a skidding class of 1) within each timbershed. To get a better idea of economically viable areas, you may want to display the TIMBERZONE image with the TIMBERZONE2 palette. The red/yellow areas are more economically viable, while blue/green areas are less so. Do you see any spatial pattern? If so, why? Also, how many categories are there in total? Why is the total not equal to 70?*

s) Finally, use RECLASS to create an image called BESTZONE that reduces each timbershed to only that area within the best access zone. To do this, run RECLASS with TIMBERZONE as the input image and BESTZONE as the output image. Assign a new value of 0 to all the old values that range from 36 to 9999. Since any value not mentioned in RECLASS is unaltered, the identifiers of the best zones within the 35 timbersheds (values 1-35) will remain. Change the display of BESTZONE to use the user-defined palette called BESTZONE.

Defining Transportation Zones

Skidding costs and haul costs define two components of the total cost of transporting wood to the mill. If you knew the actual cost of these two components they could be combined into a single economic model. In addition, if you had information about the value of particular tree types and the volume of wood per pixel, you could also model the value of timber and compare that to the cost of transporting it to the mill. For this exercise, however, we do not have this detailed information. Instead we will use the information we do have to define transportation zones that combine the various categories of haul costs and skid costs.

t) Use CROSSTAB and select the cross-classification image option. Choose HAULZONE as the first image and SKIDZONE as the second image to create a new output image called TRANZONE.

3. *Which transportation zone has the least cost associated with getting wood to the mill? Which zone has the highest costs?*

Defining Timber Volumes within Transportation Zones

Any definition of true timber volumes would require yield estimates per hectare for each forest cover type. Yield estimates are not available for this study area. However, you can get a rough sense of comparative volumes by examining the area of each cover type within various management zones. In this case, you will look at the relative distribution of the various forest cover types (FORTYPE) within each of the transportation zones (TRANZONE).

u) To do this, run CROSSTAB and indicate that you wish to produce a crosstabulation table. Enter TRANZONE as the first image and FORTYPE as the second image. A cross-classification table will subsequently be displayed.

4. *Given that each cell represents 0.01 hectare, how many hectares of White Pine are in the least cost transportation zone? (If you forgot the corresponding class values of the forest types or transportation zones, use Metadata with FORTYPE and TRANZONE and click on the Categories tab.)*

5. *Which transportation zones contain Red Maple? How many hectares are available in each? What are the economic characteristics of these zones?*

There are many more analyses of this nature that could be performed. For example, if you wanted to determine what timbershed contained the Red Maple in its most accessible zone, you could do a CROSSTAB of BESTZONE against FORTYPE.

What you have experimented with in this exercise, then, is a set of procedures for evaluating the costs of natural resource extraction and the establishment of management zones based on those costs. Think of some other analyses that are of interest to you and explore them on your own.

We would like to thank Dr. Dana Tomlin and Ms. Beni Patel, formerly of the School of Natural Resources of The Ohio State University for providing the data that were used in this exercise.

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Exercise 6: Analyzing Deforestation and Soil Loss in Northern Thailand

The tropical forests of northern Thailand have been declining due to population pressures and increasing demands for agricultural land. Thailand recently began exporting agricultural products and to increase production, lowland farmers are moving into the surrounding hillsides to expand the area under cultivation. To accommodate this expansion, forests are being cleared by slashing and burning. In this hilly to mountainous area the soils are generally nutrient-poor, so areas are cultivated for about a year and then left fallow. If the fallow period is long enough (15-20 years), the forest will begin to regenerate. However, with the increasing pressure on land the cycle of fallow has changed from 20-50 years to 7-15 years, generally impeding reestablishment of the forests. Soil erosion is also a significant problem in this area where hillsides with moderate to steep slopes are cultivated. Also, during the first years in which the land is fallow, the soil is exposed to sun and rains, further exacerbating erosion.

In this exercise, you will analyze the rates and magnitudes of deforestation and soil loss in Northern Thailand. A strategy developed as part of a joint study by the government of Thailand and UNEP/GRID (United Nations Environment Programme/Global Resource Information Database) will guide the analysis (UNEP/GRID, 1990). Some additional steps that were not included in the UNEP/GRID report will also be taken. We thank Gary E. Johnson of UNEP/GRID for providing the data for this exercise.

For this exercise, you will be working with environmental data from Chiang Mai Province. This area is a flat plain that gives way to hilly and mountainous terrain to the west. It is near the Ping River Basin, where the city of Chiang Mai is located. Local forest types tend to change with elevation. Dense evergreen forests are located in the higher elevations above 600 meters, mixed deciduous forests in the 300-600 meter range and wet to dry dipterocarps in the lower elevations and hills below 300 meters. Agriculture is the primary economic activity, with some forest-based industry in the form of furniture manufacturing. In addition, commercial rice plantations that can tolerate double cropping practices are found in the lowland areas while shifting cultivation is practiced in the higher elevations.

This exercise is broken into four parts. In Part A you will examine deforestation for the entire province of Chiang Mai. For Parts B, C and D you will use data from a smaller study area within Chiang Mai Province, the Mae Klang watershed, southwest of Chiang Mai city. In Part B, you will use the Universal Soil Loss Equation (USLE) to analyze soil loss. In Part C, you will identify high priority areas for soil conservation efforts. Finally, in Part D, you will predict future areas of deforestation and the affect of this change on soil loss for the watershed.

Part A: Measuring Deforestation

To quantify the problem of deforestation, we will use a data set that includes three images prepared by Thailand's Royal Forestry Department that show forest cover. The dates represented are 1975, 1979, and 1985. Each image is based on the classification of Landsat MSS (Multispectral Scanner) imagery by remote sensing experts at the Forestry Department. The storage size of each of these images was originally about 8 megabytes. To reduce processing time and storage requirements for this exercise, we contracted the images using pixel thinning.

a) Before performing any operations, make sure the main Working folder is set correctly in IDRISI Explorer to the folder including the data for this exercise (e.g., \UNITAR\Forestry\Data\Exer6). Also open User Preferences under the File menu and click the Revert to Defaults button, then OK, to ensure that the automatic display parameters are set properly.

b) Display each of the classified images THAI75, THAI79 and THAI85 using the Qualitative palette. Now use Metadata to look at the documentation information for the 1975 image, THAI75.

1. *What are the reference units of this image? What is the resolution? If the original cell size was 100 meters, by what number of cells has the image been contracted or thinned? What is a possible consequence of contracting images?*

c) Visually compare the THAI75, THAI79 and THAI85 images.

2. *Describe in general terms the differences you see from one year to the next.*

Now that you have a visual sense of the changes that have occurred between 1975, 1979, and 1985, you will quantify the change in forest/non-forest areas over time.

d) Run the module AREA and choose tabular output, and select the input image THAI75. Choose to calculate area units in hectares and click OK. Record the values for the forest and non-forest categories in Table 1. Note that category zero represents background areas outside the province. Repeat these steps for THAI79 and THAI85.

	FOREST	NON-FOREST
THAI75		
THAI79		
THAI85		

Table 1

3. *What is the amount of change in the non-forested area between 75 and 79 and between 79 and 85? What are the average annual increases in non-forested area for the two time periods?*

You should have seen the total amount of non-forested areas increase from 1975 through 1985. However, the annual difference between 1979 and 1985 should be quite smaller than the annual difference between 1975 and 1979. In the original report, the researchers suggested that deforestation due to the pressure to expand agriculture had slowed by the later period, while that due to shifting cultivation by the hill tribes continued.

Now that you have measured the non-forested areas in the images and have calculated the rates of change over the two time periods, create an image that shows spatially how the non-forested and forested areas have changed. To do this, you will use crosstabulation.

e) Run CROSSTAB using the Hard Classification option. Enter THAI75 as the first image and THAI79 as the second image. (Image order is critical in interpreting the legend, so be certain you use this order.) Choose the cross-classification image option and give 75-79 as the output image name.

4. *Interpret the legend categories of the output image 75-79 in Table 2. The first category has been done for you.*

Value in Image	Category Label	Interpretation
1	0|0	Background in both 75 and 79
2	1|1	
3	2|1	
4	1|2	
5	2|2	

Table 2

The legend indicates that there are areas that changed from non-forest in 1975 to forest in 1979 (value 3, label 2|1), yet these are difficult to see in the image. The category highlight facility will help you find these areas.

f) Click the mouse on the legend color box of category 3. In the display, that category is now shown in red and all other values are shown in black. There are very few pixels in this category and they are located near the bottom of the image. As soon as the mouse button is released, the display will revert to normal.

The crosstabulation has captured spatial details regarding changes between 1975 and 1979 in forested and non-forested areas that were lost in the simple area differences you calculated above.

Next you will incorporate the third image, THAI85, into the analysis.

g) Run CROSSTAB again, with 75-79 as the first image and THAI85 as the second image. Choose the cross-classification image option and give 75-79-85 as the output image name.

The interpretation of the output image requires careful thought. The image *values* in the 75-79 image are matched with those of the THAI85 image. Using the information from Table 2 above, you can interpret each value in the 75-79-85 image as a particular combination of background, forest and non-forest pixels. This is done for you and is shown in Table 3.

Value in 75-79-85	Category Label	75 category	79 category	85 category	Interpretation
1	1|0	0	0	0	Background outside the province
2	2|1	1	1	1	Forested in all three years
3	3|1	2	1	1	Non-forested in 75, but forested in 79 and 85: REFORESTED in 79
4	4|1	1	2	1	Forested in 75, non-forested in 79, then forested in 85: DEFORESTED in 79, REFORESTED in 85
5	5|1	2	2	1	Non-forested in 75 and 79, then forested in 85: REFORESTED in 85
6	2|2	1	1	2	Forested in 75 and 79, but non-forested in 85: DEFORESTED in 85
7	4|2	1	2	2	Forested in 75, non-forested in 79 and 85: DEFORESTED in 79
8	5|2	2	2	2	Non-forested in all three years

Table 3

h) Run AREA with 75-79-85 to produce tabular output in hectares.

5. *What area, in hectares, was deforested between 75 and 79? Between 79 and 85? Calculate the annual average for each time period. Why do these values differ from those you gave in question 3 above? What area was reforested between 75 and 79? Between 79 and 85?*

6. *What was the percent increase in non-forested area between 1979 and 1985? (Use values from table 1 to answer this.) What annual percent increase is that? You will use this figure in the next part of the exercise.*

i) Enhance the display of the 75-79-85 crosstab image by adding legend captions. Update the legend descriptions by using Metadata. Select the file 75-79-85 and double-click on the Categories option in Metadata. Add legend captions for categories 1 through 8 and enter legend descriptions. Save changes and redisplay the image.

The 74-79-85 image contains a wealth of useful information. However, it is difficult to interpret, even with the legend captions. It may be easier to convey the information contained in this image by pulling out specific values to create new images. You will next create a new image that highlights information about deforestation in Chiang Mai province.

j) Use information from Table 3 and the following coding scheme to create an attribute values file in Edit called DEFORESTATION. The left column of the file should list the values 1-8 of the 75-79-85 image while the right column lists the new values to be assigned. New assignments are as follows:

Value 0 areas outside the watershed

Value 1 areas that were non-forest in 1975

Value 2 areas that were deforested between 1975 and 1979

Value 3 areas that were deforested between 1979 and 1985

Value 4 all other areas

k) Use ASSIGN with the feature definition image 75-79-85 and the values file DEFORESTATION to create the output image DEFORESTATION.

l) Now, in Metadata, add legend category captions to the DEFORESTATION image. Although the image contains values 0-4, it is not necessary to enter a caption for every code. Those that do not have captions will not be displayed in the image legend. Save the changes, then redisplay the image.

m) Finally, create a special palette for use with this image. Open Symbol Workshop from the toolbar (third icon from the left) or from the Display menu. Choose File/New and choose the palette file option. Enter the palette filename DEFORESTATION then click OK. Now click each color box 0-4 and choose the color you want for each. The colors you choose should help the viewer of the image understand the information presented. Save the file you create. To apply the new palette to the image, click on the map image window to bring it into focus, choose Layer Properties on Composer, then select the new palette file. You can work between Symbol Workshop and the display in this way until you finalize the palette colors. (Note that you need to save the palette file before applying it to the image to see the changes you have made.) When you are satisfied with your palette, close Symbol Workshop.

Optional: Use Map Properties on Composer to create a map composition for the DEFORESTATION image. Add map elements as desired. For example, you may choose to include a text inset with information about methodology and area figures.

This concludes the first part of this exercise. In the following three parts, you will focus on a smaller study area to model soil loss and future changes to landcover. Do not delete the 75-79-85 image since you will use it again in Part D of this exercise.

Part B: Measuring Soil Loss

In the UNEP/GRID study of deforestation, soil loss was mentioned as a significant problem due to cultivation in hilly areas and the exposure of those areas to sun and heavy rains. In this exercise, you will try to quantify the amount of soil lost in the Mae Klang watershed, a subset of Chiang Mai Province, using a 1985 classification of land cover. To measure soil loss, the UNEP/GRID researchers applied the Universal Soil Loss Equation (USLE), using the corresponding United States Department of Agriculture (USDA) handbook. The soil loss equation is based on soil, vegetation, climate, terrain, and management factors.

The USLE was derived empirically from thousands of field measurements in the Midwestern United States. While the equation cannot be transferred to another area with the same results expected, it has been shown to produce useful indices of soil loss in some non-midwestern US locations. This is especially true when the equation is refined for local conditions by experts using local data and when actual measurements of soil loss can be used to calibrate the indices produced by the equation. Such calibration data is not available for this exercise. However, it is useful to go through the steps of the USLE, if only to get a sense of the possibilities of this type of GIS analysis.

The USLE equation is give as A=K*C*R*LS*P, where

A=soil loss in metric tons per hectare per year

K= soil erodibility factor

C=vegetative cover factor

R=rainfall and run-off factor

LS=slope and slope length factor

P=conservation practices factor

The soil erodibility factor (K) takes into account the structure of the soil and its organic matter content. For this study, the information contained on soil maps for lowland areas was sufficient to derive soil erodibility factors. For the upland soils, a field study was conducted by researchers from Kasetsart University. The soil erodibility factors were developed based on a 1 kilometer grid and then resampled to a 50 meter by 50 meter cell size.

n) Display the K factor image, KFACTOR, with the Quantitative palette. Use Cursor Inquiry Mode to check the K factor values. The value of the K factor ranges from 0.11 to 0.35.

7. *Why does the image look "blocky"?*

The C factor is usually referred to as the crop practice factor, but in this case it is called the vegetative cover factor since not all areas in the watershed are crops. This factor represents the ratio of soil loss under a vegetative cover type to soil loss from bare soil. Plant structure and stages of growth contribute to the C factor. For this study, 1984 and 1985 Landsat MSS data and a ground-truth exercise were used to describe a nine-class ground cover classification. The C factor was calculated for these nine cover types. Because of certain burning practices in the area, a subjective judgment was included in the C factor by forestry experts at the Royal Forestry Department. As the report states:

> In the area where shifting cultivation is practiced, the farmers, in clearing their fields during the dry season for preparation for food crops during the wet season, most often allow the fires to spread beyond the immediate field which causes massive forest fires in the adjacent forest. As a result the litter that normally accumulates on the forest floor is burned every year. This occurs in both the deciduous and the dry dipterocarps forest areas. The evergreen forests that are usually wetter are normally not burned by this practice. Therefore, the C factor for the forest areas has been modified to reflect this burning practice. (p. 9).

o) Display LANDCOVER with the Qualitative palette. This image contains the results of the ground cover classification for the watershed. Now, display CFACTOR with the Quantitative palette. Use Cursor Inquiry Mode to examine some values in the image. Compare the KFACTOR, LANDCOVER and CFACTOR images.

The various C factors correspond to different ground cover types. These are listed in Table 4 along with the P factor (explained below).

Mae Klang Watershed		
GROUND COVER TYPE	C FACTOR	P FACTOR
Evergreen Forest	0.001	1
Abandoned Shifting Cultivation	0.35	1
Mixed Deciduous Forest	0.10	1
Dry Dipterocarps Forest	0.25	1
Open Dry Dipterocarps Forest/Scrub	0.40	1
Active Shifting Cultivation	0.65	1
Other Crops	0.65	1
Orchards and Villages	0.30	1
Paddy Fields	0.10	0.5

Table 4

The R factor is referred to as the rainfall erosivity index. The intensity and amount of rainfall are important factors for the USLE, since rain is a major component of erosion. R represents the annual value of the erosion index which is the product of kinetic energy revealed by the maximum 30 minute intensity of precipitation per hour, divided by 100. The R factor for the watershed was calculated based on 20 years of climatic data and was determined to be 464 for the entire watershed because the study area is small in comparison with climatic variation.

p) Display RFACTOR. Check the values of the image with Cursor Inquiry Mode. (All the areas in the watershed have the same value.)

The LS (slope and slope length) factor combines the length and steepness of the slope into one index number. Slope is an important factor, since under similar conditions, higher slopes undergo greater erosion. In this study, slope and slope length were calculated from elevation contours and slope values for a particular soil type. Detailed elevation data didn't include the extreme southern part of the study area. All the soils in the watershed were classified as steep uplands.

The values for the LS factor are contained in two images, LSFACTORLOW and LSFACTORHIGH. These images contain the low and high end members, respectively, of a range of LS factors originally assigned to categories in a single image.[4] Because the USLE calculation requires each pixel to have an actual LS value, rather than a category number and because a pixel may hold only a single value, not a range of values, two files were created. (You may want to return later to test the effect on the results of the USLE calculation of assigning the average value of each range to the LS factor image instead of the end members.)

8. *Use Metadata in IDRISI Explorer to determine the range of values in LSFACTORLOW and in LSFACTORHIGH.*

q) Display one of the LS factor images. Use Cursor Inquiry Mode to examine several values in the image.

The last factor image needed is P, or the conservation practices factor. This takes into account soil conservation practices, such as mulching and terracing and is derived from soil erosion tables based on land uses. For this study, the ground cover classification mentioned above was used for determining the P factor. P was given the value 1 for all areas except the paddy fields, which were given a P factor of 0.5 based on the fact that only rice farmers appeared to practice any terracing or erosion control. P values that correspond with each land cover type are also provided in Table 4.

4. The ranges given in the original category descriptions were: 0.00-0.20, 0.21-0.40, 0.41-0.60, 0.61-0.80, 0.81-1.00, 1.01-2.00, 2.01-4.00, 4.01-5.00, and >5.00.

r) Display the image PFACTOR.

Now that you have examined all the necessary factor images, you are ready to calculate the USLE. This could be done using a series of OVERLAY multiply operations, but it is more easily done with Image Calculator.

s) Open Image Calculator. The Mathematical Expression option is chosen by default. Type the output filename USLEHIGH into the output box. Then click in the Expression to Process box. Click the Insert Image button and choose the image KFACTOR from the list. Note that this automatically inserts the image name surrounded by square brackets into the expression input box. Use the Insert Image button and the other calculator keys to input the following expression:

[KFACTOR]*[CFACTOR]*[RFACTOR]*[LSFACTORHIGH]*[PFACTOR]

Click the Save Expression button and enter the filename as USLEHIGH. Click Save, then click Process Expression. The resulting image represents expected soil loss in tons per hectare.

t) Again in Image Calculator, change the output filename to be USLELOW. Edit the expression to use LSFACTORLOW instead of LSFACTORHIGH. Save the expression under the name USLELOW and then process the expression. Compare the two images.

9. What general areas are showing the highest/lowest amounts of soil loss? Do you see any obvious differences between USLEHIGH and USLELOW?

The USLE calculation produces a figure for each pixel representing tons of soil loss per hectare. But each pixel is only 50 meters by 50 meters, i.e., only a quarter of a hectare. You could easily divide each image by 4 to account for this. However, since you are not provided with information for calibrating the USLE to local conditions, trying to determine an actual amount of soil loss per pixel is not possible. The values in the final images can be used in a relative sense, however, to point out areas more susceptible to soil loss. You can reclassify the raw values to identify the areas with the most soil loss according to the model. You can also analyze the modeled soil loss values in relation to the landcover. Both of these activities can help to identify areas in which soil conservation efforts should be aimed and are illustrated in the next section of the exercise.

Part C: Identifying High Priority Soil Loss Areas

In this section, you will identify the 10% of the watershed that has the highest soil loss values.

10. How many cells (pixels) comprise 10% of the watershed? (Be sure to exclude the background from your calculations.) How did you determine this?

The values in the image USLELOW indicate the expected amount of soil loss per hectare in tons per year. You will create an image that identifies the 6381 cells with the highest modeled soil loss.

u) A numeric histogram will allow you to determine the threshold value at which to reclassify USLELOW to create the new image. Run HISTO and enter USLELOW as the input image. Choose numeric output type, set the class width to 1, and change the maximum value to be 634. Click OK. The numeric histogram is displayed in a window. Use the scroll bars to view the entire histogram.

You want to find the value that separates the 6381 cells with the highest soil loss values from the rest of the cells in the image. The histogram begins with the lowest value in the image. Therefore, you will need to subtract 6381 from the total number of cells in the image to determine the cumulative frequency at which to set the threshold.

Total number of cells in the image: 113826 (scroll to the bottom of the histogram to find this).

Cumulative frequency separating the 10% of the watershed pixels with the highest values from the remainder of the watershed and the background pixels: 113826-6381=107445

v) Now search the cumulative frequency column for the value nearest to 107445. This exact value is not listed, but would fall between two values.

Class	Lower Limit	Upper Limit	Frequency	Prop.	Cum. Freq.	Cum. Prop.
204	204.0000	204.9999	285	0.0025	106526	0.9359
205	205.0000	205.9999	5	0.0000	106531	0.9359
206	206.0000	206.9999	0	0.0000	106531	0.9359
207	207.0000	207.9999	0	0.0000	106531	0.9359
208	208.0000	208.9999	244	0.0021	106775	0.9381
209	209.0000	209.9999	0	0.0000	106775	0.9381
210	210.0000	210.9999	0	0.0000	**106775**	0.9381
211	211.0000	211.9999	1532	0.0135	**108307**	0.9515
212	212.0000	212.9999	2	0.0000	108309	0.9515
213	213.0000	213.9999	0	0.0000	108309	0.9515
214	214.0000	214.9999	779	0.0068	109088	0.9584

There are 106775 pixels with the value 210.9999 or less, leaving 7051 pixels with values of 211 or higher. This is slightly more than the 6381 pixels needed to make up 10% of the watershed. There are 108307 pixels with the value 211.9999 or less, leaving 5519 pixels with higher values. This is less than the target 10%. There is no logical way to choose only some of the pixels with value 211 to arrive exactly at 10%. Instead, you will work with the threshold 211, identifying the 7051 pixels (approximately 11% of the watershed) with the highest modeled soil loss.

w) Use RECLASS with USLELOW to create the output image HIGHPRIORITY. Assign the new value 0 to old values from 0 to just less than 211 and a new value of 1 to old values from 211 to just less than 634.

The Boolean image just created could be used for management purposes to target soil loss mitigation efforts. However, the image might be more useful if the prioritized areas were shown with their landcover types rather than in a simple Boolean image. You will next create an image showing the landcover types of the prioritized areas, the rest of the watershed, and the background.

11. *What is a very simple way to create an image in which each high priority pixel has the value of its corresponding landcover class?*

x) Create the image as you described above and call the output image PRIORITYLANDCOV. (You may need to change to the Qualitative palette using Layer Properties.)

The image shows the landcover type for the selected pixels, but does not differentiate between the watershed and the background values. To fix this, you should first decide what the values in the final image should be. If you leave the background areas with the value 0 and the landcovers with their original values 1-9, it would make sense to set the areas in the watershed that are not high priority to the value 10.

y) To do this, first make a mask image of the watershed in which the areas inside the watershed are assigned the value 10 and those outside the watershed are assigned the value 0. This can be created using either RECLASS or Edit/ASSIGN with LANDCOVER as the input file. Call the mask image WATERSHED10.

Use OVERLAY with PRIORITYLANDCOV as the first image, WATERSHED10 as the second image and the Cover option. Call the output image PRIORITIZED SOIL LOSS AREAS.

z) To add a meaningful legend to the image, open Metadata and choose the file PRIORITIZED SOIL LOSS AREAS. The landcover legend can be copied from LANDCOVER since the class values are the same in both images. Double-click on the Cateogories option to open the Categories form, then choose the option to Copy a legend from another file. Select LANDCOVER. You may wish to add a legend category for code 10 and code 0, or you may leave these out of the legend. To display the updated legend information, redisplay PRIORITIZED SOIL LOSS AREAS.

aa) You may also wish to use Symbol Workshop to create an appropriate palette for the image. Finally, if desired, type up a summary of what the image shows and save it as a text file (.txt) in Edit. Then add this to the map composition as a text inset.

ab) In the next few steps, you will quantify the landcover composition of the high priority areas. To do so, first run AREA with PRIORITIZED SOIL LOSS AREAS and request tabular output.

12. What landcover category contributes the most area? Do some land cover categories contribute nothing? List each landcover and the area in hectares it contributes to the prioritized soil loss areas.

ac) It may also be meaningful to determine what proportion of each landcover in the watershed has been identified as contributing to areas of high priority soil loss. To calculate this percentage, you will divide the figures for the high priority areas you found above by the total area of each landcover class. This can easily be done with a calculator. Calculations for two landcovers are shown here:

	Area High Priority	Total Area	Proportion
Dry Dipterocarp Forest	68.5	5653.75	1.2%
Active Shifting Cultivation	135	184.75	73%

If there were many more landcover categories, it might not be practical to calculate the proportions by hand. There are several ways the calculation could be accomplished using only the GIS. The easiest way is to calculate the area figures as *images* rather than tabular output. These images may then be divided (using OVERLAY). The desired proportions may then be summarized using EXTRACT.

ad) Run AREA with LANDCOVER. Use the Image output option, calculate in hectares and call the resulting image LANDCOVERHA.

ae) Run AREA with PRIORITYLANDCOV. Use the Image output option, calculate in hectares and call the resulting image PRIORITYLANDCOVHA.

The values in images produced by AREA indicate the total area per class. In other words, each pixel of a landcover class is assigned a value equal to the total area of its class in the image.

af) Use Image Calculator to perform the proportion calculations. Enter PROPORTION as the output filename. In the Expression input box, enter then process the following expression:

([PRIORITYLANDCOVHA] / [LANDCOVERHA]) * 100

ag) Finally, to summarize the proportion information, use EXTRACT with PRIORITIZED SOIL LOSS AREAS as the feature definition image and PROPORTION as the image to be analyzed. Choose the average summary statistic (min and max should produce the same result since all pixels of the same category have the same proportion). Choose to create a tabular output.

13. List the landcovers in the watershed and the proportion of each that contributes to the areas identified as high priority soil loss areas.

ah) Optional: Repeat Part C of the exercise using USLEHIGH rather than USLELOW. Compare the results.

Part D: Deforestation and Soil Loss

In the exercise so far, you have looked at the problems of deforestation and soil loss separately. However, according to the UNEP/GRID study, deforestation in northern Thailand exacerbates soil erosion. How can you examine more closely the relationship between deforestation and soil loss? Part of the answer lies in the USLE. The only factors that can be affected by humans in the USLE are the P factor (conservation practices) and the C factor (land cover/crop type). If you assume that the P factor remains unchanged, but that the C factor is changed due to increased deforestation, you can then predict what effect that change would have on the USLE results. In other words, given a certain increase in deforestation in the watershed, what increase in soil loss can be expected?

You will be using the data for the Mae Klang watershed in this part of the exercise. To explore the relationship between deforestation and soil loss, you will begin with the 1985 land cover map, then you will predict what the same map might look like in the year 2000 given several assumptions and what you found in Part A about deforestation in the larger study area. Once you have created the image of ground cover in the year 2000, you can then reevaluate the USLE and compare it to results using the 1985 image.

Please note that what you will do is for the purposes of this exercise only, to illustrate how a simple "what if" scenario might be evaluated. You don't have enough information to carry out a more complex and realistic predictive study. If this were an actual study, all of your assumptions would have to be carefully examined and be based on more solid evidence.

The creation of the image of groundcover for the year 2000 will be based upon the following four basic assumptions:

1. Areas of future deforestation will be within a given distance from currently deforested areas. Areas beyond this distance will not be deforested. In addition, the probability that an area will become deforested is higher the closer it is to a currently deforested area, though there is also an element of randomness in predicting which areas will be deforested.

2. Future deforestation will take place only in the Mixed Deciduous Forest landcover class and all the newly deforested areas will become part of the Shifting Cultivation class. The sole change that will be made in the land cover map, therefore, is the change from Mixed Deciduous Forest to Shifting Cultivation.

3. The rate of deforestation between 1985 (the data of our most recent data) and 2000 will be a constant 2.4 percent per year, the rate you obtained in Part A of this exercise. You assume therefore, that there will be 36 percent more deforested area in 2000 than there was in 1985.

4. Information found using data for the entire province, such as average rates of deforestation, can be applied to the smaller watershed study area with accuracy.

Start with the first part of the first assumption. How far do people tend to move into the forest from a deforested area in order to clear new land for shifting cultivation? You can answer this question by using the 1979 and 1984 deforestation maps for the entire province. You will find the average distance between the deforested areas in 1979 and the newly deforested areas in 1985. Since this "spread" occurred over a 6 year period, you will divide the result by 6 to get an average yearly distance. You will then multiply by 15 to get the distance you expect over a 15-year period. This result will be used as the limit for the distance between deforested areas in 1985 and predicted areas of deforestation in 2000 for the Mae Klang watershed.

ai) Display THAI79 using the Qualitative palette. Then create a Boolean image in which the non-forested areas of THAI79 have the value 1 and all else has the value 0. Call the mask NONFOR79. This is the image from which distances will be calculated.

aj) To create an image of distances from the non-forested areas in the mask, use the module DISTANCE from the GIS Analysis/Distance Operators menu, with NONFOR79 as the feature image and call the output image DIST79.

Each pixel in DIST79 has the value of its distance (in meters) from the nearest 1979 non-forest pixel. The next step is to find out the average distance from the non-forested areas of THAI79 to the newly deforested areas in THAI85.

> 14. *What image created in Part B of this exercise shows all the categories of change between forest and nonforest between 1979 and 1985? Which category in that image represents areas that were forested in 1979 but deforested in 1985?*

ak) To find the average distance between nonforest in 1979 and forest in 1985, run EXTRACT and specify 75-79-85 as the feature definition image and DIST79 as the image to be processed. Choose the average option and have the information output in tabular form.

> 15. *What is the average distance from the non-forest areas of 1979 to the newly deforested areas of 1985? (Look at the category you gave in answer to question 15.) Given this distance is measured over a 6 year period, what is the average distance per year? What would be the total expected distance over a 15-year period?*

This is the distance limit you will use for the first part of the first basic assumption. While this limit was derived from data for the entire province, you must assume that it can be applied to the Mai Klang watershed as well (the fourth basic assumption).

You now want to identify all the areas on the 1985 land cover map for the Mai Klang watershed that are deforested. Any pixels falling within the calculated 15-year distance limit from these currently deforested pixels are potential sites of deforestation in the year 2000.

al) Look at LANDCOVER using the Qualitative palette. This is the 1985 landcover map. The non-forest categories in this image are abandoned and active shifting cultivation, other crops, orchids/village and paddy fields. Use RECLASS or Edit and ASSIGN to create a Boolean image in which all non-forest categories have the value 1 and everything else has the value 0. Call the result NONFOR85.

am) Run the module DISTANCE with NONFOR85. Call the resulting image DIST85.

> 16. *Check Metadata or Layer Properties for the maximum value in DIST85. It is clear from the DIST85 image that the maximum distances actually fall outside the study area. How could you find the maximum distance from nonforested areas in the watershed? What is that value?*

> 17. *According to our first assumption, which cell in DIST85 is more likely to be deforested in 2000, one with the value 70 or one with the value 39? Explain.*

To finish up the part of the prediction based on the first assumption, you must add an element of randomness in selecting those cells that will be deforested.[5] To do this, you will use the module RANDOM. RANDOM will create an image of the size you specify containing a random distribution of values.

an) Run RANDOM from the GIS Analysis/Statistics menu. Enter NONFOR85 as the reference image to define columns, rows and reference system. Call the output RAND and choose real data type and binary file type, with the rectilinear (equal frequencies) distribution type. Use Cursor Inquiry Mode to examine some of the values in RAND. Note that the minimum and maximum values are within the range of zero to one.

The element of the prediction that is deterministic (based on distance from currently deforested areas) must be combined with the element that is purely random. To combine these, you will use OVERLAY to multiply the two probability images, producing a new image that combines the properties of both.

ao) Use OVERLAY to multiply DIST85 and RAND. Call the result COMBINED PROBABILITY for "combined

5. Non-random factors other than distance from currently deforested areas may also affect the location of new deforestation. This is something you would need to investigate thoroughly if you were actually doing a study of this nature.

probability."

ap) Use Layer Properties or Metadata to find the range of values in COMBINED PROBABILITY.

18. Which cells in COMBINED PROBABILITY are more likely to be deforested in 2000, those with the higher values or those with the lower values?

COMBINED PROBABILITY doesn't account for one very important factor determining the probability that an area will be deforested. Remember, the second assumption stated at the beginning of Part C was that only mixed deciduous areas were going to be candidates for deforestation.

aq) Create a Boolean image in which the mixed deciduous areas from the landcover map, LANDCOVER, have value 1 and everything else has the value 0. Call the new image MIXEDDECIDUOUS. Use OVERLAY to multiply MIXEDDECIDUOUS and COMBINED PROBABILITY. Call the result FINAL PROBABILITY. This is the final probability image.

19. According to your assumptions, is it possible that a cell with the value 0 in FINAL PROBABILITY will be deforested in 2000? In reality, is it possible that this cell could be deforested in 2000? According to your assumptions, which non-zero cells in FINAL PROBABILITY are most likely to be deforested, those with high values or those with low values?

The remaining step is to decide how many and which cells to select as deforested in 2000. Your third basic assumption stated that you expect to see 36 percent more deforested area in 2000 than you see in 1985. You don't have information about deforested areas in the watershed. Therefore, assume that the entire area would naturally be forested, so any non-forest areas can be defined as deforested. Given this assumption, use NONFOR85 as the image of already deforested land. Figure out how many cells must be added to this category to represent a 36 percent increase in deforestation.

ar) Run AREA on NONFOR85. Ask for tabular output in cells to determine the number of cells in the non-forested category.

20. How many cells belong to the non-forested category in 1985? How many cells must change from mixed deciduous to shifting cultivation to produce a 36 percent increase in deforested area in 2000?

You now know how many cells you must select for future deforestation. The remaining step is to determine which cells to select. As you did in Part B, above, you will use a numeric histogram to determine the threshold value in FINAL PROBABILITY that separates the desired number of cells from the rest of the image. This time, however, the process is slightly more complicated in that you want to select cells with low values, but you do not want to select cells with the value zero. The easiest way to address this is to determine the number of zero value cells in the image, and then add the number of cells desired for selection. The resulting number is the frequency at which you will set the threshold. The image MIXEDDECIDUOUS defines the zero value pixels.

as) Run AREA with MIXEDDECIDUOUS and record the number of cells with the value 0.

21. How many zero value cells are in MIXEDDECIDUOUS?

at) Run HISTO with FINAL PROBABILITY and specify numeric output and a class width of 0.5. Click OK. Find the cumulative frequency closest to the number of zero-value cells (question # above) plus the number of cells you wish to select for deforestation (question # above). It is unlikely that you will find the exact cumulative frequency – simply choose the closest.

au) Use the maximum class limit for that cumulative frequency as the threshold value with RECLASS and FINAL PROBABILITY. Assign the value 1 to all values from 0 to just less than the threshold value and the value 0 from the threshold value to just less than a number larger than the maximum value in the image. Call the resulting image TEMP. This is a temporary file since you still need to differentiate the zero-value probability cells from the selected cells.

av) Now OVERLAY TEMP with MIXEDDECIDUOUS using the multiplication option. Call the resulting image SELECT. (To check your work, run AREA and check that the number of cells with value 1 is close to the number you wanted to select for deforestation.)

Now that you have predicted where future deforestation is likely to occur, you are ready to proceed with the question of the relationship between deforestation and soil loss.

Look at Table 3 in Part B of this exercise and note the C factor values for mixed deciduous and active shifting cultivation. All the pixels in SELECT with a value of 1 originally had a C factor value of 0.10. In 2000 these pixels will have a C factor value of 0.65. The next step is to create a new C factor map that corresponds to the predicted conditions in 2000.

aw) Create a new image in which the selected pixels have the value 0.65. The easiest way to do this is by using Image Calculator to multiply the image SELECT by 0.65. Call the resulting image SELECTCFACTOR.

ax) Now update the original C factor image with the new values for the pixels predicted to become deforested. Do this using OVERLAY with the First covers second except where zero option. SELECTCFACTOR is the first image and CFACTOR is the second image. Call the resulting image CFACTOR2000.

There are no other factors of the USLE model that need to be changed. You are now ready to re-evaluate the USLE for the predicted conditions of 2000.

ay) Open Image Calculator and choose to Open Expression. Select the expression USLEHIGH that you created earlier. Enter USLEHIGH2000 as the output filename. Change the C factor image from CFACTOR to CFACTOR2000.

az) Summarize the total predicted soil loss for the watershed in 2000 using EXTRACT. WATERSHED10 is the feature definition image and USLEHIGH2000 is the image to process. Choose to calculate the total (sum) and specify tabular output.

22. *With the predicted changes in landcover, what amount of soil loss is now expected for the year 2000?*

ba) Now extract the sum of soil loss for 1985. Use EXTRACT with WATERSHED10 and USLEHIGH.

23. *According to this model, what is the total expected increase in soil loss from the predicted landcover changes?*

bb) Optional: Extract sums for the low USLE prediction as well.

As you can see, predicting future changes can be quite complex. If any of your basic assumptions are not valid, the result can be quite distorted. Obviously, the more exact the result must be, the more critical you must be of the assumptions upon which you base the analysis.

Although the approaches to the questions addressed in this exercise were somewhat simplified, the exercise showed many of the available tools GIS offers to addressing complex analyses.

References

UNEP/GRID, 1990 "An Analysis of Deforestation and Associated Environmental Hazards in Northern Thailand: A Joint Thailand – UNEP/GRID Case Study", *GRID Case Study Series No. 3*. Bangkok, Thailand.

Exercise 7: Monitoring Land Use in Rondonia, Brazil using AVHRR and TM Imagery

Deforestation in tropical forest regions has received much publicity in recent years. In this exercise, you will explore the potential use of high- and low-resolution satellite imagery as a means of monitoring forest change. The study area is the central portion of the state of Rondonia in western Brazil. This area has been the subject of massive colonization and deforestation since the early 1970's.

You will use imagery from two satellite/sensor systems in this exercise: the Advanced Very High Resolution Radiometer (AVHRR) from the NOAA Advanced TIROS-N series satellites (specifically NOAA-9 Local Area Coverage) and the Thematic Mapper (TM) from the Landsat series satellites (specifically Landsat 5). Both images were acquired in July of 1988. The TM imagery was acquired from CNPq/INPE (Instituto de Pesquis Espaciais) in Brazil. AVHRR imagery was made available by The Woods Hold Research Center, in Massachusetts.

Part A: Exploring the Imagery

a) Before performing any operations, make sure the main Working folder is set correctly in IDRISI Explorer to the folder including the data for this exercise (e.g., \UNITAR\Forestry\Data\Exer7). Also open User Preferences under the File menu and click the Revert to Defaults button, then OK, to ensure that the automatic display parameters are set properly.

b) Display the image LACCOMP. The upper-right part of the image has been cropped along the boundaries of the state. The resolution of this image is 1 kilometer. This composite image is a false color composite of AVHRR bands 1, 2 and 3 for central Rondonia.

The AVHRR sensor gathers data in 5 wavelength bands as follows:

Band 1	Visible Red	0.58-0.68 micrometers
Band 2	Near Infrared	0.72-1.10
Band 3	Thermal Infrared	3.55-3.93
Band 4	Thermal Infrared	10.50-11.50
Band 5	Thermal Infrared	11.50-12.50

The false color composite is made from Bands 1, 2, and 3 assigned to display colors blue, green and red respectively. The colors thus do not reflect those you would see with your eye. Additionally, this is not a standard false color composite (which typically uses the green, red, and infrared bands). Therefore the colors may seem unfamiliar. Vegetation is displayed in green on this image for the following reasons:

• Band 1 is the area of the electromagnetic spectrum where chlorophyll absorbs strongly for photosynthesis. Since absorption is strong, reflection of sunlight is weak in this band, and it is the reflected energy that the satellite sensors measure. This band is assigned the blue color in the composite.

• Vegetation reflects very strongly in Band 2 because of leaf structure. In addition, these wavelengths are not used by plants for photosynthesis. This band is assigned green in the color composite.

• Band 3 is a thermal band. Forest areas tend to reflect less (and therefore appear darker) than non-forested areas. This band is assigned red in the color composite.

The dominant reflectance is therefore in Band 2, which is colored green on this composite.

The colonization scheme is clearly visible in this image. The river flowing across the upper-right is the Jiparana. The towns of Rolim de Moura and Ji Parana are visible at column/row positions of (182,159) and (164,65) respectively. (To find these points move the cursor over the image and look at the column/row position indicated at the bottom of the screen.) Notice how the colonization scheme branches off from the road running to the northwest of Ji Parana.

c) Now, in contrast, examine a Landsat TM color composite image for part of the same region. Display TMCOMP with the Color Composite palette.

This image is also a false color composite, created from a set of bands that were intended to produce an image similar to LACCOMP. The Landsat TM bands are:

Band 1	Visible Blue	0.45-0.52 micrometers
Band 2	Visible Green	0.52-0.60
Band 3	Visible Red	0.63-0.69
Band 4	Near Infrared	0.76-0.90
Band 5	Mid Infrared	1.55-1.75
Band 6	Thermal Infrared	10.4-12.5
Band 7	Mid Infrared	2.08-2.35

The bands that were used to create TMCOMP were bands 3, 4, and 5. Note that the bands are somewhat narrower than those of the AVHRR. Landsat bands 3 and 4 are very similar to bands 1 and 2 from AVHRR. This is the primary reason for the visual similarity between these composite images.

TM band 5 however is between two strong water absorption bands and thus tends to reflect the presence of moisture in vegetation and soils. This is apparent in the lower reflectance of forests in band 5 leading (in combination with the low reflectance in band 3 and the high reflectance on band 4) to the characteristic green color of the forest in the imagery.

The TM image has a resolution of 30 meters, over 33 times higher than that of the AVHRR image. Clearly you can see a much greater degree of detail in the higher resolution TM image.

d) Use the cursor again to locate the town of Rolim de Moura at the column/row position 2604/2052. (The town Jiparana that you found on LACCOMP is north of the image boundary of TMCOMP.) Zoom into one of the settlement areas at high resolution. You may wish to choose one of the roads branching off the large east-west road leading from Rolim de Moura.

1. *What appears to be the primary activity (land use) in these settlement areas?*

Imagery of this resolution can be very effective for the monitoring of deforestation. However, the cost and data volume involved with monitoring any substantial area is significant. In addition, TM imagery does not have the same temporal resolution as the AVHRR imagery. The AVHRR sensor images the entire earth every day. Landsat TM, however, has a 16-day repeat cycle. The time span between cloud-free images is, therefore, considerably longer with TM than with AVHRR. For this reason there has been considerable interest in the possibilities of using low spatial resolution/high temporal resolution AVHRR imagery for environmental monitoring. In this exercise you will explore this potential further. Specifically, in Part B you will attempt to gauge the accuracy with which AVHRR imagery is able to judge the extent of forest cover through image classification. Then, in Part C, you will explore, using the Normalized Difference Vegetation Index (NDVI), a relative measure of the degree of biomass as a means of monitoring deforestation with AVHRR data.

Part B: Testing the Accuracy of Forest Extent Monitoring Using AVHRR Imagery

Your first step will be to calculate the extent of forest cover for the region covered by the TM image. To do this you must first classify the images into forest/non-forested regions. The technique used is an unsupervised image classification.

e) Display TMCLUST with the Qualitative palette.

This image was created using the module CLUSTER from the TM bands 3, 4, and 5. You will notice that the legend captions for the three categories are not very descriptive.

2. *Which category appears to represent forest? What land uses do you think are represented by categories 2 and 3?*

f) Update the legend categories of the TMCLUST image by using Metadata. Choose the file TMCLUST and double-click the Categories option. Enter the codes 1, 2, and 3 along with their descriptions (according to your answer to the question above). Save the changes. Now display TMCLUST again with the Qualitative palette and a legend. You will notice that the new legend categories now appear.

g) Now run AREA on TMCLUST. Request tabular output in hectares.

3. *How many hectares belong to the forest class?*

You will use this area figure as your reference against which to compare the AVHRR results. The resolution of the TM imagery and the distinctiveness of the forest/non-forest boundary probably lead to a fairly accurate estimate.

h) Now repeat the above steps with LACCLUST. With the result, make a note of which cluster represents the forest category and update the legend captions accordingly.

At this point, you cannot simply calculate the area of the forested region in the AVHRR image to compare it to that of the TM image you calculated earlier. The AVHRR image covers a much larger region than the TM image. You will therefore first need to register the AVHRR image to the TM image and extract a sub-image of LACCLUST that matches the area covered by the TM data. To do this you will use RESAMPLE.

RESAMPLE is a rubber-sheet resampling program. It requires a set of common ground control points that can be located on both images. The procedure, which has been done for you, is to locate an X and Y location in the LACCOMP image. Then find exactly the same location in TMCOMP. These pairs of matching points are saved to a ground control point file (.cor).

i) Run RESAMPLE from the Reformat menu. Indicate that you wish to resample the input file named LACCLUST and call the output file RESCLUST. Enter the ground control point (GCP) file RONDONIA. There is one line per control point listing the current X and Y coordinates of ground control points in LACCLUST (the image to be transformed), and the X and Y coordinates they should have in the final result to match TMCLUST. You will be presented with a measure of the overall RMS error of the fit and the residuals of each point. Note that point 2 has a very high residual (1.69 cells!) Omit point 2 by selecting "No" in the Include box for point 2. Notice how the fit has improved. Now omit point 7.

4. *What was your final overall RMS error? What does this mean?*

j) Select a linear (polynomial) mapping function. Then indicate that the resampling technique to be used is nearest neighbor, and specify 1 as the background value. Then, under Output Reference Parameters, indicate that there will be 80 columns and 80 rows. Specify min. X and Y as 0, and max. X and Y as 80. Also indicate the final reference system should be plane, in meters, with a unit distance of 990 (the reason for this will be clear shortly – you are resampling this to a new grid with a cell size of 990 meters). Close the Reference Parameters dialog box.

k) After you have omitted points 2 and 7 from the fit, choose to continue with the resampling by clicking OK. Move the RESCLUST and TMCLUST images so you can view them simultaneously. Notice that the resampled image now covers the same area as TMCLUST.

l) Now run AREA again to determine the number of hectares of forest in the RESCLUST image (specify tabular output). Here you should arrive at a figure calculated from the AVHRR data that you can compare with the area results you measured from the TM data.

5. *What is the area of forest as calculated with the AVHRR image (i.e., the RESCLUST image)? How many hectares*

different is this from the TM estimate? What is the proportional difference? How well does this estimate correspond with the finding of Stone and Schlesinger (1990) that error rates of 5-20% can be expected?

Part C: Testing the Application of NDVI to Monitor Deforestation

One of the more important products that can be produced with AVHRR and TM imagery is a vegetation index image. Various indices have been proposed, but the most commonly used in the Normalized Difference Vegetation Index (NDVI). NDVI values indicate the relative amount of green vegetation present and are produced using the following formula:

NDVI=(infrared – red) / (infrared + red)

In IDRISI, NDVI can be calculated easily with the VEGINDEX or OVERLAY modules.

m) Create an NDVI image using OVERLAY. Choose the Normalized ratio option (First-Second/First+Second) and specify LAC2 as the first image (the infrared image) and LAC1 as the second image (the red image). Call the result LACNDVI. LACNDVI will be a real number image. Use Layer Properties from Composer to change the palette to be NDVI, which ranges from brown to dark green. The effects of the colonization scheme are clear. Use Cursor Inquiry Mode to explore the NDVI data values (the “z” value) for particular features.

6. *What is a typical NDVI value for forest? What is a typical value for agricultural areas? What is a typical value for urban areas? For clouds?*

You can look more systematically at the values of NDVI typically associated with forested and non-forested area. Your first step will be to window out the smaller study region covered by the TM data using RESAMPLE and then compare it to the map of forested and non-forested areas determined from the high-resolution imagery.

n) Use the same resampling procedure with the input image LACNDVI and the output resampled image should be RESNDVI. (Use the RONDONIA correspondence file, background value of 0, plane reference system in meters, unit distance of 990, background value of 0, linear/nearest neighbor resampling type, 0-80 as the min. and max. X and Y values and 80 columns and rows. Omit control points 2 and 7.) Change the palette for the RESNDVI display to be NDVI. Notice how the fishbone pattern of the settlement scheme is not so apparent as it is on the TM imagery.

To produce a comparison image of forested/non-forested areas you will first reduce the classified TM image (TMCLUST) to a similar resolution as the NDVI image (the classified AVHRR image). You could do this with resample, but since there is no change in the extent of the study area and the amount of reduction in resolution is by an integer factor, you can also use CONTRACT. You want to reduce the image 33 times to change from a 30-meter resolution to a 990-meter resolution.

o) Run CONTRACT from the Reformat menu, and indicate that you wish to contract TMCLUST to produce SMCLUST. Choose contraction by pixel thinning (this will have the same effect as the Nearest Neighbor option in RESAMPLE) and a contraction factor of 33 in both X and Y.

p) In SMCLUST, Category 1 is forest while categories 2 and 3 are non-forest. To create a Boolean image with only 1’s and 0’s to delineate forest and non-forest, you will need to reclassify all cases of 2’s and 3’s to 0. To do this, run RECLASS and indicate that you wish to reclassify SMCLUST to create SMFOREST. Use the user-defined option and indicate that you wish to assign a new value of 0 to the all values ranging from 2 to those just less than 4.

SMFOREST represents, at approximately the same resolution as the original AVHRR imagery, the best estimate of those areas that are forest and non-forest. You can use this to examine characteristic values of NDVI in the forested and non-forested areas.

q) To do this, run EXTRACT. Specify SMFOREST as the feature definition image and RESNDVI as the image to be processed. Indicate that you wish tabular output of the average (mean) NDVI in each of these two categories.

7. What are the average values of NDVI in forested and non-forested areas?

This does not seem to be a very strong difference, particularly given the wider range of contrasts you noticed in your previous exploration of LAC-NDVI. When you examined RESNDVI, you noticed that it seemed like the AVHRR sensor was not picking up the small settlement schemes very well. Perhaps it is the coarse resolution of the AVHRR that is the problem. With this coarser resolution, the sensor is essentially averaging the reflectances over the larger cell size. Perhaps these small settlement areas are being overwhelmed by the larger forested areas in this averaging process. And yet the strong differences between settlement and forest areas suggests that you should be seeing a fairly strong effect in this average.

To explore this further, you can take the TM data and mathematically simulate the effect of acquiring data with a lower resolution. To do this you need to run CONTRACT on the original TM bands to produce new ones at the 990-meter resolution. However, this time it is important to use the pixel contraction by aggregation option. This averages the values of the 33 by 33 group of pixels that form each of the pixels at the 990-meter resolution. To save time, this has already been done for you. The names of the contracted images are TM3990 and TM4990. These images are thus the red (TM band 3) and infrared (TM band 4) wavelength bands with an (approximately) equivalent resolution to the AVHRR data.

r) Use TM4990 and TM3990 with OVERLAY to create an NDVI image named SMNDVI. Use the Normalized Ratio option (First – Second / First + Second) with TM4990 as the first image and TM3990 as the second image.

s) Run EXTRACT to determine characteristic NDVI values in SMNDVI. The feature definition image is SMFOREST and the image to be processed is SMNDVI. Again, choose to have tabular output of the average.

8. What were the average NDVI values for forest and non-forest area. What differences do you find compared to the NDVI values produced with the AVHRR data?

Despite the fact that these two NDVI images were acquired from different satellites, the mean value of NDVI for the forest are similar. However, the mean NDVI in the non-forested areas is not identical. And yet, both images have the same resolution (one by simulation). How can the difference in NDVI in the non-forested areas be explained?

t) To explore this question further, display both the RESNDVI and SMNDVI images side by side.

The evidence of a reduced sensitivity to deforestation in the AVHRR data is evident. This is also consistent with the higher forest area estimate you found with the AVHRR data. However, you also need to recognize that it is not just the lower resolution that is the problem (since the TM image was gathered with effectively the same resolution). The reason for the effect you are seeing here is unknown. However, the images were not acquired on the same day. Atmospheric conditions may have been quite different between the two images. In addition, the imaging characteristics of the AVHRR and LADSAT TM sensors are not the same. The AVHRR sensor is in a much higher orbit with a very broad field of view. As a result, portions of the image that are quite distant from the image center may be acquired at a very oblique angle, yielding a much longer atmospheric path for reflected energy. Atmospheric degradation of the signal in these cases would thus be considerably stronger.

Clearly there is much to be learned about the characteristics of AVHRR imagery. This source is attractive since it is inexpensive and has a very high temporal resolution. However, for measurements to be used in a meaningful way for the monitoring of deforestation, considerable work will need to be done in discovering the inherent biases and limitations of this imagery source.

We would like to thank Peter Schlesinger of The Woods Hold Research Center, Woods Hole, Massachusetts, USA for his

assistance in the preparation of this exercise.

References

Stone, T.A. and P. Schlesinger, (1990) "Monitoring deforestation in the tropics with NOAA, AVHRR and Landsat data", *Proceedings of the ISPRS Comission 1*, Manaus, Brazil, June 1990.

Answers

Exercise 1

1. A quantitative or continuous palette, such as the Quantitative (standard IDRISI) palette, should be used to view elevation and age of forest stands since the values of these data indicate quantitative differences. Using the continuous palette in these cases allows one to quickly see where elevations are lower and higher and where forest stands are younger and older.

A qualitative, or contrast palette, is more useful in viewing landuse categories and administrative districts since the values in these images are unique identifiers indicating qualitative differences.

2. Each user may have his or her own preference, but some conditions make one or the other more useful. RECLASS must be used for real number images. It is also a good choice when data is continuous and ranges of values are being reclassified and when only a few values are being changed and the others should remain unchanged.

ASSIGN is useful when many values are being reclassified to zero, when many individual old values are being reclassified to individual new values and when an attribute values file can be easily created or imported from another source.

3. The water bodies: 0

The areas from 0-1000 meters from water bodies: 0

The areas greater than 1000 meters from water bodies: 1

4. Thirty-four groups were identified. The background has value 0 since the very first pixel of the image (the upper left corner) is a background pixel. GROUP does not distinguish between 0 and non-zero values. The first value it encounters is assigned the group number 0. Because of this, the background will not necessarily be assigned the value 0 every time you use GROUP. In addition, if the background is not contiguous, it will be divided into unique groups itself.

5. You should overlay, using multiplication, the images AREA1 and PINE-BUFF.

6. The background would have been identified as a suitable area, even though these areas were excluded by the first two criteria.

7. The purpose is to assign a unique identification number to each timber stand identified as suitable.

8. There are six.

9. Create an image of distance from roads using DISTANCE. RECLASS this image so that areas less than 500 meters from roads have the value 1. Overlay, using multiplication, this image with PINE-BUFF, and then proceed with GROUP and AREA as before.

Exercise 2

1. Resolution = 200 meters.

2. 373 square kilometers.

3. Answers will vary, but may include information such as:

The lowest elevations are found in the southernmost part of the park. The park boundary follows, for the most part, along the mountain ridges and the bulk of the park is made up of the two enclosed valleys. The northern valley has a higher elevation than the southern valley. In the center of the park there is a narrow passage linking the northern and southern valleys.

4. Minimum = 0, Maximum = 3280. The minimum is the value of the background, not the minimum elevation in the

park. The mean elevation cannot be determined with the given information.

5. The highest peak in the histogram is at value 0, representing the background area outside the park.

6. Answers will vary since this is an estimate, but the minimum elevation in the park should be around 750m. Mean value = 1761m

7. Minimum elevation = 740m. One pixel has this value.

8. Vegetative Cover

Categories: Boreal Spruce (and Balsam), Mature Lodgepole Pine, Douglas Fir, Aspen, Boreal Mixed Wood, Grassland, Not Vegetated/Herb Material, Open Larch/Avalanche Complex. [DISPLAY with legend, or Metadata.]

Categories covering the largest areas: Mature Lodgepole Pine, Boreal Spruce and Not Vegetated/Herb Material. [AREA or HISTO.]

Spatial distribution of vegetation types: The northern half of the park is dominated by Not Vegetated/Herb Material, Boreal Spruce and Mature Lodgepole Pine and Douglas Fir. There is no Aspen in the park and only small patches of Boreal Mixed Wood and even smaller patches of Grassland appear in the southern part of the park. [DISPLAY with qualitative palette.]

Eco-regions

Categories: Glacier/Rock, Subalpine, Alpine, Montane. [Metadata]

Percent covered by each eco-region: Glacier/Rock 19.6%; Subalpine 49.9%; Alpine 1.7%; and Montane 28.8%. [HISTO numeric (look in the proportion column of the numeric display, then recalculate the proportions by hand, excluding the background) or AREA (calculate the percentages based on the total area excluding the background.]

9. The answers cannot be based solely on elevation because the ranges of elevation overlap. For example, Subalpine and Alpine have different minimum elevations, but exactly the same maximum elevations. It appears that elevation is a factor in determining the eco-regions, but clearly there are other variables involved as well.

10. Run EXTRACT twice with PARKMASK as the feature definition image and ELEV as the image to be processed, first asking for the minimum, and then asking for the average.

11. Twenty classes result from the cross-classification (excluding the background). The descriptions of the relationships will vary.

12. Answers will vary.

13. Elk, deer and moose are similar though are still distinct in their distributions. The big horn sheep and mountain goat distributions are very similar. Coyote is not found in the northern part of the park in high densities in the winter.

14. Multiplication will not work here. The difficulty encountered in adding the images is that though each pixel will show how many animals are present, it will not give information about which animals of the six are present.

15. The highest value is 52. If all animals were present the pixel would have the value 63.

16. 0: no animals present, or outside the park boundary.

1: elk

2: moose

3: elk, moose

4: deer

5: elk, deer

6: moose, deer

7: elk, moose, deer

8: coyote

9: elk, coyote

10: moose, coyote

11: elk, deer, coyote

12: deer, coyote

13: elk, deer, coyote

14: moose, deer, coyote

16: sheep

29: elk, deer, coyote, sheep

32: goat

36: deer, goat

52: deer, sheep, goat

17. Answers will vary. The final image can be created with CROSSTAB or OVERLAY and RECLASS or ASSIGN.

Exercise 3

1. Answers will vary. Obviously the monthly images will be added for the two seasons. The difficulty will be in splitting the hemispheres. Several options for doing this are discussed later in the exercise.

2. Summer precipitation is highest along the West African coasts of Guinea, Sierra Leone, and Liberia and along the coasts of Nigeria and Cameroon. The maximum value in MAYOCTPREC is 5013 mm.

3. Answers will vary. Summing only three images would be most efficient with Image Calculator. However, if the process needs to be repeated several times, a macro would provide a framework in which users can find and replace input and output filenames, leaving the functions the same for every procedure. With practice, creating macro files becomes quick and easy and generally will save time if there are more than a few operations to be done.

4. The high areas of MAYOCTPREC have shifted to the south to become high areas in NOVAPRPREC. In addition, there is a wide band of high values running from Gabon to Madagascar. The maximum value is 2831 mm. Note that the colors seen in the summer image do not correspond to the same values in the winter image. Because of autoscaling, the colors show the nature of the distribution of the data in each individual image. To compare the two images, one could display both images and set the display min and max values to be the same for both through Layer Properties.

5. The pixels in the desert have very high values in RATIO because the value of winter (the denominator) is near zero and summer (the numerator) is quite a bit higher. For example, a pixel in south-central Niger (col 171, row 140) having the value 416 in RATIO has a value of 415 in MAYOCTPREC but a value of 0 in NOVAPRPREC. A pixel (col 264, row 248) in central the Democratic Republic of Congo (formerly Zaire) on the other hand has a value in RATIO of only 0.57, even though the difference between summer (641) and winter (1119) is greater than the first example. This is because in the case of the DRC, the denominator is larger than the numerator. As contrast between seasons increases with summer being the larger, the ratio approaches infinity. As contrast between seasons increases with winter being the larger, the ratio approaches zero. This will not be a problem in this analysis.

6. NORTH SOUTH

	NORTH	SOUTH
Values greater than 1	A	B
Values less than 1	B	A
Values equal to 1	C	C

7. Summer = <0.77, Winter = >1.30, Uniform = 0.77 < Z < 1.30

8. The values in the Northern Hemisphere will be unchanged. Those in the Southern Hemisphere will become negative. This would not work if RATIO had positive and negative values in both hemispheres because there would be the possibility that pixels in opposite hemispheres in the changed image would still have identical values.

9. The equator passes approximately between rows 227 and 228. Your results will not be greatly affected if your approximation is one or two rows in either direction.

10. Maximum = 416, Minimum = -4.6885. A Southern Hemisphere pixel with value 0.77 in RATIO has the new value –0.77 in NSRATIO. A Northern Hemisphere pixel with a value of 0.77 in RATIO remains unchanged in NSRATIO.

11. Northern Hemisphere (summer/winter)

New Value	Old Value Range
1	0 to 0.77
2	0.77 to 1.30
3	1.30 to 417

Southern Hemisphere (winter/summer * -1)

New Value	Old Value Range
1	-100 to -1.30
2	-1.30 to -0.77
3	-0.77 to 0

12. The continent is almost entirely a summer rainfall regime with some uniform rainfall regime areas. Only in Northern Africa and Kenya are there large winter areas.

13. There is an artificial break along the equator. This is caused by defining summer and winter according to months and applying this definition to the equatorial region, where summer and winter are not pronounced. One could reclass the equatorial region (5 degree north and south of the equator, for example) to have a uniform rainfall regime.

14. Answers may vary, but would use overlay multiply with the five suitability input images.

15. Suitable areas are concentrated in central and southern Africa and tend to be grouped. This is logical, since the variables used in identifying these areas are continuous.

16. If the overlay of the five Boolean images is done with the addition option instead of multiplication the resulting image would have values for each pixel representing the number of met criteria.

Exercise 4

Part A

1. From least to most likely to be deforested by gypsy moth:

Category	Legend Caption	Average
7	Maple	0.70
2	Spruce-fir	1.30
1	White-red-jack Pine	1.44
8	Non-forest	1.59
6	Elm-ash-cottonwood	1.85
5	Oak-hickory	2.30
3	Loblolly-shortleaf Pine	2.68
4	Oak Pine	3.76

2. Answers will vary. Elevation, temperature, prevailing wind speed, and duration, etc. could be possibilities. You would test each in the same way you tested forest species type. (For continuous variables, you might consider regression between number of years of defoliation and that variable.) You would need data covering the same study area for the variable of interest.

Part B

3. 6 km

4. Medford will have the value 0. A pixel never before infested will have the value 91.

5. One value per county or district is used because these are the units of analysis. We don't have information about the first year of infestation for each pixel and, in addition, you don't want larger units (that have more pixels) to have more weight in the regression than smaller units.

6. EXTRACT has found the minimum values in YEARMASK and DISTMASK for feature number 0 (the background and pixels that have never been infested) of UNITSMASK. It treats all pixels in UNITSMASK that have the value 0 as if they belong to "unit 0."

7. YEARM1 and DISTM1: Y = -82.803650 + 15.523647X

YEARM2 and DISTM2: Y = 13.1477 + 3.641756X

YEARM3 and DISTM3: Y = -907.520203 + 18.500837X

Fastest: Period 3

Slowest: Period 2

8. To predict future infestation, you could create an image showing distance from the areas infested in 1990, then use SCALAR and divide the distance image by the rate found for the last time period. The resulting image, with everything except the currently uninfested areas masked out, would have the values of the year of future infestation. You could use the cursor to find the value for any particular pixel.

Exercise 5

1. The value 50 was used because the resolution of the image is 10m, hence 50m * 10m = 500m = 0.5km. The 0.5km used as the cutoff is not a pure distance value, but rather the cost equivalent of moving 0.5km over a surface with friction 1, in this case, over a primary road.

2. There are 66 areas in total. The total is not 70 because some of the timbersheds do not extend beyond 0.5km.

3. The transportation zone with the least cost is category 1 in the image TRANZONE. This category is the "logical and" of the shortest distance from the road (SKIDZONE category 1) and the timbersheds nearest the mill (HAULZONE category 1). The highest cost is category 68, the cross of SKIDZONE category 2 and HAULZONE category 205.

4. There are 117 cells of white pine in the least cost transportation zone.

117 cells * 0.01ha/cell = 1.17ha

5. Red Maple grows in both the 29th and the 63rd transportation zones. Zone 29 has 89 * 0.01 = 0.89 hectares available while Zone 63 has 32 * 0.01 = 0.32 hectares available. Zone 29 represents areas that are within 0.5 kilometers of the road, which makes them economically desirable, however, they are, on average 7.5 kilometers cost distance from the mill. Zone 63 represents areas that are as far from the mill, but are also far from the road.

Exercise 6

Part A

1. Reference Units – meters; Resolution – 800 meters. Contracted by 8. This leads to loss of information. Since pixel thinning was used, the value that is retained in the output image may not be very representative of the 8x8 group of pixels in the input image. Pixel averaging could not be used because the data are qualitative.

2. There seems to be a big increase in non-forest from 1975 to 1979 and less of an increase from 1979 to 1985. In addition, 1979 and 1985 seem to have a more dispersed pattern of deforestation than 1975.

3. 1975-1979: 241,216 ha/four years = 60,304 hectare annual increase in deforestation

1979-1985: 83,840 ha/six years = 13,973 hectare annual increase in deforestation.

4.

Value in Image	Category Label	Interpretation
1	0|0	Background in both 75 and 79
2	1|1	Forest in both 75 and 79
3	2|1	Non-forest in 75 and forest in 79
4	1|2	Forest in 75 and non-forest in 79
5	2|2	Non-forest in 75 and 79

Table 2

5. Deforestation between 1975 and 1979 (cats 4+7) = 241,472 ha. = 60,368/yr

Deforestation between 1979 and 1985 (cat 6) = 135,232 ha. = 22,539/yr

The values don't match those of question 3 because in the non-spatial analysis, some reforestation compensated for some deforestation. In the spatial analysis, these are kept as distinct areas.

Reforested between 1975 and 1979 (cat 3) = 256 ha

Reforested between 1979 and 1985 (cats 4+5) = 51,392 ha

6. The percent increase in non-forested areas between 1979 and 1985 was 14.7% over 6 years, or 2.45% annually. This is found from Table 1 by subtracting the 1979 nonforest area from the 1985 nonforest area (83,840 hectares), dividing by the total amount of non-forested areas in 1979 (570,176 ha), then multiplying by 100 to change to percentages.

Part B

7. The image was resampled from a 1-kilometer grid to a 50-meter grid. Thus, even though the pixel size if 50-meters, values only change every kilometer. Groups of 20x20 pixels have the same value.

8. LSFACTLOW ranges 0-6, LSFACTHIGH ranges 0-7.

9. Answers will vary, but may include information such as: the highest amount of soil loss is in the deforested region in the southeast of the image. The lowest amount is in the vegetated areas of the north and west of the image. There shouldn't be major differences between USLELOW and USLEHIGH. The values are higher in the latter, but the pattern is nearly identical.

Part C

10. To find the number of cells in the watershed, you could run AREA on the LANDCOVER image, then total the area for classes 1-9. You might also first create a Boolean image of the watershed (by using RECLASS with LANDCOVER) so the watershed has value 1 and the background has value 0, then run AREA on this image and ask for tabular output in cells. The total number of cells in the watershed is 63812. Ten percent of this is 6381 cells.

11. OVERLAY with the multiplication option HIGHPRIORITY and LANDCOVER so that all the high priority cells (value one) will take on the value of the LANDCOVER classes, and lower priority cells will retain the value 0.

12. Scrub/Open Dipterocarp Forest is the most well-represented landcover classification present in areas determined to be priority.

Hectares Legend

12503.5000000 Background

259.5000000 Priority Abandoned Shifting Cultivation

68.5000000 Priority Dry Dipterocarp Forest

1115.0000000 Priority Scrub/Open Dipoterocarp Forest

135.0000000 Priority Active Shifting Cultivation

150.2500000 Priority Other Crops

34.5000000 Priority Orchards and Villages

14190.2500000 Watershed Area not Prioritized

13.

ProportionLandcover Type

```
0    213.490219
2     10.263002 Abandoned Shifting Cultivation
4      1.211585 Dry Dipterocarp Forest
5     43.083462 Scrub/Open Dipterocarp Forest
6     73.071716 Active Shifting Cultivation
7     51.989620 Other Crops
8      5.340557 Orchids/Village
10  1345.085559
```

Part D

14. The image 75-79-85 shows all combinations for the three years. Category 6 represents the areas that were forested in 1979 and nonforested in 1985 (see Table 3).

15. The average for category 6 is 1626.65 meters. This represents 271.1 meters per year and an expected 4066.62 meters over 15 years.

16. The maximum value is 4949.75, slightly farther than the limit of 4066 meters found above. However, that value falls outside the watershed at the corner of the image. To find the maximum distance within the watershed, use EXTRACT with WATERSHEDMASK as the feature definition image and DIST85 as the image to be analyzed. Within the watershed, the maximum distance is 1100 meters.

17. The assumption states that the closer a cell is to a cell that is already non-forest, the more likely it is to become deforested. So, the cell that is 39 meters away is more likely to become deforested than that which is 70 meters away.

18. Those with lower values are more likely to be deforested.

19. Given the model, a cell with the value 0 in the image FINAL PROBABILITY will not be selected for deforestation. In reality, every pixel has a possibility of being deforested. Those cells with low values (but higher than 0) are the most likely to be deforested.

20. There are 16640 nonforest cells in 1985. A 36% increase would add 5990 cells (.36*16640).

21. There are 101294 cells with value 0 in MIXEDDECIDUOUS.

22. 9940140 (Your answer will vary due to the random element introduced into the model)

23. 9940140-8244794=1695346 which is a 17% increase. (Your answer will vary due to the random element introduced into the model.) Remember, these values are relative, they have not been calibrated to any unit of measurement.

Exercise 7

1. The primary activity is agriculture.

2. The forest is category 1. Categories 2 and 3 are agricultural fields.

3. There are 402,536 hectares of forest.

4. The final RMS error is 0.268. This means that there is approximately a 68% chance that true locations are within a quarter pixel of their mapped position and there is approximately a 95% chance that true location are with a half pixel of their mapped positions.

5. There are 440,261 hectares of forest as calculated from the RESCLUST image. This differs from the previous estimate using TM imagery by 37,725 hectares. This amounts to a 9.4% difference which accords well with the findings of Stone and Schlesinger (1990).

6. Your results will vary depending upon the particular pixels you sample. However, typical values for forest would be in the range of 0.43-0.48; for agricultural areas, around 0.33-0.39; for urban areas, 0.12-0.17; for clouds, 0.00-0.09.

7. The average values in non-forested and forested areas are 0.40 and 0.43 respectively.

8. Here the average values for non-forest and forest are 0.31 and 0.45 respectively. The mean value for forested areas has not changed significantly, but for non-forested areas a strong change to a lower NDVI was found.