CHAPTER 11

BIOLOGICAL RESOURCE MAPPING

James D. Jacobi

Introduction

Maps are extremely useful for displaying information on the biological, physical, geographical, or cultural resources of an area. Additionally, maps can serve as the basis for designing and conducting resource inventory and monitoring programs. The first part of this chapter focuses on the process of preparing a vegetation map, including a discussion of certain issues that need to be considered in the preparation of resource maps in general. The second part provides an overview of the use of geographic information systems (GIS) in displaying, manipulating, and analyzing spatial data. A GIS is a desktop computer-based system that integrates spatial information (maps and geo-referenced databases) with data manipulation, analysis, and display tools.

Historically vegetation maps were prepared by either mapping the plant communities directly in the field using surveying techniques, or by identifying patterns that represent vegetation units on aerial photographs then transferring these polygons onto a scaled map base. However, the recent availability of digital data from satellites or aircraft, global positioning systems (GPS), remote sensing analysis techniques, and GIS has greatly enhanced the process of preparing biological resource maps, as well as manipulating, analyzing, and displaying both biological and environmental data for an area.

Preparation of a Vegetation Map

Vegetation maps are used to display the distribution of generalized units that depict the composition or structure of plant communities for an area using a two-dimensional cartographic projection. A vegetation map is one of the most basic tools in the study of natural resources as it serves as the background layer for understanding the distribution and dynamics of the other biological elements studied. A vegetation map also provides the basis for designing a field-sampling program.

Proper planning is essential for the production of a useful vegetation map. There are a number of points that should be addressed prior to and during the preparation of a map. These include:

- Identify the mapping objectives and choose a map unit classification system
- Determine the mapping strategy and select base images
- Select the mapping scale
- Compile mapped units with ground truthing
- Conduct an accuracy assessment of the completed map

A detailed discussion of several of these topics, particularly the steps needed to develop a vegetation classification and how to design and implement a field sampling program, are presented in Chapter 3 of this book. The treatment of these topics in the current chapter is intended to expand the discussion from Chapter 3 to include the opportunities presented with new types of data and analysis techniques, specifically remote sensing digital data and GIS tools, that have recently be-
come available for resource assessment programs such as PABITRA.

**Identifying Mapping Objectives and Choosing a Map Unit Classification System**

Mapping objectives and the map unit classification system are closely related issues. Choosing each of these features are the two most important initial steps in the preparation of a vegetation map. Mapping objectives may be quite variable for any particular area, depending on what components of the vegetation are emphasized (Küchler 1967). For example, a forester may focus only on species composition and saw-timber classes for the tree stands and ignore the understory species, while a map produced for pasture management of the same area may lump all trees into a “forest” category, but display the species composition of the ground-cover vegetation in great detail.

The mapping objectives must be clearly identified before proceeding with the production of a vegetation map. The team that will be preparing and working with the map should address a range of questions that relate to mapping objectives. Who will be using the resulting map and for what purposes (e.g., decision makers needing general maps or managers and researchers who need detailed maps)? Will the map display information on only canopy tree species, or will understory components also be included? Will habitat variables (e.g., elevation zones, rainfall, soil types, etc.) be included as part of the classification? How detailed and spatially accurate do the mapped units need to be? Once these types of questions are properly addressed, emphasis can be shifted to identifying an existing vegetation classification system, or developing a new classification to be used.

While there are literally thousands of vegetation maps found throughout the scientific literature, there is a great deal of variation in the way the authors have identified the plant communities (Küchler 1967; de Laubenfes 1975; Küchler 1984; The Nature Conservancy and Environmental Systems Research Institute 1994). The units displayed on a vegetation map reflect the results of a classification process to identify consistent species associations or structural characteristics of the vegetation across the area of interest (Shimwell 1971; Mueller-Dombois and Ellenberg 1974), (also see Chapter 3). Vegetation classification systems may emphasize structural, floristic, environmental, geographical, successional, or vegetation-environmental features of the plant communities (Mueller-Dombois 1986; Mueller-Dombois and Fosberg 1998). In all cases, however, the classification units reflect some level of generalization of the continuum of spatial and, for some maps, temporal variation of the distribution and abundance of plants as they occur relative to their environment.

For example, in mapping the vegetation of the island of Hawai‘i as part of the U.S. Fish and Wildlife Service’s Hawai‘i Forest Bird Survey, Jacobi (1990) used a classification system that defined map units based on tree canopy cover, tree stature, and species composition of the tree and overstory layers. These classification criteria were chosen since the major objective of the maps was to serve as a basis for analyzing habitat use by forest bird species that appear to be keying in on both species composition and vegetation structure of an area. The Hawai‘i Forest Bird Survey maps were produced at the scale of 1:24,000, based on black and white aerial photographs taken in 1976-1977.

The most complex vegetation maps are those that describe both the structure and floristic composition of a plant community, and may additionally include information on other habitat variables, such as rainfall, substrate characteristics, temperature regime. De Laubenfes (1975) pointed out a potential danger in combining vegetation characteristics and other habitat elements into the same map. He argued that to truly assess the relationships between the distribution of plant communities and the environment they are found in, each of these components must be mapped independently. Küchler (1984) similarly recognized the confusion that could arise from these types of unit component combinations on the same map, particularly if the environmental features were only vaguely defined or not applied equally to all of the map units. However, he urged ecologists to strive to systematically include more environmental information on vegetation maps, arguing that by this means we may better understand the relationships between the plant communities and the habitats in which they are found. One particularly useful application of a GIS, described in more detail in the second part of this chapter, is the ability to integrate and analyze the relationships between biotic and environmental variables even after they have been mapped independently.
Determining Mapping Strategy and Selecting Base Images

Once a map unit classification system has been chosen, the process shifts to determining how the classification units will be mapped. This step will most likely involve delineating units by hand on aerial photographs or mapping using digital image analysis. Alternatively, map units can be identified by walking around the units in the field while recording their boundaries with a global positioning system (GPS) unit, then transferring these lines to a base map. Regardless of the mapping strategy, it is essential that the classification units have characteristics that can be recognized on the mapping medium (e.g., photos or digital images), around which boundaries can be drawn. Great care should go into developing a detailed vegetation classification. The units cannot be mapped unless they are consistently delineated on aerial photographs, with digital image analysis, or in the field.

Mapping With Aerial Photographs—When working with photographs, the distribution of plant communities is determined visually and boundaries are traced on the photos around relatively homogeneous areas that represent the classification units. In most cases mapping on aerial photographs is conducted by examining overlapping pairs of photographs with the aid of a stereoscope (Figure 11.1). This provides a three-dimensional view of the study area. This also allows for a clearer recognition of the different vertical layers of the vegetation, as well as the recognition of microtopographic features of the habitat.

Two of the most important issues that must be considered when choosing photographs for mapping vegetation are the scale of the images and the type of images that are used. Image scale is directly related to how much detail can be recognized on the photograph. It ranges from very large-scale images (e.g., 1:1,000 or larger) to small-scale images (1:10 million or greater). The scale ratio identifies the relationship between a measured distance on the photograph with its corresponding distance on the ground. For example, on a photograph with a scale of 1:1,000, one centimeter measured on the image represents a distance of 1,000 cm (i.e., 10 m) on the ground. Much more detail can be recognized in a large-scale photograph than in a small-scale photograph. However, it takes many large-scale photographs to cover the same area of a single small-scale photograph. This introduces additional problems in making sure the mapped unit boundaries on each photograph match appropriately with boundaries on the neighboring photos.

The scale of a photograph can be determined by measuring the distance between two known points on an image, then dividing that value into the measured distance between these points in the field. To illustrate this process, if the distance between two points on the

Figure 11.1. Example of a stereoscope set up to view two overlapping aerial photographs.
photograph is 3.6 cm and the corresponding measured distance in the field is 256.8 m (equivalent to 25,680 cm), the photograph scale is 25,680 divided by 3.6 or 1:7,133. In practice, one should determine the scale of a photograph by averaging the results of several sets of distance measurements on the image and in the field since photographs often have distortions caused by tilt of the camera or slope of the terrain, which can result in a range of scale values across the image.

The type of photograph dictates the kind of information that is reflected from the vegetation and captured on the image. Generally there are three types of photographs used for mapping vegetation: panchromatic (black and white), true-color, and false-color infra-red (IR). Panchromatic images are generally adequate for recognizing structural characteristics of the vegetation, particularly when viewing overlapping pairs of photographs with a stereoscope. However, it is often difficult to differentiate between different plant species in this format. True-color images allow for better recognition of species than panchromatic images. However, IR photographs allow for an even greater opportunity for separation of different species as the images depict reflected light within a specific range of wavelengths that is particularly diagnostic for plants. On IR photographs, the vegetation is most often seen as different shades of red and pink colors, but with greater separation in color by species than can be found with true-color photos. Whenever possible, IR photographs should be used for vegetation mapping, supplemented by black and white or true-color photos if available.

**Digital Image Analysis**—Digital image analysis differs from photo-interpretation in that the map units are identified using a computer analysis of the combinations of spectral wavelengths that are recorded digitally from the ground scene by an array of sensors mounted in a satellite or an aircraft. Each sensor is designed to collect spectral data on a specific range of wavelengths reflected from the vegetation and other objects on the land surface. A series of statistical analyses are then performed to identify unique combinations of spectral values (“digital signatures”) that can be translated into classification units for the map. Once the signatures for the various types of vegetation units have been determined, a map can be produced that plots the distribution of each unit distinguished by different colors and/or patterns.

It is important to point out the difference between a digital image analysis and digitizing maps and other information (e.g., roads, streams, plant locations) for use in a GIS. Digital image analysis is a primary mapping procedure that can be used to prepare a vegetation map using digital data representing reflectance of specific wavelengths of light from the vegetation from a digital scene, which is analogous to a photographic image. Digitizing, on the other hand, is a process of coding the locations of points, line, or polygon (area) information into geographically referenced datasets that can be used by a GIS. For example, maps produced from aerial photographs can be traced on a digitizing table, which simply records the X and Y coordinate positions of a series of points describing the mapped unit boundaries. The coordinate system is then referenced to a common map projection system (e.g. longitude-latitude) so several sets of data can be overlain within a computer mapping system or GIS.

While the use of digital image analysis requires specialized expertise as well as significant investment in computer hardware and software, it provides a relatively objective means of mapping vegetation cover over large areas once the set of digital signatures for the classification units has been identified. However, it is critical that people with detailed field expertise be directly involved with the entire digital image analysis process to ensure that the resulting classification and mapping of the vegetation units is biologically sound. More details on the process of remote sensing and digital image analysis can be found in (Campbell 1996).

The basic spatial unit of a digital image is a pixel, which represents a specific area on the ground from which a combination of spectral information is collected. Figure 11.2 shows an example of pixels from a digital image at a very large scale relative to the same image at a much smaller scale. In the small-scale image one can distinguish the differences between recent lava flows and various types of vegetation units. However, at the very large scale, the individual pixels are seen, each containing a set of reflectance values for the various sensors that were used for this image. The size of a pixel determines the spatial resolution of the digital image, which relates directly to how much detail can be differentiated in the analysis. Images with a very small pixel size (e.g., 0.5 x 0.5 m on the ground) have much greater spatial and information resolution than images with a large pixel size (30 x 30 m). As with photographs, the type and number of sensors used to collect data from a pixel relates to what can
be recognized through the analysis of a digital image. The spectral resolution of digital images is greatly enhanced with an increased number of sensors.

During the initial years of the development of remote sensing, both pixel size and a small number of sensors limited the utility of digital images for detailed mapping of plant communities. More recently, however, sensors have been developed to sample both smaller pixels (generally 1 x 1 m or smaller) as well as much finer divisions of the spectral wavelength (now up to several hundred bands). This has led to greater spatial and spectral resolution in mapping. This increase in digital resolution has been matched by a significant increase in processor speed, memory, and storage capabilities of desktop computers, which are necessary to process digital images for a large study area.

**Image Date and Time Considerations**—Regardless of whether aerial photographs or digital images are used for mapping, consideration must also be given to date and time issues. Specifically, time of day, recent meteorological events (e.g., drought, heavy rain or snow), and the season the images were obtained, may affect their use in mapping. Additionally, images that are more than 10 years old may not truly represent the current status of the vegetation of an area. However, historical images are very important when conducting a study of the change in plant communities. There may be some difficulty in determining the actual composition or structure of mapped units on the photos if there have been drastic landscape or successional changes to the study area.

**Selecting the Mapping Scale**

Scale-related limitations on maps primarily pertain to the size of units that can be visually resolved and displayed in a two-dimensional presentation (Mueller-Dombois and Ellenberg 1974; Robinson, Sale et al. 1978), (Table 11.1). A “small-scale” map displays units that are fairly large and generalized, and may include a great deal of heterogeneity within the delineated units. A “large-scale” map, on the other hand, may display units that cover a small area on the ground, contain a great deal of field detail, and may be relatively homogenous to the observer. Most vegetation maps at the scale of 1:500,000 (1 cm on the map = 5 km on the ground) or smaller are limited to displaying potential or climax vegetation as interpreted from regional climatic, soils, geology, and topographic information. Maps at larger scales (e.g., 1:10,000 – 1 cm on the map = 100 m on the ground) may show vegetation units with boundaries that can be identified in the field, or even individual plants that can be mapped. For the types of island ecosystems that are the focus of the
When planning and producing a vegetation map, consideration must also be given to the relationship between mapping scale and image scale. For example, if one identifies and delineates mapping units on high resolution (i.e., large-scale) images, it would not make sense to portray these units on a small-scale map, which would not be able to adequately display many of the small units. Conversely, although you can display classification units produced from small-scale images on a map with a large scale, the increased mapping resolution would still result in a map with very generalized vegetation units due to the small scale of the images used to produce the map. Generally, you should strive to have the image scale and mapping scale in the same order of magnitude.

**Compiling Mapped Units and Field Verification**

Once the classification system and basic mapping strategy have been chosen, the process shifts to delineating the mapped units on the images, compiling the preliminary boundaries onto base maps, conducting field sampling of the vegetation using relevés, verifying (“ground-truthing”) the mapped units from field data, and revising the mapped units as needed. Ideally, the person doing the mapping should also be directly involved with sampling the vegetation in the field.

When starting to prepare a vegetation map of an unfamiliar area, there will undoubtedly need to be some adjustment between the preliminary mapping units that are delineated on the images and what can be identified on the ground. During this initial phase of mapping, the plant communities that are found in the area should be sampled using relevés, as described in detail in Chapter 3. Next the relevé locations should be marked on the images (either photographs or digital images) that are being used for mapping so the patterns of the vegetation that are detected on the images for these specific areas can be calibrated with the known composition and structure of the vegetation from the relevé data. In many cases, the data from the field sampling may result in mapping units that are more detailed than can be consistently identified on the images. In these situations some of the more detailed units may need to be compiled into generalized plant communities that are better recognized on the images.

**Transferring Air Photo Boundaries to the Base Maps**—When mapping on aerial photographs, you need a process to accurately transfer the unit boundaries onto a basemap. One of the simplest means of compiling a map is to use a zoom-transfer scope. With this instrument the person compiling the map looks through binocular eyepieces, with one eye viewing the basemap and the other eye focused on an aerial photograph, which has been optically enlarged or reduced to match the scale of the basemap. The lines from the photographs can then be traced onto the basemap.

In producing a set of vegetation maps for the island of Hawai‘i, Jacobi (1990) used a stereo-plotter to compile the boundaries drawn on the aerial photographs onto scale stable overlays on 1:24,000 orthophoto quadrangle map sheets. This optical plotter, which combines an adjustable-scale stereoscope for viewing the im-

---

**Table 11.1. Overview of the types of information that can be displayed for different map scales.**

<table>
<thead>
<tr>
<th>Map Scale</th>
<th>Scale Range</th>
<th>Types of Information that can be Displayed</th>
<th>Minimum Unit Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>&lt; 1:1 million</td>
<td>Generalized potential vegetation</td>
<td>&gt; 2,500 ha</td>
</tr>
<tr>
<td>Intermediate</td>
<td>1:1 million to 1:100,000</td>
<td>Regional maps; potential vegetation</td>
<td>2,500 to 25 ha</td>
</tr>
<tr>
<td>Large</td>
<td>1:100,000 to 1:10,000</td>
<td>Generalized actual plant associations</td>
<td>25 to 0.25 ha</td>
</tr>
<tr>
<td>Very Large</td>
<td>1:10,000 to 1:100</td>
<td>Detailed plant associations; individual plants</td>
<td>2,500 m to 1 m</td>
</tr>
<tr>
<td>Chart Maps</td>
<td>&gt; 1:100</td>
<td>Foliage cover for actual plants</td>
<td>&lt; 1 m</td>
</tr>
</tbody>
</table>
ages with a pantograph for drawing on the maps, allowed for a very accurate transfer of the mapped lines on the aerial photographs to the base maps. Through a process of iterative scaling and parallax correction of control points on the photo model, lines on the photographs could be compiled consistently onto the base maps to within 0.5 mm of their actual location on the map (equivalent to 12 m on the ground). This degree of accuracy during the compilation step minimized line-plotting errors in the mapping procedure. Any errors detected in the map unit boundaries can, therefore, be traced directly back to the original demarcation of vegetation unit boundaries on the aerial photographs.

Compilation of mapped units is not a problem when working with digital image analysis since this step is built directly into the mapping process from the start. Prior to initiating the analysis, all of the digital data from the scanned views must be adjusted to the same scale and map projection. Therefore, the resulting vegetation maps are already compiled to the desired base-map and can be overlain onto topographic base maps with a GIS.

**Conducting an Accuracy Assessment of the Completed Map**

The final step in producing a vegetation map, or any similar type of resource map, should include an assessment of the accuracy of the mapped units (Environmental Systems Research Institute, National Center for Geographic Information and Analysis et al. 1994). Mapping error has two components: 1) a classification accuracy component, and 2) a spatial compilation component.

The classification component relates to structural and compositional accuracy of the interpreted units. In other words, how real are the units that have been mapped, and do they adequately depict the classification units? This component of accuracy pertains directly to the validity of the classification system regardless of the way the map units are delineated (e.g., on aerial photographs or from digital image analysis).

The second mapping error component relates to the mechanical problem of compiling interpreted map unit boundaries from aerial photographs onto a base map. This issue does not arise with digital image analysis since the computer compilation process should already be based on a properly scaled and oriented mapping surface. To minimize this component of mapping error, maps produced using photographs should be compiled reliably, using an instrument such as a zoom transfer-scope.

Mapping accuracy is of particular concern as it determines the use-potential of the map. Spatial accuracy is less of a problem with small-scale maps as they are limited to displaying extremely generalized units. However, with large-scale maps, the units displayed can actually be visited in the field. Many studies involve relating field results to vegetation maps. If the maps are inaccurate their utility is limited and research or management conclusions resulting from their use may be compromised.

An accuracy assessment should be conducted by first selecting a set of random points, which serve as center points for sampling points that are established across the mapped landscape, stratified by vegetation unit. Each of these sampling points should be visited either in the field or using detailed aerial photographs, and data recorded on the map unit that best describes them independently of how they were originally mapped. These samples are then compared to how they were mapped, with a simple index of accuracy being the percent agreement between the two assessments. To be useful, maps should achieve an accuracy score of at least 80% (Environmental Systems Research Institute, National Center for Geographic Information and Analysis et al. 1994). A minimum of 30 validation plots should be used to characterize the accuracy of a map, with more plots established for large areas or landscapes with complex vegetation.

**Using a Geographic Information System for Analysis and Display of Spatial Data**

The vast improvement in computer hardware and software over the past decade has greatly expanded our opportunities for organizing, analyzing, and displaying spatial information using what is known as a Geographic Information System (GIS). Basically, a GIS is an integrated computer program and database that allows the user to input, manipulate, analyze, and display different kinds of information, including polygon (i.e., mapped area) data, line data, and point data, that are all spatially referenced to a common map base and coordinate system. In its simplest application a GIS can be used to display or print maps depicting one or
more layers of resource or basemap information (e.g., topography, plant communities, plant species locations, transect locations, land-use classification, annual rainfall, land ownership or tenure, roads, soil types, etc.) for a given area (Figure 11.3). More sophisticated GIS uses include optimal path or risk assessment (e.g., determining least damaging pathway for construction of a new road through an area with sensitive biological resources), distribution modeling, and multivariate spatial analysis, which allows for determining probability relationships between different spatial data layers.

Today, a GIS provides the foundation for many natural resources programs that involve research, surveys, monitoring, or management. The data sets used in a GIS are contained in spatial themes, which are analogous to overlay sheets placed on top of a paper base map. There are many advantages to using a GIS instead of manually overlaying information from different paper maps. These include an easy means of adding or deleting data themes (overlay information) for a given map; the ability to quickly modify the characteristics of the information that is displayed (e.g., color and texture fill for polygons; line thickness, color and line type for line data; and point type, size, and color
Biodiversity Assessment of Tropical Island Ecosystems

Biological Resource Mapping

for point data); and a simple way to change the scale and printed size of the map. Additionally, it is relatively easy to construct a map legend for the various sets of information that are included on the map. Once a GIS map is put together on the computer, it can be printed on a plotter for use in the field or for display, or output to a graphics file that can be included in a report or publication.

There are also a number of issues to consider prior to working with a GIS. These include the fact that all of the data layers must be created or digitized in an appropriate format, the software and hardware needed for a GIS are somewhat expensive, and the person operating the GIS must have some specialized training or experience with this type of computer program. Fortunately, today’s GIS programs are much more user-friendly than the earlier versions and a person with basic computer skills and an understanding of mapping can be trained to use this powerful tool. In summary, a functioning GIS will greatly enhance all aspects of the process of working with maps and spatial data.

Several uses of a GIS are demonstrated next. These examples are taken from ongoing work by the author relative to different research programs on the island of Hawai‘i.

Simple Uses of a GIS: Displaying Resource Information for a Project Area

The first example involves mapping the distribution of rare plant species relative to basemaps that include roads and forest canopy cover for a research and management program within the Ola‘a-Kīlauea Management Area (Figure 11.4). The rare plant data have been further manipulated to show areas that are within 500 m from known locations of the plants. This is the type of map that would be produced if the managers for the area wanted to make sure that any planned development of the area was kept away from these known plants.

The following steps were taken to prepare this map. 1) The desired resource or basemap layers (rare plant locations, roads, and forest cover units) were first selected for display by the GIS, 2) units for each of the canopy cover categories were grouped together from more detailed vegetation map units with appropriate shading and patterns applied, and 3) the location of each of the rare plants was marked by a large black asterisk. A 500 m buffer area around each of the plant locations was then produced using a simple buffering function in the GIS that allows the user to construct a zone of any desired distance away from the center of a data point. Similar buffer zones can be constructed around linear data (e.g., roads or streams), or polygons (e.g., ownership parcels, soil types, etc.).

A More Advanced Use of a GIS: Modeling Species Distribution Across a Landscape

The second example demonstrates the use of a GIS in predicting the historic or potential range of a rare plant species on the island of Hawai‘i based on elevation, rainfall, and vegetation parameters that are characteristic of the known locations of the different species (Figure 11.5). This type of potential distribution map can be used to help identify additional areas to survey for a species, or for choosing appropriate sites for reintroduction.

For this study, the locations of the endangered plant species, Clermontia lindseyana (Lobeliaceae), were compiled and basic data relating to each point (observer, date, location coordinates, status of plants, etc.) were put into the GIS. Also included in the GIS were themes with elevation data, median annual rainfall, and vegetation units that had been previously mapped. Using the GIS, each of the valid plant location points were then used to code the elevation, rainfall, and vegetation type for the different sites. This coding step can be done automatically using a program macro routine that adds data from each map layer (e.g., elevation or plant community), to the record for that data point. In this case, the maximum and minimum values for elevation were used to generate a zone that is characteristic of the habitat for this species, based on these variables. Next, the elevation-rainfall zone for Clermontia lindseyana was refined by selecting only those parts of the habitat that contained vegetation types this species was found to occupy. Finally, a historic range map for this species was drawn that only included those portions of the modeled distribution that contained valid records for this species.
Figure 11.4. GIS generated map of a portion of the Olaa-Kilauea Management Area showing the distribution of rare plant species with 500 m buffer zones, relative to forest canopy cover and access roads.
Figure 11.5. Map of the range of *Clermontia lindseyana* on the island of Hawai‘i showing the locations for known populations, as well as distribution of habitat occupied by this species based on a GIS model constructed using elevation, median annual rainfall, and occupied plant communities.
Literature Cited


