# CHAPTER 5

# *PLOTS, PIXELS, AND PARTNERSHIPS: PROSPECTS FOR MAPPING, MONITORING, AND MODELING BIODIVERSITY*

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## INTRODUCTION

Sound resource inventories and monitoring are basic needs for sustainable management of the world's vegetative ecosystems if environmental, economic, and social goals are to be balanced. These needs, stated in the 1992 conclusions of the United Nations Conference on Environment and Development (UNCED), are known as Agenda 21.

The Convention on Biological Diversity initiated a commitment by all nations of the world to conserve biological diversity, to use biological resources sustainably, and to share equitably the benefits arising from genetic resource uses (Glowka *et al.***,** 1994). Article 7 specifies that each contracting party shall:

(1) identify biological diversity components important for conservation and sustainable use;

(2) monitor, through sampling and other techniques, biological diversity components, paying particular attention to those requiring urgent
conservation measures and those which offer the greatest potential for sustainable use;

(3) identify processes and activity categories that have, or are likely to have, significant adverse impacts on biological diversity, conservation, and sustainable use and monitor impacts through sampling and other techniques; and

(4) maintain and organize, by any mechanism, data derived from identification and monitoring activities following the above.

According to Annex 1, identified categories to be monitored include:

(1) Ecosystems and habitats that: (a) contain high diversity, large numbers of endemic or threatened species, or wilderness characteristics; (b) are required by migratory species; (c) are of social, economic, cultural or scientific importance; (d) are representative, unique, or associated with key evolutionary or other biological processes;

(2) species and communities that are: (a) threatened; (b) wild relatives of domesticated or cultivated species; (c) of medicinal, agricultural or other economic value; (d) of social, scientific or cultural importance; (e) important for research into the conservation and sustainable use of biological diversity, such as indicator species; and

(3) genomes and genes of social, scientific or economic importance.

The conclusion from Agenda 21 is that contracting nations must inventory, monitor, and assess their biological resources. From 28 August to 2 September 1994, the International Union of Forestry Research Organizations (IUFRO) sponsored an international workshop, 'Measuring and Monitoring Biodiversity in Tropical and Temperate Forests' in Chiang Mai, Thailand (Boyle and Boontawee, 1995). Many papers stressed the inventory or counting of species. This information is valuable, and such inventories must be continued. It is necessary to know which flora and fauna exist if they are to have any chance for protection. At the very least, a species existence should be cataloged before the species is lost.

However, decision-makers need mapped information on species and biotic community type distribution patterns, information about effective use of available technology, and data at multiple scales of resolution (Miller, 1994). Knowledge of species' and community types' responses to various management activities and understanding about the maintenance of ecological functions are important as well. Species and community type identification, abundance information, and location are common inventory products. Responses to change over time by species, population, and community type are monitoring products. Also contributing to information about biodiversity are inventory and monitoring efforts directed at economically important resources, efforts that support sophisticated data base, map, and satellite image products.

Scattered around the world are many biodiversity inventories that are limited to species, community type, and abundance information from a few preserves, national parks, or unique habitats. Species ranges and community types are often assembled from archives, recorded sightings, personal observations, and ecological and taxonomic literature (Hall, 1994). While such data are valuable, particularly for rare species and community types, they do not provide a true account of range, density, regional pattern, or change over time. In fact, few nations have an inventory and monitoring system in place that provides the information called for by the Biodiversity Convention. This paper identifies potential information sources that allow one to model, map, and monitor biodiversity over large areas.

## Definition of terms

Note the following definitions of key terms used in this paper.

- Biodiversity (biological diversity), according to the Convention on Biological Diversity, is the variability among living organisms from all sources, including *inter alia*, terrestrial, marine - and other aquatic - ecosystems, and the ecological complexes of which they are a part. This encompasses diversity within species, among species, and of ecosystems.

- Inventory is an accounting of goods on hand that serves as a snapshot in time for modeling and monitoring. A resource inventory usually includes information on the kind, amount, extent, and condition of products useful to humans.

- Mapping is the process of determining and graphically portraying the distribution of variables in geographic relation to one another.

- Modeling is the development of formulas that predict the kinds of variables found under certain conditions. Models also predict responses to natural or human-induced disturbances (e.g. experimental treatments for a given set of conditions).

- Monitoring is periodic observation at a given location at two or more points in time. Monitoring, preferably through the use of protocols and standards, is the basis for measuring change and modeling trends.

- Partnership in relation to data is the arrangement, or nesting, of mutually beneficial information among sampling frameworks that permit translation to other scales of resolution. Concerning people, it is a cooperative effort among two or more survey programs or data sources to which all stakeholders contribute and from which all stakeholders benefit based upon common needs or goals.

- Pixel is the smallest picture element in digital remote sensing. A broader definition, used in this paper, is the aggregation of pixels in the smallest area mapped.

- Plot is the Earth cover area for which a sample observation or measurement is made.

## PLOTS

Identifying, tallying, and monitoring each plant over large areas are impossible tasks. Thus, the question arises, how does one effectively obtain an estimate of abundance and change over large areas? One solution is to use periodically remeasured permanent plots with statistical sampling and remote sensing.

Field plot measures provide details about vegetation - kind, amount, condition, and uses. Monitored field plots provide information on changing environmental conditions, uses, and government programs. There are at least four plot networks on forested land in the United States. These include Smithsonian Institution/Man and the Biosphere (SI/MAB) plot network, the environmental monitoring network of the US Environmental Protection Agency (EPA) and the US Department of Agriculture (USDA) Forest Service (USFS) Forest Health Monitoring (FHM) Program, the field and photo plot network supporting forest resource supply inventories by the USFS Forest Inventory and Analysis (FIA) Program, and the field and photo plot network on nonfederal land supporting agricultural supply and natural resources conservation programs by the USDA Natural Resources Conservation Service's (NRCS) National Resources Inventory (NRI) Program. Each of these networks is described below. We note that other countries have similar networks.

### SI/MAB plot network

The SI/MAB biodiversity plot network provides information oil vegetation and establishes an ecological framework for monitoring other taxa and ecosystem characteristics. This baseline information has been used for a variety of other studies (Comiskey *et al.*, 1993). The SI/MAB network was originally targeted for tropical forest work through the MAB programme, A total of five plots in the United States were used to test and refine the methods, training, and education. Experience from these plots encouraged SI to consider further expansion within the United States.

SIIMAB has established two plot scales. The first is a network of nearly 130 1-ha plots mainly in the tropics where woody species > 10 cm diameter at breast height (dbh) are tallied. Ecological information gathered includes geography, descriptions of current and historical uses, coordinates for mapping, soil types, slope, status (live, standing, broken, etc.) of woody specimen measured height, genus, and species. Plots are measured yearly, every two to three years or every five years, depending on site changes ill mortality, recruitment, effects of' hurricanes, typhoons, etc.

The second scale is a network of permanent forest plots 50 ha in size (L. Barnett, personal communication) established at several sites in Bolivia, Peru, Venezuela, Guyana, and other locations (Comiskey *et al.*, 1993). Information is gathered on all taxa through studies conducted by the Smithsonian Center for Tropical Forest Science (CTFS). The CTFS serves as a global center for promoting and coordinating research on the ecology and management of natural tropical forests. Monitoring is long term, and inventories depend on the research priorities and funding.

## Forest Health Monitoring (FHM)

In the United States, the broadest range of attributes collected from a grid-based plot network is found in the FHM program. The network's purposes are to evaluate current conditions and monitor changes in vegetation and soils caused by natural and anthropogenic factors. The work is funded and directed by the USFS, EPA, and various state governments (Stolte, 1994). Data are collected annually on a broad suite of forest condition indicators. When completed, there will be approximately 12,600 sample locations, 27 km apart, systematically situated on a triangular grid across the United States. Those plots falling on forested lands (approximately 4,000) are measured and maintained by the program cooperators (Alexander and Barnard, 1994).

Projections are for complete coverage of all states by the year 2000. So far, FHM plots are established in the states of Alabama, California, Colorado, Connecticut, Delaware, Georgia, Maine, Maryland, Massachusetts, Michigan, Minnesota, New Hampshire, Pennsylvania, New Jersey, Rhode Island, Tennessee, Vermont, Virginia, West Virginia, and Wisconsin. Some work has also been done in North and South Carolina, Oregon, and Washington. A subset of FHM plots is measured to detect subtle changes in vegetation and soils. Data about land use and damage to forest trees are also collected from off-plot surveys.

FHM plot networks are also being initiated in other countries. Estonia, Latvia, and Lithuania have established FHM plots and are gathering data similar to those in the United States, and plots were scheduled for establishment in Belarus, Indonesia, Poland, and Ukraine in 1995.

## Forest Inventory and Analysis (FIA) plots

Most plots measured under FHM are a subset of a broader plot network maintained by USFS Forest Inventory and Analysis (FIA) units. There are six FIA units located throughout the United States. The FIA network consists of a systematic sample grid of photo-interpreted points on aerial photos. Data from field and photo plots traditionally generate state, national, and global forest resource estimates for periodic timber resource assessments. However, there has been a growing use of the same data to address wildlife habitat (Ohmann, 1992; Rudis and Tansey, 1995), range, recreation, and other resource concerns (Rudis, 1991) and emerging issues of forest health and biological conservation (Powell *et al.*, 1994).

The grid covers all private and many public lands in the United States with more than 6.5 million photo samples, and a subsample of some 400,000 field locations. Grid design, historical records, and attributes measured vary by region and over time. Sampling in the eastern United States began in the 1930s and spread westward in later years, principally on state and private land. Field plots are now being expanded along the grid to incorporate large areas of federal land in the western United States and reserved land across the country. Estimates for these lands were previously obtained only from remote sensors, land management records, or locally administered surveys.

Data extracted from photo plots are geographic location (some in UTM coordinates), land use, and selected earth cover classes principally to distinguish between forest and non-forest conditions. The remeasurement cycle varies from seven to 13 years.

Most nations have some form of forest inventory and collect data similar to those found in the United States. Of the 41 countries submitting data for the Food and Agriculture Organization (FAO) of the United Nations' 1990 Global Forest Assessment, only Angola, Togo, and the Slovak Republic stated they have no plot networks for forest inventory (Nyyssönen, 1993).

## National Resources Inventory (NRI) plots

The NRCS was known as the USDA Soil Conservation Service from April 1935 until October 1994. The agency's NRC uses a stratified, two-stage area sampling design (Goebel, 1995), consisting of geographic stratification with sample sites located in every county and parish in the United States. The primary sampling unit is a nominally square plot, generally containing 65 ha. Three point samples are located within most sampled primary units. Some data are collected for tile entire primary unit, while other more specific data are gathered at each point. Categories of data include: soils, Earth cover and land use, erosion, conservation practices and treatment needed, wetlands classifications, wildlife habitat diversity, irrigation, rangeland transacts, Conservation Reserve Program land under contract, general ownership, and geographical location (Goebel and Dorsch, 1984). Presently data are not collected for samples falling on federal land.

The purpose of the NRI is to provide information that can be used for effective policy formulation and development of natural resource conservation programs. The 1992 NRI data base contains site-specific data gathered at three points in time (1982, 1987, and 1992) for more than 800,000 sample sites. Though containing few determinants of forest condition, the NRI estimates existing forest type and potential natural vegetation and categorizes land use and Earth cover where sampled (USDA, 1994). The NRI data base provides regional scale habitat structure indices useful to predict avian species richness (Flather *et al.*, 1992) and suggested causes for losses of wetlands from 1982 to 1992 (Brady and Flather, 1994).

## Variables

Tables 5.1 through 5.5 summarize the forest-related variables collected through various US networks. Data collected by the FIA units vary from region to region (consult USDA Forest Service, 1992, for listings of variables collected by each FIA unit). Variables collected by all FIA units are listed as 'All' in Tables 5.1-5.5, and those collected by five or fewer units are identified by 'Some'. For the FIA network, disturbances, surrounding features, and selected site and understory vegetation variables are not standardized nationally.

Variables for monitoring biodiversity relate to the ability to collect, analyze, and report the data collected and to assess them accurately. Diversity, often reported as indices based on composition, frequency, and abundance of species, is frequently voluminous at national, regional, and global scales. To use diversity information in assessment or risk analysis, one must develop systems to collect, process, and disseminate large quantities of data in a timely manner. Users also must have some idea of how accurate the data are. A well-defined quality assurance and control program for data collection and confidence intervals associated with analyses must be in place.

Table 5.1 Overstory-related variables collected in US national plot networks

| | US national plot networks | | | |
|---|---|---|---|---|
| *Overstory variables* | *SI/MAB* | *FHM* | *FIA* | *NRI* |
| Dbh (diameter at breast height) | yes | yes | all | yes |
| Species | yes | yes | all | - |
| Tree class | - | - | all | - |
| Crown class | - | yes | all | - |
| Crown ratio | - | yes | all | - |
| Crown length | - | - | all | - |
| Crown diameter | - | yes | some | - |
| Crown density | - | yes | - | - |
| Crown die back | - | yes | - | - |
| Crown vigor | - | yes | - | - |
| Foliage transparency | - | yes | - | - |
| Tree age | - | yes | all | - |
| Tree growth | yes | - | all | - |
| Tree biomass | - | - | all | - |
| Tree grade | - | - | all | - |
| Tree history | - | yes | all | - |
| Total height | yes | - | all | - |
| Height class/stratum | - | yes | some | - |
| Percent cull | - | - | all | - |
| Tree location | yes | yes | all | - |
| Tree identification | yes | yes | all | - |
| Tree stocking | yes | yes | all | - |
| Bark thickness | - | - | all | yes |
| Damage/cause of death | - | yes | all | - |

Table 5.2 Understory-related variables collected in US national plot networks

| | US national plot networks | | | |
|---|---|---|---|---|
| *Understory variables* | *SI/MAB* | *FHM* | *FIA* | *NRI* |
| Species abundance | - | yes | all | - |
| *Plant* | | | | |
| Trees | yes | yes | all | - |
| Shrubs | yes | yes | some | - |
| Herbs | - | yes | some | - |
| Mosses | - | yes | some | - |
| Lichens | - | yes | some | - |
| Ferns | - | yes | some | - |
| Livcrworts | - | yes | - | - |
| | | | | |
| *Vegetation profile* | | | | |
| Percent cover | yes | yes | some | yes |
| Height | yes | yes | some | - |
| | | | | |
| Biomass | - | - | all | - |
| Habitat suitability | - | - | some | yes |

**Table 5.3** Soil-related variables collected in US national plot networks

| | *US national plot networks* | | |
|---|---|---|---|
| *Soil variables* | *FHM* | *FIA* | *NRI* |
| Physiography | - | all | yes |
| *Physical characteristics* | | | |
| Strata | yes | - | yes |
| Soil texture | yes | some | yes |
| Drainage class | yes | some | yes |
| Slope shape | yes | some | - |
| Slope position | yes | some | - |
| *Depth* | | | |
| Rooting | yes | some | inferred |
| Fibrous organics | yes | some | inferred |
| Impervious layer | yes | sonic | inferred |
| Decomposed organics | yes | some | inferred |
| Saturated soil | yes | some | inferred |
| Mottles | yes | some | inferred |
| Litter | yes | some | inferred |
| pH | yes | - | inferred |
| C/N ratio | yes | - | inferred |
| Soil erosion | yes | some | yes |

**Table 5.4** Stand-related variables collected in US national plot networks

| | *US national plot networks* | | | |
|---|---|---|---|---|
| *Stand variables* | *SI/MAB* | *FHM* | *FIA* | *NRI* |
| Forest type | yes | yes | all | yes |
| Stand age | - | yes | all | - |
| Stand origin | - | yes | all | - |
| Treatment opportunities | - | - | all | yes |
| Past treatment | - | yes | all | - |
| Accessibility | - | - | all | - |
| Stand size/seral stage | - | yes | all | - |
| Disturbance (natural and human caused) | - | yes | all | - |

**Table 5.5** Control and location variables collected in US national plot networks

| | *US national plot networks* | | | | |
|---|---|---|---|---|---|
| | *SI/MAB* | *FHM* | *FIA* | | *NRI* |
| *Variables* | | | *Photo* | *Field* | |
| *Control variables* | | | | | |
| Location coordinates | yes | yes | all | some | yes |
| Location identification | yes | yes | all | some | yes |
| Photo class | - | - | all | all | - |
| Political subdivision | - | yes | all | - | yes |
| Cruiser | - | yes | all | - | - |
| Survey date | - | yes | all | all | yes |
| *Site variables* | | | | | |
| Ownership | - | - | all | - | yes |
| Site class | - | yes | all | - | - |
| Site index | - | yes | all | - | - |
| Earth cover | - | - | all | all | yes |
| Land use | - | yes | all | - | yes |
| Slope | yes | yes | all | - | yes |
| Aspect | yes | yes | all | - | - |
| Elevation | yes | yes | - | - | - |
| *Other variables* | | | | | |
| Distance from other | | | | | |
| land uses | - | - | some | - | yes |
| earth covers | - | - | some | - | yes |
| Water presence | - | - | some | - | yes |
| Size of water body | - | - | some | - | yes |
| Burn history | - | yes | some | - | - |
| Animal use, browsing | - | yes | some | - | yes |
| Artifacts of human use | - | - | some | - | - |

## PIXELS

The discussion to this point has described data collection at ground sample locations. Decision-makers also need to know what resources lie in between sample points. Various remote-sensing products provide 'wall-to-wall' information and offer rapid coverage of areas at relatively low cost. Interpretation, however, requires special skills and equipment. All remote sensing efforts need to be verified on the ground for accuracy and to provide information that cannot be obtained directly from the imagery. Global positioning units are useful in linking remote sensing and field plots with a GIS.

### Sensors/platforms

A good review of the various kinds of sensors available and their uses for measuring and monitoring vegetation biodiversity is contained in Lund *et al.* (1995). Typical forms of remote sensing include aerial photography and satellite imagery.

*Aerial photography*

Aerial photography is the most widely-used form of remote sensing imagery for vegetation surveys. Modern camera systems and films can provide imagery of high resolution over a broad range of scales. Aerial photographic systems record reflected energy in the visible and near infrared portions of the spectrum. Factors that define aerial photography utility include area of coverage, mission time and date, scale of the imagery, film emulsion, camera format, lens focal length, and atmospheric condition at the time of the mission.

*Satellite imagery*

Digital imagery from remote sensors, e.g. meteorological satellites, supplies information for specialized natural resource applications. Geo-synchronous satellites provide synoptic low resolution coverage on an hourly basis. Imagery from the Advanced High Resolution Radiometer (AVHRR) carried aboard the US National Oceanic and Atmospheric Administration (NOAA) series of satellites has been used in assessing forest fuel condition and for developing national vegetation cover maps for several parts of the world. AVHRR imagery has a nominal resolution of 1.1 km at nadir and daily coverage. A 'scene' covers an area of approximately 1,750 x 6,000 km.

Multi-date AVHRR data are valuable for basic mapping, land-cover change detection, and documenting vegetation conditions. Acquired daily, AVHRR data can be used to develop nearly cloud-free image composites based on several consecutive days. These products, compiled over a one-year interval, are used to identify phenological vegetation characteristics.

The US Landsat and French SPOT (Systeme Probatoire d'Observation de la Terre) satellites provide easily accessible imagery with global coverage. Circling the Earth in near-polar sun-synchronous orbits, these satellites carry sensors that acquire imagery at a consistent solar time during each daylight pass. Repeat vertical coverage is available from a single Landsat satellite on an approximate 16-day cycle. When multiple satellites in the same series are operating, the repeat frequency of vertical coverage is proportionally increased.

The current Landsat satellites (4 and 5) carry the Multispectral Scanner (MSS) and the Thematic Mapper (TM). Both instruments are mechanical scanners that employ a rotating mirror to acquire data in the cross track direction. A full scene of Landsat data covers an area of 185 x 185 km. TM has a resolution 30 m in six bands of reflected energy extending from the blue portion of the spectrum to the middle infrared and an emissive thermal infrared band with a resolution of approximately 120 m. TM data have been available since 1982. There are many successful examples of using Landsat TM for vegetative cover mapping, including forest condition and type. Mapping of old-growth vegetation, forest type, and structure in the Pacific Northwest region of the United States is one example (Steffenson and Wilson, 1993). Landsat TM has also been used to monitor subtle changes in vegetation such as that reported on the Mark Twain National Forest in the United States (Platt *et al.*, 1993).

The Multispectral Scanner has a resolution of 80 m in four spectral bands in the green, red, and near-infrared portions of the spectrum. Multispectral scanner data have been available since 1972. The current Landsat 5 is the last satellite in the series to carry a multispectral scanner instrument. Although of significantly lower resolution than TM, MSS data have been available for more than 20 years, beginning in 1972, making the data especially suitable for evaluating landscape change.

## US remote sensing programs

The most common 'wall-to-wall' data sources in the United States include vegetation type maps developed by various local land management agencies and companies; the Gap Analysis Program sponsored by the US Department of the Interior's (USDOI) and the US Geological Survey's (USGS)

Biological Resources Division, previously a US Fish and Wildlife Service program; Multi-resolution Land Characterization Project (MLRC) sponsored by EPA and other cooperating agencies; North America Land Characterization (NALC) project sponsored by EPA and National Aeronautics and Space Administration (NASA); and Global Land Cover Characterization Data Base (GLCCDB) sponsored by the US Geologic Survey (USGS) and the United Nations Environment Programme (UNEP). Some of these mapping programs include activities abroad.

*Agency/industry vegetation maps*

Most US land management agencies and land-based industries have vegetative type maps and data bases developed from remote sensing interpretation, particularly aerial photographs. In the US National Forest System, forest stand maps usually show primary forest type, stocking, size class, and age or year each stand was established. State and private land management groups have similar information. While these maps are important information sources, so are the aerial photographs from which the vegetation maps are developed. Given high-resolution photography and proper equipment, one can also measure tree height and crown diameter. From interpreted image data and information collected from ground plots, regression or prediction equations expand sample data to areas covered by the imagery. The US Forest Service maintains its photographs, maps, and data bases at the local level (ranger district, area office, etc.).

Vegetation maps and aerial photo interpretation could become more useful for biodiversity estimates if measurements were standardized across the United States. Precise geographic coordinates and additional Earth cover classes would be beneficial. Estimates can also be improved by interpreting forest cover, vegetation type, stand height, canopy cover, and landscape pattern features and linking them with broader remote sensing efforts (Päivinen *et al.,* 1994).

*Gap analysis of natural terrestrial cover*

Gap analysis is a domestic program of the National Biological Service to identify species not adequately represented in areas managed for long-term biodiversity conservation (Scott *et al.*, 1993). Procedures focus chiefly on vertebrate species ranges, rather than on abundance or quality of habitat, although resulting maps help identify both flora and faunal 'hot spots' containing biologically diverse communities (Butterfield *et al.,* 1994). Information on species ranges derived from professional judgments and recorded sightings are used interactively with satellite imagery, other available data layers I from NRI and FIA surveys, weather recording stations, and soils in a geographic information system (GIS). Imagery, species records, and ancillary data used for displaying mapped information vary by State.

*Multi-resolution Land Characterization Project (MRLC)*

The MRLC is an effort to acquire a set of the most accurate Landsat TM data (30-m resolution) of the conterminous United States. Cooperators in this project include EROS Data Center (EDC) National Mapping Division and the Water Resources Division of the USGS, EMAP, the Gap Program, the Coastwatch program coordinated by the NOAA and the North American Land Cover (NALC) program within EPA. It involves integration of the data bases from Landsat TM-based Earth cover and the ground reference data developed in the different agencies' national programs to produce land-cover data tailored to the needs of each participating agency. Emphasis is on registration (geo-referencing the satellite imagery with a coordinate system) and preprocessing of the Landsat imagery rather than on specific vegetation classes. However, several vegetative cover/use categories are envisioned, including forest (evergreen and deciduous), woodland, and cropland.

*North American Land Characterization*

NALC is part of the NASA Landsat Pathfinder project that seeks to obtain Landsat MSS imagery (80-m resolution) of various parts of the world from the 1970s through the 1990s for global change research. The NASA focus is on reprocessing data already collected and stored in national and international archives and exploiting those data to obtain new insights about global-change phenomena. Eleven federal agencies participate, coordinated by the Committee on Earth and Environmental Sciences. The program will provide long-term, consistently processed, medium to high resolution data sets selected for their local, regional, and global importance in global change research.

NALC is specifically designed to support US and international Global Change Research Program efforts. The goals are to collect the MSS data of North America, assemble geo-referenced data sets, develop land cover classifications (forest, deforested, reforested, and non-forest), and analyze the land cover changes related to global change research activities. About 200 Landsat triplets have been produced thus far. Priority test areas include Central Mexico, the Chesapeake Bay region, and Central Oregon. Future plans call for completion, in priority order, of the western United States, Central America, and the eastern United States. Data for Canada will be compiled by that government (B. Levinson, personal communication; EPA, 1993b).

The Humid Tropical Forestry Pathfinder is a related program that focuses on the Brazilian Amazon and tropical portions of Africa and southeast Asia to map the rates of deforestation, The project is acquiring several thousand Landsat scenes for the 1970s through the 1990s. The intent is to compile a comprehensive inventory of deforestation and secondary growth to support global carbon-cycle models (C. Justice, personal communication; D. Skole, personal communication; Lauer *et al.*, n.d.). Classes include forest, deforest, revegetated, non-forest, cloud, and water areas. The results from tile Pathfinder projects, as well as the imagery scenes used, may be made available, to US government agencies and their cooperators at little or no cost (C. Justice, personal communication).

*Global Land Cover Characterization Data Base (GLCCDB)*

This is an international effort designed to characterize global land cover at a 1-km resolution using multi-source data, both coarse-resolution advanced Very High Resolution Radiometer (AVHRR) imagery satellite data and ancillary data such as elevation and ecological region data sets (Brown *et al.*, 1993). A prototype has already been completed for the conterminous United States. These data bases will be developed as five continent-based coverages (North America, South America, Europe/Asia, Africa, and Australia/Oceania). Primary input to this database will be 1-km AVHRR time-series composites based on 10-day compositing periods from baseline data of April 1992 to the present. Other data will include digital elevation data, climate station data, and ecoregions. The data will be used to determine seasonally distinct land cover regions comprised of relatively homogeneous land cover associations. Each region will be further documented by attributes that describe vegetation composition, seasonal characteristics (onset, peak, duration of greenness), and site characteristics (topography, soils, climate). The global AVHRR data will consist of composites over an 18-month time span.

Key points of the effort are to ensure that the data have been collected, processed and organized in a standard fashion and that data base development methodology is in place, or is being developed so users can make their own analysis of the data. A US prototype is published on a CD-ROM available from the USGS EROS Data Center. This procedure is supported by the United Nations Environment Programme (UNEP) and several federal agencies including the EPA and USFS. Examples of the sort of land cover types described in the global database are cropland/pasture, woodland/cropland, mixed-forest/crop, western conifer and northern forest. For each of these general 'cover types', primary vegetation types can be listed as a group (L. Pettinger, personal communication; Sturdevant, personal communication; Loveland *et al.*, 1991), *Other international activities*

Other US federal agencies involved in remote sensing activities abroad include NOAA, the US Agency for International Development (USAID), the USDA Foreign Agriculture Service (FAS), and the Department of Energy (DOE).

NOAA is working towards two goals: 1) to continue current work in product development, research and applications, and validation; and 2) to support and encourage full and open data sharing among the United States and members of the international community. Products include Pathfinder (a cooperative effort with NASA to provide research quality global change data sets from operational satellites), global vegetation indices (GVI), and the Global Change Data Base. The focus is on agricultural lands, primarily crop yields. NOAA is also working on automated fire-detection alarm systems from real-time AVHRR imagery (F. Kogan, personal communication; A. Hambleton, personal communication).

The FAS monitors crop production abroad (R. White, personal communication). USAID has the Famine Early Warning System (FEWS) that monitors weather patterns and crop production in Africa, primarily using AVHRR (D. Dworkin, personal communication; J. Olsson, personal communication). DOE is using GVI data with many GIS layers to model land suitability for sequestering additional carbon.

The European Space Agency Tropical Ecosystem Environment Observations by Satellite (TREES) program also monitors forest conditions in the tropics. Broad classes are mapped, including forest, deforested lands, croplands, and non-forest lands.

## PARTNERSHIPS AND PROSPECTS

One important goal of biodiversity research is to be able to predict biologically diverse locations over extensive areas using existing information. If plot selection is unbiased, one can make statements about the more extensive areas with a statistical degree of confidence. However, such use of existing information requires linkages among data sets and data sources.

### Data set linkages

Environmental groups, such as Conservation International (Tangley, 1992) and The Nature Conservancy (Iremonger and Sayer, 1994), use expert information and limited-area sample plots to predict locations with high biodiversity potential. More data-rigorous mapping employs field plots linked directly with remote sensing.

Field measures provide detailed physiography as well as vegetation information; i.e. biomass, production, species, disturbance, and uses. Data from remote sensing can include landscape complexity, landform, and vegetation information such as spectral reflectance, overstory type, percentage canopy cover, height, and crown diameter. Ancillary information from digital elevation models can provide physiographic characterization such as slope, aspect, elevation, and terrain position. Information from field plots can be combined with remote sensing attributes through regression analysis modeling - a topic discussed in most sampling texts (e.g. Cochran, 1977) or through spatial statistics. When combined with remote sensing efforts, models characterize factors present in an extensive area; e.g. basal area and tree volume (Lund, 1974), biomass (Leblon *et al.* 1993), forest fragmentation effects by species (Rudis, 1993a) and community types (Rudis, 1995), red-cockaded woodpecker habitat (Lennartz and McClure, 1979), and old-growth community types (Bolsinger and Waddell, 1993).

Ideally, one should use all sources of information to make biodiversity estimates. Data extracted from field plots and remote sensing may be mutually beneficial. Field plots, for example, can serve as a means for developing classification systems for use with remote sensing and provide a vehicle for accuracy assessments and validation of interpretation, On the other hand, remote sensing can provide the means to expand or extrapolate field data to sites not visited on the ground, while seasonal and multi-spectral imagery help determine species and overstory community composition.

Modeling with detailed field data measures and remote sensing is required to estimate composition and disturbance to understory vegetation. A key data 'linkage' is to estimate field measures that correspond with attributes measured by remote sensors. For forest land monitoring, Päivinen *et al.* (1994) recommend a minimum data set to be recorded from field plots and remote sensing for monitoring forested lands, including vegetation type, height, canopy cover, geographic coordinates, and the size of the surrounding area to which the ground sample applies.

One could possibly develop correlations among the less intense plot networks (e.g. SI/MAB plots) with the more intense FHM, FIA, or NRI plots using geographic coordinates and common data sets. These plots would then be used to develop correlations with the FIA or NRI photo plots which in turn could be used to tie in with wall-to-wall satellite imagery. In addition, biomass-structure information usually requires some height estimation from stereo imagery, radar, or laser devices.

Remote sensing also serves as a basis for detecting changes. Baseline information for determining broad-scale change can be developed from AVHRR data when supplemented by radar, Landsat, SPOT, and aerial video imagery for verification. This may be accomplished with USGS in cooperative efforts in world vegetation mapping. The primary goal is to identify and stratify distribution of forest and other vegetation types and areas of' suspected change (logging or natural disturbances). Areas suspected of large-scale change would be studied in detail with other imagery. A map of the country, derived from AVHRR, could be combined with other data to form a sampling frame for use with higher resolution imagery.

In addition to satellite data verification, higher resolution photography and videography can be used for updating detailed maps, monitoring field plots, and analyzing vegetation attributes. Current interest at the USFS Southern Forest Inventory and Analysis Unit (SO-FIA) is in the use of stereo pairs from video to generate 3-D images to visualize canopy characteristics. SO-FIA is also obtaining measurement information on trees and stands from videography. This type of work should help researchers measure diversity and estimate change in specific forest plots over time. Since the video is linked to global positioning systems (GPS), the same plots could be re-imaged periodically to look for changes in canopy structure associated with forest disturbances.

Table 5.6 provides comparisons of use of some satellite/airborne systems for estimating various vegetation attributes when linked with field and ancillary data.

## People linkages

Cross-disciplinary working relationships among agencies and individuals involved in field and remote-sensing data collection are mandatory. Approaches to bridging social and political barriers across disciplines are discussed elsewhere (Rudis, 1993b).

A first step is make contact with the data custodians to acquire the information. For US federal data sources, this should not present much of a barrier because data collected by federal agencies using public funds generally are made available through the Freedom of Information Act. There may be some expense in getting the information to cover reproduction costs. On private lands, the exact location of data collected may not be shared so as not to compromise the trust of landowners. In addition, acquiring information from outside the United States could prove difficult. One way to gain access to data is to become a cooperator in the data collection effort. Examine the needs of all parties concerned, including personnel and technological needs, as well as the political considerations. Support can encompass funding, people, and in-kind services. Respect tile privacy and confidentiality of the data of others. Agree to co-author publications and share in any benefits that may arise from the surveys. Request that cooperators or external data sources review your findings before publishing.

**Table 5.6** Recommended uses of some remotely sensed data sources for vegetation information (from Lackowski 1990 [unpublished USDA Forest Service report] and Lund et al. 1994)

| | | *Landsat* | | *Photography* | |
|---|---|---|---|---|---|
| *Attribute* | *AVHRR* | *MSS* | *TM* | *1:24K* | *1:12K* |
| Forest/non-forest | 3b | 1-3c | 1-3 | 1-3 | 1-2 |
| Hardwood/conifer | 3b | 1-3bc | 1-3c | 1-3 | 1-2 |
| Species | 0 | 3abc | 3 abc | 1-3b | 1-2b |
| Canopy cover | 3b | 2-3bc | 1-3 bc | 1-3b | 1-2b |
| Vegetation height | 0 | 0 | 0 | 1-3 | 1-2 |
| Vegetation density | 3b | 2-3c | 1-3 c | 1-3 | 1-2 |
| Structure | 0 | 0 | 2-3bc | 2-3 | 1-2 |
| dbh (size class) | 0 | 2-3bc | 1-3bc | 1-3b | 1-2b |
| Basal area | 0 | 3bc | 2-3bc | 2-3b | 1-2b |

| Where recommended use is: | when used with: |
|---|---|
| 0 = not recommended for data layer | a = terrain data |
| I = small areas (e.g. stands) | b = field-collected data |
| 2 = medium areas (e.g. districts) | c = photo-interpreted data |
| 3 = large areas (e.g. forest) | |

*Plot data*

Information about the SI/MAB plot network may be obtained from SI/MAB, Smithsonian Institution, 1100 Jefferson Drive SW, Suite 3123, Washington, DC 20560 USA (telephone: +1-202-357-4793; fax: +1-202-786-2557). For information about US plot networks in general, see EPA(1993a). For information on the FHM or the FIA plot network, contact the USFS; for NRI plots, contact the NRCS.

Those addresses are: 1) USDA Forest Service, FIERR, P.O. Box 96090, Washington, DC 20090-6090 USA (telephone: +1-202-205-1747; fax: +1-202205-1087; E-mail: fswa/s=fierr/ou1=w01c@mhs-fswa.attmail.com) and 2) USDA Natural Resources Conservation Service, Resource Inventory Division, PO Box 2890, Washington, DC 20013 USA (telephone: + 1-202-720-5420; fax: + 1 -202-690-3266; E-mail: jgoebel@nhq.nrcs.usda.gov).

Sources of information on forest inventory plots include ministries of forestry, universities, industries, etc.The Forestry Division of the FAO can provide contacts in other countries for forest inventory information. The International Union of Forestry Research Organizations (IUFRO), working in partnership with UNEP, maintains a data base on permanent plot networks throughout the world. This data base is voluntary and contains information about permanent plots used for research and inventory. Contact Forest Resources Division, FAO of the United Nations, Viale dellc Terme di Caracalla, 00100 Rome, Italy (telephone:+39-6-522-52251; fax:+39-6-522-53152) and IUFRO Permanent Plot Data Base Manager, GEMS PAC, UNEP, PO Box 30522, Nairobi, Kenya (telephone: +254-2-621234; fax: +254-2-226491; E-mail: myint@un.org).

*Vegetation maps and imagery*

Imagery in a variety of forms exists from a wealth of sources, including mineral and oil companies, military and intelligence departments, survey departments, bureaus of census, utility and electric companies, highway departments, natural resource agencies, donor organizations, space agencies, and universities. Such imagery can be used to measure and monitor key aspects of vegetation diversity. Each type of' imagery has its own uses, advantages, disadvantages, and availability.

For information about national- and regional-level vegetation mapping, contact the following: World Resources Institute, 1709 New York Ave., NW, Washington, DC 20006 USA (telephone: +1-202-662-2572; fax: +1 -202-6280878; E-mail: dirk@wri.org) and World Conservation Monitoring Centre, 219 Huntingdon Road, Cambridge, CB3 ODL, UK (telephone: +44-1223-277314; fax: +44-1223-277136).

Information about remote sensing activities in the United States may be obtained from the USGS; for other countries, contact the r-AO: US Geological Survey, EROS Data Center, GLIS User Assistance, Sioux Falls, SD 57198 USA (telephone: +1-605-594-6099; E-mail: GLIS @glis.crusgs.gov); Remote Sensing Center, FAO of the United Nations, Via delle Terme di Caracalla, 00100 Rome, Italy (telephone: +39-6-522-54026; fax: +39-6-522-55731).

## CONCLUSIONS

Many biodiversity inventories are conducted in relatively small areas, yet information is needed at the national, regional, and global levels. Most nations have forest inventory plot networks. While forest inventories may not contain the detailed species information that biodiversity inventories do, the forest inventory plot networks do represent large areas. Linkages can be developed among plot networks and extrapolated through remote sensing. A first step is to locate resource inventory and remote sensing information. A second step is to obtain and make use of information. This may require the formation of linkages and partnerships among data sets and data collectors.

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