# B

# BIODIVERSITY

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## Biodiversity in Forests

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### Introduction

Interest in biodiversity began in the mid-1980s with the Biodiversity Symposium, held in Washington, DC, sponsored by the National Academy of Science. Within increasing human populations and rising demands for resources and living space, the need to conserve biological diversity rose to the forefront with the development of the Convention of Biological Diversity (CBD) in 1992. The purpose of the Convention is to conserve biological diversity, promote the sustainable use of its components, and encourage equitable sharing of the benefits arising out of the utilization of genetic resources. Biodiversity inventories provide the building blocks upon which to carry out the intent of CBD and to meet local needs. Using inventories as the base, industry and other development opportunities should incorporate biodiversity within their management practices.

The concept of biological diversity is defined in Article 2 of the CBD as follows:

> ‘Biological diversity’ means 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 part; this includes diversity within species, between species and of ecosystems.

It is widely recognized that the earth’s biodiversity is poorly known. Although 1.75 million species have been discovered and described, the number will be much greater once we include bacteria, viruses, most of the marine species, and most of the arthropods. There is no doubt that we are now destroying this diversity at an alarming rate. No one knows exactly what the current extinction rate is, but recent calculations put it at between 1000 and 10 000 times greater than it would naturally be. The rate of extinction also appears to be increasing. Species are threatened in every habitat on every continent, though the severity of threat varies from place to place. A vital question is how badly this loss affects ecosystem functioning and our eventual well-being. Although current studies are impressive, they are tiny in comparison to the amount of unknown diversity and the urgency and importance of finding out what are available and taking steps to preserve and sustainably use the remaining.

The CBD obliges signatory nations to undertake an inventory of their biological diversity to provide basic information about the distribution and abundance of biodiversity. Such data are necessary for the long-term sustainable management, use, and conservation of biodiverse areas. Parties are to monitor the elements of biological diversity, determine the nature of the urgency required in the protection of each category, and sample them in terms of the risks to which they are exposed. They are to report on the biotic wealth and national capacity, the goals and gaps, strategic recommendations, and characteristics of the action. Specifically, under Article 7. Identification and Monitoring, nations are to:

- Identify components of biological diversity important for its conservation and sustainable use
- Monitor components of biological diversity, paying particular attention to those requiring urgent conservation measures or which offer the greatest potential for sustainable use

- Identify processes and categories of activities which have adverse impacts on the conservation and sustainable use of biological diversity, and monitor their effects
- Maintain and organize data derived from identification and monitoring activities.

Forest certification systems resulting from agreements in the United Nations Conference on Environment and Development (UNCED), Agenda 21, include criteria, indicators, or principles that address biodiversity as a critical component to sustainable development.

In order to meet the above requirements, parties need inventories of biological diversity. The objectives of biological diversity inventories may be to:

- Identify priority conservation areas
- Provide the necessary baseline data for monitoring the effects of anthropogenic disturbance or climate change on the biota
- Detect changes in ecological diversity that exceed the range of natural variation, across a range of spatial and temporal scales
- Provide an 'early warning' of impending irreversible changes
- Provide reports to the public on the status of ecological diversity in a timely and accessible manner
- Meet national and international commitments for monitoring biodiversity
- Provide data consistent with the requirements of forest certification programs.

## Biodiversity Types

CBD addresses three types of diversity: genetic, species, and landscape or ecosystem. Each has special features and challenges for inventory.

### Genetic Diversity

Genetic diversity is the degree of variability of the genetic material of an organism. Assessment of genetic diversity is time-consuming and prohibitively expensive, requiring modern laboratories and expensive chemicals. Species are defined by the differences in their genes. Therefore, one often uses species diversity to estimate genetic diversity.

### Species Diversity

Species diversity encompasses the number, types, and distribution of organisms found in a given area. Species diversity is the standard unit of measurement in most biodiversity surveys. The advantage of inventorying species is the advantage of being natural biological divisions and that they are easily identifiable. Many people already know high-interest organisms such as flowers and birds so identification of these organisms is relatively easy.

However, there are a very large number of species. A high proportion of them, particularly invertebrates, are as yet undescribed. Moreover, the identification of described species often requires a high level of expertise. Identifying all species in even a limited area is generally impracticable.

A common solution is to select certain taxa as indicator groups to act as surrogates for the whole biological diversity. Using indicator species can reduce the cost of the survey. The following options for indicators are in order of preference.

1. Best estimates: using genealogy to predict genetic or character richness.
2. Popular estimates: using species richness.
3. Practical estimates: using higher taxa or environmental variables as surrogates.
4. Relationship among estimates: a scale of surrogacy for mapping more of biodiversity value at lower cost.

To be effective, indicators should be:

- readily quantifiable
- easily assessed in the field
- repeatable and subject to minimal observer bias, and cost-effective
- ecologically meaningful – that is, to be representative of the taxic variation, microhabitats, and trophic diversity in the area and in close association with, and identification of, the conditions and responses of other species.

Scarce and less familiar species with short mean generation times may respond most rapidly to environmental deterioration. Thus these may make better indicators for environmental monitoring than the larger, better-known organisms.

### Landscape Diversity

Landscape diversity refers to the spatial heterogeneity of the various land uses and ecosystems within a larger area. Surveys of landscapes are useful for locating and prioritizing areas to protect. The natural environment is a highly variable continuum and is difficult to divide into a series of discrete, discontinuous units. Remote sensing and geographic information systems (GIS) obviate the need to develop the complex habitat and ecosystem classifications. Different, measurable attributes of the environment can be stored in separate layers within a GIS, such as soil characteristics, altitude, rainfall, percent canopy cover, mean height of dominant vegetation, and distributions of individual species. These can then be played back in any number of ways.

## Inventory Challenges

When compared to traditional forest surveys, the challenges for biodiversity inventories include the number of species, their mobility and/or seasonality, and time and resources available.

There are between 10 and 20 million species on earth. This is about 10 times as many as have been formally described by taxonomists in the past 250 years or so. Most species occur in the tropics, where taxonomic resources are scarcest. When considering all the species that may be present in an area – from insects to mammals, and from fungi to trees – it is generally impossible to enumerate and count each and every species in a given area. Consequently, taxonomically complete inventories are rarely conducted unless the area is very small.

Because of the vast differences in goals and areas to be surveyed, there are no well-defined rules as to how to perform biodiversity surveys. Unlike trees, fauna are mobile. Some flora and fauna may only be found during certain times of the year. Selecting the time to do an inventory is a major challenge.

Lastly, inventories take time – for planning, execution, and analysis – and time is running out for many species. Any inventory is costly. Inventories involving biological diversity are exceptionally costly, primarily because of the expertise necessary to locate and identify species. Taxonomic resources available to undertake large-scale inventories are few and far between. Accurate inventory requires access to reference collections and literature. These resources are primarily concentrated in the large museums of a few temperate countries.

To be able to make judgments concerning status and changes we have to have methods of measurement. Information on the identity, location, population size, or community distribution of a resource is obtained initially by field inventory and frequently displayed as resource maps. Inventory and monitoring of biological resources provide baseline information on the presence and distribution of biological resources and biological information necessary to implement adaptive management.

## Types of Biological Surveys

There are two general types of biological surveys – taxonomic and abundance. Taxonomic and abundance surveys may be scientifically designed, where the sampling is repeatable, or search-based inventories, where it is not. The limitations of search-type inventories include nonrepeatability due to lack of predetermined and documented sampling protocols. The advantage of searching is that it may provide the most taxonomically complete inventory.

### Taxonomic Surveys

Taxonomic surveys are undertaken to locate and document occurrences of particular species, in other words, what species exist in forest A. The primary goal of surveying the flora and fauna is to develop a list of the different species that are present on the site and not necessarily their numbers and condition. The data gathered are used to identify new occurrences of sensitive species, monitoring endangered populations, evaluating conservation priorities of an area, and bioprospecting. Sampling should take place in both undisturbed and disturbed areas.

The sampling of vegetation is more or less straightforward – plots and transects. The survey of fauna – things that move – is slightly more difficult. As a result, we see more subjective and opportunistic methods being used.

Vegetation is frequently observed and measured using fixed-area nested plots. The size of the plot or subplots will depend on the vegetation being observed. Large plots, such as $5 \times 20$ m, may be used for recording trees where plots as small as $2 \times 0.5$ m may be used for herbaceous vegetation. A series of permanent nested plots may provide information on spatial patterns of species and allow for statistical comparisons and can be used to detect trends in richness over time.

Transects for noting both flora and fauna biological diversity often utilize gradient-directed sampling. Transects are selected to transverse the steepest environmental gradients present in the area, while taking into account access routes. This technique is appropriate for rapidly assessing species diversity, while minimizing costs, since gradient transects usually capture more biological information than randomly placed transects of similar length.

Arthropods are often sampled using pan traps or pit-fall traps placed in microhabitats. Microhabitats may be identified based upon soil particle sized, amount and type of litter, surface moisture, vegetation structure, dominant plant species, and degree of shade. Voucher specimens are also used to sample invertebrates since most species are poorly known and difficult to identify.

Amphibians and reptiles are sampled using a variety of methods, including visual and audible searches along transects and within quadrats, sticky traps, and pit-fall traps. Sites are often subjectively selected to ensure sampling of all habitats and to minimize the number of species encountered.

Birds are sampled using mist-netting, point counts, and transects. The advantages of mist-nets are that:

- relatively little training is necessary to set up the nets and collect the birds
- identification tools may be used with birds in hand
- the method does not require vocalization knowledge
- the repeatability and accuracy of the data collected are high
- data can be collected on the physical condition of the birds
- recapture provides demographic data
- secretive and inconspicuous species may be detected.

Vocalizations and observations are used in point counts and transects. They have the advantage that they are less labor-intensive than mist-netting, they sample a larger proportion of the bird community, and estimates of population density may be obtained. The main disadvantage is the significant training in recognizing the birds and their calls.

Trapping is often used to sample small mammals. The advantage of trapping is that it may also provide voucher specimens.

Large mammals are surveyed using direct observations, aural identification of animal vocalizations, scent-post surveys, use of mammalian signs, and trapping.

### Abundance Surveys

Abundance surveys focus on the number of given species – in other words, how many gold finches are found in forest A? They are used for developing and evaluating management plans. These generally use remotely sensed data, GIS systems, preexisting cartographic maps and inventories and field sampling. One may collect either qualitative data (presence/absence, also known as binary) or quantitative data, in which the numbers of individuals for each species are counted.

## Biodiversity Inventory Strategies

There are two strategies for conducting biodiversity inventories – those for rapid assessment and those for baseline. Both may be used as a base for monitoring.

### Rapid Assessment

Rapid-assessment methods and sampling for indicator species are designed to identify and monitor selected biotopes of critical value. These surveys are often conducted on a regional or national basis to supply information necessary for the selection of conservation areas and other types of land-use planning. They may also be conducted locally where some type of land-use activity is planned. Speed is critical. Thus it is natural to focus on well-known and easily recognized organisms, such as mammals, birds, trees, and butterflies.

These assessments often employ a 'top-down' analysis that begins with an assessment of the natural communities present and their relative quality and condition. This information is subsequently used to determine where different species-oriented surveys should be conducted. This approach, commonly referred to as 'coarse filter – fine filter,' concentrates inventory efforts on those sites most likely to contain target species. These are very quick surveys that can be used to identify, with high spatial resolution, and within a short time frame, priority areas for the conservation and sustainable management of biodiversity.

Rapid assessments are carried out to identify areas quickly that need immediate protection. They usually consist of mapping out areas to be preserved. They are often conducted by teams of scientists and local experts aimed at identifying areas that have or are likely to have considerable diversity of species – especially those that may be considered rare or endangered.

### Baseline Assessment

Once one has established conservation areas or areas of concern or importance, then there emerges the need for monitoring and for knowing what is present in order to manage the resource. This requires the second type of inventory – baseline assessment, which focuses species. Baseline assessments are designed to find out what is in a given area and may include taxonomic surveys or abundance surveys. They are used as a foundation for monitoring change.

Sources for baseline assessments include satellite data, aerial survey, existing maps, field survey, and expert advice. One can combine these disaggregated data sets in a GIS to generate maps according to need.

### Monitoring and Evaluation

Monitoring is the act of observing something, especially on a regular or ongoing basis, and keeping a record of observations made. The main objective of monitoring is to reveal discrepancies between forecast and achievement in time for remedial actions to be taken. It also provides critical information to identify natural changes from human-induced changes.

Repeated surveys allow examination of time and spatial changes. Monitoring sites may consist of both permanent sites (visited one or more times each year) and nonpermanent sites. The permanent sites may be stratified across the different kinds of habitat/plant communities, replicated for each habitat/plant community monitored, and reflective of the different grades of habitat quality or condition. Landscape-level monitoring at the ecoregion level is often dependent on acquiring the appropriate GIS-based vegetation maps.

Monitoring can serve as a warning system, alerting managers that change in biodiversity may require changes in management regimes to ensure protection of scarce resources. Monitoring involves the repeated collection and analysis of observations and measurements to evaluate changes in populations of species and environmental conditions.

If there is the possibility that a sampling area may again be visited again, permanently mark the plots for remeasurement. Use care in remeasurement, take care to prevent an area from being overly disturbed. Permanent monitoring plots that collect reliable data can also act as standard reference points for the interpretation of changes observed by satellite.

Monitoring often occurs at the population (individual or multiple species) or ecosystem (individual or multiple habitats/plant communities) levels to facilitate tracking trends in resource size or distribution. Monitoring may also be conducted to obtain information on the condition of the resource and includes tracking characteristics such as contaminant concentrations, health of individuals, population vigor, and habitat quality. Lastly, monitoring can occur at regional scales that enable tracking changes in land use and fragmentation patterns.

For monitoring to be effective:

- Baseline (i.e., inventory) information must be collected or available.
- Monitoring objectives must be established.
- Monitoring actions must be repeated over time using consistent, standardized procedures.
- Monitoring results must be interpreted relative to the baseline information and the monitoring management objectives.

Quantitative data are more desirable for monitoring. They allow changes in the population to be measured instead of the population simply being recorded as present or absent.

## Steps for Developing a Biodiversity Inventory

The steps are similar to those for developing most any other type of resource inventory and monitoring program:

1. Carry out a stakeholder consultation to identify the issues.
2. Gather known information.
3. Define assessment and baseline programs together with management objectives.
4. Define the issues and develop options throughout the process.
5. Implement assessment.
6. Implement adaptive management, assess and monitor.

### Carry out a Stakeholders' Consultation to Identify the Issues

Develop and record the long-term rationale, objectives, and design of the monitoring program. Establish goals and objectives and the biodiversity endpoints that an agency, organization, or company wishes to assess and maintain.

### Gather Known Information and Lay Necessary Groundwork

Make use of existing biodiversity-related data and analyze in a GIS-based format if possible. Existing information may consist of maps, reports, data, taxonomic specimens, personal knowledge, and remote sensing imagery. Information on areas similar to the one under study is also helpful.

### Define Assessment and Baseline Programs Together with Management Objectives

The purpose may be to determine the extent, distribution, and condition of existing vegetation types, the probable distribution of species of concern, and the distribution (and intensity) of stressors (e.g., habitat fragmentation). Establishing baseline conditions may require the integration of monitoring programs and data-sharing among other landholders and resource agencies within the ecoregion.

- Delineate areas of high species richness and endemism, as well as areas and ecosystems at high risk of impoverishment because of their particular susceptibility to human-induced stressors. The preceding areas warrant more intensive monitoring.

- Identify indicators of structural, functional, and compositional biodiversity at several levels of the hierarchy that correspond to endpoints.
- For each major class of habitat (which may contain different plant communities), identify control areas (i.e., generally free from human-induced impacts) and areas subject to more intensive management or environmental stress.

### Define the Issues and Develop Options Throughout the Process

Through the stakeholder workshops and consultation process, identify critical biodiversity issues related to the operation. Formulate specific questions to be answered by monitoring. Typical questions may include:

- Are populations of species of concern declining, stable, or increasing?
- What are the patterns of species diversity across habitats and plant communities?
- Is the diversity, at its different levels of organization, declining, stable, or increasing?
- How are the size, distribution, and condition of native habitats and plant communities changing? How does biodiversity differ between natural and artificial ecotones (i.e., transitional areas between ecosystems or plant community types)?

Specify thresholds for the biodiversity endpoints that will trigger the need for changes in management practices.

**Identify resource needs** Understanding the resource needs and ascertaining the level of support are essential to ensure success of the biodiversity inventory. Critical resources may include time, commitment, and funding allocated to the project, as well as a sufficient number of people trained to conduct biodiversity assessments, devise the monitoring strategies, and improve the sampling protocols. These elements need to be balanced with professional expertise, adequate technology to manage information and voucher collections, and an appropriate budget for field equipment, data management, and publications.

**Define spatial and temporal scales** The scale at which the survey is carried out depends upon the goals of the project and on the unit of biodiversity being used. The scale should be appropriate to the organisms being surveyed.

The frequency of monitoring depends largely upon the goals of the project and the life history of the species; population changes that may be the result of regular cyclical fluctuations may appear drastic if the cycle is not known. Consideration of such natural cycles is important to the monitoring of populations.

**Design protocols** The next step is to design a monitoring protocol to address issues such as sampling design, data management and analysis, interpretation of results, and reporting mechanisms. Design requires a balance between time and effort and interpretability of data.

For taxonomic surveys, sampling effort can be expressed in many ways: as search time per site, as search within a given distance of a reference point or line, or as total number of sites or replicates needed to find a pattern. Setting a definite time limit also allows the survey to be more standardized and results can be compared from year to year.

For a survey to be considered scientific, it should be random. Consider using a grid covering the entire area of interest. A systematic network of fixed sample points across the entire region is one approach that would sample most vegetation types proportional to their size and at the same time be low-cost.

Different data collection approaches may be used to meet the above objectives.

**Respond to emerging lessons and reassess objectives** Ask:

- Have the objectives been clearly stated and are they realistic?
- What monitoring protocols are required to achieve the biodiversity conservation objectives? What is the timeline for accomplishing the objectives?
- Will the information that is gathered assist managers in making informed decisions?
- Can the results of the management decisions be statistically analyzed?
- Has a cost – benefit analysis been completed?
- What is the scale of the monitoring program?
- What kinds of teams and organizations are required to achieve the objectives?

The monitoring strategy will continually evaluate the relevance of its biodiversity endpoints, the questions asked, the indicator variables selected for monitoring, and their relationships. Changes to the monitoring strategy and its in-the-field protocols will be made as necessary.

**Implement adaptive management, assess, and monitor** Assessment and monitoring protocols are essential to develop a solid scientific foundation for biodiversity monitoring. In recent years, there has been an increased emphasis on standardizing monitoring protocols to facilitate comparisons among different projects. The long-term data obtained from implementation of such protocols are helpful in detecting the magnitude and duration of change, how related taxa are changing, and early-warning indicators of ecosystem health. They serve as the basis for formulating additional research hypotheses, and most importantly, the data can be used to guide management decisions for biodiversity conservation.

The results of monitoring should be analyzable in a statistically rigorous manner. Also, the results should be capable of synthesis into an assessment that is relevant to policy-makers and that can be used to make positive changes in management direction.

Continually evaluate how well the selected indicators correspond to the biodiversity endpoints of concern. The results of the biodiversity monitoring effort should be used as an important component of adaptive management. If monitoring indicates an adverse change in the resources then the monitoring results should be used to formulate appropriate changes in management actions.

## Linking with other Inventories

Biodiversity inventories, by design, are often limited to very specific sites. However, such inventories may overlook other sites that need protecting. Therefore some types of broad area inventories are desired. Where possible and feasible, these inventories should be incorporated within existing resource management inventories such as forest surveys by adding new variables to be collected in the field such as:

- characteristics of habitats (springs, moist land, land with a high biological value)
- characteristics of forest/vegetation margins (length, form, and structure)
- description of vegetation in the grass, shrub, and tree strata
- effects of other uses of the land (agriculture)
- geohydrological features: surface and subsurface water resources
- land-use history and changes over time (grazing, agriculture, special practices)
- quantities and dimensions of standing and fallen dead trees, and of rotten trees, and the extent of such rot
- soil and the land form/geological features, including variables subject to change over time
- remarkable vegetation from the viewpoint of their phenotype.

Such additions to ongoing natural resource inventories may effectively improve our knowledge of the biological resources with minimum effort.

*See also*: **Biodiversity**: Endangered Species of Trees; Plant Diversity in Forests. **Ecology**: Biological Impacts of Deforestation and Fragmentation; Human Influences on Tropical Forest Wildlife. **Environment**: Environmental Impacts. **Genetics and Genetic Resources**: Forest Management for Conservation. **Landscape and Planning**: Landscape Ecology, the Concepts. **Resource Assessment**: Forest Change; GIS and Remote Sensing.

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# Plant Diversity in Forests

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## Measurement of Diversity

Diversity can be measured either as species richness, the number of species per unit of land surface area or per unit number of individuals in a sample, or as a derived index that attempts to reflect the variation in relative abundance within a community as well as its richness. Commonly used indices of diversity are the Simpson's index ($D$) and the Shannon index ($H$), which are defined as follows:

$$\text{Simpson's index } D = \frac{1}{\sum_{i=1}^{S} P_i^2}$$

and

$$\text{Shannon index } H = -\sum_{i=1}^{S} P_i \ln P_i$$

where $S$ is the total number of species in the community and $P_i$ is the proportion of individuals represented by the $i$th species. These indices have the useful property that their values increase with greater evenness in the relative abundance of species for a given species richness.

## Distribution of Diversity at Large Scales

At a global scale, the diversity of plants in forests, as in all plant communities, varies with climate and soil conditions, although there is also a pervasive imprint of history that disrupts large-scale relationships between plant diversity and biophysical conditions under some circumstances. The relationship between climate and plant distribution was promoted by the systematic collation of climate data by the German ecologist Heinrich Walter that allowed him to conduct a comparative analysis of the distribution of diversity at large spatial scales. By representing climates using a standardized format (referred to as a 'klimadiagram'), Walter proposed a hierarchical classification of world vegetation in which vegetation 'types' are nested within vegetation 'zones.' Four of Walter's vegetation zones possess vegetation types that can be described as forests: the tropical-cum-subtropical, warm temperate, cool temperate and cold temperate vegetation zones (the fifth, the Arctic vegetation zone, does not possess forests although dwarf trees are present in Arctic vegetation). Walter determined that the distinction between vegetation zones was determined on the basis of temperature, and that the series of vegetation types within each vegetation zone were differentiated on the basis of rainfall-related criteria.

## Temperature

Classifying vegetation was the first step to obtaining a mechanistic understanding of the distribution of world vegetation. Subsequent work has refined our knowledge of the distribution of diversity, and robust generalizations are now possible. First, it is evident that forests lying closer to the equator possess a higher plant species richness and diversity than forests at higher and lower latitudes. This statement assumes that the comparison being made is of forests at the same altitude, subjected to equivalent rainfall regimes and excludes forests growing on soils that are deficient in their availability of plant nutrients, such as N, P, or K, or supply an extreme of potentially toxic elements such as Ni or Al. Thus a hypothetical transect starting on the equator in wet evergreen tropical lowland rainforest in Southeast Asia and running north through the warm temperate evergreen and cool temperate deciduous forests of eastern Asia and thence into the cold temperate (boreal) forest of eastern Siberia would encounter forests of decreasing plant diversity with increasing latitude. This gradient in plant diversity is expressed among the trees that form the forest canopy, but is also observed among other life-forms such as shrubs and herbs. Some life-forms (such lianas and epiphytes) are rare or absent outside the tropics. Similar transects running north from equatorial forests in Africa and South America would not encounter such a well-ordered sequence of vegetation zones. The southern hemisphere lacks cool temperate deciduous forests at low altitudes and lacks boreal forest entirely because the continental land-masses do not extend sufficiently far south. Diversity of plants in forests also declines with increasing altitude on mountains at all latitudes, although the