Tropical Forest Management and Biodiversity
Information and Indicators

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1. Introduction

This manual is aimed at those helping to develop and implement forest policy at the national level and those concerned with forest management at the national and local levels in tropical moist forest (TMF) countries.

The manual aims to show how different kinds of information can be used to help make informed decisions about forest policy and management in the context of biodiversity. It does <u>not</u> intend to tell users what those decisions should be, although it uses current knowledge to indicate what the possible effects of given decisions on biodiversity might be. It also tries to make clear what the limits of current knowledge are, and to show where forest managers themselves can make significant impacts on the state of knowledge.

2. Biodiversity and its importance

What is biodiversity?

Biological diversity, or *biodiversity*, is an imprecise term that is used to refer to the diversity of life. It is usually referred to at three levels – genes, species and ecosystems – and can be applied at a single locality or over broad geographic areas including, ultimately, the Earth as a whole. Biodiversity is used to refer not only to the numbers but the types of genes, species and ecosystems existing in the area in question. These three levels are inextricably inter-linked: the diversity of species is in large measure determined by genetic diversity, and diversity at ecosystem level is a product of different species interacting with their physical environment. However, species are arguably the most natural level at which to consider biodiversity and the most useful for management and planning purposes. Indeed, biodiversity is commonly taken to mean species diversity, and particularly species richness, that is a measure of the number of different species occupying a particular place.

Biodiversity can be considered at a variety of different scales. It can refer to diversity (usually of species) at a given site or within a habitat (alpha (α) diversity), or to differences between habitats (beta (β) diversity). Thus an area with a wide range of dissimilar habitats, each with different constituent species, will have a high β-diversity even if each of those habitats is itself not very diverse, that is has a low α-diversity.

Why is biodiversity important?

At the most fundamental level, at least some biological diversity is necessary for the maintenance of a functioning biosphere and to provide basic materials for human consumption and use. Thus, biodiversity in its broadest sense is important for at least four reasons:

- It includes resources that are used by human beings for survival and for economic activity. These include the full range of species important for use as food, fibre and pharmaceuticals.
- It preserves the possibilities or options for future use of resources not currently exploited

- Living systems provide a number of environmental services that are critical to mankind and to the health of the planet. These include sequestration of carbon dioxide that can contribute to global climate change, protection of soil and water resources through watershed protection, and maintenance of global water and nutrient cycles.
- Its existence and persistence has as intrinsic value for many members of current and future generations.

These values of biodiversity and its overall importance have led to recommendations that policy and management decision-making should exercise the so-called *precautionary principle* and seek to minimise adverse impacts on biodiversity wherever possible.

The importance attached to biodiversity and the recognition of growing threats to many of its components posed by the demands of modern society and growing human populations led to the convening of the UN Conference on Environment and Development, or Earth Summit in 1992. There, the importance of biodiversity was acknowledged through the drafting of the Convention on Biological Diversity (CBD).

The Convention on Biological Diversity

The Convention on Biological Diversity (CBD), which entered into force at the end of 1993 in response to the perceived global crisis in the state of biodiversity, is the most important international agreement concerning biodiversity. The great majority of the world's countries (179), including almost all those with significant amounts of tropical forest, are signatories (or Parties) to the Convention.

The Convention has three objectives:

- the conservation of biodiversity;
- the sustainable use of its components; and
- the equitable sharing of the benefits arising from the use of genetic resources.

In order to meet these objectives, Parties to the Convention are obliged to implement a series of provisions, set out in the various Articles of the Convention, that relate to such issues as: identification and monitoring of biodiversity; *in-situ* conservation; *ex-situ* conservation; research and training; impact assessment; and access to and transfer of technology.

In effect the CBD aims to encourage and enable its signatories to conserve biological diversity, to ensure that its use to support national development is sustainable, and to reconcile national interests with the maintenance of the highest possible levels of global biodiversity. To meet these goals, each country needs a sound baseline understanding of its own biodiversity and how it fits into the global pattern. It then needs to be able to evaluate changes in the status of biodiversity over time and their relation to policy and management decisions.

3. Tropical forests and biological diversity

Tropical moist forests are almost certainly the most diverse ecosystems on earth. Although they only cover around 6% of the land surface, they hold well over half, and may conceivably hold more than 90%, of all the world's species. This means that with very few exceptions there are large numbers of species at any given site. Tropical moist forests also tend to differ greatly from place to place in their constituent species. Areas close to each other with similar ecological conditions share more species in common than areas far apart, but it is still extremely unlikely that any two sites will have exactly the same constituent species.

The species composition of any given site in a tropical moist forest is not fixed, but changes with time, as a result of natural perturbations such as storms and wildfires and through unpredictable or stochastic variations in the population levels of individual species.

In global terms the importance of any given forest area for biodiversity is a reflection of how rich that area is (effectively how many different species occur there) and how distinctive it is. The latter is determined by how many species occur there that occur nowhere else (endemic species), or in few other places (restricted range species). In terms of planning for maintenance of biodiversity, the number of globally threatened species present is also of great importance.

4. Human impacts and change in tropical moist forest biodiversity

Natural global patterns in biodiversity have been altered almost everywhere by human action. In the contemporary world, human activities are almost certainly the most important influence on forests' capacity to maintain their original biodiversity. Such activities as commercial and artisanal logging, large scale land conversion, fuelwood and charcoal production, slash and burn agriculture, harvesting of non-timber forest products, hunting and mining all affect forest biodiversity. Climate change resulting from modification of the atmosphere by anthropogenic emissions of carbon dioxide and other "greenhouse gases" is also affecting the distribution and status of forest biodiversity

Each of these types of human influence affects forests differently, and the magnitude of the effects will depend strongly on the methods employed locally, the forest type, and on other factors within and around the ecosystem. For example, commercial logging in temperate forests is often by clear cutting, which entirely removes forest cover in some areas and fragments remaining forest cover. In contrast, commercial logging in tropical forests is usually by selective felling, which disrupts canopies and forest structure and alters species composition but may not alter total forest cover or its spatial configuration. Secondary effects of logging such as increased access and resultant hunting are also important determinants of the status of forest biodiversity and the prospects for its preservation. Small-scale timber extraction differs yet again in its effects on forest condition. The effects of climate change are less localised, and are only beginning to be recognised. Thus, many factors influencing forest biodiversity are affected in varying and complex fashions by human activity.

Changes in tropical moist forests caused by human action

In general human activities tend to affect any of five major aspects of forests that in turn affect their biodiversity:

1) The *total area of forest remaining* – many of man's activities remove forest cover either temporarily or permanently. Some forest types may disappear locally, and reduction in the total amount of habitat is a significant pressure on some forest species that can lead to local extinction.
2) The *configuration of remaining forest cover* – reduction in forest area is often accompanied by division of remaining forest cover into fragments, rather than continuous blocks. Forest biodiversity is affected by the consequent local reduction in habitat area, by the exposure of forest edges to new environmental and biotic influences and by isolation from other forest areas.
3) The *structure of remaining forest* – some human activities alter stand and canopy structure, both directly and indirectly.
4) The *composition of remaining forest*, including the species present, their abundances and the age-structures of populations – extractive activities in particular tend to focus on particular species and specific components of their populations.
5) Some of the *underlying processes*, such as nutrient cycling and turnover of individual trees.

These changes are all clearly inter-linked with each other. Moreover, any one human activity, such as logging, is likely to produce a whole range of different changes. This makes it often difficult to determine cause and effect, and to develop appropriate mitigation measures.

Forest extent and configuration

The changes in forest extent and configuration that accompany changes in land use, and especially conversion of forest to agriculture, can have substantial effects on the capacity of forest ecosystems to maintain biodiversity. As forest ecosystems are divided into smaller patches, there are numerous effects on their biota, and the responses may vary substantially among species and among forest types. The effects of forest fragmentation can be broken down into three major groups:

- area effects,
- edge effects, and
- isolation effects.

What follows is a brief summary of characteristic components of these effects.

Area effects

When large forest blocks are broken into smaller ones, not all species are included in all the remaining patches. This is especially true for rare species and for non-mobile organisms, such as trees and many invertebrates, which may be sparsely or patchily distributed within the original forest. Large animals and top carnivores are well known to require large areas of habitat. These species are especially vulnerable to the reduction in habitat area caused by forest fragmentation, and they may disappear entirely from forest patches because food or other resources are inadequate to support them.

Other species persist, but in smaller populations, which may encompass less genetic diversity and lead over time to the vulnerability of those species to other ecological changes such as disease. Rare species and those that normally occur at low population densities are especially vulnerable to these effects. Below a certain population level – which varies greatly from species to species – these smaller populations become significantly more vulnerable to extinction, from random variations in population level, increased susceptibility to single catastrophic events or serious outbreaks of disease and (usually at very low population levels) the deleterious effects of inbreeding. The minimum area of forest needed to maintain a viable population of a given species varies enormously among species and forest types.

Smaller forest patches may also include less environmental variability and therefore fewer microhabitats than more extensive forest areas. This can contribute to the loss of individual species and may cause a reduction in the total species richness per area of forest. Fragmentation of forest cover may also alter the nature and proportional impact of natural disturbance regimes and regeneration processes

Edge and gradient effects

Another important effect of forest fragmentation results from the creation of interfaces with non-forest environments. These interfaces are associated with environmental gradients resulting from the exposure of the forest edge to drying winds and increased sunlight.

The physical gradients affect the vegetation along forest edges – for example there is often a prominent shrub layer and a higher proportion of light-demanding species, which may be sparse or absent in the interior of the forest. Such differences lead to changes in animal populations as well: in studies in the Congo, it was found that the species diversity of rodents, and the population densities of most of these species, was higher along forest edges (in this case along logging roads) than in the forest interior.

Edges also influence ecological processes, including canopy gap formation, biomass and nutrient cycling, regeneration and predation, which can profoundly affect native species.

Forest edges can serve as dispersal channels for invasive species, both native and non-native, so that substantive changes in species composition have been documented in forest fragments. In many parts of the world, alien invasive species (e.g. *Lantana camara* (Lantana) and *Carica papaya* (Pawpaw) in the Old World Tropics, various rat *Rattus* species almost everywhere) are particularly prevalent along disturbed forest edges and may penetrate from these some distance into the forest itself.

Although some 'edge effects' have historically been regarded positively, principally because many game species make use of forest edges, they are generally regarded as detrimental to most native forest species. The magnitude of edge effects within forest fragments can be strongly affected by the land-cover characteristics in the surrounding landscape, and they are also dynamic, frequently increasing in magnitude and extent over time.

Isolation effects

The other major group of effects of forest fragmentation results from the separation of the forest fragments from each other, and from larger blocks of forest, by expanses of other land use. The gaps between forest blocks serve as barriers to dispersal of many organisms by reducing the movement of species that are reluctant or unable to cross non-forest areas. While many birds, bats and strong-flying insects can cross wide gaps even if the habitat within the gaps is completely altered, for other organisms including many amphibians and non-flying moisture-loving invertebrates such as molluscs, an open gap of only a few tens of metres may serve as a virtually impassable barrier – such species are generally slow-moving and crossing such a gap will make them very vulnerable to desiccation and predation. Reduced movement and dispersal also increase the chance of local extinction of individual species, as the supply of colonisers or seeds is limited. Isolation of fragments may also reduce the genetic diversity within populations by limiting the opportunities for cross-fertilisation between them. Connections among habitat fragments are an important means of reducing genetic isolation and providing additional foraging and refuge areas.

Responses to all of these effects vary among species, but a body of empirical evidence is accumulating that facilitates predictions about the likely effects of fragmentation on any particular forest ecosystem. The following generalisations, based largely on empirical observation, can be made:

i. Habitat that is more widely distributed across its original range is more likely to persist than habitat confined to small parts.

ii. Large blocks of habitat are superior to small blocks of habitat.

iii. Blocks of habitat close together are better than blocks far apart.

iv. Habitat in contiguous blocks is better than fragmented habitat.

v. Interconnected blocks of habitat are better than isolated blocks.

The long-term maintenance of forest integrity depends on promoting these characteristics in landscapes. The more that landscapes retain these characteristics, the less is their vulnerability to human-induced change. These generalisations provide a useful basis for assessment and communication of information about forest status in this respect.

Forest spatial integrity

It is possible to express those changes in the spatial configuration of a forest that might be expected to have a major impact on its capacity to maintain biodiversity in the form of a single compound measure of spatial integrity. This takes into account how fragmented a given area of forest is, how spatial coherent it is (that is a measure of how much edge there is for a given area of forest) and how isolated from a core forest area (defined as a forest block over some given size) it is.

Forest structure

A number of structural changes may occur in forests as a result of reductions in their area and other effects of fragmentation. Human activities, especially those involving substantial removal of biomass, also affect forest structure directly by changing the size and distribution of the trees that make up the forest. These in turn lead to changes in canopy structure with respect to its height and continuity.

Gaps in the canopy are a natural feature of forests and play an important role in ecosystem processes, particularly in tree regeneration (many tropical moist forest trees have light-demanding seedlings that only grow successfully in gaps) and in providing habitat for many animal species. Changing the average size of gaps, their number and the frequency of their creation favours some species over others, and can thus have a major impact on the species composition of a forest. For example, in the Americas, mahoganies *Swietenia* spp. appear to be favoured by the infrequent occurrence of very large gaps as they regenerate well in such conditions and can out-compete many other tree species. Large gaps may lead in the short term to changes in microclimate, water and nutrient balances, and to a predominance of pioneer species. Where these effects are severe, the ability of the forest to regenerate may be heavily compromised.

Where the canopy structure is made much more open, without necessarily creating discrete gaps, the density of the shrub layer of increases greatly. Again this is believed to have a potentially important impact on the species composition of forests, favouring some animals and plants over others. As an example, birds classified as “sallying insectivores” appear to decrease in abundance under these conditions. Sallying insectivores typically feed by perching on branches at the bottom of or under the forest canopy and flying out into the clear spaces around the trunks of trees to catch insects. When the shrub layer increases in density, these clear spaces largely disappear and these species appear to be out-competed by birds that use other feeding methods.

As with the creation of gaps, opening of the canopy can lead to changes in water balance in the vegetation, on the forest floor and in the soil. Often, moisture levels decrease, adversely affecting organisms that are dependent on high levels of humidity and generally making the forest much more susceptible to fire. It may also open the way for colonisation by invasive species.

Removal of dying or dead trees, particularly large ones, may have limited impact on the canopy but itself affects habitat availability for many organisms, including saproxylic invertebrates (animals that inhabit and feed on dead wood) and the other animals that feed on them. It may also affect nutrient cycling within the forest.

Species composition

Species composition of forest can be affected by changes in forest area, configuration and structure. It can also be affected directly by exploitation of particular species and knockon effects on non-target species. Such effects are principally through changes in the distribution and relative abundance of forest species.

Removal of target species can reduce their populations and strongly affect the populations of species that depend on them. Where target species are predators or herbivores, reductions in their populations can lead to explosions or imbalances among their prey or their food species. For example, the disappearance of seed-eating rodents from forest islands in Gatun Lake in Panama profoundly affected the tree communities. Conversely, alterations in the abundance of prey species or food plants can reduce populations or alter balances among consumers.

Invasive species have already been mentioned in the context of forest fragmentation. Removal of key species, such as grazers, can make it easier for invasive plant species to colonise a forest area, and changes to animal communities can lead to dispersal and establishment of species within the forest that would not normally occur there.

Ecological processes

Human activities may also affect ecological processes. The effects of fragmentation on tree mortality have already been mentioned, as have those of canopy opening on water and nutrient cycles and vulnerability to fire. Edge and gap-related microclimate effects may also alter such processes as litterfall, which in turn affect nutrient cycles and may affect ground-dwelling and foraging species. Intensive harvesting of fruit or hunting of seedeaters may affect processes of dispersal and regeneration within the forest.

Major human activities that cause changes in tropical moist forests

The relation between specific human activities in forests and the kinds of ecological impacts outlined above is summarised below:

Extraction of wood

Clear-cutting

Clear-cutting self-evidently has a major effect on forest biodiversity, as it results in the complete or virtually complete removal of all aboveground forest structure. The long-term effects of clear-cutting depend on the fate of the area after cutting, the size and location of the clear-cut area and soil and climate conditions. Often clear-cutting is a prelude to conversion, for example to agriculture or pasture, in which case loss of forest biodiversity in the cut area will be very largely irreversible. Where the cut area is not converted to other uses, it may regenerate. The rate and characteristics of regeneration depend on the availability of colonisers – seeds, seedlings, saplings and regenerating roots or stumps in the clear-cut area, or seeds dispersed from adjacent forest areas and on soil and climatic conditions within the cut area.

Faunal composition of regenerating forest also depends on sources for recolonisation (that is adjacent or nearby forest areas), as relatively few forest-dwelling animal species can sustain populations in clear-cut areas. Cutting an isolated forest fragment is therefore likely to have a profound effect on the faunal composition of any regenerating forest. In contrast a clear-cut area within a larger forest block will often be rapidly recolonised by much of the original fauna.

Clear-cutting also has an effect on remaining forest areas. A clear-cut within a larger forest block effectively creates a gap (see above), while a clear-cut that divides existing forest blocks up increases fragmentation (also discussed above).

Selective logging

Selective logging involves felling and removal of only a proportion of trees in a forest; generally those with highest timber value. Often only 2-3 trees per hectare are removed, usually the largest healthy individuals of those species of interest. This clearly affects populations of the species concerned, as mature healthy individuals are usually the ones cut, leaving a higher proportion of juvenile and weak or diseased individuals.

Collateral damage caused by logging activities affects *forest structure* and both non-harvested individuals of the target species and non-harvested species. Falling trees open the canopy and damage other individuals, and the damage is increased where lianas and epiphytes physically link tree crowns. Many large-scale selective logging operations result in the loss of between 40 and 70% of the forest canopy/trees above 10 cm dbh. The removal of felled trees along skid trails and roads also has profound effects on forest structure and microclimate; this may increase the vulnerability of even relatively intact forest to fire. It may also affect animal populations.

In most circumstances, the immediate damage caused by selective logging is non-selective in terms of the sizes and species of trees affected. Thus even though over half of the individual trees may be destroyed in a logged plot, the *species composition* of the forest and the relative proportion of trees in different size classes remains effectively unchanged. Selective logging also has an impact on populations of epiphytic plants as it destroys a significant proportion of their habitat. As with trees, this impact may be expected to be largely indiscriminate. Populations of plants in the herb and shrub layers will be directly affected by logging activities and also by altered environmental conditions due to canopy disruption. Logging roads, as discussed under fragmentation above, may also serve as channels for dispersal of invasive plant species.

The impact of selective logging on animal species in tropical moist forests has proven difficult to quantify. Logging activities themselves are a major cause of disturbance and may lead to mortality of individuals, to behavioural disruption or to animals emigrating from the area being logged. As outlined above, the effects on forest structure may affect animal foraging patterns and reproductive success.

A major impact of logging is the construction of roads and the access this provides to forest areas for other forms of extractive use and land conversion.

Fuel-wood/charcoal extraction

The effects on forest biodiversity of extraction of wood for fuel and charcoal are strongly dependent on the intensity of the harvest. Although such extraction usually leaves forest extent and configuration unaffected, it may have significant effects on forest structure and microclimate that can increase vulnerability to fire, and may have impacts on ecological relationships such as nutrient balance. The extraction activity itself is likely to affect behaviour patterns of animal species, and is often associated with extraction of other forest products and/or hunting, which have additional effects on populations of forest species

Extraction of non-wood plant forest products

In general, harvest of non-wood forest plant products has smaller effects on forest biodiversity than either timber or fuelwood extraction, though this depends on the intensity of harvest and the methods used. The target species are usually the most affected, by removal of individuals or propagules, which affects population structure. Animal species may also be affected by human presence and activity.

Animal harvest

Depending on the methods used, hunting can have major impact on populations of target and non-target species alike. Stalking and targeting of prey tends to affect only the target species. However, for many species, juveniles are more vulnerable as are diseased individuals. In contrast, the use of snares and traps is more indiscriminate and may have significant impacts on species that are not important to people for food and other products.

Depending on the species, hunting may also have indirect effects on the populations of predators and or prey of the target species, disrupting ecological processes of population regulation. In some cases, hunting may remove key seed dispersers from the forest and ultimately lead to changes in plant species abundance and distribution.

Land use change

The conversion of forest to other land uses affects not only the forest converted, but that remaining. Forest extent and configuration are affected, resulting in the range of effects of fragmentation outlined above on forest structure, composition, and ecological processes. In addition to producing fragmented forest landscapes, road building and agricultural and other land uses tend to increase access to the forest and hunting and other uses of it.

Generalised impacts: wilderness measures

Many human impacts on forests are difficult to quantify but may be of great importance in the ability of a forest to maintain biodiversity. Some indication of the likely severity of these can be gained by using wilderness measures. These assess how far any given point in a forest (or other natural ecosystem) is from an identified locus of human activity. The latter include permanent settlements, roads, railways and navigable rivers. Areas with a high wilderness measure are those that are distant from such features and can correspondingly be deduced to be less likely to suffer adverse effects from human activity than are those with a low wilderness measure.

5. Tropical forest biodiversity: policy and management

National policy and planning

Tropical moist forests are extremely valuable resources, with a wide range of uses. Sustainable management of such forests will ensure that not only is value derived from them at present but also that value can continue to be derived from them in the future. Maintaining the biological diversity of these forests is an important aspect of ensuring their ability to continue delivering value. Planners and forest managers at all levels, from the national to the local forest management unit, need to recognise the value of forest biodiversity and to be able to recognise the impacts of their decisions upon it.

Ideally, use of the entire forest estate should be planned at the national level. In most cases, such national level planning will involving zoning of existing natural forest into areas slated for conversion, for extractive uses and for non-extractive uses, the last two being roughly equivalent to traditional categories of production and non-production or protection. In many countries, plantation forest (of either native or non-native species, or both) plays an increasingly important part in overall forest management and wood production strategies.

National level planning of use of the forest estate is a complex business that has to take into account the wide range of often conflicting pressures and demands placed on forest lands, as well as constraints such as existing land tenure and resource-use rights, legislative and institutional infrastructure, available resources for implementation and the prevailing political climate.

Biological diversity should be incorporated as a major factor in national level forest planning, with areas of national or international importance for biodiversity set aside for non-extractive uses or for extractive use that is carefully managed so as not to adversely affect the important components of biodiversity. As a corollary, maintenance of forest biodiversity should be an integral part of each country's national biodiversity strategy and action plan (NBSAP). Where forest lands cross national boundaries, transboundary co-operation in management should be undertaken wherever possible.

Local management

On a regional basis, forests should ideally be managed at the landscape level, as integral parts of larger interlinked ecological complexes. Generally the most important landscape unit in this context is the catchment basin. Often, however, political administrative units do not coincide particularly well with natural landscape divisions, making environmentally sound management difficult to plan and co-ordinate. At the landscape level, some of the most important questions to address are the impacts of management activities within forests on adjacent non-forested ecosystems (particularly aquatic ones) and the relationship between different forest blocks, particularly in terms of connectedness and degree of isolation.

At the most local level, management should consider impacts on biodiversity within each individual forest management unit. This should involve:

- ♦ assessment of biodiversity resources and their importance in local, national and international contexts,
- ♦ evaluation of the direct and indirect effects of management interventions on ecosystems and populations of forest occurring species within that forest unit, and
- ♦ implementation of appropriate measures to mitigate adverse impacts.

International policy

The importance of maintaining and managing global forest resources to ensure their continued contribution to global biodiversity is recognised in a number of international instruments and processes. The CBD itself has a major work programme on forest biodiversity. The Intergovernmental Panel on Forests, the Intergovernmental Forum on Forests and the UN Forum on Forests have all emphasised the importance of considering national forest resources in their entirety, together with their multiple values and benefits, in developing national forest programmes.

Chapter 11 of Agenda 21 and the "Forest Principles" call for the identification of criteria and indicators for evaluating progress in national efforts to practice sustainable forest management. As a result, a large number of national, regional and international initiatives have been developed, including the ITTO, Pan-European (or "Helsinki"), Montreal, Tarapoto, Lepaterique, Near East, Dry Zone Asia and Dry Zone Africa processes, which have each generated sets of criteria and indicators. Currently, about 150 countries are participating in these processes. While the different processes share similar objectives and overall approach, they differ in structure and specific content. However, all of the ten major processes have identified the conservation of forest biological diversity among the criteria for sustainability, and many of the numerous indicators that relate specifically to the biodiversity criterion are common to more than one process.

6. Biodiversity-relevant Information for Forest Policy and Management

The previous sections have demonstrated the importance of biodiversity in tropical forests and set out the different ways that human activities can affect it. In order to try to minimise the adverse impacts of these activities on tropical forest biodiversity, it is important that decision-makers have access to adequate relevant information. This is not straightforward, for a range of reasons, many of which have been alluded to in parts 3 and 4 above. First is the sheer complexity of tropical forests, along with the range of human activities that can impact them and the range of different impacts that each of these activities can have. Second are the limits to our current knowledge, which are often severe. What data do exist mostly come from scientific research, which is often very local in scope and restricted in focus. These data are often not easily accessible, nor available in a form amenable for use by managers and decision-makers. Where results from such research are published, this is usually in scientific literature, which is again often not widely distributed in the countries concerned, nor are the results presented in a form that is of great relevance to managers.

One way which has been proposed to address these problems is the development of **indicators.**

Indicators are measurements that are intended to convey information about more than just themselves. They provide means for quantifying and simplifying information on complex issues. They are purpose-dependent, almost always open to various interpretations, and never tell the whole story. Indicators are needed because assessing and monitoring everything is impossible and because what ***is*** known needs to be conveyed to non-experts in policy-relevant form.

Good indicators are:

scientifically valid, i.e. they relate appropriately to what they are supposed to represent;
based on easily available data;
responsive to change;
easily understandable;
relevant to focal issues and users' needs;
subject to target or threshold setting.

The twin challenges in developing indicators are (1) to identify the key questions that affect policy and management, and (2) to confine development to measures that are feasible. Because biodiversity is such an all-encompassing concept, it is vital that the questions asked of it are properly focused, with particular reference to context and spatial scale and, most importantly, the purpose of asking the question.

Indicators can then be developed to summarise the most important and useful information that can be distilled from more detailed data to help answer these questions. With respect to forest biodiversity, key questions might include:

How much forest biodiversity is there and where is it?
How is it managed at present?
Do current efforts to manage or preserve it target the right areas?
Is its status changing?
What pressures affect it and how are they changing?

Each of these questions needs a spatial context, and must be adjusted to accord with the scale at which it is posed. The data and information required to answer them are similarly scale-dependent and require activity in both biodiversity assessment and monitoring.

Biodiversity assessment is the process of determining the biodiversity complement and value of particular areas or resources. It is generally aimed at comparisons among sites and prioritisation of sites for management with an emphasis on biodiversity. Many different approaches to assessment have been developed to provide information about a range of ecosystem types under different conditions of financial and technical resource availability. Assessment does not generally involve repeated measurement though some programmes do anticipate the use of the results as baselines for monitoring. This should be encouraged.

The goal of monitoring is explicitly to address changes over time, and therefore depend on measurements that can be repeated and are comparable between occasions. Thus, it is essential that approaches are used that can realistically be sustained with changing and probably limited resource availability. A detailed and resource-intensive biodiversity assessment may therefore not provide an appropriate baseline for subsequent monitoring programmes using limited resources.

Thus, in the development and use of indicators, it is important to:

- Identify and address the correct questions
- Identify the data needed to address them
- Initiate *and sustain* measurement programmes to obtain those data
- Work adaptively and within the constraints of available data.

In the following sections, we explore how indicators may be grouped and used to address particular types of questions and what types of data from what types of sources may be used to generate useful indicators.

6 a. Indicator foci

In addition to responding to the global demand for information on forests and their management, forest biodiversity indicators serve two principal purposes:

They help identify priority areas for, and components of, forest biodiversity, and
They help to evaluate the impacts of policy and management on forest biodiversity, so that negative impacts can be minimised.

Thus they are required both for *assessing* biodiversity in space and at a particular point in time and for *monitoring* changes in biodiversity status that may result from particular policies or management actions.

Assessment of biodiversity and prioritisation of areas for management is usually based on information about co-occurrence of many species (high species richness), or about the occurrence of particular unique or distinctive ecosystems or species. There is no single set of standards or scales for collecting data or for establishing priorities, once the data are obtained. What is clear is that exhaustive inventories of species are rarely possible, so indicators will almost certainly depend on data on particular key groups (see below). Assessment indicators, which help to quantify biodiversity, can thus be used to identify areas that are important for high total biodiversity or for particular priority components. Prioritisation can be based on locally or nationally determined values attached to particular components of forest biodiversity or on any of a number of international criteria or prioritisation schemes, including global threat status or international designations such as World Heritage status.

Prioritisation based on biodiversity assessment can also be used in combination with assessments of threats (pressures) or likely impacts to prioritise investment in monitoring and reporting of other indicators.

A wide range of indicators, which can be grouped in a number of different ways, can be used to monitor the impacts of policy and management on forest biodiversity. Broadly they address these impacts in three different ways:

By evaluating the **coverage** of the policy or management actions;
By evaluating **status and trends in biodiversity** itself;
By evaluating changes in the **pressures** that affect forest biodiversity.

Coverage indicators can be used to show how much area and which types of forest are affected by particular types of management or policy decisions. For example, forests may be divided into those under protection, those under different types of management for production and those earmarked for conversion to other and uses. Coverage indicators can be used to summarise the potential impacts of these different types of management on particular forest types and on areas identified according to a range of criteria as having particular importance for forest biodiversity.

Indicators of the **status and trends** of components of forest biodiversity usually relate directly to the types, areas and condition of ecosystems and to the numbers and population sizes of species. Changes in status, or shifts in previous trends can sometimes be linked directly to particular management or policy changes. However, such links are not necessarily causal, so that observed changes in the indicator more frequently highlight the need for further investigations of their possible causes. In general, the data necessary for biodiversity status indicators are less easily available (see below).

Indicators of the **pressures** that act on forest biodiversity are based on a wide range of data types and are sometimes more easily related directly to policy and management impacts. Pressures that are relevant to forest biodiversity include direct use of forest species, as in timber extraction and hunting, and indirect pressures such as population growth, agricultural expansion and changing landscape configuration. Both types can be measured, though indirect approaches are sometimes needed, especially when activities like hunting and logging are regulated with less than complete effectiveness. The types of information required come from a wide range of disciplines (see below), so co-ordination across sectors is an important part of the efficient data management that is necessary for effective monitoring.

These four broad categories of indicators (assessment, coverage, biodiversity status, and pressures) are not by any means mutually exclusive. For example, some data and the indicators derived from them relate both to the status of biodiversity and to the pressures on it. Measures of forest fragmentation quantify changed ecosystem status and provide evidence of likely changes in species populations, but also represent changes in the vulnerability of the forest to other pressures and impacts. For this reason in the indicator framework, which follows, some indicators appear in more than one section to emphasise the several different uses to which they can be put.

6b. Data types:

The data available for the development of the types of forest biodiversity indicators outlined above are of a broad range of types, including:

- Spatial, or mapped, data on forest extent and on the distribution of forest types and species;
- Forest structure data derived using a number of different approaches;
- Data on species composition, from inventory plots and other forms of survey of plants and animals;
- Data on species abundance, acquired using various census techniques, including inventory plots and other forms of quantified survey;
- Data on forest management regimes;
- Data on human activities that affect forest biodiversity.

All of these data types can contribute to both assessment and monitoring of forest biodiversity.

Spatial data on forest extent and distribution are usually derived from satellite remote sensing or aerial survey, though older mapped data based on ground survey can provide useful reference points and baselines for trend analysis. Satellite data can be very useful for examining landscape configuration and the changes to it that can influence forest biodiversity. However, they can also be very expensive to acquire and process.

Spatial data are critical to general planning processes and may easily be used to generate some simple indicators and to support planning and decision-making directly. However, their analysis to generate some more complex indicators can require geographic information systems (GIS), which are not accessible at the level of individual forest management units due to limitations of both financial resources and personnel. Therefore, agencies with larger resources may need to play a role in generating the GIS analyses to support use and reporting of complex spatial indicators by individual management units.

It is important to ensure that the data are of an appropriate resolution to the scale of monitoring desired, and that processing and analysis approaches are consistent between times. The coarser resolution satellite data, mainly 1.1-km data from the AVHRR sensor, are useful principally for summarising land cover and assessing gross changes in its extent and configuration. The finer resolution data (mainly Landsat and SPOT), can be used for site-specific monitoring and for detailed analysis of landscape change.

Some coarse resolution data can be obtained in already-processed form from various global or regional initiatives, and this can be used to provide a useful baseline. However, the land cover classification of these data may not be the most appropriate for national and local use, and replicating the processing approach for subsequent time periods may be problematic. There is no international initiative at present that effectively provides comparably processed data for different time periods, though a number are in their infancy. Some older high-resolution (unprocessed) satellite data are available at low cost, but the processing costs are high, so the costs of monitoring programmes based on high-resolution data remain relatively high, despite falling prices for newer data.

Quantitative data on forest **structure** most frequently come from forest inventories, done either for evaluation of timber stocks or for ecological study, and take the form of listings of individual trees with diameter (and sometimes height) measurements, or of total numbers of trees in each diameter class. As with other data types, their utility for monitoring rests with consistency in methods used over time (or careful inter-calibration between methods). They can be used both to identify particular forest types and to monitor natural and man-made changes to the forest and its dynamics and successional status. Unfortunately, many traditional forest inventories focus so strongly on the potential for timber harvest that they provide little or no information on the smaller trees or their spatial distribution. Of course, inventory programmes can be expanded to provide these data as well as other measures related to structure, such as the frequency of cut stumps. The relationship between forest species and forest structure is complex and often poorly known. However, where particular species are management priorities the relationship may have been better studied, so that changes observed in a monitoring programme can be used to predict changes in the species of concern and to direct decision-making for management. Qualitative observations of particular aspects of tropical forest structure, such as the frequency of non-vascular epiphytes (mosses and liverworts), may be key to identifying unique forest types or habitats for priority species.

Data on forest **species composition** can come from a number of different sources. Tree species composition information most frequently comes from forest inventory. However, many approaches to forest inventory, such as timber cruising or reconnaissance survey, confine observations to trees of potential use for timber harvest and thus focus only on larger individuals and/or on particularly desirable species. Therefore, many species may be ignored either because they are not regarded as timber species, or because they are not present as large enough individuals in the study area. In some cases, detailed inventory of timber species may be supplemented by listing of other species present. Though less useful than complete quantitative data on species occurrence, if the sampling effort or area is quantified, such data can be useful estimates of species richness and can identify areas important for tree species of interest.

For data on species other than trees, forest departments are likely to rely on other sources, including wildlife and parks departments, academic ecological studies and amateur surveys. Data from many of these sources are still more likely to take the form of checklists, which simply document the presence and (by inference) absence of particular species. These data are most useful if they include some quantification of the area surveyed and the effort expended in doing so. Particularly for more cryptic animal species, the quantification of effort is fundamental to the estimation of total richness.

A great deal of attention has been paid to the relative utility of different groups of organisms as indicators for determining areas of high overall species richness. In general, it seems that no one group can be used to represent richness patterns of other groups, but data for some groups are more easily available as they are both easier to observe and more frequently surveyed by amateurs. The most commonly surveyed indicator groups are birds, mammals and butterflies, but many other groups have been proposed as useful indicators, including termites, several groups of beetles and non-vascular epiphytes.

It is important to recognise that checklist or presence/absence data are of limited use for monitoring because once a species that is formerly present disappears from the list, it may be too late to take appropriate corrective action. Nonetheless, changes in presence/absence data, especially if based on controlled-effort surveys can be important pointers to where more detailed investigation of changes is needed.

The appropriateness of any particular group for monitoring purposes will depend largely on the availability of data or ease of observation, as well as the types of pressures that are most important. Larger diurnal mammals and birds are the groups for which it is most feasible to determine presence or absence reliably on repeated occasions. This can be achieved both by direct sightings and by observation of indirect signs such as tracks and droppings. These animals are most affected by the extent and configuration of available habitat and by hunting pressure.

Data on **species abundance** are more useful, but are also more difficult to collect in a rigorous and consistent manner. Inevitably, when abundance is measured, monitoring must be confined to relatively few species, which must be carefully chosen along with the methods used. The criteria for selecting species should include:

- importance to specific management goals
- conservation status
- extent to which taxonomy is resolved and accepted
- ease of observation
- ease of identification
- sensitivity or responsiveness to key pressures

The organisms for which changes in abundance are most easily measured in tropical moist forest include diurnal primates. Declines in the abundance of these species will be good indicators of overall hunting pressure and of changing habitat extent.

Species as indicators – some words of caution

Much discussion on biodiversity indicators, both in tropical moist forests and elsewhere, has concentrated on the search for, and characteristics of, indicator species or groups of species. For purposes of assessment, that is comparisons between areas, these are groups whose presence or richness is expected to provide indications of how important an area is overall for biodiversity. For purposes of monitoring, these are species whose status can be tracked in a particular area in order to provide information on general or underlying trends in biodiversity in that area. In both contexts, the use of species presents problems, although from a theoretical standpoint these are more significant in the latter than in the former.

Species as indicators for assessment

No two sites in a tropical moist forest have precisely the same species complement, nor do any two species ever share exactly the same distribution (other than in the rare cases where two or more species are mutually interdependent, so that one cannot exist without the other). For this reason no one species or group of species can ever be used as an unequivocal indicator of the presence of species in other groups. However, it is certainly true that the distributions of species with similar ecological requirements in the same biogeographic region may well be quite strongly correlated with each other, so that the presence of one species is a good indicator of the presence of others. More generally, an area that is rich in localised or endemic species in one group is likely to be similarly rich in such species in other groups, because the factors leading to such richness (long-term isolation and environmental conditions conducive to speciation) are likely to affect a range of taxonomic groups similarly. Thus, for example, the island of Madagascar is extremely rich in endemic species in a wide range of taxonomic groups of plants, animals and lower organisms, because it is a large island with a tropical climate that has been separated from other land areas for a very long time (perhaps 120 million years). In contrast, the forests of Belize are poor in endemic species in those groups that are well studied (vertebrates, higher plants, conspicuous invertebrates such as butterflies) because they are of relatively small extent and are adjacent to extensive areas of ecologically very similar forest in Mexico and Guatemala where almost all Belizean forest species are also found.

However, care must be taken when automatically extrapolating from one group to all others. An area with few localised or endemic bird species (the taxonomic group most frequently cited as a good indicator group) may, for example, be very rich in endemic plant species. This applies to many continental areas where limits to distribution for plants (for example a change from alkaline limestone substrate to acidic substrate) are unlikely to affect birds, so that while the flora of the region may be highly distinctive, the avifauna may be extremely similar to that in adjacent areas. Conversely, isolated oceanic islands may be rich in endemic bird species but have no resident terrestrial mammals or amphibians at all, let alone a significant number of endemic species in these groups.

Species as indicators for monitoring

No two species are exactly alike. Each occupies its own unique ecological niche – that is has its own specific set of ecological requirements – and will therefore respond in its own way to any given change in its environment. Almost invariably, changes that might lead to population increases in one species are very likely to lead to population decreases in others. For example, increasing the number of gaps in a forest will lead to the decrease in abundance of light-avoiding understorey plants, but an increase in light-demanding plants. Clearly, at the most basic level, it is not possible to find one single species that can act as an indicator for all other species.

More realistically, it may be expected that groups of species may respond in similar ways to the same changes. Such groups may be taxonomic groups – for example orchids (family Orchidaceae) or ants (family Formicidae) – or may be species with similar ecological characteristics, such as feeding guilds of birds. Feeding guilds are groupings of species that share similar diets and modes of feeding. Examples are foliage-gleaning insectivores, which typically feed by carefully moving among the leaves on trees, turning them over and catching insects and other small animals, and terrestrial frugivores, which feed largely on fallen fruit and other plant matter on the ground.

Studies of the responses of species to changes in tropical moist forests, in particular those brought about by selective logging, have however generated inconclusive and sometimes inconsistent results. One reason for this is that populations constantly change under natural conditions. These changes are brought about by climatic fluctuations, disease, predator-prey cycles and other interactions between species, as well as random or stochastic variation. It is often very difficult to disentangle these variations from changes brought about by human actions. Secondly, because of the low population densities of most rainforest species and, in the case of animals, the problems of censusing them, it is often difficult to detect any significant change in population over the short- or medium-term, let alone ascribe a particular cause to it.

Even where a significant change in a species can be detected, and ascribed to a particular cause, there is no guarantee that related species or those in the same guild will behave in the same way at that location. Such species often potentially or actively compete with each other, as they tend to have similar, though not identical, ecological requirements.
Some habitat changes, particularly less drastic ones, may be expected to change the competitive balance between similar species occurring in the same place so that while one may decrease in abundance another may increase.

In some cases it can be useful to combine relatively fragmentary data on different species to provide an overall assessment of trends in species abundance (see below).

Data on **forest management** are essential to an understanding of how management is affecting forest biodiversity. These are likely to include area statistics on forests under different kinds of management, including strict protection, timber production, commercial concession, certified management etc. They will come mostly from central government records and site management plans.

Data on **human activities** affecting forest biodiversity come from a still wider range of sources, including socio-economic studies and policy and management documents. By definition, they are unlikely to have been collected with a view to assessing pressures on forest biodiversity, and it can require initiative and creativity to identify and obtain relevant data sets. Furthermore, direct measurements of real levels of activity are rare, so that it may be necessary to use proxies to build a complete picture of the magnitude of the pressure.

Among the types of data that are important are those that address forest management itself. These data will come from policy documents and management plans, principally from the forest sector. However, as shown in the list of data types below, similar documents from other sectors can be equally important. For each type of activity that affects forest biodiversity, several broad types of data can be used to build an accurate estimate of the likely impacts of a particular activity:

- data on the planned or authorised levels of that activity – these come from management plans, licensing agreements and policy documents
- data on the intensity of demand for that activity, or the numbers of people involved in it – these come from demographic and socio-economic surveys of use of forest products and livelihoods of local people as well as market research and estimates of access to the forest;
- data on the actual levels of activity – these may range from assessments of area under cultivation and rotational cycles to extraction records and registered catch (unauthorised and/or clandestine activity may go undetected);
- data on the outputs or products of that activity – including throughput at sawmills and forest products reaching the market and used by local households;

Some of these data are statistical and others are in spatial form. The use of the spatial data is subject to the resource constraints that apply to GIS analysis, as discussed above, but visual (low-tech) evaluation of them can support decision making at the local level very effectively. GIS analysis can provide additional value through quantification of the patterns observed, but skilled managers can derive a great deal of value from a map.

7. Indicators

The remainder of this document provides suggestions for the construction of forest biodiversity indicators addressing each of the four foci discussed above, using the various data types that may be available. Each class of indicators is presented in two groups: those appropriate for use at national level and corresponding ones for use at the level of individual forest management units. Although, as discussed above, the landscape level is the most appropriate one for evaluating and managing forest biodiversity, appropriate data are so rarely available that indicators at this scale are not discussed. Appropriate questions to be addressed by each indicator type at each scale are suggested and candidate indicators are listed.

The lists are not exhaustive; rather they focus on those indicators that can most feasibly be developed from existing data, or from data that can be acquired with a minimum of additional effort, to build an effective monitoring programme. Some indicators are presented under more than one type because they can be used to address several foci in decision making about forest management.

I. Assessment indicators help to quantify biodiversity, can thus be used to identify areas that are important for high total biodiversity or for particular priority components.

> ***National level*** **–** at national level, assessment indicators are used to answer questions about the magnitude, composition and importance of the 'national forest biodiversity estate'. That is, questions such as:
>
> 'How much' forest biodiversity is there?
> How many of its components have international importance?

NB Each indicator in the following tables is given a number that locates it within the technical guidelines that follow and an overall indication of its feasibility (**** = highly feasible, *** = feasible with some difficulty, ** = somewhat difficult, * = very difficult).

Indicator	**No.**	**Feasibility**
Total area of each forest type	1	****
Size of the largest single patch of each forest type	2	****
Types and size of forest areas occurring within any of the global biodiversity priority areas	3	***
Total numbers of endemic forest-occurring species	4	* to ***[1]
Total numbers of globally threatened forest-occurring species	5	** to ***[1]
Total richness of individual taxonomic groups occurring in forests	6	* to ***[1]

[1] = depending on taxonomic group in question

> ***Forest Management Unit (FMU) level*** **–** at the level of individual forest management unit, assessment indicators address the following questions:
>
> 'How much' biodiversity is present in the FMU?
> How important is this biodiversity locally, nationally and internationally?
> Which are the elements of greatest interest at these three levels?

Indicator	No.	Feasibility
Total area of each forest type within FMU	7	****
Proportion of national total area of each forest type this represents	8	****
Proportion of FMU falling within global priority areas	9	***
Total tree species richness	10	**
Proportion of national tree species complement this represents	11	**
Total mammal species richness	12	*
Proportion of national mammal species complement this represents	13	*
Total bird species richness	14	**
Proportion of national bird species complement this represents	15	**
Total species richness in other taxonomic groups	16	*
Number of local people largely or wholly nutritionally dependent on forest products	17	**
Proportion of local population this represents	18	**
Number and proportion of local people largely or wholly dependent on forest products for income	19	**
Proportion of local population this represents	20	**
Number and proportion of local people for whom the forest is important for other reasons	21	**
Number of nationally endemic species occurring in the FMU	22	*–***[1]
Proportion of the national complement of endemic species this represents	23	*–****[1]
Proportion of total population of each endemic species occurring in FMU (% range or extant habitat is a proxy)	24	*–**[1]
Number of globally threatened species occurring in FMU	25	**
Proportion of the national complement of globally threatened species this represents	26	**
Proportion of total population of each globally threatened species occurring in FMU (% range or extant habitat is a proxy)	27	**

[1]= depending on taxonomic group in question

II **Coverage indicators** are most relevant at national level, where they address the questions of the extent to which national biodiversity priority areas are managed in ways that take account of the importance attached to their biodiversity, and whether efforts in biodiversity-targeted and biodiversity-friendly management are targeting the right areas. Essentially they evaluate the intent or effort put into managing the forest to limit adverse effects on important biodiversity. Ultimately, it is desirable to understand the proportion of each species under particular forms of protection and management relative to their total global and national populations. However, this is feasible for only a few high profile target species. For some others the proportion of species range or habitat can serve as a proxy.

National level

National level coverage indicators represent the attention or effort devoted to important forest biodiversity.

	Formally protected areas		Certified management		Covered by management plans that explicitly address biodiversity considerations	
Area of each forest type	28	****	29	****	30	****
Area of forest occurring within global biodiversity priority areas	31	****	32	****	33	***
Percentage of endemic forest species	34	*** (some groups)	35	**	36	**
% of globally threatened forest species	37	*** (some groups)	38	**	39	**
% all national forest primate species	40	**	41	**	42	*
% all national forest large carnivore species	43	**	44	**	45	*
% all national forest mammal species	46	*	47	*	48	*
% all national forest bird species	49	*	50	*	51	*

Forest Management Unit level

Coverage indicators at this level address the question of whether the management of the FMU takes into account the significant ecosystems and species identified in the assessment process and their particular values.

Indicator	No.	Feasibility
Number and proportion of globally important ecosystems occurring within the FMU that are explicitly addressed in the management plan	52	****
Number and proportion of globally threatened species occurring within the FMU that are explicitly addressed in the management plan	53	***
Number and proportion of nationally important ecosystems (defined according to threshold proportion of national total) occurring in the FMU that are recognised and addressed in the management plan.	54	****
Number and proportion of nationally important species populations (defined according to proportion of national total, for which thresholds will vary) occurring in the FMU that are recognised and addressed in the management plan.	55	***
Number and proportion of biodiversity resources identified in stakeholder dialogue that are addressed in the management plan in ways that reflect the importance attached to them by stakeholders.	56	****

III Indicators of Status and Trends in Forest Biodiversity

Although these measures address biodiversity and its status directly, the data they require for correct quantification and use are difficult to obtain, particularly for those indicators that are relevant at species level.

National level

These indicators address the question of whether the national forest biodiversity estate is improving in status or deteriorating. This question is extremely difficult to answer in quantitative terms, and the indicators suggested here include only the most tractable approaches.

Indicator	**No**	**Feasibility**
Area of each forest type	57	****
Rate of change of area of each forest type	58	***
Area of each forest type belonging to each spatial integrity class	59	***
Area of forest with high spatial integrity index, for each forest type	60	***
Rate of change of area of forest with high spatial integrity in each forest type	61	***
Estimated total national population of endemics, threatened or other target forest-dependent species	62	*
National forest species trend index derived from sample population data sets for studied species	63	***
Change in number of species identified as being of global or national conservation concern (categorised by degree of threat)	64	***

Forest Management Unit level

These indicators address the question of whether biodiversity within the particular forest management unit is improving in status or deteriorating. Although direct measures of population changes in species (indicator 75) are difficult to obtain in most tropical moist forest ecosystems other indicators, which can serve as surrogates for this, are much more tractable provided than some baseline monitoring is undertaken.

Indicator	**No.**	**Feasibility**
Total area of each forest type within FMU	65	****
Rate of change of area of each forest type	66	***
Area of each forest type within FMU belonging to each spatial integrity class	67	***
Area of forest in FMU with high spatial integrity index, for each forest type	68	***
Rate of change of area of forest with high spatial integrity in each forest type	69	***
Change in area of FMU with given gap regime	70	***
Number of standing dead trees per unit area and change therein	71	***
Rate of change in frequency of largest diameter class of trees	72	***
Forest stream turbidity index (suspended sediments) and change therein	73	***
Area of FMU with high incidence of invasive species	74	***
Trends in populations of management priority species (determined by national and international conservation priority and local value).	75	**

IV Indicators of pressure on forest biodiversity

National Level

While direct measures of changes in the national forest biodiversity estate are difficult to obtain, a strong indication of likely present and future changes can be gained from measures of pressures on forest biodiversity. Although some of these remain highly intractable at aggregated, national level (for example indicators 86 and 87 on fuelwood consumption and indicators 90-92 on bushmeat consumption in the table below), others are considerably more amenable to measurement and analysis.

Indicator	**No.**	**Feasibility**
Area of forest per capita	76	****
Average wilderness index of each forest type	77	***
Total area of each forest type with a high wilderness score	78	***
For each forest type, size of largest forest patch with a high wilderness score	79	***
Area of each forest type within areas of global biodiversity priority allocated to commercial concessions	80	***
Area of each forest type adjacent to protected areas allocated to commercial concessions	81	***
Area of each forest type with populations of species of conservation concern allocated to commercial concessions	82	**
Annual timber harvest in relation to total forest area	83	****
Annual timber harvest in relation to forest area allocated to production	84	****
Annual timber harvest from forest areas within areas of global biodiversity priority	85	***
Annual fuelwood production in relation to total forest area	86	*
Annual fuelwood production in relation to forest area within areas of global biodiversity priority	87	*
Area of each forest type converted annually	88	***
Area of each forest type within areas of global biodiversity priority converted annually	89	***
Amount of bushmeat from forest sources consumed annually	90	*
Per capita annual consumption of bushmeat from forest sources	91	*
Percentage annual protein needs supplied by bushmeat from forest sources	92	*
Value of plant non-timber forest products exported annually	93	**
Percentage of annual export value provided by export of plant non-timber forest products	94	**

Forest management unit level

At forest management unit level, the following indicators are all reasonably amenable to measurement and analysis provided that some baseline monitoring is undertaken.

Indicator	**No.**	**Feasibility**
Average wilderness index	95	***
Total area of forest with a high wilderness value	96	***
Area of forest allocated to production	97	****
Area of forest logged annually	98	****
Annual cut	99	****
Incidence of cut stumps	100	***
Annual volume of round-logs processed in local sawmills	101	**
Annual harvest of species of conservation concern	102	***
Local area burned in the past five years	103	***
Hunting effort required to obtain given quantity of bushmeat	104	**
Number of people living within 5 km of forest	105	***
Accumulation of fruits under understory palms	106	***

8. Indicators - Technical guidance

Some of the indicators summarised above are described in more detail in this section. Included in the description of each indicator are:

- the data required
- the units for reporting;
- the appropriate monitoring frequency;
- particular cautions for data collection and use;
- the likely trends (for the monitoring indicators); and
- guidance for interpretation and decision-making based on the indicator, including cautions about constraints imposed by data quality.

I. Assessment indicators

Although some of these indicators can also be used in a monitoring context, this section discusses only their use for assessment. Therefore, it includes minimal guidance on re-evaluation frequencies for monitoring purposes and none on likely trends. Guidance on these matters can be found where the same indicators are discussed in subsequent sections.

National Level

1. **Total area of each forest type**:

    Data needed: This indicator derives from mapped data on land cover and depends on the existence (or development) of a classification of forest types that is meaningful in biodiversity terms. Such data are likely to derive from remotely sensed data, but meaningful classification will depend on their integration with a number of other types of information, including forest structure, soils, topography and expert knowledge.
    Units: Tabular tally of forest types with area of each in square km or in hectares, depending on the country, the size of the forest resource, and the spatial resolution of the source data.
    Monitoring frequency: For assessment purposes, a single careful baseline evaluation is the most important, and updates on a five-year cycle would ensure that changes in priority based on this parameter are detected. (More frequent evaluation is advisable for other purposes - see below).
    Cautions: Revisions of the forest classification or the availability of improved source data may make re-evaluation necessary, but comparisons with previous versions may not be valid unless harmonisation is very careful.
    Interpretation and use: The indicator will help to identify and locate specific forest types that are relatively rare and may need to be prioritised.

2. **Size of the largest single patch of each forest type**:

Data needed: This indicator also depends on spatial data on distribution of forest classes derived from remote sensing and ancillary data as described above.

Units: Listing of forest types with area of largest single patch in square km or in hectares

Monitoring Frequency: As 1 above

Cautions: As 1 above, with additional emphasis on the confounding effects of changes in scale or resolution.

Interpretation and Use: Can help to prioritise individual forest areas based on the total high quality habitat they represent, relative to that occurring elsewhere in the country or internationally. It is important to recognise that the accuracy and resolution of the spatial data will determine how patches are perceived as contiguous or separate, and therefore affect the value reported.

3. **Types and size of forest areas occurring within any of the global `biodiversity priority areas**

Data needed: Spatial data on forest cover and global biodiversity priority areas. The sets of priority areas could include: World Heritage Sites, Ramsar Sites, Endemic Bird Areas, WWF Global 200 Ecoregions, CI Biodiversity hotspots, Centres of plant diversity, and any other sets of priorities that are considered relevant.

Units: Lists of priority sites or areas with area of relevant forest types expressed in square km or hectares.

Monitoring Frequency: as above. In addition, re-assessment against newly emerging global prioritisation efforts will be desirable.

Cautions: as above.

Interpretation and Use: Global biodiversity priorities, though sometimes coarse, are one basis on which to evaluate the responsibility a nation holds for its biodiversity resources in international terms. This kind of assessment can add to national information resources, and add weight to bids for international assistance for the management of priority areas.

4. **Total numbers of endemic forest-occurring species**:

Data needed: Species lists for key groups from each forest type and/or site or management unit; information on distribution or endemicity of species.

Units: Tabular tally of forest types and sites or management units, with total numbers of endemic species for each site.

Monitoring Frequency: Reassessment is indicated only when substantial changes to the data available have occurred, as in for example, the investment of substantial additional survey efforts in particular areas.

Cautions: The amount and quality of survey effort invested in generating species lists needs to be taken into account, especially for less conspicuous groups. Where surveys are inadequate, additional investment may be needed, and/or predicted distributions of endemic species may be combined with forest cover data to provide information supplementary to existing species lists.

Interpretation and Use: Endemic species are those for which a country has ultimate and sole responsibility at the global scale. Therefore the occurrence of a large number or of particular endemic species should help to prioritise areas for management to ensure their continued presence.

5. **Total numbers of globally threatened forest-occurring species**

Data needed: Species lists for key groups from each forest type and/or site or management unit; information on global status of these species.

Units: Tabular tally of forest types and sites or management units, with total numbers of threatened species for each site.

Monitoring Frequency: Periodic reassessment is indicated in the light of changes in the global status of species or when substantial changes to the data available have occurred, as in for example, the investment of substantial additional survey efforts in particular areas.

Cautions: Usefulness depends on the availability of a reliable and updated global data set of threatened species as well as on reliable data for that country. The amount and quality of survey effort invested in generating species lists needs to be taken into account, especially for less conspicuous groups. Where surveys are inadequate, additional investment may be needed, and/or predicted distributions of threatened species may be combined with forest cover data to provide information supplementary to existing species lists.

Interpretation and Use: Preventing threatened species becoming extinct is the most immediate global priority for the maintenance of biodiversity. Therefore the occurrence of a large number or of particular threatened species should help to prioritise areas for management to ensure their continued presence. Threatened endemic species should be regarded as the highest biodiversity management priority of all.

6. **Total richness of individual taxonomic groups occurring in forests**

Data needed: Species lists for individual taxonomic groups from each forest type and/or site or management unit.

Units: Tabular tally of forest types and sites or management units, with total numbers of species in individual taxonomic groups for each site.

Monitoring Frequency: Reassessment is indicated only when substantial changes to the data available have occurred, as in for example, the investment of substantial additional survey efforts in particular areas.

Cautions: The amount and quality of survey effort invested in generating species lists needs to be taken into account, especially for less conspicuous groups. Because of the extremely high diversity of most tropical moist forests, complete national species lists are only feasible for a small number of taxonomic groups. Where surveys are inadequate, additional investment may be needed, and/or predicted distributions of species may be combined with forest cover data to provide information supplementary to existing species lists.

Interpretation and Use: Can provide an indication of total forest biodiversity, and can be used to place national resources in an international context as well as to compare with other habitat types and sectors.

Forest Management Unit (FMU) level

7**. Total area of each forest type within FMU**

As 1 above, but forest type classification is likely to be more detailed and higher resolution source data are required.

8. **Proportion of national total area of each forest type this represents**

Data needed: As 1 above, but harmonisation of more detailed forest classification with national level scheme may be necessary.

Units: Tabular tally of forest types and management units or sites, with percentages of former in each of the latter.

Monitoring frequency: As 1 above.

Cautions: As 1 above.

Interpretation and use: Areas representing a large proportion of the national total of a particular forest types are likely to be viewed as more important for maintaining biodiversity at the ecosystem level

9. **Proportion of FMU falling within global priority areas**

Data needed: As 1 and 3 above.

Units: Tabular tally of forest types and management units or sites, with percentages of former in each of the latter.

Monitoring frequency: As 1 above.

Cautions: As 1 and 3 above, and the coarse scale of boundaries for global priorities should be recognised.

Interpretation and use: This information can be used principally to add weight to the case for preserving a forest unit, or implementing low impact management or protection, and to bids for international assistance in doing so.

10. **Total tree species richness**

Data needed: Ideally, forest inventory data with adequate taxonomic identifications, diameter thresholds and area basis. Alternatively, checklist data that incorporate a clear relation with area covered and effort expended.

Units: Numbers of tree species per area above a given diameter threshold.

Monitoring Frequency: Should be updated as new inventory or research efforts bring in data on new or extended study areas. Mechanisms (e.g. guidelines for granting permits) should be in place to ensure that researchers pass on data to forest managers in an appropriate form for contributing to the indicator and that their methods are appropriate for this. Data incorporated in the indicator should be reviewed periodically (e.g.

every 5 years) to ensure that recent results have been received and incorporated.

Cautions: Use of large diameter thresholds or focus on timber species only can limit the utility of data from inventories. Taxonomic uncertainty in relation to common names can also cause problems, which can be minimised by using only a few skilled individuals (tree spotters) for identification and attempting to maintain consistency of these personnel. Voucher collections also help in this respect, but can generate a substantial backlog in processing that cannot be cleared without substantial investment.

Interpretation and Use: The richness estimates provided by this indicator can be used to identify areas with high concentrations of tree species, which may be paralleled by high richness in other groups. Great care needs to be taken in comparison between areas where different diameter thresholds (or indeed sampling methods) have been used to obtain richness estimates. Lower diameter thresholds provide a better estimate of total richness, but appropriate rankings may still be obtained using higher threshold data that are more commonly available and/or less labour-intensive to generate.

11. **Proportion of national tree species complement this represents**

Data needed: Data for 10 above plus national tree flora that ideally includes some indication of size classes attained by the different species.

Units: percentage or proportion

Monitoring frequency: as 10 above

Cautions: as 10 above, plus care needs to be taken to compare with that part of the national tree flora that corresponds to the diameter thresholds used in inventory.

Interpretation and use: Areas holding higher proportions of the national complement may be very important for tree conservation at the national scale, and may also be important for other groups. Caveats in 10 above apply, especially when comparing between areas.

12. **Total mammal species richness**

Data needed: Ideally full site-specific listing of mammals present based on field surveys with some measure of area and/or effort to which total applies. However, constraints including ease of observation and taxonomy will mean that some groups, such as primates are more amenable to this kind of study. Trapping programmes can help to inventory smaller mammals. Some estimates of probable species richness for high profile groups can also be assembled from literature and species distribution maps as well as local knowledge.

Units: Numbers of species of particular mammal groups per area or per survey effort.

Monitoring frequency: as 10 above

Cautions: Care is needed to ensure that survey teams are equally trained and that identifications are sound. Survey efforts and methods should be as consistent as possible among areas and with those used at other sites.

Interpretation and use: The richness estimates provided by this indicator can be used to identify areas with high concentrations of mammal species, which may be paralleled by high richness in other groups. Great care needs to be taken in comparison between areas where different survey methods or analytical approaches have been used to obtain richness estimates.

13. **Proportion of national mammal species complement this represents**
See 11 and 12 above.

14. **Total bird species richness**
Data needed: Ideally full site-specific listing of birds present based on field surveys with some measure of area and/or effort to which total applies. Some estimates of probable species richness can also be assembled from literature and species distribution maps as well as local knowledge.
Units: Numbers of bird species per site, per area or per survey effort.
Monitoring frequency: As 10 above
Cautions: Constraints including ease of observation and site accessibility will mean that some groups and sites are better studied than others**.**
Interpretation and use: The richness estimates provided by this indicator can be used to identify areas with high concentrations of bird species, which may be paralleled by high richness in other groups. Great care needs to be taken in comparison between areas where different survey methods or analytical approaches have been used to obtain richness estimates.

15. **Proportion of national bird species complement this represents**
See 11 and 14 above

16. **Total species richness in other taxonomic groups**
General guidance as above

17. **Number of local people largely or wholly nutritionally dependent on forest products**
Data needed: Local socioeconomic surveys to identify local people obtaining food from forest products and estimate their consumption of food derived from forest products relative to their total intake. Usually obtained through interviewing and careful sampling design.
Units: numbers of people
Monitoring frequency: If possible baseline should be updated every 5-10 years
Cautions: The surveys required are intensive and require establishment of long term rapport with local communities. The forms in which questions are asked can affect the survey outcomes, so expert guidance in survey design should be sought. Careful selection of criteria to define "local" is required to ensure consistency and coherence in the data.

Interpretation and use: This indicator provides information about how important the persistence of the forest unit as forest may be to local people's subsistence. It also can help to inform decisions affecting access and use rights.

18. **Proportion of local population this represents**

    Data needed: Data from 17 plus estimates of total local population. Careful selection of criteria to define "local" required.
    Units: percentage or proportion
    Monitoring frequency: as 17
    Cautions: as 17
    Interpretation and use: This indicator serves similar functions to 17, but provides a measure of importance at the community or wider level, beyond individuals.

19. **Number and proportion of local people largely or wholly dependent on forest products for income**

    As 17 above, but addresses economic activity beyond subsistence. Requires attention to markets as well as interviews with producers.

20. **Proportion of local population this represents**

    See 17, 18 and 19

21. **Number and proportion of local people for whom the forest is important for other reasons**

    Data needed: Survey data as for 17 and 19, but with a broader focus aimed at eliciting both use and non-use values of the forest in the eyes of local people.
    Units: numbers, percentages, proportions of people
    Monitoring frequency: As 17
    Cautions: As 17 and 19. Because of the more general focus there is a substantial danger of generating 'false positive responses'
    Interpretation and use: This indicator provides information about how important the persistence of the forest unit as forest may be to local people's subsistence.

22. **Number of nationally endemic species occurring in the FMU**

    Data needed: Species lists from FMU and national listings of endemic species
    Units: numbers of species
    Monitoring frequency: Should be updated as new inventory or research efforts bring in data on new or extended study areas.
    Cautions: Survey data need to be carefully judged.
    Interpretation and use: As 4 above plus should help to identify species that should be of greatest concern in planning management.

23. **Proportion of the national complement of endemic species this represents**

    As 11 above – areas with highest concentrations of endemics are likely to be highest priority for protection or low impact management.

24. **Proportion of total population of each endemic species occurring in FMU (% range or extant habitat is a proxy)**

Data needed: Field-based population estimates for endemic species plus estimated national population (see 62). Alternatively, spatial or numerical data on total area of species ranges and/or remaining extant habitat.

Units: Tabular tally by species of proportion of national complement included in FMU

Monitoring frequency: Update when on-site surveys performed and to take account of new national data on population sizes or ranges.

Cautions: Good population estimates are resource-intensive and technically demanding. Good total estimates are available for few species.

Interpretation and use: Indicates which species are most dependent on a particular forest area for continued survival. As 11.

25. **Number of globally threatened species occurring in FMU**

As 5 above.

26. **Proportion of the national complement of globally threatened species this represents**

As 5 and 11 above

27. **Proportion of total population of each globally threatened species occurring in FMU (% range or extant habitat is a proxy)**

As 24 above

II. Coverage indicators

These indicators evaluate the intent or effort put into managing the forest to limit adverse effects on biodiversity.

National Level

28. **Area of each forest type formally reserved (by statute or customary law) for biodiversity protection (i.e. IUCN management categories I-IV)**

Data needed: map of forest types or area statistics, maps and/or area statistics of PAs

Units: ha or km^2

Monitoring Frequency: In most cases changes to this indicator will result from changes to legislation and from loss of forest cover within protected areas. Updates every two to five years should track these changes effectively. More frequent evaluation would not be supported by the available data in most cases.

Likely trends: In most cases, protection is likely to increase, but de-gazettement and encroachment or other disturbance could lead to opposite trends.

Interpretation and Use: Formal protection is an important measure of effort to conserve biological diversity. It does not ensure conservation, but is one important step. This indicator provides a national measure of effort in this respect.

29. **Area of each forest type under certified management**

Data needed: Details of FMUs with management certification, either with descriptions of forest types involved, or with mapped boundaries that can be overlaid on maps of forest types.

Units: square km or hectares

Monitoring Frequency: In most cases, changes to this indicator will result from the certification of new management units, and the indicator should be updated when details of new certifications are obtained. Annual or biennial review should be undertaken to ensure the currency of the data, which should be cross-checked insofar as possible with the certification bodies.

Likely trends: It is likely that area under certified forest management will increase, but change in practises or ownership could in theory lead to loss of certification in some areas.

Interpretation and Use: The standards and criteria used to certify forest management are aimed at preserving the functions of the forest, including biodiversity preservation, to provide long-term benefits. Although the standards in relation to biodiversity are often rather vague, the very process of certification implies recognition of good standards of environmental management and consequent reduction in adverse impacts. Therefore, steadily increasing amounts of certified forest should indicate an increasing investment of time and energy in wise forest management and consequent improvements in biodiversity status over uncertified production forest.

30. **Area of each forest type with a management plan that explicitly addresses biodiversity considerations**

Data needed: Management plans that include either detailed accounts of forest types covered or mapped boundaries of different management units.

Units: square km or hectares

Monitoring Frequency: The indicator should be updated as new management plans are submitted and an annual or biennial review should be undertaken to ensure the currency of the data.

Likely trends: Increasing global awareness of the importance of biodiversity as well as national commitments and policies are likely to increase the area of forest with formal management plans addressing biodiversity.

Interpretation and Use: As in the case of certification, management plans that address biodiversity are no guarantee of biodiversity preservation. However, management plans must often be lodged with government agencies and so can be reviewed to obtain this indicator of area where some attention at least is paid to biodiversity in formulating forest management.

31. **Area of forest occurring within global biodiversity priority areas that is under formal protection**

As 3 and 28

32. **Area of forest occurring within global biodiversity priority areas that is under certified management**

As 3 and 29

33. **Area of forest occurring within global biodiversity priority areas covered by a management plan that explicitly addresses biodiversity considerations**

As 3 and 30

34. **Percentage of endemic forest species occurring within formally protected forest areas**

Data needed: Species lists for forest protected areas, national lists of endemics, distribution maps for endemic species or mapped data for protected areas.

Units: Tabular presentation of numbers and proportion of endemics by PA.

Monitoring Frequency: Update as 4 and 28 and with additional survey efforts in PAs.

Likely trends: As protected area networks are expanded, the indicator should increase, but de-gazetting and changes in species populations and distributions may cause decreases.

Interpretation and Use: Endemic species are those for which a country has ultimate and sole responsibility at the global scale. Therefore the protection of these species is an important contribution to conserving global biodiversity, and showing progress in this respect is key.

35. **Percentage of endemic forest species occurring within forest areas under certified management**

As 4, 29 and 34

36. **Percentage of endemic forest species occurring within forest areas covered by a management plan that explicitly addresses biodiversity considerations**

As 4, 30 and 34

37. **Percentage of globally threatened species occurring within protected forest areas**

Data needed: Species lists for key groups from each protected forest area and data from 5. Alternatively, data on distributions of threatened species can be combined with geographic information on PAs to provide

Units: Tabular tally of threatened species by protected forest area, allowing calculation of total and percentage included in PA system.

Monitoring Frequency: as 34

Likely trends: As protected area networks are expanded, the indicator should increase, but de-gazetting and changes in species populations and distributions may cause decreases, revised assessment of species conservation status may also cause changes.

Interpretation and Use: Preventing threatened species becoming extinct is the most immediate global priority for the maintenance of biodiversity. Formal protection is an important measure of effort to conserve biological diversity. Inclusion of threatened species in protected areas does not ensure their conservation, but is one important step. This indicator provides a national measure of effort in this respect.

38. **Percentage of globally threatened species occurring within forest areas under certified management**

As 5, 29 and 37

39. **Percentage of globally threatened species occurring within forest areas covered by a management plan that explicitly addresses biodiversity considerations**

As 5, 30 and 37

40-51. **Percentage of all nationally forest-occurring mammal, bird, and tree species occurring within each of the above classes of forest management.**

To the extent that reliable data can be assembled, these indicators provide insight into the degree to which national efforts to manage forests in ways that maintain biodiversity do in fact address the total national biodiversity complement. They may be useful in identifying key gaps in these efforts.

Forest management unit level

52 and 53. **Number and proportion of globally important ecosystems / globally threatened species occurring within the FMU that are explicitly addressed in the management plan**

Data needed: management plan and data as for 9 and 25

Monitoring Frequency: management plan revision cycle

Likely trends: As information improves, it is likely that management plans will increasingly address species and ecosystems of concern explicitly.

Interpretation and Use: These indicators are measures of the degree to which forest management aims to take account of important biodiversity within the FMU. If these elements are not mentioned in the management plan, it will be difficult to ensure that action is taken when warranted and adverse impacts avoided.

54 and 55. **Number and proportion of nationally important ecosystems / species populations (defined according threshold proportion of national total, for which thresholds will vary) occurring in the FMU that are recognised and addressed in the management plan.**

Data needed: Data for 8, 24, 27, plus lists of species/ecosystems with restricted national occurrence and management plan.

Monitoring Frequency: management plan revision cycle.

Likely trends: As information improves, it is likely that management plans will increasingly address species and ecosystems of national importance explicitly.

Interpretation and Use:

56. **Number and proportion of biodiversity resources identified in stakeholder dialogue that are addressed in the management plan in ways that reflect the importance attached to them by stakeholders.**

Data needed: Results of stakeholder dialogue about importance of various elements of biodiversity, management plan

Monitoring Frequency: update on management plan revision cycle or when new stakeholder data available

Likely trends: As information improves, it is likely that management plans will increasingly address species and ecosystems of local importance explicitly, but there may be a time lag between improvement in information and corresponding management plan revision.

Interpretation and Use: This indicator is a measure of the degree to which forest management aims to take account of elements of biodiversity within the FMU that are important to local stakeholders. If these elements are not recognised in the management plan, it will be difficult to ensure that action is taken when warranted and adverse impacts avoided.

III. Indicators of Status and Trends in Forest Biodiversity

These indicators address biodiversity and its status directly, but tend to be very demanding of data and analytical effort.

National level

57. **Area of each forest type**

Data needed: This indicator derives from mapped data on land cover and depends on the existence (or development) of a classification of forest types that is meaningful in biodiversity terms. Such data are likely to derive from remotely sensed data, but meaningful classification will depend on their integration with a number of other types of information, including forest structure, soils, topography and expert knowledge.

Units: Reporting should be in square km or in hectares, depending on the country, the size of the forest resource, and the spatial resolution of the source data.

Monitoring Frequency: In areas of rapid change, annual monitoring may be desirable, but the costs and data processing effort involved mean that this is rarely practical at national level. A five-year monitoring cycle is appropriate, and biennial re-evaluation would be ideal.

Likely trends: In most tropical moist forest countries the total area of most forest types is declining. An active monitoring programme for this indicator will highlight the rate of change and identify particular areas or forest types where it is disproportionately high.

Interpretation and Use: In many countries forest policy will set an acceptable limit for change in forest area, either explicitly or through the issuance of various forms of permits and authorisations. As these are frequently issued in a number of different sectors (forestry, planning, transport, etc.), this indicator provides a cross check of the actual human impacts on forest area compared to those projected or authorised. Major discrepancies should prompt a review of the relevant policies and cross-sectoral co-operation as well as investigation of factors contributing to high forest loss in particular areas.

58. **Rate of change of area of each forest type**

Data needed: Repeated data from the evaluation of indicator 57. In many cases it may be valuable to analyse older data to provide longer-term basis for change calculations. This presents problems of comparability of resolution, accuracy and classification over time.

Units: Though evaluated over longer time intervals, reporting should be in square km or in hectares change per year, depending on the country, the size of the forest resource, and the spatial resolution of the source data. Output in tabular and graphical forms showing rate of change by forest type.

Monitoring Frequency: as 57

Likely trends: In most tropical forest countries the area of forest cover is declining, but this varies between forest types, as land use changes are not homogeneously distributed

Interpretation and Use: Active monitoring of this indicator will help to identify new trends in forest biodiversity status and highlight particular forest types requiring policy attention

59. **Area of each forest type belonging to each spatial integrity class**

Data needed: Spatial data on current forest cover, analysed to evaluate forest fragmentation effects on patch size, shape (or edge effects) and isolation. These can be quantified separately or summarised in both mapped and statistical forms in a single spatial integrity index.

Units: The spatial integrity index itself is without units, but it can be most meaningfully reported as forest area (in square km or hectares) belonging to particular integrity classes.

Monitoring Frequency: The spatial integrity of forest is changed as the forest area changes. Therefore, monitoring of this indicator should parallel that of forest area change – i.e. on a 2-5 year cycles at national level, except where particularly active change is occurring.

Cautions: The interpretation of integrity indices is dependent upon the resolution and accuracy of the source data. Especially when applied to coarse resolution data, they should be seen as a guide rather than an absolute measurement. It is very important that the indicator be expressed in terms of absolute area rather than percentage, so that real changes can be seen. Measurements in percentage terms can appear to show an improvement when in fact the real change is that areas of lower quality have been lost. Although this may in fact be the more desirable mode of change, it needs to be clearly perceived rather than potentially confused with, for example, the connection of previously separate forest patches through natural regeneration or restoration.

Likely trends: In areas where agricultural expansion, colonisation and other forms of land use change are causing forest loss, the trend will be towards a decline in spatial integrity of the remaining forest. Forest restoration or plantation programmes can improve spatial integrity locally.

Interpretation and Use: The index provides an evaluation of forest cover that is more meaningful in biodiversity terms than simple forest area statistics. It can therefore highlight changes that may have adverse impacts on forest biodiversity and help to identify areas where action is needed. The response could range from restrictions to limit land use change in areas of concern to forest restoration programmes to reverse the effects. Planning can reduce the adverse impacts of land use change on forest spatial integrity, especially in priority areas, and in fact the indexing can be used as a forecasting tool to examine the potential impacts of changes of particular magnitudes in particular areas.

60. **Area of forest with high spatial integrity index for each forest type**

As 59; decision will need to be made about index threshold for inclusion. Loss of high spatial integrity forest may have higher long-term biodiversity impacts than loss of low integrity forest. However, additional information, e.g. on species distributions, is needed.

61. **Rate of changes of area of forest with high spatial integrity index in each forest type**

As 58, 59, 60.

62. **Estimated total national population of endemic, threatened or other target forest-dependent species**

Data needed: Direct census estimates for all of species' range, or local censuses and data on habitat dependence combined with spatial data on habitat extent.

Units: Estimated numbers of individuals by species.

Monitoring Frequency: Varies according to species and resources, but re-evaluation every 2-5 years

Interpretation and Use: Although potentially very resource-intensive, if adequately quantified this indicator is the fundamental basis on which forest biodiversity-related policy and management decisions should be made. The challenge is to identify the management priority species and monitor success in maintaining on enlarging their populations. Realistically this level of monitoring will only be feasible at national level for the species of greatest concern. Expert advice will be needed to define threshold changes in this indicator that should prompt substantive changes to policy and/or management. The threshold change will differ between species.

63. **National forest species trend index**

Data needed: Census-based estimates of trends in individual populations or whole national populations of key species, combined to provide normalised estimate of average trend across species.

Monitoring Frequency: usually compiled for 5-year moving windows to allow combination of data based on different time frames.

Interpretation and Use: This indicator provides a means to make fragmentary data on species trends available and understandable to a more general audience. It is principally a communication tool, rather than one on which management level decisions can be made, but is potentially useful in state-of –environment and similar reporting.

64. **Change in number of species identified as being of global or national conservation concern**

Listings of species conservation status at global and national scales are usually revised infrequently and changes to them often reflect changes in taxonomy and knowledge of status as much as they actually reflect changing status. Therefore, frequent assessment of this indicator is not warranted, but it should evaluated with some care when new conservation listings are published.

Forest Management Unit level

65. **Total area of each component forest type within FMU**

Data needed: High-resolution data (SPOT, Landsat or aerial photography) on forest cover combined with ancillary data (e.g. topography or soil types) and/or expert knowledge to provide classified vegetation map of FMU.

Units: km^2 or ha per forest type

Monitoring Frequency: Every 2-5 years. Determined by resources available and general information on rates of change; more rapid change justifies more frequent monitoring.

Likely trends: variable

Interpretation and Use: Loss of forest cover has a major impact on biodiversity. Therefore periodic assessment of the area of each forest type using a biologically meaningful classification can be used to highlight forest types of concern within the FMU and to change management strategies accordingly to deal with internal and external causes of loss of area in forest types of concern.

66. **Rate of change of each component forest type within FMU**

As 58 and 65. It will be necessary to draw on older data to establish baseline rates of change. This represents a higher analytical burden, but the spatial data may be available at low cost.

67. **Area of each forest type within FMU belonging to each spatial integrity class.**

As 59, but based on higher resolution data as 65. It will be necessary to select thresholds in the analysis appropriate to the resolution of the data, and ideally also based on known habitat preferences of species given high management priority.

68. **Area of forest in FMU with high spatial integrity index, for each forest type**

As 60 and 67.

69. **Rate of change of area of forest in FMU with high spatial integrity index, for each forest type**

As 60, 66 and 67. Very demanding of analytical effort, but a powerful indicator of biodiversity trends.

70.**Change in area of FMU with given gap regime**

Data needed: Systematic canopy openness measures or gap mapping as part of forest inventory, allowing characterisation of forest areas belonging to particular classes of dynamics.

Units: ha by class of gap frequency

Monitoring Frequency: as general forest inventory. Ideally every 5 years.

Interpretation and Use: The frequency of canopy gaps is related to the successional stage of the forest and natural turnover processes. It varies among forest types and has implications for the persistence of species that are dependent gaps for survival or regeneration. Changes in prevailing gap regimes should prompt further investigation.

71. **Number of standing dead trees per area**

Data needed: snag counts per unit area from forest inventory

Units: numbers per area, by size class if feasible

Monitoring Frequency: as general forest inventory. Ideally every 5 years.

Interpretation and Use: Standing dead trees are important habitat elements for many components of biodiversity and are often regarded as indicating low levels of disturbance and older forest. Changes from baseline numbers suggest changes in underlying forest dynamic processes and should be investigated.

72. **Rate of change in frequency of largest diameter class of trees**

Data needed: Tree diameter data from forest inventory.

Units: numbers per ha.

Monitoring Frequency: as general forest inventory. Ideally every 5 years.

Interpretation and Use: Like standing dead trees, large diameter trees tend to be associated with low levels of disturbance and older forest. They are also important for supporting other components of biodiversity such as epiphytes. While their absolute frequency is very much a function of forest type, change in that frequency is likely to indicate other changes in biodiversity.

73. **Forest stream turbidity index**

Data needed: Average turbidity measures per stream in all or a subset of streams within the FMU.

Monitoring Frequency: Because stream turbidity varies seasonally and with individual rainfall events it will be important to establish a regular sampling program. As field effort is relatively low, this could be as frequently as bi-monthly, with reassessment of the indicator based on annual averages.

Interpretation and Use: It is important to recognise that forest biodiversity includes that within aquatic systems and that forest management can have a major effect upon it. Turbidity is a simple measure of aquatic habitat quality that can be strongly affected by forest management. Increases in average turbidity are cause for concern.

74. **Area of FMU with high incidence of invasive species**

Data needed: Quantitative or qualitative measures of invasive frequency, probably associated with forest inventory (for plant species).

Units: ha by frequency class.

Monitoring Frequency: as general forest inventory. Ideally every 5 years. Regular, more frequent observational data are also important to highlight changes.

Interpretation and Use: Invasive species can have major impacts on native biodiversity and often enter a forest as a result of forest management or disturbance. The frequencies of more common invasive plant species can be readily evaluated, at least qualitatively, on a per plot basis by field teams during forest inventory. Increasing area affected by invasives may indicate that forest management is not adequately safeguarding local native biodiversity and remedial action may be required.

75. **Trends in populations of management priority species**

See 62. This indicator requires intense species-specific monitoring, which is the most direct approach to evaluating the status of priority species within the FMU. The methods and monitoring frequencies used will depend on the species given priority. It is important that priority species be identified for each FMU and that, here possible, resources be invested in monitoring those of greatest concern. However these monitoring efforts are likely to be additional to normal forest management practice.

IV Indicators of pressure on forest biodiversity

National Level

76. **Area of forest per capita**

Data needed: As 1 and 57 with national population estimates
Units: km^2 or ha per person
Monitoring Frequency: as 57
Likely trends: in most tropical moist forest countries the area of forest per capita is declining, though plantations and restoration may help to mitigate this trend.
Interpretation and Use: This indicator provides a coarse measure of the demands being placed upon forest resources. Declines suggest increasing pressure on remaining forest and that action may be needed to mitigate these pressures.

77. **Average wilderness index of current cover of each forest type**

Data needed: Spatial data on forest cover, classified as meaningfully as possible, plus mapped data on roads, settlements and other forms of infrastructure.
Units: The wilderness index itself has no units. It is a combined measure of the relative remoteness of each point on a grid from human access (settlements, roads, rail) or interference (permanent man-made features, biophysical naturalness), expressed on a numerical scale.
Monitoring Frequency: Because of the limited degree to which available data on infrastructure change, measuring real change can be quite difficult and (except in the case of scenario testing) is likely to be due to change in forest cover. Therefore, the appropriate monitoring interval is dictated by these changes and is likely to be 2-5 years.
Cautions: In many cases the available digital spatial data on roads and other infrastructure are poor and out-of-date, and sometimes better data sets are available in paper form. Harmonisation and upgrading of the

available data sets is needed to create a good quality access and settlement layer. Attention needs to be paid to the grading of these features as major or minor, and in tropical forest countries the role of rivers and coastlines as access must also be considered.

Likely trends: Reduction in forest cover will tend to generate a reduction in the average wilderness of remaining forest, except where the forest loss is by total elimination of low-wilderness fragments.

Interpretation and Use: The wilderness indexing procedure provides a useful visualisation of the accessibility or vulnerability of forest areas to human interference. Thus it is a measure of generalised human pressure on biodiversity that takes no account of specific activities or their outcomes. While this generality limits the method's utility in predicting specific local pressures and their outcomes, it makes it broad scale comparison among areas feasible and makes it possible to include a standardised measure of vulnerability in the decision-making process. If forest wilderness values decline appreciably, it is likely that forest biodiversity is at increasing risk and policy action needs to be taken to limit the development of new access routes and or the spread of population.

The index can be scaled to local conditions so that it reflects relative wilderness within an appropriate range. It is potentially a very useful tool for scenario testing and planning as new roads or population centres can be provisionally "constructed" within the infrastructure data set and the magnitude of their likely impacts evaluated. scaled and can be used for scenarios

78. **Total area of forest with a high wilderness score**

Data needed: Spatial data on forest cover, classified as meaningfully as possible, plus mapped data on roads, settlements and other forms of infrastructure.

Units: Square kilometres or hectares of forest in each wilderness category, where the categories are derived by breaking the continuum into a number of intervals.

Monitoring Frequency: Because of the limited degree to which available data on infrastructure change, measuring real change can be quite difficult and (except in the case of scenario testing) is likely to be due to change in forest cover. Therefore, the appropriate monitoring interval is dictated by these changes and is likely to be 2-5 years.

Cautions: In many cases the available digital spatial data on roads and other infrastructure are poor and out-of-date, and sometimes better data sets are available in paper form. Harmonisation and upgrading of the available data sets is needed to create a good quality access and settlement layer. Attention needs to be paid to the grading of these features as major or minor, and in tropical forest countries the role of rivers and coastlines as access must also be considered. Decisions about the classes should be made empirically in the first instance, but should not be altered in future assessments without very strong justification. When such a decision is made the initial assessment should be repeated using the new categories.

Interpretation and Use: The wilderness indexing procedure provides a useful visualisation of the accessibility or vulnerability of forest areas to human interference. Thus it is a measure of generalised human pressure on biodiversity that takes no account of specific activities or their outcomes. While this generality limits the method's utility in predicting specific local pressures and their outcomes, it makes it broad scale comparison among areas feasible and makes it possible to include a standardised measure of vulnerability in the decision-making process. If forest wilderness values decline appreciably, it is likely that forest biodiversity is at increasing risk and policy action needs to be taken to limit the development of new access routes and or the spread of population.

Considering the total area of forest belonging to a category of maximum wilderness value provides an estimate of the total forest area likely to be subject to the least human interference. ….

79. **For each forest type, size of largest forest patch with a high wilderness score**

As 77, 78. This indicator provides an estimation of the magnitude of the forest resource subject to little human pressure and the likelihood of its remaining so. Reductions in this indicator may represent a reduction in national capacity to retain biodiversity over the longer term

80. **Area of each forest type within areas of global biodiversity priority allocated to commercial concessions**

Data needed: Concession allocation information with detailed location data and the data required for 3.
Units: ha or km^2 by forest type and priority area
Monitoring Frequency: to reflect concession granting process, annually or biennially usually appropriate
Interpretation and Use: Granting of timber licenses represents a direct increase in pressure on forest biodiversity and an increased probability of forest disturbance. This is of the greatest concern in conservation priority areas. Rises in this indicator should prompt policy review.

81. **Area of each forest type adjacent to protected areas allocated to commercial concessions**

Data needed: Spatial data on forest concessions allocated and protected areas
Units: ha or km^2 by forest type
Monitoring Frequency: as 80
Interpretation and Use: Granting of timber licenses represents a direct increase in pressure on forest biodiversity and an increased probability of forest disturbance. This can have significant impacts in adjacent forest areas and can therefore disrupt the management of protected areas for biodiversity conservation. Rises in this indicator should prompt policy review and management guidelines to minimise impacts beyond the boundaries of the concession.

82. **Area of each forest type with populations of species of conservation concern allocated to commercial concessions**

Data needed: Spatial data on distributions of species of conservation concern and on forest concessions allocated.
Units: ha or km^2 by forest type
Monitoring Frequency: as 80
Interpretation and Use: Granting of timber licenses represents a direct increase in pressure on forest biodiversity and an increased probability of forest disturbance. This indicator can help evaluate the potential impact this may have on species of conservation concern.

83. **Annual timber harvest in relation to total forest area**

Based on national timber production statistics and the data for 1 above this indicator provides a measure of the intensity of timber exploitation pressure on the national forest estate and therefore the likely intensity of impacts on forest biodiversity.

84. **Annual timber harvest in relation to forest area allocated to production**

Based on national timber production statistics and the data for 1 above this indicator provides a measure of the intensity of timber exploitation pressure on the national production forest estate and therefore the likely intensity of impacts on forest biodiversity within those forests.

85.**Annual timber harvest from forest areas within areas of global biodiversity priority**

As 3, 31-33, and 83. More complex to evaluate because of need to determine harvest from subsets of concessions and production forests. If the forest areas in question are well defined, then it may be possible to acquire data through of timber operators and/or timber truck counts along key access routes

86.**Annual fuelwood production in relation to forest area**

Difficult to quantify requires market surveys plus consumption estimates based on household surveys. Higher production implies both higher pressure on forest biodiversity and higher dependence on the forest.

87. **Annual fuelwood production in relation to forest area within areas of global biodiversity priority**

As 85 and 86

88. **Area of each forest type converted annually**

As 58. From remotely sensed data and land use designations. The most basic indicator of pressure on forest biodiversity.

89. **Area of each forest type within areas of global biodiversity priority converted annually**

As 88 and 3. Requires spatial analysis of forest loss in relation to priority areas. Indicates magnitude of conversion likely to be of greatest conservation concern. Acceptable levels need to be decided and action taken when these are surpassed.

90. **Amount of bushmeat from forest sources consumed annually**
Based on extrapolation from local studies and market surveys. Often difficult to quantify with confidence because of sensitivities. A measure of the total hunting pressure.

91. **Per capita annual consumption of bushmeat from forest sources**
As 90expressed on per capita basis.

92. **Percentage annual protein needs supplied by bushmeat from forest sources**
As 90 with additional information on protein supply. Indicates dependence on forest biodiversity as well as pressure.

93. **Value of plant non-timber forest products exported annually**
Difficult to trace except for high profile products. Provides a measure of economic value of the forest, but also of pressure on its resources.

94. **Percentage of annual export value provided by export of plant non-timber forest products**
As 93 combined with national trade statistics. A higher percentage implies lack of alternative income sources and therefore higher pressure.

Forest Management Unit level

95. **Average wilderness index**
As 77. A measure of accessibility and therefore generalised disturbance pressure on forest biodiversity. It is appropriate to use higher resolution infrastructure data, which may include walking trails as well as roads,

96. **Total area of forest with a high wilderness value**
As 78 and 95.

97. **Area of forest allocated to production**
From management plan, indicates what fraction of FMU is likely to be directly disturbed by timber harvest.

98. **Area of forest logged annually**
A measure of logging pressure on forest biodiversity. Straightforward reporting from FMU records, but should be based on operations rather than on authorisations. Therefore requires either aerial or ground survey.

99. **Annual cut**

As 98; may require logging truck surveys or other direct measure of harvest.

100. **Incidence of cut stumps**

Data needed: numbers of cut stumps per area as part of plot-based forest inventory

Units: numbers of stumps

Monitoring Frequency: as forest inventory interval 5 years, with more frequent resurveys if there is cause for concern

Interpretation and Use: Cut stumps are a good indicator of logging activity and the associated pressures on forest biodiversity. Numbers of cut stumps should be compared with authorised harvest rates. Rapid increases may suggest timber poaching and management action should be taken

101. **Annual volume of round-logs processed in local sawmills**

Based on sawmill records and surveys, this indicator is a measure of pressure on local forest resources and is especially useful when compared against records of authorised harvest from the FMU.

102. **Annual harvest of species of conservation concern**

Data can be difficult to obtain because of sensitivities and difficulty in tracing products. However, this is a real measure of the pressures on these species and sharp increases should prompt management action.

103. **Local area burned in the past five years**

From aerial photographs, ground survey and local knowledge. Radical changes should prompt changes to fire management.

104. **Hunting effort required to obtain given quantity of bushmeat**

Data require interviews with local hunters. Sensitivities may make data difficult to obtain. Increasing effort requirements indicate declining game populations.

105. **Number of people living within 5 km of forest**

Based on census data or local survey, this indicator provides a measure of pressure on resources within the forest. Sharp increases should prompt re-evaluation of management approaches and community relations.

106. **Accumulation of fruits under understorey palms**

A relatively easy parameter to assess during normal field operations, this indicator can highlight where major changes are occurring in fruit eating mammals and other dispersers. A change in the indicator should prompt investigations of hunting and other pressures

9. Conclusions –

The indicators listed and the accompanying technical guidance list demonstrate that some basic indicators and monitoring are eminently feasible to establish. It is critical that monitoring programmes are begun, even at the most basic level.

One of the most valuable data sets for assessment and monitoring of forest biodiversity is a map of forest ecosystem cover that uses a meaningful classification. This may be derived from satellite data, aerial photos or other forms of survey. Even relatively old data can be useful for biodiversity assessment and prioritisation, and with careful harmonisation can serve as a baseline for modern monitoring programmes.

The goal is to minimise adverse impact, and therefore the baseline is whenever monitoring begins. There is no necessity or desirability in determining a 'natural state'.