Biodiversity indicators in national forest inventories

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Abstract

Future global forest assessments should incorporate a greater emphasis on biodiversity. This could be partly achieved through use of indicators, which should be appropriate for use at the local scale, but enable information to be aggregated at larger scales. Many indicators of forest biodiversity have been developed in recent years, within the various processes focusing on sustainable forest management. Here we identify eight generalised indicators common to some or all of these processes, which are appropriate for implementation at the local scale. Methods are highlighted by which data to support these indicators might be derived from standard forest inventories. In addition, we suggest that information collected at the local scale may be aggregated by summarizing data in categorical form, and presenting them in relation to forest area. Such an approach would assist countries in contributing to the C&I processes of which they are a part, as well as meeting their reporting obligations to international conventions.

Introduction

It is now widely recognised that assessments of forest biodiversity are essential if forest resources are to be effectively conserved and sustainably managed (Hunter 1999). However, any assessment of forest biodiversity faces a number of challenges. Firstly, given its complexity, there is a need to express biodiversity in the form of simplified variables based on indirect measures, typically in the form of indicators (Noss 1990, 1999). Secondly, as decisions relating to forests are made at a variety of scales, there is a need to aggregate data across different scales for monitoring and reporting purposes (Noss 1990, Turner 1995).

The Expert Consultation on the Global Forest Resources Assessment (FRA) 2000 ('Kotka III') recommended that the assessment should address key indicators that might contribute towards a better understanding of the status and trends in forest biological diversity, specifically relating to the naturalness, protection status and fragmentation of forest ecosystems. These were subsequently incorporated into the FRA 2000 report (FAO 2001c). In addition to estimates of forest area and changes in forest cover, the FRA 2000 report provided statistics on the proportion of forest area incorporated within protected areas, the distribution of forest area by ecological zone, and the number of endemic and threatened species for seven species groups (FAO 2001c). This information provides a useful basis for monitoring future changes in the status of forest ecosystems, and associated biodiversity. However, in conclusion, the FRA 2000 highlighted the need to monitor trends not only in forest quantity, but also in forest quality, and suggested that future action focus on the further development, testing and implementation of indicators related to globally accepted criteria for sustainable forest management (FAO 2001c).

The aim of this paper is to explore how future global forest assessments might provide more detailed information on status and trends in forest biodiversity, specifically through use of indicators. Such indicators should be appropriate for use at the local scale, but should provide information that can be readily aggregated at larger scales, to be consistent with the overall FRA approach (FAO 2001c). To ensure that future assessments are practicable, they should employ indicators of biodiversity that can be generated from data collected by standard forest inventories as far as possible. In addition, the proposed indicators should build on the many international initiatives that have attempted to develop forest biodiversity indicators in recent years. This paper therefore firstly provides a brief overview of these initiatives, with reference to their policy context. The various frameworks for indicator development that have been proposed are then considered, and the methods by which appropriate indicators can be identified are highlighted. Finally, the application of forest inventory data to such indicators is examined.

Biodiversity indicators: policy context and initiatives

The UN Conference on Environment and Development (UNCED) in 1992 recognised the importance of indicators for enabling countries to make informed decisions regarding sustainable development. The need for countries, as well as other organizations, to develop such indicators, was recognised explicitly in Chapter 40 of Agenda 21. During the decade following UNCED, a large number of initiatives have sought to identify indicators of sustainable development, including those undertaken as part of the Programme of Work implemented by the UN Commission on Sustainable Development (UNCSD 2001). Given that the concept of sustainable development embraces such a wide variety of different aspects, relatively few indicators relate explicitly to forest biodiversity. The relevant indicators presented by UNCSD (2001) include forest area as a percent of land area, wood harvesting intensity, protected area as a percentage of total area, and abundance of selected key species.

The Convention on Biological Diversity (CBD) provides a more explicit policy context for indicators of biodiversity. Article 7 of the Convention requires Parties to identify and monitor ‘components of biodiversity important for conservation and sustainable use’, and to identify processes or activities likely to have adverse effects on biodiversity. The text of the Convention also recognises the role of indicators in assisting Parties with monitoring the status of biodiversity and the effects of measures taken for its conservation and sustainable use. CBD (2001) provides an overview of how the issue of biodiversity indicators has been dealt with by the Convention. To date, meetings held under the auspices of the CBD, such as the various Conferences of the Parties (COP), have sought to encourage Parties and Governments to identify appropriate biodiversity indicators (for example, COP5, decision V/24, paragraph 4), and to increase regional cooperation and capacity-building for the development and use of indicators. Decisions (such as those made by COP4) have stressed that the primary role of indicators should be as a tool for management of biological diversity at local and national levels, and for assessing implementation of the Convention, but have also emphasised the need to adopt the ecosystem approach in indicator development. Proposals have also been made for a 'core set' of biodiversity indicators suitable for use by Parties in compiling their national reports, and to enable the effectiveness of measures taken to be evaluated (CBD 1997a). Indicators specifically relating to forest biodiversity have also been proposed (CBD 1997b).

The Forest Principles and Chapter 11 of Agenda 21 call for the identification of criteria and indicators (C&I) 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 ITTO, the Pan-European (or 'Helsinki') Process, the Montreal Process, and the Tarapoto, Lepaterique, Near East, Dry Zone Asia and Dry Zone Africa processes, which have each generated sets of C&I (Grayson and Maynard 1997, FAO 2001a, Castañeda 2001). Currently, around 150 countries are participating in these processes (FAO 2001b). While the different processes share similar objectives and overall approach, they differ in structure and specific content (FAO 2001b).

Development of C&I for sustainable forest management has also been encouraged by the Intergovernmental Panel on Forests (IPF), which was established by the CSD to develop an international consensus on forest issues, specifically relating to implementation of Agenda 21. The IPF, together with its successor the International Forum on Forests (IFF), recommended more than 270 proposals for action to be adopted by the international community. A number of these proposals related explicitly to the further development and implementation of C&I for sustainable forest management. Implementation of these proposals is currently being assessed by the United Nations Forum on Forests (UNFF).

Comparison of the large number of indicators relating specifically to biodiversity that have been generated indicates that many are common to more than one process (CBD 1997b). However, field evaluations of C&I undertaken by CIFOR in a number of different countries indicated that most, if not all, of the proposed C&I relating to biodiversity for use at the local level are in some sense deficient (Prabhu et al. 1996). In particular, many of the criteria appeared either to be impractical, or of little relevance to forest management. In response, CIFOR proposed a preliminary list of indicators, together with a practical framework for applying biodiversity C&I in field situations (Stork et al. 1997).

Frameworks for the development of biodiversity indicators

It is widely recognised that some form of framework or conceptual model is required in order for meaningful indicators to be developed (Holdgate 1996). The most widely used is the 'pressure-state-response' (P-S-R) framework, which was developed by the OECD (OECD 1993) on the basis of the "stress-response" model developed by Friend and Rapport (1979). The P-S-R framework states that human activities exert pressures on the environment (such as clearance of forest for agriculture), which can induce changes in the state of the environment (for example, the extent of forest cover). Society may then respond to changes in pressures or state with policies and programs intended to prevent, reduce or mitigate pressures and thereby reduce environmental damage. Indicators provide tools for identifying P-S-R relationships, both at the reporting stage and during policy analysis.

The P-S-R framework has been widely applied to indicator development; for example it is explicitly recognised by the CBD (CBD 1997a). A variant of this approach, namely the "Driving Force - State – Response" (D-S-R), has been applied by the CSD (CSD 2001). In the D-S-R framework, the term "pressure" has been replaced by that of "driving force" in order to accommodate more accurately the addition of social, economic, and institutional indicators. In addition, the use of the term "driving force" allows that the impact on sustainable development may be both positive and negative, as is often the case for social, economic and institutional indicators.

The PSR scheme was further expanded by the European Environment Agency to include drivers and impacts, forming the DPSIR framework (EEA 1998). Both the PSR and the extended DPSIR models are based on the fact that different societal activities (drivers) cause a pressure on the environment, causing quantitative and qualitative changes of it (changing state and impact). Society has to respond to these changes in order to achieve sustainable development. According to the DPSIR framework, different indicators of sustainability may be developed, relating to drivers, pressure, state, impact and response.

A number of other indicator frameworks have been proposed by researchers. For example, Hyman and Leibowitz (2001) suggest that development of a conceptual model based on ecological principles can enable the relevance of different indicators to be evaluated, by identifying the relationships between proposed indicators and assessment 'endpoints', such as biodiversity. Noss (1990) presents a hierarchical framework for development of biodiversity indicators, recognising that three attributes of biodiversity, composition, structure and function, can be considered at a number of different levels of organization. Stork et al. (1997) provide a framework based on a conceptual model of the relationship between anthropogenic activities affecting forests, and the processes that influence biodiversity. Indicators may therefore be developed for particular human interventions or mediators (pressure indicators), as well as processes maintaining biodiversity, and biodiversity itself (state indicators). An operational framework is provided by these authors illustrating how indicators for forest biodiversity could be developed and applied in practice.

These examples highlight some of the approaches that have been employed in development of biodiversity indicators. However, it should be emphasized that research in this area has been characterised by a high degree of confusion in the terminology adopted, and uncertainty about which methods are the most appropriate (Larsson and Esteban 2000). For example, the terms ‘framework’ and ‘conceptual model’ are often used interchangeably. Here, we support the suggestion of Boyle (1998) that a conceptual model and a framework are both required for indicator development, the former to define the relationship between the indicator and the endpoint, and the latter to categorize the variables, and define which are appropriate for assessment.

Use of forest inventories for assessing biodiversity

A variety of different approaches for assessing biodiversity are available (Groombridge and Jenkins 1996, Jermy et al., 1995, Heywood 1995). These range from Rapid Biological Assessment (Beattie *et al.* 1993) to All Taxa Biodiversity Inventory (Janzen and Hallwach 1994). These approaches vary with respect to sampling intensity and requirement for taxonomic expertise, and therefore cost. Where the aim is to explicitly address changes over time, methods are required that are repeatable, and can provide measures that are comparable between sampling events. As resources are often limiting, there is also a need to adopt approaches that are practical and efficient, and that can be sustained over time.

Future global forest resource assessments will need to address not only biodiversity, but biophysical status and development of forests, information about how forests are used, and the types and quantities of benefits that are derived from forests (FAO 2001c). Therefore, there is a need to integrate biodiversity assessments with inventories of other forest characteristics. Biodiversity assessment should also be undertaken in a manner that ensures accordance with the criteria and indicators processes with which a particular country is affiliated, together with international reporting obligations such as the CBD and CSD.

Although forest inventories and biodiversity survey methodologies differ in a number of important respects, there are a number of commonalities between the two approaches (Vanclay 1998). Methods of forest inventory have principally been developed for estimating the standing volume of wood in forests and for recurrent measurements to indicate changes in stand structure and growth with time. Traditionally, such inventories focus on assessing timber yield, and therefore do not generally incorporate measures of other ecosystem components, such as animals or non-woody plants (Burley and Gauld 1995). However, in recent years, there has been an increasing effort to establish sample plots explicitly for the purposes of biodiversity assessment in forests. For example, in 1986, UNESCO MAB and the Smithsonian Institution began a joint initiative (SI/MAB) to establish a global network of forest areas under different management regimes, together with protocols for biodiversity monitoring (Dallmeier and Comiskey 1998b). These protocols have been adopted at nearly 200 research sites in 23 countries (Dallmeier and Comiskey 1998b).

In many countries, however, forest inventories are inadequate or entirely lacking. For example, Kapos and Jenkins (2002) examined the extent to which existing forest inventories can serve as a source of information appropriate for biodiversity assessment and monitoring, with a focus on tropical moist forest. Results indicated that existing forest inventories, surveys or networks of permanent plots are often inadequate for providing a representative assessment of forest biodiversity. For these reasons, there will often be a need to design and implement a new inventory system. The following section suggests how such an inventory might be designed and implemented in practice, focusing on use of biodiversity indicators in conjunction with standard forest inventory approaches.

Biodiversity indicators and national forest inventories: a proposed approach

As noted by Stork et al. (1997), most of the forest biodiversity indicators that have been proposed to date are not amenable to practical implementation, or are not appropriate for use at the level of the Forest Management Unit (FMU). This reflects the early emphasis on development of national-level C&I (e.g. under the Helsinki and Montreal Processes), which are not sufficiently sensitive to be useful at the FMU level (Raison et al. 2001). With respect to biodiversity, where important changes may only be detected at the local scale, data collected within the FMU can potentially be aggregated or extrapolated to larger scales, to assist with reporting at the national or regional level (Raison et al. 2001). In this way, trends in indicators at the FMU level could help adjust forest management approaches to ensure that national goals are met. At the same time, national-level indicators are required for the development and updating of national and international policy instruments (Castañeda 2001).

Whilst recognising that indicator development is dynamic, and that research employing novel approaches could contribute greatly to further indicator development (Prabhu et al. 2001), we focus here primarily on biodiversity indicators that have been proposed by existing C&I processes. Specifically, we examine how data required for such indicators could be derived through the use of forest inventory approaches. We suggest that this approach to forest biodiversity assessment could assist countries in implementing the C&I processes in which they are participating (Castañeda 2001), as well as helping them meet their international reporting obligations for the CBD and CSD.

Selection of indicators

As noted by Dallmeier and Comiskey (1998b), a clear statement of goals and objectives is critical to the development of any assessment or monitoring programme. The selection of indicators will depend upon the precise objectives of the assessment, and the framework for indicator development that has been adopted. Ideally, the relationship between selected indicators and endpoints should be analysed using appropriate statistical approaches (Hyman and Leibowitz 2001). Although many indicators of forest biodiversity have been proposed, many have been poorly tested and require rigorous validation in order to be interpreted with confidence (Noss 1999). The suggestions made here should therefore be viewed as tentative.

Although a large number of different biodiversity indicators have been proposed (Prabhu et al. 1996), those appropriate for implementation at the FMU level can be divided into eight generalised groups (Table 1). Some of these, such as area of different forest types and protected forest area, are common to all of the C&I processes, and international reporting obligations. Others, such as forest structure and area affected by disturbance, are recognised by a minority of the processes considered here (Table 1). In this assessment, we did not consider indicators of genetic variation, as these will generally require sophisticated laboratory-based analyses (Namkoong et al. 1996; but see Jennings et al. 2001).

Structural characteristics of forest stands are widely recognised to be of fundamental importance for biodiversity (Noss 1990, 1999, Ferris et al. 1998, Ferris and Humphrey 1999). Forest stands tend to be structurally heterogenous, owing to variation in the relative abundance of different structural components in both vertical and horizontal planes (Ferris and Humphrey 1999). Structural complexity may determine habitat availability for plant, animal and microbial communities, and therefore influence diversity of such groups of organisms (Ferris and Humphrey 1999). Structural features of forest stands are also relatively easy to assess in practice (Ferris et al. 1998, Boyle and Sayer 1995).

Similarly, the incidence and intensity of both natural and anthropogenic disturbance have a major influence on forest biodiversity. Disturbance may take the form of small-scale processes such as the senescence and death of individual trees, or large-scale effects caused by hurricanes or fire. The disturbance regime can profoundly influence forest structure and composition, and therefore affect the availability of habitat for different groups of organisms. However, assessing disturbance can be difficult in practice; often it will be necessary to develop or adapt indicators of disturbance at the local level according to the particular characteristics of the disturbance regime prevalent at the site (Ramírez-Marcial et al. 2001).

Methods of assessment and analysis

The data required for the biodiversity indicators considered here can largely be provided through the use of traditional forest inventory approaches, supported by the application of remote sensing and geographic information system (GIS) technologies. A full description of appropriate methodologies is beyond the scope of this paper; however, an overview of the approaches relevant to each indicator is provided on Table 2, together with references to sources of more detailed information on particular techniques. Practical examples of forest biodiversity assessment relating to forest inventories are provided by Dallmeier and Comiskey (1998a), Bachmann et al. (1998) and Boyle and Boontawee (1995).

Vanclay (1998) provided a detailed overview of different biodiversity survey techniques, with particular reference to forest inventory approaches. Most programmes focusing on monitoring of forest biodiversity employ establishment of permanent sample plots so that measurements can be repeated over time (Dallmeier and Comiskey 1998a, Bachmann et al. 1998). Some form of stratification is generally implemented, as this permits increased efficiency; however, if no prior data are available, then a systematic sampling approach may be adopted (Vanclay 1998). Sample size is of critical importance in biodiversity surveys, as both bias and precision are affected (Vanclay 1998). Determination of an appropriate sample size will depend on the inventory goals, the nature of the forest being inventoried, and allowable sampling error.

Appropriate analysis and presentation of the data collected is also of critical importance. As many of the biodiversity indicators considered here (Table 2) relate directly to forest area, GIS is of particular value for both data analysis and presentation. GIS is essentially a spatially referenced database that allows different data layers to be combined and presented as maps. As datasets can be overlayed, GIS is of particular value for analysis of spatial data; many software packages now provide tools for analysis of areas, perimeters, distances and other measures. For example, spatial data relating to species distributions or protected areas can be overlaid onto maps of forest cover, to examine the linkages between them, and generate statistics relevant for use as indicators. GIS also offers a particularly powerful tool for communicating information (Firbank et al. 1997).

Methods are also required that enable results of forest inventory gathered at the local scale to be aggregated for reporting at the national scale. In addition, data need to be presented in a manner that will permit regional and global scale evaluations of resources, as well as enabling monitoring of change over time. We propose that this can most readily be achieved by summarizing data in categorical form, and presenting in relation to forest area. This approach links directly to the indicators of the extent of forest types, but also offers a meaningful way of expressing other indicators. For example, forest fragmentation as evaluated by an index of spatial integrity can be expressed as forest area belonging to each class of spatial integrity (Figure 1). A country might characterise the structural complexity of its forest resources in terms of the total area of forest within different classes of canopy openness or crown depth, or numbers of canopy layers. Species richness could similarly be presented as area of forest possessing more than a certain number of tree species within a given area. Such categories could be expressed in qualitative terms determined according to local or national conditions. For example, disturbance classes of high, medium or low timber extraction could be defined on the frequency of cut stumps encountered in inventory plots.

Role of remote sensing

Remote sensing technologies are potentially of great value to forest biodiversity assessment, by providing tools for mapping and monitoring vegetation. Maps derived from remote sensing images can serve as a basis for resource assessment and conservation planning, or as a basis for stratifying field sampling efforts.

Many different types of remotely sensed data are available, ranging from aerial photography and videography to complex multispectral instruments mounted on satellites or (rarely) aircraft. The criteria which determine the usefulness of data from a particular satellite or other instrument for biodiversity-related assessment include spatial resolution (or pixel size), temporal resolution (or return time), spectral resolution (or numbers and types of spectral bands in which data are recorded), and cost of the data. Spatial resolution (ranging from 10 x 10 m to 1100 x 1100 m) determines both the detail which can be detected and the extent or scale of investigation which is practicable (local/landscape/regional). Temporal resolution (return times of 1-44 days) determines not only the absolute frequency of observations possible, but the probability of obtaining cloud free imagery for any given location. Increasing spectral resolution usually increases the subtlety of differences among vegetation types that can be detected in the images (Tanner et al 1998). The satellite sensor data currently of use in biodiversity assessments are principally from Landsat-MSS and Landsat-TM, from SPOT-HRV. Global analyses tend to be based on data with coarser spatial resolution, such as NOAA-AVHRR and MODIS, but they are less useful at more local scales. For national forest assessments, the higher resolution forms of remote survey, Landsat TM, SPOT or aerial photography are preferred.

All approaches to the analysis of remote sensing data require heavy investment in verification or ground truthing, and this requirement increases with the level of detail sought. Structurally distinctive vegetation types may be located with a high degree of confidence and with relatively little ground verification, but more subtle resolution of vegetation types requires far greater investment in ground verification. In many cases, reconnaissance flights can provide a useful intermediate level of verification, with detailed ground sampling then being required with less frequency. Stratified sampling using both aerial reconnaissance and intensive fieldwork has been recommended for verifying satellite data (Groombridge & Jenkins 1996). In general, only strongly contrasting vegetation types can be mapped with a high degree of consistency without intensive fieldwork.

There is as yet little evidence that remote sensing can provide any information on species level diversity. It may provide indications of ecosystem level diversity as indicated by spatial distribution of different vegetation types, which has implications for species diversity, but the relationship between the two is not direct nor clearly defined. However, mapping distinctive vegetation types from remotely sensed data provides a basis for mapping distributions of species that are closely associated with distinctive vegetation types and for identifying, prioritising and stratifying areas for more intensive field study. This approach is used by the Nature Conservancy in its Rapid Ecological Assessment methodology to provide an integrated picture of areas of conservation importance at national and regional scales (Grossman et al. 1992). It could equally be applied to any programme of field sampling and inventory.

The most reliable use of remotely sensed data is in generating maps of forest cover in contrast to non-forest vegetation. These can then be combined with ground data and other ancillary data in GIS to:

- evaluate the extent of forest of particular types or with given characteristics (e.g. Hall et al.1991);
- measure changes in forest cover over time (e.g. INPE 2000)

- evaluate some measures of pressures on forests, such as wilderness or accessibility indices (Lesslie & Maslen 1995).
- evaluate the condition of forest ecosystems, including fragmentation (Skole & Tucker 1993, Chatelain et al. 1996, Kapos et al 2000).

Conclusions

A considerable effort has been devoted to development of indicators of sustainable forest management in recent years, which has generated a large number of indicators relating to forest biodiversity. Many of these have been found to be impractical for application at the local level. In addition, the effectiveness of different indicators has rarely been evaluated, and their relevance remains largely untested. This may reflect a lack of conceptual models concerning the processes influencing forest biodiversity. Future research is likely to generate new insights into the relationships between indicators and the variables or processes of interest, together with a more explicit consideration of the uncertainty surrounding these relationships.

Similarly, a variety of different frameworks are available for the development and implementation of biodiversity indicators. Although some of these (notably PSR) are now in widespread use, future research is likely to produce more refined methods of structuring and organising indicators. In particular, there is a need to develop practical tools that can assist in the development and application of biodiversity indicators, based on such frameworks. The provision of such tools, together with a programme of capacity building, would help increase the use of indicators among decision makers, and improve the quality of environmental monitoring. To date, despite the international effort focusing on indicator development, only rarely have such indicators been implemented in a practical way to inform policy development or management interventions.

Here we identify eight generalised indicators for forest biodiversity that are consistent with those developed by C&I processes, but are amenable to practical implementation at the local level. For each of these indicators, it may be necessary to adapt them to local circumstances and the characteristics of the particular forests being assessed. However, methodologies for assessing these variables are available, and could be implemented at relatively low cost, through integration with standard forest inventory approaches.

Of particular importance is the need to aggregate information collected at the local scale to provide information at higher levels, such as nationally. We propose that this can be achieved by summarizing data in categorical form, and presenting in relation to forest area. Such an approach would enable countries to present information to the C&I processes of which they are a part, as well as meet their international reporting obligations to the CSD and CBD. In the context of the latter, the process of national reporting is still under development. The second national reports generally focus on response measures undertaken by parties to the Convention. In future, it is likely that consideration will be given to monitoring the effectiveness of these response options, and their impact on biodiversity. The approaches outlined here would provide an appropriate method for achieving this, with respect to biodiversity associated with forest ecosystems.

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Table 1. Coverage of biodiversity indicators among C&I processes for sustainable forest management, and sets of indicators produced by international organizations or processes.

*Refers not to an officially endorsed list of indicators, but a provisional list of forest biodiversity indicators published in an information paper (CBD 1997b)

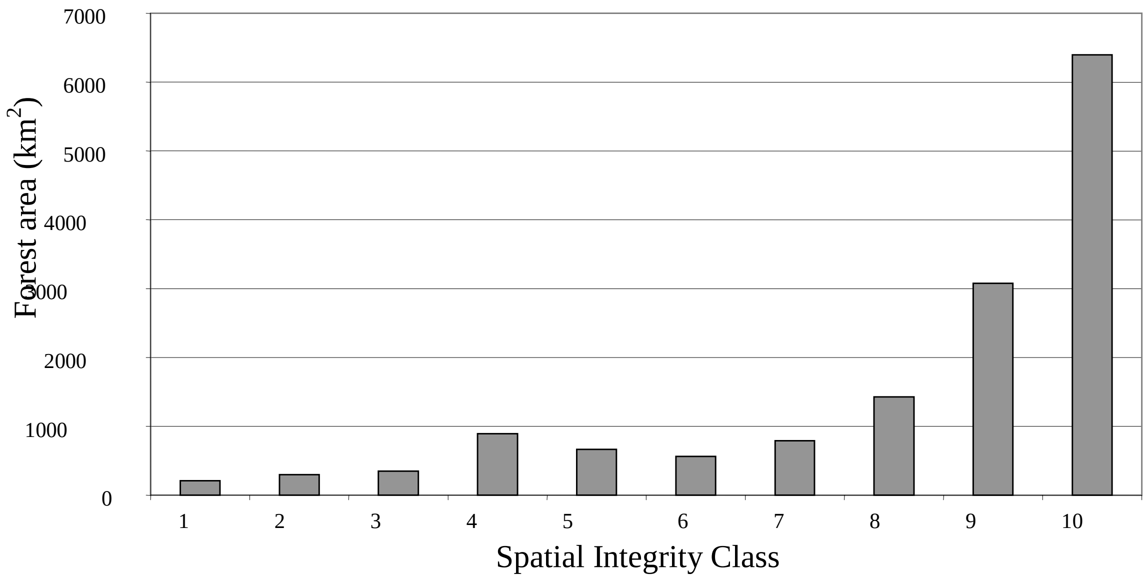
Generalised biodiversity indicator	Montreal	PanEuropean	Tarapoto	Dry Zone Africa	Dry Forest Asia	Lepaterique	Near East	ATO	ITTO	CIFOR	CSD	CBD*
Forest area by type, and successional stage relative to land area	√	√	√	√	√	√	√		√	√	√	√
Protected forest area by type, successional stage and protection category relative to total forest area	√	√	√	√	√	√	√	√	√	√	√	√
Degree of fragmentation of forest types	√			√		√			√	√		√
Rate of conversion of forest cover (by type) to other uses.			√	√		√				√		√
Area and percentage of forests affected by anthropogenic and natural disturbance.			√			√				√		√
Complexity and heterogeneity of Forest Structure			√					√		√		
Numbers of forest-dependent species	√	√		√	√	√	√			√	√	√
Conservation status of forest dependent species	√	√		√	√	√	√	√	√	√		√

Table 2. Methods for collecting information required for biodiversity indicators

Indicator	Methods	Considerations	References
Forest area by type, and successional stage relative to land area	Remote sensing or aerial survey combined with carefully designed sample of ground inventory plots. Remote survey provides estimate of forest extent. Plots provide ground truth and refinement of estimated forest extent derived from remote survey, as well as data on composition and structure that in turn can be used to identify forest types and successional stages.	• Remote survey data need to be of appropriate scale and resolution. • Sampling design of inventory needs to be of adequate intensity and representativeness. Remote survey can be used for stratification. • Ground inventory must incorporate measures that elucidate forest type and successional stage, such as diameter class distribution, species composition and occurrence of distinctive structural elements such as vines and epiphytes. • Forest types need to be defined in a national context, but with reference to international systems such as UNESCO or IGBP to facilitate regional and global assessments.	Holopainen and Wang 1998 McCormick and Folving 1998.
Protected forest area by type, successional stage and protection category relative to total forest area	Remote sensing or aerial survey combined with sample of ground inventory plots and mapped data on protected areas (and/or PA inventory data). Remote survey provides estimate of forest extent. Plots provide ground truth and refinement of estimated forest extent derived from remote survey, as well as data on composition and structure that in turn can be used to identify forest types and successional stages. Overlay of protected areas boundaries to determine proportion protected.	• Protected area boundary maps need to be available in (or converted to) electronic form. • IUCN management categories are the most widely accepted classification of protection. Mapped boundaries need to be attached to category. • Care needs to be taken to avoid double counting of forest in overlapping protected areas.	Iremonger et al. 1997
Degree of fragmentation of forest types	GIS analysis of forest cover data derived from above approaches to provide summary statistics on forest area belonging to spatial integrity classes (or other fragmentation index)	• Thresholds used in spatial integrity analysis will need to be determined in accordance with the resolution of the spatial data and national biodiversity priorities. • Regional and global summaries may need to be based either on qualitative combination or on regional/global analyses.	Kapos et al. 2000

Rate of conversion of forest cover (by type) to other uses.	Re-iteration over time of above approaches and comparison of results. Initial estimate will require use of historical data, which may require calibration for comparison. Land use data are needed if specific changes in use are to be reported. Change in cover is more easily verified.	• The timescale of re-assessment needs to be decided. • Reassessment methods need to be consistent over time, including with respect to scale and resolution (or cross calibration needs to be performed) • The possibility of reestablishment of forest cover needs to be included	
Area and percentage of forests affected by anthropogenic and natural disturbance.	Recording in ground inventory of frequency or intensity of characteristic evidence of principal forms of disturbance, e.g. paths, cut stumps, fire scars, evidence of grazing animals. Extrapolation via remote survey and spatial analysis.	• Factors recorded and disturbance classes will need to be determined according to national conditions and needs. Therefore, regional and global summaries will need to be based on qualitative classes. • Spatial analysis of exposure or accessibility to human activity can serve as useful indicator of anthropogenic pressure related to disturbance	Ramírez-Marcial et al. 2001
Complexity and heterogeneity of forest structure	Ground-based forest inventory that includes measures of stand structure and canopy openness.	• The importance of various structural characteristics varies with management priorities. Therefore specific measures may need to be decided in the national (or local) context and aggregation based on classification of forest area.	Ferris-Kaan et al. 1998, Ferris and Humphrey 1999
Numbers of forest-dependent species	Ground-based forest inventory can provide tree species richness, and could be used to express forest area in terms of tree species richness classes. Other species groups require purpose-designed sampling of their own and skilled survey teams – likely to be outside the scope of forest inventory. Estimates can be derived from review of national fauna lists combined with distribution data and/or habitat requirement information.	• DBH thresholds will determine the richness recorded; data are more complete if broader DBH ranges are adopted • For non-tree species, defining and confirming forest dependence is problematic. • Measurement of species numbers in relation to survey area and/or sampling effort is essential for monitoring or cross-comparison of the data.	Vanclay 1998 Dallmeier and Comiskey 1998b
Conservation status of forest dependent species	Species lists (see above) cross-referenced to national and global assessments of conservation status (e.g. Red Lists) and/or specific assessments	• Endemic species should be among national priorities for inventory and assessment. • Global and national conservation status may be very different.	Hawthorne and Juam Musah 1993

Figure 1. Forest area of Belize by spatial integrity class



(1 = lowest or most fragmented, 10 = core forest in large expanses)