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Criteria and Indicators for Assessing the Sustainability of Forest Management: Conservation of Biodiversity

N.E. Stork, T.J.B. Boyle, V. Dale, H. Eeley, B. Finegan, M. Lawes, N. Manokaran, R. Prabhu and J. Soberon

Summary

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Criteria and indicators need to be applied at the forest management unit level and those for biodiversity are just one part of a package that includes socio-economic and other categories. Biodiversity is an extraordinarily broad concept and, given the huge diversity of life in tropical forests, it is impossible to make rapid direct assessments of biodiversity in forests in anything other than a superficial manner. It is likely that there will be limited skilled human resources and time for biodiversity assessment in any system of criteria and indicators, so it is important that we design tools that do not require expert application and interpretation.

The usefulness of "indicator groups", "keystone" species and other concepts is still argued among biologists and their utility is questionable. This paper suggests that, in contrast to more traditional approaches to assessing taxonomic diversity, it may be possible to assess the effects of management practices on biodiversity by examining the state of those processes that generate or maintain biodiversity. The indicators and verifiers that we have suggested examine the state of these processes. We recommend that for each indicator, quick and easy verifiers, which we designate "Primary" verifiers are used first, and more sophisticated ("Secondary") verifiers are used only if clear results are not obtained from Primary verifiers.

This paper is merely a first step in creating a suitable framework for applying a proposed a set of forest biodiversity indicators and verifiers. The framework and the indicators and verifiers require field testing, and we fully expect there to be changes resulting from the field trials, which will be reflected in major improvements in their effectiveness. For the sake of brevity we have not discussed the advantages and disadvantages of the verifiers in full. While changes are expected, the approach taken is powerful in that it recognises the relationship between interventions and consequences, and it demonstrates that some indicators are more widely valuable than others.

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INTRODUCTION

Tropical forest biodiversity is of great concern, as these forests face serious threats, mainly due to human activities. Forest and biodiversity issues received much attention in the negotiations leading to the 1992 UN Conference on the Environment and Development (UNCED) and resulted in a number of instruments, including Conventions on Climate Change and Biological Diversity and the Statement of Forest Principles. These agreements all reflected concern for the sustainable use and management of biodiversity in forests.

Recently, eight priorities for biodiversity research were identified by the Conference of the Parties (COP) to the Convention on Biological Diversity (CBD) at its third meeting, in Buenos Aires, in November 1996, based on recommendations made by its Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA). The COP decided to focus its immediate attention on two critical issues: developing criteria and indicators for forest quality and biodiversity conservation as part of sustainable forest management; and assessing the human impacts on forest ecosystems. The Intergovernmental Panel on Forests (IPF 1997) too has identified the need to develop relevant and cost-effective criteria and indicators for sustainable forest management as a high priority and recognised the role that the Center for International Forestry Research (CIFOR) has been playing in this context. They requested that CIFOR collaborate with various organisations and internationally recognised experts to further develop these criteria and indicators. CIFOR also has received encouragement and support, in this context, from other organisations such as the African Timber Organization, the Forest Stewardship Council and the European Union.

Criteria and indicators (C&I) are tools which can be used to collect and organise information in a manner that is useful in conceptualising, evaluating and implementing sustainable forest management. The value of information lies in the way it is organised (Larsen in Rauscher and Hacker 1989). C&I may be identified at various levels: global, regional (and eco-regional), national and local. Examples of regional initiatives to develop appropriate C&I include the Helsinki and Montreal Processes, for European and non-European temperate and boreal forests, respectively. The Tarapoto and Dry Zone Africa Processes are examples from the Amazon Basin and Africa. National level C&I are being developed in many countries (e.g., Malaysia, Indonesia and Australia), while various systems of C&I applicable at the local level have been developed by governmental and non-governmental organisations. In order to be effective and to gain acceptance, C&I need to be easy to understand and simple to apply. They must provide information to forest managers and policy makers that is relevant, scientifically sound and cost-effective.

Prabhu *et al.* (1996) initiated CIFOR's involvement in the development of C&I. This research used independent, international, multi-disciplinary teams, involved comparative field testing of over 1100 C&I, selected from several different proposed systems of C&I, and covered all aspects of forest management (Prabhu *et al.* 1996). Sustainable forest management includes the need to ensure the maintenance of biodiversity in managed forest systems and forest managers therefore require information on how management is affecting biodiversity. However a consistent conclusion of CIFOR's research on local level C&I in field trials in Germany, Indonesia, Côte d'Ivoire, Cameroon, Brazil and Austria, was that most or all of the currently proposed local level C&I for conservation of biodiversity were deficient (Prabhu *et al*. 1996). Concern was most commonly raised about the practicality of proposed indicators, or their relevance to forest management. This deficiency led to a recommendation that CIFOR should co-ordinate a broad-based effort to develop improved C&I for biodiversity.

The first step in this process of developing improved C&I for biodiversity was a workshop held near Bogor, Indonesia, in April 1996 which looked at genetic C&I. The results of this workshop and subsequent field trials have been published (Namkoong *et al.* 1996). A further workshop held in Bogor (April 21-25 1997) continued this process by developing C&I for assessing conservation of biodiversity in managed forests, with a focus on species and ecosystems. This document describes the biodiversity C&I proposed as a result of that workshop. It is our intention to field test and improve the proposed C&I, and subsequently to harmonise biodiversity C&I with those proposed for genetic resources by Namkoong *et al*. 1996. In a later stage of the harmonisation process the biodiversity C&I will be integrated with other biophysical, social and economic C&I (Prabhu *et al*. 1996).

We have paid most attention to designing a framework for C&I for the conservation of biodiversity in managed forests, and the first part of this document presents our conceptual model. The second part presents a first list of indicators and verifiers (see Box 1 for definitions of Principles, Criteria, Indicators and Verifiers) and, in the final part, a practical framework for applying biodiversity C&I in field situations is presented. We recognise that we may have not selected the most relevant or appropriate indicators and verifiers for all situations, but those presented here are intended as a guide for managers. We expect that modifications may have to be made to facilitate the most appropriate analysis of the impacts of management on biodiversity in forest management units in different forest types and situations.

We recognise that C&I assessment for biodiversity needs to be practical. Measurements should be quick and relatively inexpensive if they are to be adopted by forest managers and governments. Such measurements, which we here designate "Primary" verifiers, pose many difficulties and require compromises in the level of detail and perhaps value of the information derived. The main reason for field testing these proposals is to determine the extent to which they are suitable and practical for field assessment of biodiversity C&I. We present this paper as a discussion document to generate broader discussion of these issues.

The diversity of tropical forests means that it is not feasible to develop C&I that are globally relevant. It is inevitable that indicators, and especially verifiers (see below), will need to be adapted to local conditions. Thus, the proposals made here are not intended to be prescriptive. However, through involvement in the workshop and preparation of this working paper of individuals representing many disciplines and geographical regions, it is hoped that the proposed C&I will be widely applicable, especially following the field testing process.

It is important to clarify at the outset how we perceive the relationship and utility of C&I and Rapid Biodiversity Assessment. RBA and C&I differ in terms

BOX 1: PRINCIPLES, CRITERIA, INDICATORS AND VERIFIERS

Criteria and Indicators form part of a hierarchy of assessment tools. The four levels of this hierarchy are Principles, Criteria, Indicators and Verifiers. Each level in the hierarchy is defined as follows:

Principle: *A fundamental truth or law as the basis of reasoning or action*. In the context of sustainable forest management, principles are seen as providing the primary framework for managing forests in a sustainable fashion. They provide the justification for criteria, indicators and verifiers. Consider that principles embody human wisdom, where wisdom is defined as: *a small increment in knowledge created by a person's (group's) deductive ability after attaining a sufficient level of understanding of a knowledge area.* Wisdom therefore depends on knowledge.

E.g., "Ecosystem integrity is maintained or enhanced" or "Human well-being is assured".

Criterion : *A standard that a thing is judged by.* A criterion can therefore be seen as a "second order" principle, one that adds meaning and operationability to a principle without itself being a direct measure of performance. Criteria are the intermediate points to which the information provided by indicators can be integrated and where an interpretable assessment crystallises. Principles form the final point of integration. In addition, criteria should be treated as reflections of knowledge. Knowledge is the accumulation of related information over a long period of time. It can be viewed as a large-scale selective combination or union of related pieces of information.

E.g., "Processes that maintain biodiversity are maintained".

Indicator: *An indicator is any variable or component of the forest ecosystem or the relevant management systems used to infer attributes of the sustainability of the resource and its utilisation*. Indicators should convey a "single meaningful message". This "single message" is termed information. It represents an aggregate of one or more data elements with certain established relationships.

E.g., "Landscape pattern is maintained".

Verifier: *Data or information that enhances the specificity or the ease of assessment of an indicator*. At the fourth level of specificity, verifiers provide specific details that would indicate or reflect a desired condition of an indicator. They add meaning, precision and usually also site-specificity to an indicator. They may define the limits of a hypothetical zone from which recovery can still safely take place (performance threshold/target). On the other hand, they may also be defined as procedures needed to determine satisfaction of the conditions postulated in the indicator concerned (means of verification).

E.g., "Areal extent of each vegetation type in the intervention area relative to area of the vegetation type in the FMU".

of their goals and their methodology. RBA is most often used to identify and prioritise areas for special conservation efforts, or to assess the conservation value of specific areas, whereas C&I are used for assessing sustainability in managed forests. Most RBA methods involve teams of experts. In contrast, criteria and indicators are designed to be applied by teams of generalists, rather than biodiversity specialists. Nevertheless, RBA and C&I can be complementary and the tools used may sometimes be the same. Any system of criteria and indicators will benefit enormously from access to baseline information on biodiversity, and this information is best provided by RBA. Situations where it is possible to conduct RBAs in support of C&I should be sought.

The relationship between RBA and criteria and indicators was the subject of considerable debate in the workshop leading to the present document. We consider that such a debate is healthy and should continue since both concepts have much to offer each other.

PART I: CONCEPTUAL MODEL AND ITS APPLICATION

The Scope of C&I Assessment at the Forest Management Unit Level

A Forest Management Unit (FMU) is defined by Prabhu *et al*. (1996) as "a clearly demarcated area of land covered predominantly by forests managed to a set of explicit objectives and according to a long-term management plan". Sub-units may be managed under separate management regimes, for example a FMU may include protection forests set aside for the protection of watersheds, or areas set aside for conservation of wildlife. A FMU may cover a few hundred to several hundred thousand hectares, and may incorporate one or more logging concessions.

Landscapes are usually large areas encompassing several ecosystems or habitats, consisting of a mosaic of forests, grasslands and agricultural areas, water bodies such as lakes and human settlements. Although, from an ecological perspective, the delineation and management of FMUs should coincide with landscape boundaries, this arrangement is rarely the case as FMU boundaries are determined by political, administrative or market factors. FMUs will usually operate at scales smaller than landscapes. Therefore, while the assessment of sustainability should most appropriately use a landscape scale, this approach may not be feasible, and some indicators and verifiers may only be incompletely applied.

Natural forests are considered to be those forests which have arisen through natural processes. This includes forests recovering from drastic natural disturbance and secondary forests growing on land which, in the past, has been converted from forest to some other use, and subsequently abandoned. We exclude vegetation classified as woodland in frameworks such as that of FAO (1996), on the basis of criteria such as canopy height and percentage ground cover. In the context of C&I for managed natural forests we include forests in which natural regeneration and enrichment planting are utilised, but management involving clear-cutting and replacement with plantations of fast-growing species we define to be "conversion", and therefore outside the scope of natural forest management. C&I for plantations are being developed by CIFOR in a separate process.

When C&I at the forest management unit (FMU) level are made operational, it is envisaged that assessments of individual FMUs will be made by a small team of 3-5 people, over a period of 1-2 weeks. This is because C&I assessment will clearly be a costly exercise, and larger teams or longer periods will make the process too expensive to be acceptable to those who bear the costs, be it industry, governments, or non-governmental organisations. In the time available, these teams will need to assess C&I related to all aspects of sustainability – biophysical, social and economic. These constraints have several implications. First, they imply that members of the assessment team will be selected for their broad-based knowledge, and it cannot be assumed that one of them will be a "biodiversity expert". Secondly, they imply that the conservation of biodiversity will need to be assessed in only a few (± 10) person-days. It is anticipated that additional personnel from the FMU, some with good local knowledge of forests and their biota, will be available to assist the team, but the time available to skilled, trained personnel will be limited.

These considerations dictate that the most important characteristic of an effective indicator or verifier (see below) will be the practicality of assessment in a very short period. This need for practicality is a serious constraint for the assessment of "conservation", which implies a need to consider temporal dynamics, and for the assessment of biodiversity, which is an extremely broad concept. The failure of most of the currently proposed biodiversity C&I when assessed by expert field test teams was a result of these problems of practicality (Prabhu *et al.* 1996).

It is not anticipated that C&I will be applied to situations where land-use change is planned, for example on areas scheduled for "conversion" to agriculture, tree plantations, urban areas or industrial/infrastructure development. The impacts of such land-use changes on biodiversity are obviously potentially serious, but fall outside the scope of C&I assessment. In these circumstances rapid biodiversity assessment would be more appropriately applied to evaluate the relative biodiversity values of the forests prior to their conversion (see pages 2-3). Rather, C&I will be used to assess the sustainability of FMUs that form part of the "permanent forest estate" of a nation. These may contain areas of agriculture, fast-growing plantations and other non-natural forest land uses, and the impact of these areas on the overall sustainability of the FMU is included in the scope of this C&I assessment.

Human interventions in forests inevitably affect biodiversity, so "sustainability" in the context of conserving forest biodiversity must be considered in relation to the goals of a forest management plan. The first requirement for sustainability is therefore the existence of an articulated management plan. Key questions are:

a. is the new level of biodiversity stable or continuing to decrease (or increase); and
b. is the new level adequate to support all ecological processes (i.e., above a critical threshold level)?

These questions must consider multiple scales both because the definition of biodiversity requires such an approach, and because the processes affecting biodiversity operate at different scales.

Defining Principles, Criteria, Indicators and Verifiers

Assessment (or evaluation) in the context of sustainable forest management is the process by which information is collected with a view to establishing, within a defined framework of expectations, the current status and probable future direction of the interactions between human beings and forests, using certain C&I (Prabhu *et al*. 1996). Assessment can thus be seen as an important step in a process that Munda (1993) describes as cycling through initial disorientation, reorientation or choice, towards a solution or decision.

Probable users of C&I will include:

- certification bodies interested in the best ways to assess timber management for certification purposes;
- government officials trying to design more sustainable policies pertaining to forestry and other related sectors;
- donors wanting to evaluate the sustainability of the activities undertaken by various natural resource management projects;
- forest managers wanting to improve the sustainability of their management at the forest management unit level;
- project managers trying to plan, implement and evaluate their own conservation and development projects; and
- scientists interested in the causal links among ecological, forestry and human factors of sustainability.

The Relationship between Human Interventions in Forests and Biodiversity: A Conceptual Model

Biodiversity is an all encompassing term for the diversity of landscapes, species, populations and genes (see Heywood 1995). It has been the quest for many scientists to find relatively simple measures for specific organisms and communities that will provide a good indication of the health of forests and other ecosystems. For example, some scientists have advocated the use of a few indicator species (or groups of species) as surrogates for others. An indicator species (or group of species) has characteristics which "indicate" changes in biotic or abiotic conditions in tropical forest due to anthropogenic use (see Stork and Sherman 1995). The implicit assumption in this use of indicator species or groups of species is that they provide reliable assessment of habitat quality and that, if the habitat is maintained for the indicator, conditions will be suitable for other species. The validity of this assumption is questioned on the grounds of the extent to which extrapolation from one species (or group of species) to another is possible (Landres *et al.* 1988; Lawton *et al*. submitted). There have been some excellent examples of indicator species/groups for old growth temperate forests (e.g., Spence *et al.* 1997), but the value of this concept for tropical forests has yet to be proved.

Indicator species must be chosen carefully in accord with local assessment goals – an indicator from one area may not be appropriate for use in another area. Some have focused on the utility of keystone species or groups of species whose impact on the community is disproportionately large and greater than would be expected from its relative abundance (Paine and Levin 1981). One problem with the definition of a keystone group is that it is, to an extent, arbitrary. Another, and perhaps more serious, problem of using keystone species for monitoring biodiversity in forests is that their role needs to be demonstrated.

Because of the practical and conceptual difficulties of measuring changes to biodiversity in forests and the uncertainty and utility of indicators/keystone species we have taken a different conceptual approach. We suggest that ***changes in biodiversity may be assessed indirectly through assessment of the processes that maintain and generate biodiversity***. For example, pollination of trees is essential for those species that require pollination to survive. Changes in pollination success will indicate changes in the diversity, abundance or behaviour of pollinating species as well as the structure of future plant (and animal) communities.

The relationship between human activities in forests and biodiversity is not always simple. Our conceptual model identifies two steps in the chain of cause and effect (Figure 1). *Mediators* are the immediate physical consequences of each category of human activity. *Ecological processes* respond to the mediators and, in turn, determine the magnitude and maintenance of forest biodiversity. Looking ahead to the discussion of indicators, it should be observed that indicators may be identified at any point in the causal chain from human intervention to biodiversity. As discussed by Brown *et al*. (1997), Pressure indicators are easier to develop than State or Response indicators, but provide much less valuable information. Response indicators, potentially the most valuable indicators, are also the hardest to develop and apply.

Human interventions

The types of human interventions (Figure 1) discussed in this paper are those which occur in natural tropical forests and which do not involve large-scale conversion to other land uses. More than one type of intervention may occur within a FMU. Selective logging is the most common form of intervention in tropical

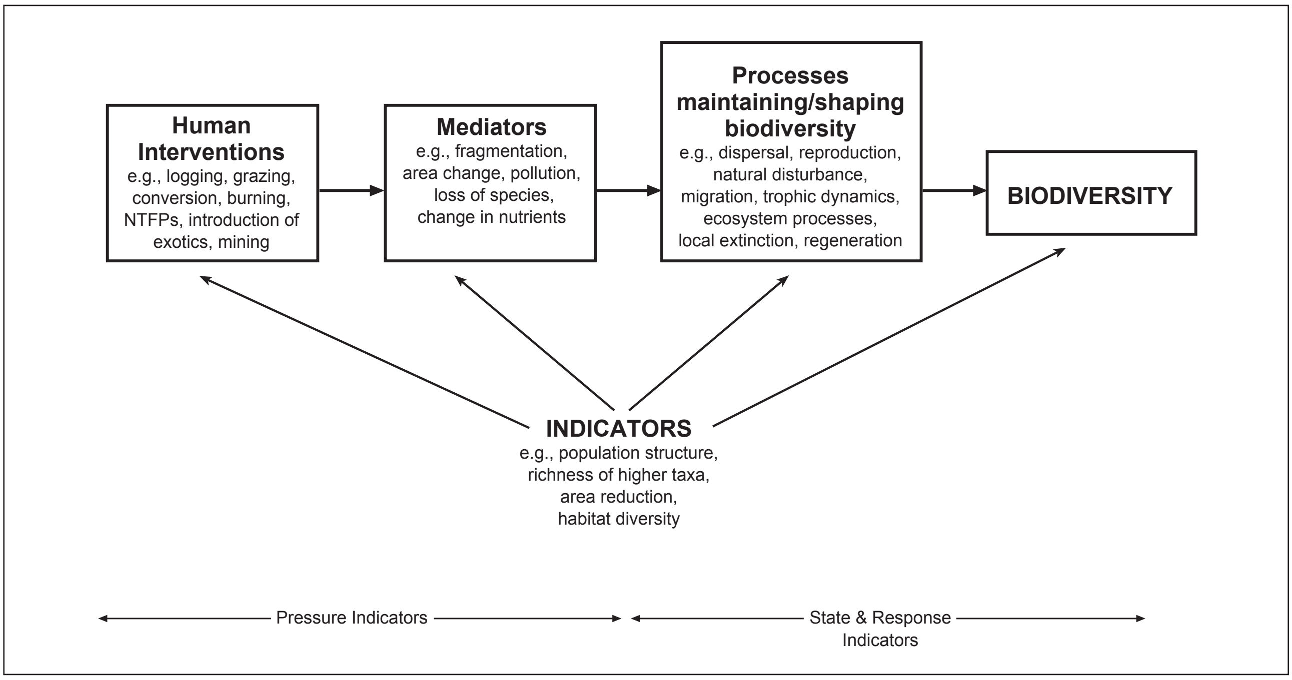

Figure 1. A conceptual model of the relationships between anthropogenic interventions under different forest management regimes, mediating processes, ecological processes which shape biodiversity, and biodiversity. Indicators that are relevant to the left-hand side of the Figure are “Pressure” indicators, while those on the right are “State” or “Response” indicators, which are better surrogates for biodiversity.

forests. In the context of C&I it includes all associated infrastructure such as skid trails, roads, river landings, etc.). It also includes “pole removal”, i.e., the removal of understorey trees for building material. The collection of non-timber forest products (NTFPs) is also very common. We distinguish three types of NTFP harvesting: reproductive structures (fruits, nuts, seeds, flowers), non-reproductive structures (bark, latex, branches for firewood, foliage), and whole individuals (ornamentals, hunting, fishing).

Grazing of livestock occurs seasonally in many forests in Latin America, Africa and Asia. Burning is also common, especially in drier forests. This intervention involves changes to natural fire regimes, including the frequency, intensity or extent of fires.

As discussed above, large-scale forest conversion is not considered in this paper. However, the clearing of patches within a FMU for plantations of fast-growing (often exotic) species, infrastructure development, or agriculture is included. Agriculture may include both permanent and shifting cultivation, and, in contrast to infrastructure development, forest regeneration is more easily achieved.

Roads are a special case, for they are linear changes in the pattern of forests. Some roads are established for the purpose of moving people into the forest – largely for colonisation purposes – but forest managers may not be able to control such developments. In these cases, as for large-scale conversion projects, Environmental Impact Assessments are the appropriate tool for assessing impact, rather than C&I.

The introduction of exotics (other than for plantations) is usually accidental or the result of other interventions, but there are examples of deliberate introductions, especially of pollinators and seed dispersers. Enrichment planting is another operation associated with logging which may involve the introduction of exotic species.

Mediators/impacts/influences

The direct effects, or mediators, of human activities on forests (Figure 1) cause impacts on the processes which generate and maintain biodiversity. They include:

Changes in area
Area changes can occur within some or all vegetation types within a FMU. In some cases, forests become non-forest vegetation types; in other cases, they are transformed into another vegetation type.

Fragmentation
When a forest becomes fragmented, there is a change in the spatial mosaic of the forest. For example, the number, size and/or shape of patches of a vegetation type may change. These changes may result in modifications in patch connectivity across the landscape. Patch edges can change both in their length and com-

plexity. These spatial changes can affect the ability of an organism to move within a landscape, because for some organisms different vegetation types act as either barriers or corridors to movement and dispersal.

Loss of species
Some human interventions cause a direct loss of species which act as mediators because the loss of these species can cause the loss of other species (e.g., loss of obligate pollinators).

Loss/gain of nutrients
A change in nutrient conditions can alter processes which influence biodiversity. For example, increases in nitrogen availability may result in a decline in species associated with nitrogen-fixing bacteria.

Pollution
Pollution can change ecological processes such as reproduction, predator-prey relationships and nutrient cycling (Primack 1993).

Processes

As shown in Figure 1 and discussed above, mediators of human interventions affect the processes that generate and maintain biodiversity. These processes are:

Natural disturbance regimes
Biodiversity in natural forests is strongly controlled by natural disturbance regimes. Changes in the disturbance regime (intensity, frequency or pattern) may consequently affect biodiversity. For example, the loss of large herbivores from coastal dune forests of South Africa due to hunting may have altered gap phase dynamics (Everard *et al*. 1994). Logging can open up forests so that they are more susceptible to windthrow, drought, etc. (Franklin and Forman 1987).

Dispersal/migration
Human interventions may affect the capacity of the landscape to provide suitable sites for dispersal or migration. For example, in neotropical forests the majority of tree species are dispersed by vertebrates so hunting may affect the dispersal agent. Migration refers to the movement of organisms on which successful completion of the life cycle depends.

Reproduction
Impacts on the process of reproduction can have rapid, direct and dramatic consequences. In the case of species with short generation periods, non-overlapping generations or highly specific mutualisms, such as the *Ficus*-fig wasp interactions (Janzen 1979), changes can be particularly devastating.

Regeneration/succession
An obvious, and highly publicised, consequence of logging is the reduction in area of mature, or “old-growth” forest, and replacement with forest dominated by pioneer or early successional species. However, other impacts are possible, such as the equally well-publicised change in successional dynamics of forests in Yellowstone National Park (USA), due to fire suppression and control (Schullery 1989).

Trophic dynamics
Trophic dynamic processes refer to the ways that species from different trophic levels interact. These include pollination, predation and herbivory. As each trophic level is dependent on other levels, impacts on trophic dynamics can be very serious.

Ecosystem processes
Ecosystem processes are the interactions of nutrients, water and energy that allow the growth and reproduction of species. These processes typically involve a complex mix of species, each influencing the processes in different ways, though not all species present in an ecosystem are essential for ecosystem functioning.

Local extinction
In some cases the dominant process determining change in species composition may be local extinction. For example, in a system characterised by small patches of a particular vegetation type, the loss of a patch and the ensuing local extinction of a species dependent on that vegetation type result in a more broad-scale extinction (Lomolino 1996).

PART II: FOREST BIODIVERSITY CRITERION, INDICATORS AND VERIFIERS

For the reasons discussed above, we have chosen to adopt a "process-oriented" approach to the assessment of biodiversity through criteria and indicators. If the processes that generate and maintain biodiversity are conserved, a sustainable level and pattern of biodiversity will be maintained. This reasoning generates the following criterion:

CRITERION : The processes that maintain biodiversity in managed forests are conserved

The formulation of this criterion is attractive for several reasons. As shown in Figure 1, indicators of processes fall into the categories of "state" and "response" indicators, which are closely linked to the status and fate of biodiversity. Indicators of processes also offer the possibilities of rapid assessment and assessment by non-experts, which are required by the constraints of the C&I assessment approach.

Table 1 lists processes that maintain biodiversity and human interventions. Those processes that are affected by each intervention are indicated. Although different interventions may potentially affect most or all processes, an attempt has been made to distinguish those processes that are always or most significantly affected by specific interventions (indicated by a large X) from processes that may only be affected occasionally or slightly (small x).

State indicators are simple to develop and apply, and can be thought of as characterising the system. Response indicators incorporate a temporal dynamic, as they indicate actual historical or future predicted changes in response to pressures. The temporal nature of response indicators creates an inherent problem for C&I assessment that must be accomplished within a very limited time span. However, this problem is not insuperable. Combinations of indicators may generate response-type indicators. For example, the absence of young cohorts in a population structure verifier, combined with a deep litter layer in a nutrient cycling verifier, may indicate a breakdown in the decomposition process. Although time-series data may not be feasible, an approximation to a time series may be possible, for example by assessing adjacent areas logged at different times, using a chrono-sequence approach. Finally, as

Table 1. Consequences of different types of forest interventions on forest processes.

Intervention/Process	Landscape Level		Habitat Level				Species Level
	Natural Disturbance Regime	Dispersal/ Migration	Regeneration/ Succession	Local extinction	Ecosystem processes	Trophic dynamics	Reproduction
Selective logging	**X**	**X**	**X**	x	**X**	x	x
Grazing			**X**	x	x	x	x
Fire			**X**	x	x		
NTFP: Reproductive structures			x	x		x	**X**
NTFP: Non-reproductive structures							**X**
NTFP: Whole individual				x			**X**
Other land use: Agriculture	**X**	**X**	x	x	**X**		
Other land use: Plantations	**X**	**X**			**X**		
Other land use: Roads	x	**X**	x				
Enrichment planting			**X**			x	x

Notes: Each X indicates the type of forest intervention that is likely to change the indicated process. Note that the changes depend on the specific biological situation and the intensity of the intervention).
X = Highly important indicator of process; x = Less important indicator of process

Table 2. Indicators of processes that maintain biodiversity.

Process/Indicator	Landscape pattern	Habitat diversity	Guild structure	Taxic richness	Population structure	Nutrient cycle/ decomposition	Water quality and quantity
Natural disturbance	**X**	**X**		x	**X**	x	**X**
Dispersal	**X**	**X**	**X**	x	x		x
Migration	**X**	**X**	**X**	x	x		x
Regeneration/ Succession	x	**X**	**X**	**X**	**X**	x	x
Trophic dynamics	x	x	**X**	x	**X**	x	
Ecosystem Processes		x	x	x	x	**X**	**X**
Local extinction	**X**		x	x	**X**		
Reproduction	x	**X**	x		**X**		x

Note: **X** - Highly important indicator of process; x - Less important indicator of process

C&I assessment becomes operational, time-series data will become more feasible with repeated assessments of the same FMU.

Table 2 shows the relationship between the seven proposed indicator groups and the processes that maintain biodiversity. Each process is represented by more than one indicator group. Tables 1 and 2 combine to generate Table 3, which shows the relationship between human interventions and indicator groups. The assessment of impacts of logging involves all seven indicator groups, although as discussed below, it may not be necessary to assess all indicators in practice

Table 3. This table is obtained by combining Tables 1 and 2 and illustrates how forest interventions can be explicitly linked to indicators through the processes which affect biodiversity.

Intervention/ Indicator	Landscape pattern	Habitat diversity	Guild structure	Taxic richness	Population structure	Nutrient cycling /decomposition	Water quality and quantity
Selective logging	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Grazing		**X**	**X**	**X**	**X**		
Fire		**X**	**X**	**X**	**X**		
NTFP: Reproductive structures		**X**			**X**		
NTFP: Non-reproductive structures		**X**			**X**		
NTFP: Whole individual		**X**			**X**		
Other land use: Agriculture	**X**	**X**	**X**		**X**	**X**	**X**
Other land use: Plantations	**X**	**X**	**X**		**X**	**X**	**X**
Other land use: Roads	**X**	**X**	**X**				
Enrichment planting		**X**	**X**	**X**	**X**		

(see Operational Framework, pages 21-23). Habitat diversity is the only indicator group which occurs for all interventions.

The seven indicator groups described above are organised in terms of the scale at which they operate. In the subsequent descriptions, indicators and verifiers are ordered in terms of decreasing scale.

1. Landscape Pattern

A landscape is an area composed of a mosaic of interacting ecosystems or patches (Forman and Godron 1986), with heterogeneity among the patches significantly affecting biotic and abiotic processes in the landscape (Turner 1989). Patches comprising a landscape are usually composed of discrete areas of relatively homogeneous environmental conditions (McGarigal and Marks 1993). Both landscapes and patches are dynamic and occur on a variety of spatial and temporal scales that vary as a function of an organism's perceptions (McGarigal and Marks 1993). For instance, a long-lived and far-ranging bird will view its environment at broader spatial and temporal scales than a short-lived, wingless insect (Urban *et al*. 1987). These differences must be incorporated and used in landscape analysis by changing the spatial or temporal resolution of a database or simulation model.

Human-induced changes in forests can produce landscape-level changes in forest characteristics and structure, including area and distribution of habitat types. Changes in landscape pattern through fragmentation or aggregation of habitats can alter patterns of abundance for single species and entire communities (Quinn and Harrison 1988; Rylands and Keuroghlian 1988; Becker *et al*. 1991; Saunders *et al*. 1991; Bierregaard *et al*. 1992). A decrease in the size and number of natural habitat patches increases the probability of local extirpation, whereas a decline in connectivity between habitat patches can negatively affect regional species persistence (Fahrig and Merriam 1985). Thus, there is empirical justification for managing entire landscapes, not just individual habitat types, in order to ensure that diversity is maintained (McGarigal and Marks 1993).

While some minimum area of native habitats in a landscape is necessary for maintaining species richness and population viability, the spatial pattern of habitat is also important. Habitat fragmentation is recognised as a threat to biodiversity (Whitcomb *et al*. 1981; Skole and Tucker 1993), and occurs when an area with one continuous land cover is altered to a mosaic of land cover types. Such changes can occur either by natural processes or as a result of human activities. Natural fragmentation generally results in habitat patches with more irregular edges than human-created patches (Krummel *et al*. 1987). Natural disturbance and forest management practices can interact with existing landscape patterns to dramatically affect the risk of species loss (Gardner *et al*. 1993). Species which are most vulnerable are those which become isolated as a result of fragmentation and are also restricted to specific habitat types. Land management practices that increase the degree of fragmentation can change the competitive balance between species, further jeopardising the maintenance of native species diversity (Gardner *et al*. 1993).

Landscape pattern deals with the areal extent and spatial distribution of vegetation types across the landscape. Changes in landscape pattern indicate those vegetation types or distributions that have been influenced under specific management regimes. Thus, the indicator for landscape pattern can be simply expressed as:

Indicator: Landscape pattern is maintained

Over sixty indices have been developed to quantify landscape pattern (see Krummel *et al*. 1987; O'Neill *et al*. 1988; Gardner and O'Neill 1991; Turner and Gardner 1991; Baker and Cai 1992; Gustafson and Parker 1992; Plotnick *et al*. 1993). These indices allow researchers to choose measures that quantify characteristics of landscapes directly related to ecosystem and population processes. Each index measures different aspects of landscape pattern, so a number of measures are required to provide a complete description of the abundance and spatial pattern of cover types.

The proposed verifiers of pattern quantify changes in areal extent of vegetation types and fragmentation of the landscape. Knowledge of areal extent is critical for species which require large areas. Fragmentation can affect patch structure, connectivity and edges, and it is useful to measure at least one verifier for each aspect of fragmentation. Patch structure considers the size and distribution of patches of each vegetation type within the landscape or is a measure of pattern for the entire area (i.e., a single number is provided for the FMU). Connectivity measures the degree to which patches are linked. Edge verifiers convey the amount and distribution of edges which can provide important habitat for some species but can be disruptive to other species.

Critical values for all landscape pattern verifiers may be ± ***10% deviation from historical norms or values for "undisturbed" portions of the FMU.***

i) Area

Verifier 1.1.1: Areal extent of each vegetation type in the intervention area relative to area of the vegetation type in the total FMU. A decrease in the total area of habitat available often correlates with species decline

(Wilson 1988; Saunders *et al*. 1991). The area of each vegetation type is basic information for most landscape-level analyses. Because impacts may be severe in vegetation types which have a high value of this verifier (i.e., most of this vegetation type will be affected), attention will be directed to these types.

ii) Fragmentation

Patch structure verifiers

Verifier 1.2.1: Number of patches of each vegetation type per unit area/concession. The number of patch types present is important because many organisms are associated with a single type, and thus patch richness may correlate with species richness (McGarigal and Marks 1993). Following this line of reasoning, Stoms and Estes (1993) outline a remote-sensing agenda for mapping and monitoring biodiversity which focuses almost exclusively on patch richness. A frequency distribution of patch sizes can be used to examine the connectivity or fragmentation of habitat.

Verifier 1.2.2: Largest patch size of each vegetation type. The ecological characteristics of the landscape may be highly related to the characteristics of the largest patch. Information on maximum patch size may provide insight into long-term population viability because populations are unlikely to persist in landscapes where the largest patch is smaller than that species' home-range.

Verifier 1.2.3: Area-weighted patch size. This verifier reflects the average patch size/total area for each vegetation type.

Verifier 1.2.4: Contagion. This verifier is a landscape metric (i.e., there is a single measure for the entire map). The contagion index measures the extent to which land covers/vegetation types are clumped or aggregated. Contagion is a useful metric for those species which require large contiguous areas of a particular land cover.

Verifier 1.2.5: Dominance. This verifier is a landscape metric of how common a single vegetation type may be over the landscape. It measures evenness, in contrast to richness of patch structure. Its value indicates the degree to which species dependent on a single habitat can pervade the landscape.

Verifier 1.2.6: Fractal dimension. Fractal dimension is a landscape metric that uses perimeter-to-area calculations to provide a measure of complexity of patch shape. Natural areas tend to have a more complex shape and a higher fractal value than human-altered landscapes (Krummel *et al*. 1987). This difference can influence the diversity of species that inhabit edges or require multiple habitats (e.g., large herbivores, which require both cover and open areas for forage; Senft *et al*. 1987).

Connectivity verifiers

Verifier 1.3.1: Average, minimum and maximum distance between two patches of the same cover type. Gustafson *et al*. (1994) provide an example of how measures of patch proximity can be used for estimating the isolation of particular patches.

Verifier 1.3.2: Percolation index. This measures the connectedness of a landscape from one edge to the other. The term derives from measures of the ability of water to percolate through the soil when the soil pores are connected. This index may be important for organisms who need to be able to move across the landscape using a single vegetation type (Gardner *et al*. 1987).

Edge feature verifiers

Verifier 1.4.1: Linear measure of the total amount of edge of each vegetation type. Patches with elongated and complex shapes (i.e., high edge: area) may serve as dispersal corridors, but have extensive edge effects. The length of edge between different land-cover types is useful for assessing habitat for species that prefer or avoid certain types of eco-tones, and can change processes such as predation rates (Andren and Angelstam 1988).

Verifier 1.4.2: Amount of edge around the largest patch. To the extent that the largest patch has significance, its perimeter can provide a measure of diversity.

Spatial indices and other landscape-level measures of pattern can be developed in the office using the best available maps of the FMU. Analogue maps can be used, but such a process is very time-consuming. Sources of digital data, from air photos or satellite imagery are far more useful, and can be used with geographic information systems (GIS) and computer simulation models to project changes in diversity over time. Satellite remote sensing allows data to be collected rapidly and frequently over large areas and has a very high information content. Free, public-domain software is available for image analysis.

In implementing landscape measures, the first step is to decide on the extent and pixel size of the area being considered. The choice of pixel size can affect the interpretation of the verifiers (Turner *et al*. 1989) and depends on the FMU size, the type of human interventions, the organisms which are known to be at risk in the area, and the natural pattern or fragmentation of the site. For example, if a small lake exists on the site and the presence of the lake is an important attraction or barrier to movement for some species, the pixel size should be small enough to detect the lake. Of course linear features (such as rivers or roads) can be treated as a special data layer in digital maps.

It is valuable to have some knowledge of the size and placement of the FMU within the larger landscape, relative to the habitat of species of concern at the site. If the FMU fully encompasses the habitat, then the landscape and habitat verifiers can portray information about how the intervention may affect the species. However, if the size or placement of the FMU falls within the species habitat then the verifiers, as applied based on this paper, will not be adequate. On the other hand, the changes within the FMU may be so small as to not affect the larger habitat. In other words, some of the habitat necessary to maintain such a species is beyond the control of the FMU.

The choice of pattern verifiers should be based on information from the area affected by the specific human intervention to the total FMU. In cases where a map is not available in a digitised form, the development of verifiers for contagion, dominance, fractal dimension and percolation index is not possible. In the case of limited expertise or maps not being available in digital forms, the minimum set of parameters to be measured includes:

- Area: Verifier 1.1.1 is the areal extent of each vegetation type in the intervention area relative to the area of the vegetation type for the entire FMU.

- Patch structure: Verifiers 1.2.1, 1.2.2 and 1.2.3 can be easily measured by counting patches and determining the area of patches.

- Connectivity: Verifier 1.3.1 is based on a simple measure of the distance between patches.

When digital maps are available, then the advantage of using verifiers 1.2.4, 1.2.5, 1.2.6 and 1.3.2 are that they provide a single metric of the entire map and thus are relatively direct to interpret (Gardner *et al*. 1987; O'Neill *et al*. 1988).

2. Habitat Structure

There is an intimate relationship between species and their habitats and, for this reason, habitat diversity is potentially a powerful indirect indicator of species diversity (Bell *et al.* 1991). The great structural and resource heterogeneity provided by plants is the principal reason for the high animal diversity in tropical forests (Huston 1994, p. 543). High habitat diversity contributes to high animal diversity in forests, particularly among small animals such as birds (Thiollay 1992 but see Johns 1992), mites (Walter *et al.* 1994) and sap-feeding herbivores (Denno and Roderick 1991), but for larger more mobile animals, such as primates, physical heterogeneity of the forest is less important for maintaining diversity than the productivity of their food resource (Terborgh 1983; Johns 1992). In order to maintain species diversity in managed forests, it is important to conserve habitat diversity. Indeed, habitat diversity is an indicator that is related to all human interventions that have been defined in this document (Table 3).

Interventions such as logging can create new habitats, which partly explains the commonly observed phenomenon of an increase in species diversity of many groups of organisms following, for example, logging (Whitmore 1984; Kuusipalo *et al.* 1996). Therefore, while the creation of new habitats is unavoidable, sustainable forest management should avoid any major shift in habitat diversity from the levels encountered in undisturbed landscapes. An appropriate indicator is therefore:

Indicator: Changes in habitat diversity as a result of human interventions should be maintained within critical limits

These *critical limits*, or threshold values, need to be defined. However, until research can provide objective critical limits, a reasonable threshold might be ± ***1/2 standard deviation of the spatial diversity observed in "undisturbed" patches of the same vegetation type in the FMU.***

Verifiers of habitat diversity, together with those for guild structure, taxic richness and population structure (below) are subject to the previously discussed problem of going beyond simple site characterisation to the development of response indicators. The usual way in which this problem can be overcome will be to make use of "pseudo-time series" by assessing the verifiers on (for example in the case of logging) unlogged areas and areas logged 2, 5 and 10 years ago, or whatever range of ages is available. It is also essential that habitat diversity be assessed in conjunction with guild, population structure and taxic richness indicators.

Habitat constitutes the interaction of all biotic and abiotic attributes of an organism's or a species' environment. Thus habitats will vary according to differences in these biotic and abiotic attributes. Human interventions will not change most abiotic attributes, such as elevation, aspect, slope, soil type, etc. Therefore, key abiotic elements of the environment can be used in a primary stratification process, within which the biotic elements of habitat are assessed.

Biotic elements include interactions among all organisms. However, vegetation structure is a predominant determinant of habitat, and is also simpler to assess than non-vegetation structure. Therefore the verifiers listed below are descriptors of vegetation structure and the variation in these over the intervention area.

Measures are taken within different vegetation types inside the intervention area and compared to the same vegetation types (where possible) in the FMU outside the intervention area (i.e., control plots). Measurements could be made in each vegetation type occurring in the intervention area or, in the interests of efficiency, only in those vegetation types identified as a focus of interest (e.g., as identified by verifiers of the pattern indicator, discussed above). Vegetation types that are important for other reasons, such as being required by specific (flagship) species (e.g., pandas), could also be included in the assessment.

Measurements should be made within small standard plots, which encompass the range of known environmental heterogeneity, e.g., based on topographic position (valley bottom, ridge slope and top), aspect (north and south) and so on.

Verifiers of habitat structure refer to two components of vegetation structure: vegetation texture and architectural or physiognomic complexity (Kareiva 1983; cf. Oldeman 1983). Vegetation texture describes the diversity of habitats within a forest (e.g., gap zones, riparian belts, flooded forest), while physiognomic complexity refers to the structural (and functional) heterogeneity of the forest plants (e.g., horizontal and vertical arrangement of components of the vegetation, evergreen or deciduous habit, leaf size).

Two observations may be made before describing the verifiers suggested for this indicator. Firstly, we believe that the first step in the evaluation of habitat structure and diversity should be to determine what information is routinely collected during forest management operations, and what part of this may be relevant to the assessment of the verifiers described below. Forest inventory data, for example, may permit the analysis of the size-class distributions of whole stands and individual populations of tree species. Where post-harvest silvicultural diagnosis is practised, as in Costa Rica and Malaysia, the data may permit calculation of the surface area of different phases of the forest regeneration cycle. Secondly, where data gathered during routine forest operations do not, for some reason, contribute to the evaluation of habitat structure and diversity, efforts should be made to change this situation. All the verifiers described below are to be measured using simple subjective scales in small sample plots, which means that they require no more effort and training than do traditional forest sampling operations. Thus the gathering of data for C&I evaluations may in principle be integrated with operational sampling, with obvious benefits to all concerned.

We suggest that in any case, all the following verifiers be measured using the sample plot sizes and plot spatial distributions already used by the operators of the FMU. Sampling intensities may have to be varied to obtain statistically adequate estimates of the values of some of the verifiers, but it is clear that each verifier should be evaluated as part of one single inventory; that is, that each variable should be evaluated simultaneously in each sample plot. The evaluation of these verifiers depends to a certain extent on summary and analysis of data using simple statistical methods, and it is important to mention that all the data manipulation and analysis mentioned below may be carried out on PC spreadsheet programs.

i) Canopy and tree structure

Verifier 2.1.1: Vertical structure of the forest: While it is desirable in principle to obtain some measure of canopy height and vertical stratification of the forest, accurate height measurements are exceedingly difficult and costly in tropical rain forests, and are not recommended. Canopy height may be estimated subjectively using broad height classes (e.g., 30-40 m) while, due to the close correlation between stem diameter and height, dbh measurements (verifier 2.1.2) can be used as a surrogate, or regression equations parameterised and used for estimations of canopy height and frequencies of trees by height classes. A similar procedure may be used for estimations of crown diameters and their variability, while crown forms can be evaluated using Dawkins' five-point scale (Alder and Synnott 1992). Trees with broken stems or crowns should be scored as such. Various methods for greater quantification of forest vertical structure, usually involving the estimation of foliar biomass, are available (Blondel *et al.* 1973; Cody 1983; Erdelen 1984) and could be applied.

Verifier 2.1.2: Size class distributions: The measurement of tree stem diameters at breast height (dbh: 1.3 m) is a basic operation of forest inventory and the use of data to develop frequency distributions of trees by classes of dbh is a basic tool of stand structural analysis. If the operator of the FMU does not have this information, it should be taken. Simple statistical procedures, such as the χ^2 test are sufficient for comparison among stands. For purposes of interpretation in the present context, dbh measurement should be taken from a minimum diameter of at least 10 cm. All trees which should be identified to species if possible, to permit the analysis of the size-class distributions of species populations, as well as their spatial distributions. Simple and easily calculated measures such as the variance/mean ratio (Greig-Smith 1983) can be employed to determine the type of spatial distribution. Finally, it is important that both standing dead trees (canopy gaps are treated under verifier 2.1.4) and lianas whose maximum stem diameters exceed the minimum dbh for measurement be recorded and identified as such on filed forms.

Verifier 2.1.3: Frequency distributions of leaf size and shape*:* This verifier is essentially the same as verifier 4.1.6 under the taxic richness indicator. Since pioneer species generally have larger leaves, an assessment of leaf size variation may provide insight to changes in tree structure due to presence of pioneers. Assessment can simply be by samples of recent litter fall, dividing the leaf sizes into a number of classes, and recording the frequency of classes in quadrats within the standard plot. In addition, leaf shape can provide important information on environmental change. For instance, compound leaves may be adapted to warm and seasonally arid situations, and may be associated with deciduous habit or with species that occupy light gaps or are early pioneers (Givnish 1978). One need only distinguish between the frequency of simple and compound leaves in the canopy strata of trees.

Verifier 2.1.4: Frequency distribution of phases of the forest regeneration cycle: The regeneration cycle of old-growth tropical rain forests can be simply divided into three phases (gap, reconstruction and mature; Whitmore 1984) and each sample plot should be scored according to this scheme. For logged forests, new categories such as skid trails, or log landings, should be added to the scheme and gaps should be classified as natural or man-made. Comparisons among locations can be made on the basis of the area of forest in each phase as estimated by sampling, or by comparing the frequency distributions of individual samples by forest phases.

Verifier 2.1.5: Canopy openness in the forest understorey: The amount of light reaching the forest understorey, and its critical role in the determination of understorey microclimate and other factors, such as decomposition rates, are extremely important aspects of habitat quality. Light can be estimated subjectively at a fixed point and height in each sample plot using Dawkins' scale (Alder and Synnott 1992), or the modification of it established and tested by Clark and Clark (1992), which is particularly useful in evaluation of understorey conditions. More sophisticated measurements of understorey light regimes require equipment and effort which may be beyond the scope of C&I, and measures obtained by methods such as hemispherical photographs may give little insight beyond those obtained from subjective measures.

ii) Understorey habitat structure

Verifier 2.2.1: Standing and fallen dead wood: Diameter and height/length of all standing and lying dead wood over 10 cm diameter can be measured within the standard plots. For fallen wood, the state of decay can be assessed on a scale of 1 to 5. The depth of leaf litter and relative abundance of small dead wood (< 10 cm diameter) can also be assessed.

Verifier 2.2.2: Other structural elements: For plants less than 1.5 m in height, the relative abundance of different growth forms can be recorded in the standard plots using the domin scale (Gillison 1988). Growth forms may include shrubs, vines, grasses, geophytes, ferns and other herbs. The abundance of woody and non-woody lianas and epiphytes can also be recorded on a 5-point scale.

3. Guild Structure

A guild is a group of species or organisms which use the same environmental resources in the same way (see Stork 1987). Examples of guilds are plant species grouped according to their tolerance or intolerance of shade, or groups of birds categorised by their feeding habits: insectivores, frugivores, granivores. To the extent to which the use of the same environmental resources implies similar roles in ecosystem processes such as primary production or consumption, the guild concept may be considered synonymous with the more recent idea of functional groups. The proposal that the guild concept be used in the development of C&I is based on three premises:

- The guild may, in many situations, be the most practical taxonomic unit. Reference to a small number of guilds saves time and effort in comparison with reference to a large number of species (see discussion below under the taxic richness indicator). While the use of taxa above the species level in the determination of taxic richness serves the same purpose, guilds have the advantage of linking species to ecological processes.

- Important information on the response of forest biodiversity to the management process may be obtained at the guild level.

- Key ecological roles are played by certain animal and bird guilds, such as pollinators and seed dispersers.

The guild structure indicator is as follows:

Indicator: Community guild structures do not show significant changes in the representation of especially sensitive guilds, and pollinator and disperser guilds

As for habitat diversity, assessments are required using "pseudo-time series" by locating plots in areas having different intervention histories, which provide some indication of temporal dynamics. ***Critical values*** for verifiers may be similar as for habitat diversity, namely ± ***1/2 standard deviation of the spatial diversity observed in "undisturbed" patches of the same vegetation type in the FMU.***

i) Sensitive guilds

Verifier 3.1.1: The relative abundances (percentages of total numbers) of seedlings, saplings and poles of canopy tree species belonging to different regeneration guilds (e.g., pioneer, intermediate and shade-tolerant guilds). This information may be collected during the normal inventory process for forest management, in which case, at least for tree guilds, real time-series data may be available.

Verifier 3.1.2: The abundances of selected avian guilds (e.g., Thiollay 1992). The selected guilds may be terrestrial consumers of insects or fallen fruits, specialised with respect to understorey microclimates, such as the antbirds of the neotropics. The abundance of these birds may be estimated by recording call frequencies in plots or along transects. Interpretation of the data will be carried out in combination with studies of habitat diversity (see above).

ii) Pollinator and disperser guilds

Verifier 3.2.1: The abundance of nests of social bees. The abundance of actual or potential roosting sites for pollinating bees, such as over-mature and hollow trees. Measurement can potentially be integrated with normal forest inventory procedures.

Verifier 3.2.2: Pollination success in key plant species of the mature forest understorey. Key species may include shade-tolerant palms. Pollination success can be recorded in terms of seed set per unit reproductive effort (e.g., in relation to flowering intensity) where monitoring over a period of weeks or months is possible. Alternatively, raw figures (including subjective estimates) of amounts of fruit/seed are suitable for comparisons among plots.

Verifier 3.2.3: Fruiting intensity in known bat-pollinated tree species. Dedicated studies of pollination and phenology would have to be implemented for verifiers 3.2.2 and 3.2.3, using methodologies such as those described by Newstrom *et al.* (1994).

Verifier 3.2.4: The abundance and activity of terrestrial frugivorous mammals. This verifier may be evaluated using a combination of approaches, including consultation with local people and observation of animals during routine fieldwork. Simple seed removal experiments such as those described by Hammond (1995), using seeds of key plant species, may be conducted to provide a useful, though indirect, measure of the activity of the animals of this guild.

Pollination and dispersal each may involve large numbers of generalist organisms – both the providers of the services (animals and birds) and the users of the services (plants). It is felt that generalist organisms may not represent useful or sensitive indicators of the response of forest diversity to management as, by definition, they are much more flexible in terms of resource use. Examples of generalists from tropical forests are avian dispersers of drupes and berries and the plants such as understorey palms and shrubs (Janson 1983; Thiollay 1992), and the participants in the "diverse small insects" pollination mutualism (Bawa *et al.* 1985). Bats, on the other hand, may be considered more specialised pollinators in terms of floral resources used (in the neotropics, canopy tree species from a small number of families such as Caryocaraceae, Bombacaceae and Leguminosae). Bat populations are also especially vulnerable to forest management operations if these do not take into account their roosting requirements. Particularly critical dispersal mutualisms are those mediated by forest vertebrates such as the agouti (*Dasyprocta azarae*), a disperser of large-seeded palms and trees (Smythe 1986), and the short-tailed macaque (*Macaca nemestrina*), a key disperser of some South-east Asian *Ficus* species.

4. Taxic Richness and Composition

Detailed assessment of taxonomic richness requires reliable lists of species. Since generation of lists is impossible in C&I assessment, alternative approaches are required. Two such approaches are the use of indicator species (but see comments on page 5) and higher order taxa. Commonly proposed indicator taxa include vertebrates, plants, butterflies, dung beetles and tiger beetles. Where RBA methods or more detailed research have been conducted, use should be made of the results. However, Balmford *et al.* (1996a) found that species richness within a group may be better predicted from family-, or even order-level richness than from species richness in putative indicator groups. Also lists of most taxa require the work of trained experts over a long period of time. Balmford *et al.* (1996b) estimated that assessment of tree species richness in Sri Lanka required three times the time, and 2.5 times the cost of genus-level assessment. Between three and four person-days were required for the field assessment of only nine 0.05-hectare plots, plus more than 5 person-days of herbarium time. Local people can often provide very quick and reliable estimates of the species present, at least for groups like mammals, snakes, birds, some invertebrates and many plant families.

The indicator for taxic richness can be expressed as:

Indicator: The richness/diversity of selected groups shows no significant change

As for habitat diversity and guild structure, this indicator implies the use of plots in areas having different histories, complemented where possible by historical data. Again, appropriate critical levels may be ± ***1/2 standard deviation of the spatial diversity observed in "undisturbed" patches of the same vegetation type in the FMU.***

i) Measures of richness

Verifier 4.1.1: Species richness of prominent groups as reported by local people. Local people, especially representatives of indigenous groups, may have detailed knowledge of the presence, and even the abundance, of species of some groups that are important to them, even though their concept of species may not be consistent with taxonomic orthodoxy. This knowledge may result from hunting, collecting or from general observation. If checklists exist (and local names are known) interviews may provide a very rapid approximation of "species" richness in some groups and more importantly the decline/increase in abundance of some taxa. If local people report that they do not hunt in certain areas (e.g., areas logged several years previously), this information can provide valuable clues as to the impact of the intervention on sustainability.

Verifier 4.1.2: Number of different bird calls. Plot- or transect-based records of bird calls can be quickly and easily collected, especially in the early hours after dawn. Local people will usually be able to identify a large number of the calls, but training required to recognise bird calls is minimal. Automated methods for recording vocal records of birds, bats, frogs, etc., are being developed and hold great promise for the monitoring of certain groups.

Verifier 4.1.3: Numbers of large butterfly species feeding at key sites/attracted to bait. As large butterflies are distinctive and can be morphologically separated relatively easily, recording numbers of morphologically distinct types over a fixed time period (e.g., 1 hour) can provide a quick approximation of taxic richness for this group. The choice of bait will dictate which taxonomic groups are assessed. However, hidden dangers are the problems of polymorphic species and mimicry complexes. Smaller butterflies such as Hesperiidae and Lycaenidae are notoriously difficult to distinguish taxonomically. The task of identifying is made easier if there is a guide to butterflies for the region. Weather conditions and time of day can affect results, so butterfly counts should only be attempted in the early morning.

Verifier 4.1.4: Numbers of species removed from the forest/for sale in local markets. This indicator is useful when it is possible to record the origin of individuals.

Verifier 4.1.5: Number of morphologically different leaf types in litter within a 4 m^2 quadrat. This verifier is essentially the same as verifier 2.1.3 under habitat structure.

Verifier 4.1.6: Lists compiled by acknowledged experts. Lists obtained by trained experts will be very useful as background material and as the basis for further comparisons. It is possible, to an extent, to train para-taxonomists, thus easing the task of the professional (Janzen 1991), but supervision by an expert will always be needed (see Trueman and Cranston 1994) . The most useful and practical groups are the birds, large mammals, certain plant families and conspicuous or well-known invertebrates such as butterflies, dung beetles and carabid beetles (Kremen *et al.* 1993; Spence *et al.* 1997).

ii) Measures of change

As an alternative to collecting data from areas subject to different histories (e.g., logging/no logging), it may sometimes be possible to collect real time-series data. As with measures of taxic richness, local people or experts can be used, but the effort required will inevitably be greater than for taxic richness.

Verifier 4.2.1: Temporal changes in species richness. This verifier accounts for species that are gained and lost from specific sites.

Verifier 4.2.2: Time series of composition of mature forest species/secondary growth species ratios. Time series can be developed for a number of groups of species, such as butterflies (Kremen 1992), moths (Holloway 1985), bats (Rautenbach *et al.* 1996) and birds. It is also possible to resort to rapid morphological or ethological identifications not requiring a taxonomic expert. A full list is not required.

Verifier 4.2.3: Time series of α and β diversities. When abundance is recorded and documented spatially (for example, as in all different habitats relevant to the taxa or in the cells of a grid), the diversity within a sampling unit is termed α-diversity. The reciprocal of the average number of sampling units occupied per species is the β component. Separating the α and β components is useful because they are related to different environmental factors. For example, a progressive homogenisation of the forest should generate a decrease in the β component. Again it is important that the groups selected for this analysis are well known and easily identified.

5. Population Structure

It may be important to have measures on the demography, age structure, numbers and meta-population structure of certain important species. These may be keystone species within the guilds chosen above, or economically important tree species, or species that have been identified as indicators of important processes or that correlate well with the population size of many others. As is the case with other indicators, it will often be impractical or impossible to obtain a full population analysis for the species chosen. We will list verifiers in order of simplicity of data acquisition.

Indicator: Population sizes and demographic structures of selected species do not show significant changes, and demographically and ecologically critical life-cycle stages continue to be represented

Measures of the size of populations of important (keystone, indicator, economic) species can be obtained and used to assess either the state of the population (with a single absolute measure) or its trend (with time series).

i) Population size

Verifier 5.1.1: Measures of the absolute population size of selected species. Acquisition of absolute numbers (rather than relative to sampling effort) may be useful *per se*, without reference to a time series. They are possible for many taxa, but as a general rule they are more labour-intensive and require better training than relative methods.

Verifier 5.1.2: Time series of relative population-size estimates. It is often comparatively easy to get data on number of individuals per unit effort. Fixed routes, fixed time or areas can be defined and the number of individuals sighted, marked or otherwise identified as the verifier of population size (Krebs 1989). These measures should be taken over long periods of time, to determine temporal changes in the population-size estimates. Although the acquisition of data can be relatively simple and quick, repeat measures over many dates are required. Changes in the trends of the time series should be interpreted in accordance with the role of the particular species in the forest. For example, a positive trend in an invasive exotic is an indicator of a problem, whereas a stable population of a large carnivore may be taken as an indicator of good management.

ii) Demographic structures

Verifier 5.2.1: Age or size structure. Counting the numbers of individuals in different age categories, size classes or stages is often practical and gives valuable information about past and/or present perturbations. Of particular importance are the seedlings (or juveniles in animals), mature and reproductive stages. In general, a very important point is that critical life-cycle stages continue to be represented in the population.

Verifier 5.2.2: Life tables and their statistics. When complemented with observations of fecundity per class (which are often much more difficult to obtain), survivorship tables become life tables and can be used to estimate population growth rates, which may allow a correlative analysis of trends.

iii) Meta-population structure

Verifier 5.3.1: Spatial structure of populations. Documenting changes in the spatial position of subpopulations, as well as the migration rate between them, may be important for many species (Hanski 1991), especially when the forest is being fragmented as a consequence of logging or other human activities. Roads, shrinking habitat, loss of certain tree species and other similar phenomena can cause important changes to the reproductive structure of a large population. The magnitude of these changes will depend on the size and degree of fragmentation of the FMU.

6. Ecosystem Processes: Decomposition and the Nutrient Cycle

Indicator: The status of decomposition and nutrient cycling shows no significant change

While it is recognised that many ecosystem processes contribute to the maintenance of community structure and levels of biodiversity within any system, the processes of decomposition and nutrient cycling are considered here to be the most useful as potential indicators of changes in those processes which maintain and shape biodiversity. Decomposition is the process by which plant and animal organic matter is physically broken down and converted to simpler chemical substances, resulting in the production of carbon dioxide, water and the release of energy (Chapman 1986). Decomposing organisms (bacteria, fungi and detritivorous animals) are responsible for this breakdown of organic compounds. Nutrient cycling describes the flow of nutrients, including carbon and nitrogen, as well as potassium, phosphorus, calcium, sodium, magnesium and iron through the ecosystem. The two processes are intimately related, the release of nutrients from more complex organic compounds by the decomposer system being central to nutrient recycling through the system. Within most tropical forest systems, and particularly on nutrient-deficient soils, rates of decomposition are relatively fast and the nutrient cycling is tight, and thus levels of nutrient loss from the system are relatively low (Bruijnzeel 1990; Richards 1996).

Many human interventions may disrupt the normal processes of decomposition and nutrient cycling. Burning, for example, may release a large proportion of a community's stored carbon and nitrogen within a relatively short time (Begon *et al.* 1990; Richards 1996). The impact of burning, however, depends on the scale and intensity of the burn and the local conditions at the time. The planting of exotic species, such as eucalyptus, may affect the decomposition process by introducing new secondary plant compounds to the system. Road building too may have a major impact by increasing the exposure of soil and soil compaction, resulting in the loss of both topsoil and nutrients (Richards 1996, and reference section on water quality and quantity).

A suite of verifiers is presented below from which a sub-set may be selected in the assessment of any one FMU. It is suggested that any such sub-set include at least one verifier relating to decomposition and one relating to nutrient cycling. Different management interventions might also direct the choice of verifiers. For example, shifting cultivation involving burning will result in the direct mobilisation of nutrients in the system and it would be appropriate to direct the assessment more towards changes in nutrient cycles than decomposition. The basis for the assessment of these verifiers lies in comparisons between sample areas (see Operational Framework pages 21-23). However, it may be appropriate in some cases also for some before-and-after measurements to be made. The time interval between such procedures needs careful consideration to ensure that real (not temporary) changes are identified and also to allow management practices to be altered if adverse impacts on the biodiversity processes are identified.

i) Decomposition

Verifier 6.1.1: Standing and fallen dead wood. Diameter and height/length of all standing and lying dead wood over 10 cm diameter can be measured within standard plots (which is related to the verifiers of habitat structure – see verifier 2.2.1). Immediately following logging there will clearly be large amounts of fallen wood, so in areas that have been logged recently this verifier is inappropriate and should not be used.

Verifier 6.1.2: State of decay of dead wood. This verifier could be measured in various ways. First, within the standard plot, the state of decay of all fallen dead wood over 10 cm in diameter can be assessed on a scale of 1 to 5. Again care must be taken in the assessment of recently logged sites. Second, a sample of five similarly sized pieces of dead wood could be selected in each plot and again assessed on a 1 to 5 scale. Third, comparative graveyard tests could be established using posts of a locally occurring, relatively decomposable wood, of an appropriate diameter. In this way such tests can be conducted quite rapidly, but if necessary they could be established by FMU personnel in advance of the C&I assessment.

Verifier 6.1.3: Abundance of small woody debris. Small woody debris (under 10 cm diameter) can also be assessed on a scoring scale from 1 to 5. Again the temporary effects of recent logging or other interventions should be considered.

Verifier 6.1.4: Depth of leaf litter and gradient of decomposition. A comparison between areas of litter depth may provide evidence of variation in decomposition rates, while the absence of a gradient of decomposition (from least broken down material at the top of the litter layer to most decomposed at the bottom) may indicate a breakdown in the decomposition process.

Verifier 6.1.5: Abundance of decomposer organisms. Certain groups, for example fungi and termites, play key roles in the decomposition process in different areas. Comparative assessments of decomposer abundance (particularly of these taxa) may provide indication of variation in the decomposition process. This verifier is linked to verifiers of guild structure (see pages 14-15), but no assessment of diversity is required.

Verifier 6.1.6: Leaf bags. Mesh bags can be filled with litter and anchored on the ground in different areas to assess variation in decomposition rates. It may be appropriate to use a number of bags of varying mesh size, which determines the organisms that can enter the bags (Edwards and Heath 1963; Chapman 1986). Again, it may be necessary for the bags to be placed by FMU personnel in advance of the C&I assessment.

ii) Nutrient cycling

Verifier 6.2.1: Soil conductivity and pH. Soil conductivity and pH may give an indication of nutrient levels in the soil, although these measures will not identify what those nutrients are. It is important that soil type and parent material are considered when comparative sites are chosen.

Verifier 6.2.2: Soil nutrient levels. The chemical analysis of nutrients in soil water may give an indication of the quantity and variety of nutrients available to the plant community. A lysimeter system can be used for sampling (Parizek and Lane 1970; Knowles 1980; Chapman 1986), but analysis relies on laboratory techniques. See Allen *et al*. (1986) for details on chemical analysis.

7. Water Quality and Quantity

Indicator: There is no significant change in the quality or quantity of water from the catchment

The run-off from a forested catchment can provide useful information as to the status and health of the ecosystem. This indicator is intimately linked with 6 above, as the nutrient recycling of a forest ecosystem is never perfect and some nutrients are inevitably lost by run-off into the streams and rivers of the catchment. Indeed, the most substantial loss of most nutrients from the system may occur via stream flow in either dissolved or particulate form (Begon *et al*. 1990). However, estimating these losses in remote areas or by occasional samples is very difficult (see below). The volume of water and the levels of dissolved and particulate matter may vary considerably throughout an annual cycle, and between years, depending on levels of rainfall. Likens *et al*. (1977) have shown an increase in the gross annual output of calcium, sodium, magnesium and potassium with increasing total annual stream-flow and these effects need to be considered in any investigation. Richards (1996) warns also that catchment monitoring may underestimate the scale of erosion if much of the eroded material is stored at the base of slopes or headwater tributaries within the catchment and does not reach catchment monitoring stations. The low levels of nutrients and other dissolved material in many forest stream systems mean that even small events can cause large fluctuations in solute concentrations; even in high-nutrient and/or well-buffered systems, background fluctuations may be large. These fluctuations cause major problems for monitoring programmes based on irregular visits, the results of which may or may not represent “normal” conditions and may not be interpretable. Therefore, because measurements of physical and chemical variables in the water reflect only most recent events, they may not be useful in monitoring unless included in a continuous or, at worst, very regular monitoring programme.

Many human interventions have an impact on the characteristics of the catchment run-off. For example, poor logging practices (including poorly constructed logging roads) and over-intensive logging activities result in the loss of canopy cover, increased soil compaction and increased surface flow (Malmer 1990; Nortcliff *et al*. 1990), having a major effect on the quality and quantity of water flowing from the system, and on the freshwater biota. Intense rainfall, common in the tropics, can lead to a significant increase in the washout of topsoil and leaching of nutrients from the logged forest into the nearby streams and rivers (Richards 1996 and references therein). Ross *et al*. (1990) monitored hydrology and soil erosion in virgin forest, partly cleared and totally cleared plots at Maraca Island, Amazonia. Overland flow and mineral soil erosion increased five-fold and seven-fold respectively in the totally cleared plots compared to the virgin forest. In the partly cleared plots only minor increases were observed. The loss of topsoil in turn affects regeneration in the logged stand, while the increase in dissolved and suspended sediments in the water affects the level and distribution of aquatic diversity. In contrast, the planting of exotic species such as pine or eucalyptus may cause a lowering of the water table and decrease the volume of water-flow from the catchment.

i) Water quality

Verifier 7.1.1: Abundance and diversity of aquatic stream organisms. This verifier is related to verifiers of guild structure and taxic richness (see pages 14-17). The diversity and abundance of different stream organisms are related variously to water quality variables, such as the quantity of suspended organic matter, nutrients, and pollutants in the water. Stream invertebrates are easy to sample, and can be sorted and identified to the family level by technicians with only a moderate level of training. While diversity at the family level of identification may not always be a good surrogate for species diversity, it is very useful as a guide to water quality because, even at the family level, different taxa react differently to disturbance. The usually high level of diversity even at the family level leads to good discrimination between types of disturbance. Moreover, invertebrates provide temporal integration of past conditions: those taxa present at a site indicate not only present events, but also the recent history of disturbance. Therefore, occasional samples can indicate previous condition over periods up to the generation time of the invertebrates. Physical and chemical analyses can provide useful back-up to community composition but, because of the limitations on their use, cannot replace the value of monitoring of the fauna. Even changes in the light regime would be reflected by an increase in grazing taxa, as aquatic algae production increases.

Other components of the biota also provide useful information. For example, fish species diversity is useful at the catchment and stream section scales, but because of the mobility of fish, is less helpful at the local scale. Diversity of plants, especially algae and diatoms, may also be a useful indicator; however, the invertebrates are the preferred biotic indicators because of their diversity, ease of sampling and relative ease of identification to the family level.

Verifier 7.1.2: Chemical composition of stream water. This verifier is useful as a back-up to biological sampling when it is suspected that poor condition is current, in which case it can pin-point the source of poor water quality problems. It is not very good at indicating past or intermittent disturbance (see above). Some important variables (e.g., dissolved oxygen concentration, pH, conductivity, turbidity) can be measured with meters, but these can be problematic in tropical climates. Moreover, some variables vary naturally through the diurnal cycle, so standardised or continuous sampling is required. Dissolved nutrients, metals, etc. normally require laboratory analysis, in some cases within 24 hours of sampling, and with the samples preserved on ice. Again, these requirements reduce the practicality of chemical analyses in remote and/or tropical environments.

Verifier 7.1.3: Leaf bags. Decomposition in fresh waters is a similar process to that on the forest floor: litter is leached of soluble components, colonised by micro-organisms and consumed by animals. The rate of processing varies with natural conditions (water quality, leaf species, etc.) but is expected to be predictable at particular sites. Because decomposition is a process that involves a diverse sub-set of the biotic community, its progress relates to the community composition which is itself affected by water quality, light input, etc. Verifiers that relate to processes are thus very useful because of their integrative nature. Mesh bags can be filled with litter and anchored in the water to assess decomposition rates. Use of coarse mesh retains the litter material while allowing access to microbes and invertebrate consumers. As with terrestrial litter bags, it may be necessary for the bags to be placed by FMU personnel in advance of the C&I assessment.

ii) Water quantity

Verifier 7.2.1: Stream flow. As a first order verifier, stream flow may be easier to estimate than levels of nutrients in water. If the relationship between nutrient concentration, rainfall and run-off rates can be established, estimates of the quantities of nutrients lost to the system can be made from the volume of water leaving the catchment, providing of course that there are no additional nutrient inputs, for example from burning. Changes in the quantity of water in a stream may relate to major changes in the vegetation of the catchment; however, this indirect method is unlikely to be more use than direct observation of catchment disturbance.

PART III: OPERATIONAL FRAMEWORK FOR APPLYING C&I

Biodiversity is a complex concept, and biodiversity attributes vary continuously over time and space. Similarly, a forest management unit is highly variable in terms of spatial and temporal variation in the types and intensity of human interventions. Verifiers of biodiversity indicators cannot be assessed at all sites within a FMU, therefore operational guidelines are required to assist in the application of biodiversity C&I. Below we present a step-wise process for the application of C&I.

Step 1. Characterisation of the FMU

Primary considerations in the application of the C&I are the extent of the FMU and its internal variability. Even within a single country, there will be differences in the extent to which different FMUs cover the diversity of forest types found within the country. The degree to which FMU boundaries may or may not coincide with landscape or ecological boundaries is also significant. A further consideration is the amount and quality of data available for a FMU at the start of assessment. The assessment of some verifiers, for example those associated with the pattern indicator, requires either remotely sensed data or detailed maps of the FMU. The resolution of remotely sensed data, especially in relation to the scale of inherent forest variability, and the scale of human interventions will be important in determining the value of some verifiers.

The first step in the process is therefore to compile as much information as is available, in the form of maps, remotely sensed images, and/or digital, spatially referenced data sets for the following attributes:

- management plan;
- FMU boundaries;
- vegetation types within the FMU;
- vegetation structure (e.g., degree of canopy closure);
- historical and current areas of interventions (e.g., logging, NTFP collection);
- inventory data;
- contours, stream lines and other physical elements; and
- roads, settlements and other infrastructural elements.

This step can be done in the office.

Step 2. Selection of Indicators and Site of Application within the FMU

Based on the types and areal extent of intervention, the indicators that are required to assess the impact on biodiversity processes are selected (Table 3). For different interventions there will be different suites of indicators and within any one FMU there may be more than one intervention type and therefore different suites of indicators. Attention needs to be given to where these are applied within the FMU. Some will be applied across the FMU, and others only in selected sites (see below).

It is important next to determine whether there is an order or sequence to the indicators that have been selected. Table 3 lists the indicators in a scale order from left to right. It may not be necessary to apply all indicators within a selected suite if a conclusion about biodiversity conservation can be derived based on a limited sub-set of those indicators. Therefore, a process is required to identify the most efficient approach that will lead to a conclusion in a cost-effective manner. Such an approach should be based on a hierarchical principle, in which the highest level indicator of the selected suite is assessed first. For example, for selective logging, the starting point would be the landscape-level and pattern indicator, and for NTFP collection, the ecosystem-level and habitat indicator. Lower-level indicators need only be assessed if results of the higher-level indicators are inconclusive or ambiguous.

In addition, assessment will represent a single "snap-shot" view of the FMU, integrating the impacts of past and current interventions. Intuitively, historical over-exploitation should affect the level of current exploitation that can be considered sustainable, and this relationship needs to be understood.

Step 3. Selection of Verifiers

Some of the proposed verifiers are quick, easy, cheap to apply in the field, and can be done by untrained or semi-trained personnel. These are the ones which are initially going to be the most useful. As discussed below, these types of verifiers, which we designate "Primary" verifiers, should be the first to be used in any operational assessment. However, because of their very nature, they will lack precision, and their outputs must be considered approximate. In many cases the outputs may be considered sufficient, but where, on the basis of applying "Primary" indicators a judgement on sustainability remains equivocal, more complex, time-consuming, expensive, but more precise verifiers may need to be used. These we designate "Secondary" verifiers. As new technologies and methodologies are developed, it is possible that some Secondary verifiers may become Primary verifiers.

Primary verifiers, i.e., those which are easier, quicker and cheaper to assess (Table 4), should be assessed first. Similarly, as some of the processes that maintain biodiversity operate at more than one spatial scale, or are linked across scales, some verifiers serve to link scales by generating information at more than one scale (Figure 2). The shaded areas reflect overlaps

Table 4. Types of verifiers

Indicator	**Primary**	**Secondary**
Landscape pattern is maintained	V 1.1.1: Areal extent of each veg. type* V 1.2.1: Number of patches per unit area* V 1.2.2: Largest patch size of each veg. type* V 1.2.3: Area weighted patch size* V 1.2.4: Contagion* V 1.2.5: Dominance* V 1.2.6: Fractal dimension* V 1.3.1: Average distance between 2 patches of same cover type* V 1.3.2: Percolation index* V 1.4.1: Total amount of edge for each veg. type* V 1.4.2: Edge round largest patch*	
Changes in habitat diversity within critical limits	V 2.1.1: Vertical structure V 2.1.2: Size class distributions V 2.1.3: Relative abundance of leaf sizes V 2.1.4: Gap frequency/forest regeneration phase V 2.1.5: Canopy openness V 2.2.1: Standing and fallen dead wood V 2.2.2: Other structural elements	
Community guild structures do not show significant changes	V 3.1.1: Relative abundances of tree species in different guilds V 3.1.2: The abundances of avian guilds V 3.2.1: Abundance of nests of social bees	V 3.2.2: Pollination success in key plant species V 3.2.3: Fruiting intensity in bat-pollin'd spp. V 3.2.4: Abundance/activity of terrestrial frugivorous mammals
The richness/diversity show no significant changes	V 4.1.1 Species richness reported by local people V 4.1.2: Number of different bird calls V 4.1.3: Numbers of large butterfly species V 4.1.4: Number of species in local markets V 4.1.5: Number of leaf types in litter	V 4.1.6: Lists compiled by experts V 4.2.1: Temporal changes in species richness V 4.2.2: Time series of mature/secondary growth species ratios V 4.2.3 Time series of α and β diversities
Population sizes/ structure do not show significant changes	V 5.1.1: Measures of the population size of selected species** V 5.2.1: Age or size structure**	V 5.1.2: Time series of relative population-size estimates V 5.2.2: Life tables and their statistics V 5.3.1: Spatial structure of populations
Decomposition and nutrient cycling show no significant change	V 6.1.1: Diameter and height/length of all standing and lying dead wood V 6.1.2: State of decay of all dead wood V 6.1.3: Abundance of small debris V 6.1.4: Depth of litter/gradient of decomp. V 6.1.5: Abundance of imp. decomp'ers V 6.1.6: Leaf bags V 6.2.1: Frequency of N-fixing plants V 6.2.2: Soil conductivity and pH V 6.2.3: Soil nutrient levels	
No significant change in water quality/quantity from the catchment	V 7.1.1: Abundance/diversity of aquatic organisms V 7.1.3: Leaf bags V 7.2.1: Stream flow	V7.1.2: Chemical composition of stream water

Notes: * If maps are available - otherwise Secondary
** Depending on species/groups selected

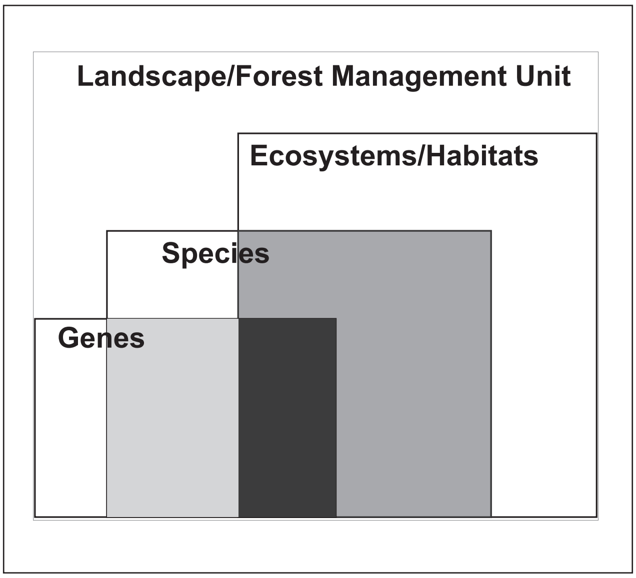

Figure 2. A representation of the overlap in processes at different scales.

in verifiers of the processes that maintain biodiversity at each scale, and these should be assessed in the order of the numbered boxes in Figure 2.

Step 4. How and Where to Apply Verifiers

Having selected the suite of verifiers the methodology of assessment requires a sampling strategy which includes consideration of how and where these are applied. How the verifiers are assessed will be largely determined by available information and the suite of verifiers selected (i.e., they each have their own methodology). However, we anticipate that in many circumstances gradient-based methods will be used within the stratified sample area. As far as possible, plots for different verifiers will be combined and plots of differing sizes will form nested sets. Appropriate plot sizes for plot-based verifiers should be established, which will depend on resources available and inherent diversity of the vegetation types. For example, for the assessment of vegetation structure, appropriate plot sizes may be in the range 0.01-0.04 ha.

Sensitive areas

- High proportion of the total area of a particular vegetation type is affected by proposed management plan.
- Fragile habitats/localities.
- Key habitats e.g., salt-licks or water-holes.

Stratified sample

- Stratification of the environment so as to aid efficient sampling of variation. If appropriate spatial data is available, habitats within vegetation types should be stratified to permit efficient use of plot-based verifiers. If no such data is available, plot locations should be established at random locations within vegetation types.

- Special considerations as dictated by individual verifiers.

Step 5. Decision Process

At each level, three types of Decisions can be reached.

1. We have a definite conclusion and we do not need to continue. This conclusion may be either that management is not sustainable in terms of biodiversity, or that it is.

2. We have reached a definite conclusion at this level, but we want to continue to look at other levels anyway.

3. We cannot reach a definite conclusion at this level, by looking only at Primary verifiers.

All Primary verifiers are assessed first, i.e., if it is not possible to reach a Decision 1 conclusion at a particular level, you go on to look at Primary verifiers of the indicator level below. Only when no conclusions can be reached using only Primary verifiers is it recommended that Secondary verifiers are assessed, again beginning at the highest level of indicators.

Example sequences of the decision process:

LEVEL	**Example 1**	**Example 2**	**Example 3**
Landscape	2	2	2
Habitat	2	2	3
Species	1 STOP	2	2
Genetic		2 STOP	2 STOP/or Apply Habitat Secondary Verifiers

FUTURE REQUIREMENTS

The intended field testing of the criterion, indicators and verifiers proposed here will provide a strong indication as to their utility and should lead to suggestions for revision and replacement of indicators and verifiers. New technologies and solutions to problems are being created all the time and no doubt, cheaper, quicker and more reliable verifiers will be produced. It will also be valuable to pool ideas from those groups who are developing C&I for particular countries and international groups. In this context we suggest that an international workshop in late 1997 or early 1998 should be convened for this purpose.

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