Article

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Implications of the Hierarchical Structure of Biodiversity for the Development of Ecological Indicators of Sustainable Use

The increasing interest, and the actual necessity, for adequate means to evaluate how sustainable human activities are, has led to efforts to define indicators of sustainability. We propose the use of ecological indicators of sustainability that take into account the hierarchical structure of biodiversity, distinguishing composition, structure and function at the different levels of biological organization: ecosystem and landscape, community, and population and genetic levels. We evaluated the advantages of selecting and combining indicators of different hierarchical levels by examining several use and management projects. Examples of transformed land like large-scale plantations, perform well when evaluated by ecosystem-level indicators, but lead to neglect of some composition and structure components if evaluated at different levels. Limitations in using a small number of indicators become evident in cases of intensive exploitation of resources, such as the extractive reserves, which yield good results under the ecosystem and community levels, but fail under the population and genetic indicators. Wild species management, a common example of the use of population-level indicators, do not perform well under other indicators at broader scales. We also reviewed projects that are sustainable at different hierarchical levels, like some multispecific exploitation forestry management, in which harvesting of resources is at or below sustainable levels, selective extraction is performed, and where natural regeneration and recruitment of species is allowed. It is evident that the adequacy of indicators is not universal and must take into account the complexity of processes and variables involved in the different biological levels and human components, highlighting possible conflicts and contradictions, while increasing knowledge about maintenance of quality in the use and exploitation of resources that the relevant stakeholders regard as important.

INTRODUCTION

The increasing perturbation of natural ecosystems from anthropogenic sources, including habitat loss, pollution, overharvesting, introduction of exotic species and diverse negative impacts on wildlife, highlights the necessity of developing methodologies for the rapid detection of ecosystem change, as well as for the evaluation of sustainability of use of the different components of biodiversity (1, 2). One approach has been to focus on a set of variates or indicators, which allow detection of change in ecosystems following perturbation and indicate the possible causes of the observed change (3, 4).

The first challenge is to define sustainability. A sustainable process is one that can be maintained indefinitely without progressive diminution of value qualities inside or outside the system in which the process operates or the condition prevails (5, 6). It is the interplay of the ecological, economical and social factors of a given situation, what determines what it is that should be "sustained" (7, 8). This may encompass the whole gamut from the relatively well defined and simple single-species harvesting cases, in which it is assumed that one wants to sustain the target species population at economical levels, up to something as abstract as sustaining "development". In this context, the function of ecological indicators of sustainability is to provide a manageable system of evaluation criteria that can be used by the stakeholders involved, to evaluate whether the management of any particular system is depleting the qualities in which people are interested (9).

Defining and using indicators of sustainability is a challenge because, on the one hand, most managed ecosystems are a mixture of the natural component, forests, fisheries, grasslands and others, and the human component, social, economical, cultural aspects. Thus, they are, thus, complex and poorly understood hierarchically organized systems. The structure and functioning of managed ecosystems is normally described or modelled through variables that tend to be difficult to measure and monitor, and also by using complicated theoretical constructs for their interpretation. On the other hand, the harsh realities of the managed system often preclude the attempt to get very fine and detailed observations of most relevant variables. Lack of time, budgets, human capabilities or combinations of these, imply that a compromise should be found between indicators that fulfil the requirements of ecological science and those that can and will be obtained in the field.

A system of sustainability indicators should take into account existing interactions between different organization levels, from species to ecosystems (10), since a recognized hierarchy of diversity exists among whole ecosystems, at the broadest level, and discrete pieces of genetic information at the molecular level (11, 12). Effects of environmental stresses are expressed in different ways at different levels of biological organization, and effects at one level can be expected to reverberate through other levels, often in unpredictable ways (4, 13, 14). The task is to find adequate indicators of sustainability at these different levels. Our aim in the present document is to propose the use of indicators from the perspective of a hierarchical structure of biodiversity. The selection of a good set of indicators largely depends on being able to find variables that are: *i*) relevant in terms of the biodiversity components and processes being affected by the management; *ii*) sensitive enough to detect an early warning of change; *iii*) easy to measure; and *iv*) amenable to straightforward interpretation.

Following the above ideas, management or use projects were reviewed to illustrate the advantages of selecting and combining indicators of different hierarchical levels. Based on the list of indicators to monitor biodiversity developed by Noss (13), we examined what indicators were used in these projects. A large degree of overlap was found. Some of the indicators proposed by Stork et al. (2) were applied to evaluate the sustainability of the Plan Piloto Forestal in Mexico. This project, considered a good model of forest management, is a community-based exploitation of different tree species of a tropical semideciduous forest. Finally, some preliminary and critical issues are presented that need be considered in the integration of ecological indicators among and within the economic and social factors which, collectively, determine and constitute the actual and future sustainability of biodiversity.

ECOLOGICAL INDICATORS OF SUSTAINABILITY AT DIFFERENT HIERARCHICAL LEVELS

A hierarchical classification of ecological indicators may contribute to better and more complete ways to measure sustainability, taking into account the complexity of processes and the interlinkage of biological systems (10, 15). Consider a hypothetical and simplified example of the harvesting of a single tree species in a forest (example inspired in logging of Mahogany in Bolivia; 16). There will be direct and indirect effects of the harvesting, which will be felt over the whole structure of the ecosystem (Table 1). The logging company has strong incentives to extract all the trees without replanting and then move to another species and so on. This might have specific effects. If one defines the target species and the logging company as the system, and the biological indicator is population numbers of Mahogany in the forest, the harvesting of Mahogany is unsustainable because the system will be managed by quick harvest with no replanting, based on what economics dictates is the best option.

On the other hand, if one defines the system as the whole forest and includes, with the logging company, other stakeholders like local and foreign environmentalists and perhaps the forest dwellers as well, and the indicators are Mahogany (individual) numbers together with indicators of integrity of forest structure and function, community composition, and population dynamics of indicator and keystone species, the harvesting of the forest (for a single component, which is Mahogany), might well be regarded as sustainable. This, despite the fact that in the medium term one of its components will disappear and, in the long term, perhaps even several components will do so. Still, many indicators of the composition, structure and functioning of the forest will remain within acceptable limits for long periods of time.

Is forest harvesting for Mahogany in the above example sustainable? The answer is yes or no or perhaps, depending on the spatial and temporal scales chosen, the elements or processes measured and who are the social actors. The question cannot be decided in the abstract. It is clear, however, that from an ecological point of view, information about the composition, structure and functioning at all levels of organization would allow us to pinpoint some key elements of the forest being transformed radically (Mahogany populations), while many others are not affected at all, or very slowly. A hierarchical set of ecological indicators can be used in a complementary way to provide elements for a decision.

It is clear from the above example that interpretation and value judgements may always be necessary. Often, projects that are regarded as sustainable from a certain perspective, level, or time scale, are unsustainable under other conditions. Characterization of biodiversity that identifies the major components at several levels of organization is necessary. This provides a framework for identifying specific, measurable indicators to monitor change and to assess the sustainable use and conservation of biodiversity. Composition, structure, and function at the different levels of organization are the attributes that determine, and constitute, the biodiversity of an area (13).

The higher the hierarchical level, the more complex the processes involved. Despite the fact that studies about ecosystems have increased, this level remains poorly known, whereas population and community levels are the most often studied (17, 18). However, even at the relatively well known population level, for which there is abundant literature on estimators of abundance, population size or recruitment rates — considered good indicators of population processes — there is an almost universal lack of information about specific cases and examples (17). The breach between this and the next level is enormous and, at the community level, mainly in tropical regions, theory and field data are extremely limited (4).

CASE STUDIES AND THE PERFORMANCE OF ECOLOGICAL INDICATORS

We review some projects under the perspective of the hierarchical classification of ecological indicators of sustainability. The objective is to illustrate the problems of selecting a set of indicators at only one hierarchical level. As in the Mahogany example, the studies and projects most frequently found in the literature are those that are sustainable for some indicators, but unsustainable for others.

There is a continuity from nonuse to intensive use of land. In one extreme we find some wilderness protected areas, and in the other the industrialized and intensive exploitation of resources, such as large-scale plantations of timber, intensive agriculture and fisheries (19, 20). The profound differences inherent in these extremes can render conflicting results when sustainability is being evaluated. For example, a large-scale plantation or large-scale fishery would obviously fail if evaluated by most diversity indicators; however, under a regional (hierarchical) context, if well-planned and integrated with other management regimes, those activities may indeed fulfil an overall view of sustainability. Ecosystem level indicators should be considered first.

Ecosystem and Landscape Level

Changes in the number of total species have been used to assess long-term trends in the conservation of biodiversity and, recently, some experimental studies have provided evidence that reduced diversity may indeed alter the performance of ecosystems (4, 21). Prestcott-Allen and Prescott-Allen (7) identified some general issues and basic assumptions to measure

Table 1. Direct and indirect effects of logging Mahogany trees in Bolivia. Based on Rice et al. (16).

Level	Action	Direct effects	Indirect effects	Sustainability
Ecosystem		Compression of soils; Increase in runoff.		Large-scale forest structure maintained.
Community	Opening of clearings for roads.	Alteration in the gap structure of the forest.	Changes in the recruitment patterns. Changes in the species distributions.	Overall species richness maintained; Changes in composition regarded as acceptable.
Population	Harvesting	Increases in death rate; Decreases in population sizes; Decrease in genetic variation.	Short-term decreases in the growth rates of mutualistic or predators of the target species and increases of competitors.	Number of target species not sustainable because of economic reasons.

sustainability, when considering indicators at the ecosystem level. These include the naturalness or conversion of ecosystems (how much is natural, modified, cultivated or built?); the quality or degradation of the ecosystem (extent and severity of degradation of land, water and air); conservation or depletion of resources supplied by the ecosystems; and the functions and services obtained from ecosystems (consumptive and nonconsumptive resources and values). Ecosystems vary greatly in regard to their resiliency, persistence and resistance, to environmental change, thus monitoring programs should be sensitive to these ecological differences. Such criteria were considered for the formulation of Table 2.

Some authors consider the landscape or regional level different from the ecosystem level (13, 22, 23) and emphasize some particular attributes of this level: *i*) a mosaic of heterogeneous land forms, vegetation types and land uses; *ii*) differences in the amount, distribution and size of patches in the landscape, including both human-created and natural or seminatural types; *iii*) ecotones and species assemblages that change gradually along environmental gradients; and *iv*) interdependence of patches within and among landscapes, through balanced inputs and losses. Despite the fact that, because of their similarities, both the landscape and ecosystem levels can be evaluated using the same indicators (Table 2), there are some important differences in measuring methods and indicators. For example, the gradient-associated assemblages present at the landscape level are often rich in species, but seldom considered in conventional vegetation analysis and community-level conservation (24, 25).

Therefore, sound regional planning should consider indicators for the landscape level such as the kind and size of patches, heterogeneity measures, perimeter-area ratios, and connectivity, because these factors can be major controllers of species composition and abundance, and of population viability for sensitive species (13). This is critical for measuring sustainability that encompasses all levels of biodiversity.

Examples of the uncertainty of using a reduced number of indicators can be appreciated in cases of transformed land such as large-scale plantations. These plantations are often established over extensive areas and characterized by their, relatively, ecological simplicity (19). In general, these projects are assessed *via* ecosystem level indicators which indicate, by structure and function, an increasing soil coverage, prevention of erosion, regulation of the water cycle, restoration of degraded lands, and increments in productivity-biomass and yield (26; Table 2). These indicators have also shown the potential capacity of these plantations in relation to the climate change problem, because of their ability to act as carbon sinks.

Nevertheless, certain processes that can not be fulfilled by plantations are not identified through the consideration of ecosystem-level indicators. These processes might be in direct conflict with a plantation project for which the main purpose is the production of goods. For example, maximizing timber yields usually involves reduction of species diversity through elimination of pests, predators and competitors. Evans (27) has emphasized that, in the tropics, almost 85% of the plantation forestry is dominated by two genera (eucalyptus and pines) and one species (teak); in Chile and New Zealand, production plantations are composed mainly of *Pinus radiata* (28). These examples reveal that the result of focusing only on the productivity (ecosystem function indicators; Table 2) of few elements of a project, can lead to neglect of the composition and structure components, which are integral and essential parts of biodiversity (13).

Community Level

Indicators of community diversity are less developed than species or population indicators (4, 10). Relative abundance, richness, and diversity of species are the most common and are easier to use in measuring characteristics of communities. However, some other ways to measure the diversity of a community are useful for the generation of indicators: the taxonomic richness, i.e. a region containing many closely related species, would rank lower than one containing an equivalent number of distant related species (29, 30). In the absence of good measurements of taxonomic richness, the richness of genera or families may provide a more accurate reflection of species diversity than does the measurement of species richness (30).

The concept of patch dynamics, in which systems are viewed as mosaics or habitat islands, has become a popular theme in both terrestrial and marine literature and has led to new views

Table 2. Indicators of sustainability at different hierarchical levels. Modified from Noss (12).

Level	Composition	Structure	Function
Ecosystem and Landscape	Identity, distribution, richness and proportion of patch (habitat) types; Collective patterns of species distribution; Percentage of area in strictly protected status; Patchiness and habitat fragmentation.	Substrate and soil variables; Slope and aspect; Water and resource availability; Fragmentation and degradation of ecosystems. Connectivity.	Land-use change (land-use conversion rate; grazing gradients); Non-natural degradation (pollutant concentration; acidification; water quality; erosion; salinization; desertification); Biomass and resources productivity; Nutrient cycling rates (carbon cycle); Water regulation; Watershed protection; Soil stabilization; Climate regulation.
Community	Identity, relative abundance, frequency, richness, evenness and diversity of species and guilds; Proportion of endemics, exotics, threatened and endangered species; Life form proportion; Similarity coefficients; Taxonomic richness (genera, families).	Vegetation composition and physiognomy; Foliage density and layering; Horizontal patches; Canopy openness and gaps proportion; Fragmentation and related changes in species diversity.	Herbivore, parasitism and predation rates; Colonization and local extinction rates; Patch dynamics (fine-scale disturbance processes); Recruitment; Succession.
Population and Genetic	Absolute or relative abundance; Frequency; Importance or cover value; Biomass; Density; Number of species used by local people; Allelic diversity; Number of subspecies.	Dispersion; Migration; Range; Population structure (sex ratio, age ratio); Population threatened with extinction, extirpation; Population dynamics of indicator and keystone species; Morphological variability; Allelic/haplotype variability; Heterozygosity; Genetic polymorphism.	Demographic processes (fertility, recruitment rate, survivorship, mortality); Population abundance; Metapopulations dynamics; Life history; Phenology; Loss of genetic variability (Inbreeding/outbreeding rate); Gene flow.

of community structure (31, 32). The fragmentation of a community has significant influence on the numbers and types of species that can be supported. Thus, knowledge of patch processes and the role of humans in fragmenting habitats are essential for dealing with problems like the persistence of rare species and the spread of pests (33). Hence, evaluation of patch dynamics is important to measure trends in the community and landscape levels.

Accordingly, habitat fragmentation and the related changes in a certain area provide good information about changes in species diversity. The theory of island biogeography and particularly the species-area equation, despite warnings to the contrary, may still be the best guide for predicting the consequences of habitat fragmentation on a large scale; e.g. the case of the widespread deforestation in the Amazonian Basin (23, 34). Certain ecological relations such as the curves of richness and abundance of Preston also provide information about the health of the communities, for example, the concentration of a few species with high population numbers indicates a clear reduction of species diversity. However, these are notoriously difficult to obtain on a regular basis.

Physical habitat measures and resources inventories also are necessary in order to monitor changes in structure and function of communities. These include vegetation composition and physiognomy, herbivory and predation rates, colonization and extinction rates, as well as diversity of guilds, comparative distribution of top predators, pollinators, fruit dispersers and proportions of endemic, exotic, threatened and endangered species, among others (13). Identification of areas of maximum geographic overlap of endemic species, of areas of concentrated biodiversity or at high risk of impoverishment, can be obtained through these indicators, which also have direct application in protection efforts, like prioritizing the selection of locations for conservation action and research (35).

When we move from low use to intensive exploitation of resources, the limitations of using a reduced number of ecological sustainability indicators are more evident. A clear example is found in the extractive reserves, which were created as an alternative to the intense destruction of tropical forests (36). In Alto Jurua and Chico Mendez Extractive Reserves, Brazil, protected forest areas are combined with zones for small-scale agriculture and agroforestry systems (36). As a result, additional values through local forest-products processing enterprises, have helped to enhance the quality of life of the local “siringueiros” and to establish bases for protection of natural resources. However, the viability of these reserves has been recently debated and criticized, mainly because of the consequences of human population settlements on other components of biodiversity. The rubber taper groups that live in the extractive reserves of Amazonia have had major impacts on wild animals and, therefore, on diversity as a whole (37).

The indicators for overall forest structure and composition of most plant and invertebrate guilds will probably be satisfactory. However, it will most likely fail for abundance of large vertebrate species. The system appears to function correctly at the ecosystem and community levels (indicators of structure and function mainly) and biodiversity in general is maintained but, when indicators at the population and genetic levels are explored, it becomes evident that some species (key and indicator species) are being lost, along with part of the genetic variability of these animal populations.

Population and Genetic Levels

The most useful and common indicator of status and trends in populations is number, ideally as a time series. At this level, ecological indicators tend to center on monitoring changes in population size and structure (sex and age ratios) and less often to evaluate demographic processes (fertility, survivorship, mortality) and the natural or induced dynamics of the habitat that directly affect populations (7).

Typical examples of the use of indicators at a population level are the projects of wild species management. Monitoring changes in population numbers, sex and age ratios, of hunted or harvested species, is the tool most often applied to evaluate the sustainability of the projects (38, 39). Monitoring demographic changes of keystone species has been an extended method for measuring sustainability; these species are recognized as playing a major role in maintaining ecosystem structure and integrity. Similarly, ecological indicator species that adapt to changes in specific environmental factors, which may be correlated with that of several or many other species, have been used to monitor sustainability (4, 40; Table 2). This, despite the fact that the concept of indicator species has been criticized (41, 42).

However, there are some examples of wildlife management projects which perform well when using population level indicators, but fail under other indicators at broader scales, like maintenance of habitat, habitat fragmentation and corridors. An interesting example is the Campfire (Communal Areas Management Programme for Indigenous Resources) in Zimbawe. The policy views wildlife as a renewable resource, with special attributes that are used to enhance rural productivity for the benefit of landholders, their communities and the state (43). Sustainable exploitation of certain animal species has discouraged local habitat destruction, while the *per capita* income of many villages has increased. However, the destruction of the surrounding areas is a threat to this project that needs be considered in an integral evaluation. The project resorts mainly to indicators of population and community levels (some species of wildlife), as well as some economic variables, but lacks evaluation at the ecosystem level. Metapopulation dynamics, patch structure, edge and area effects, could render the project unsustainable in the medium or long-term (Table 2).

Metapopulation models, in which systems are viewed as a complex of interacting populations of local demes, have been shown to be important in conservation biology. These models have become the focus of considerable theoretical efforts to understand the role that the metapopulation structure plays in facilitating the coexistence of species (44, 45). In this sense, indicators of metapopulation dynamics are another important issue to take into account when measuring sustainability (Table 2). However, since obtaining single-population data is complicated and time consuming, monitoring metapopulations beyond the simplest measures of incidence most likely would multiply the effort and may render the task impossible.

Population fluctuation and size measures do not make sense without reference to their natural spatial and temporal scales (46); understanding how variability is associated with area and time period is fundamental to defining and measuring sustainability. Therefore, achieving sustainability requires characterization of the natural patterns of variability within an ecosystem or landscape and understanding what biotic and abiotic processes are fundamental for their maintenance. Particularly in the case of wild species, monitoring processes at both community and ecosystem levels are essential to an understanding of population dynamics (31).

Indicators of sustainability at a genetic level have been less developed (47). Interest in measuring and conserving genetic resources has centered on zoo populations of rare species, as well as on agricultural or commercial species, which encompass economically useful and heritable characteristics (13). Nevertheless, there is an increasing interest in evaluating genetic variation of noncommercial species, together with the combining of phylogenetic and biogeographical approaches. This has immediate and practical applications for some valuable species, for designing captive breeding programs for rare species, and for identifying groups of populations that have been historically isolated. This will allow us to define or delimit regions worth protecting (47, 48).

ADEQUACY OF THE USE OF A HIERARCHICAL EVALUATION

Projects that appear to be sustainable at different hierarchical levels can also be found. Most of these are regions of low human population density, low human population growth and, in general, low pressure on natural resources (9). Most of these projects are developed at local scales, involve management of one or a few species, or encompass relatively simple ecosystems (6, 38, 39).

The typical case is the fur trapping in Yukon, Canada (38). The Yukon Territory consists of arctic and alpine tundra and boreal forest, where most of the ecosystem is undisturbed. Fourteen species of mammals are trapped, and the furs are sold on the national and international fur markets, or are used locally for clothing and for the cottage garment industry. Trapping methods in Yukon are managed through a system of Registered Trapping Concession (RTCs) and cover 93% of the territory. Population level indicators, such as monitoring of catch per unit effort, changes in relative abundance, and sex and age structure, all are sensitive enough to ensure that the harvest is at or below sustainable levels. In addition, the boreal forest ecosystem is resilient to various "catastrophes" such as fires, and trapping has negligible impact relative to these events. The harvest is slow enough to ensure that components at other hierarchical levels are unaffected.

Another example is forest management in the Peruvian Amazon (49). The Yanesha Forestry Cooperative (COFYAL) is using a strip-cutting technique, which permits the sustained production of timber from virtually all tree species and also simulates the gap-phase dynamics of natural forests, thus promoting natural regeneration of hundreds of native tree species. An interesting aspect of natural regeneration is the appearance of rare tree species. Again, in this case it seems that the different levels are maintained, but a more complete census of different indicators is needed to corroborate overall sustainability, like human impact indicators (ecosystem level; Table 2). Accordingly, indigenous forest people have developed techniques that allow them to live using the forest while conserving the resources they exploit. However, when population densities exceed certain levels, the sustainable practices of indigenous people cannot be maintained.

Nevertheless, as in many similar cases in the developing world, long-term biological, social and economic indicators of sustainability are lacking and the evidence for sustainability is anecdotal or by comparison with nearby obvious failures. In the previous forest example, when other population indicators are examined like medium-size mammal population trends, abundance declines may become evident, which in turn may indicate some degree of unsustainability.

Plan Piloto Forestal, Quintana Roo, Mexico

The Plan Piloto Forestal, a multispecific exploitation of tropical forest in Quintana Roo, Mexico (50, 51) is an interesting real case to evaluate the set of indicators and verifiers proposed by Stork et al. (2), which are arranged according to a hierarchical structure and designed to be easily obtained by nonexperts. It also is appropriate for a comparison with the forest management of the Mahogany exploitation in the Bolivian forests.

The Plan Piloto involves much of the semideciduous tropical forest ecosystem of southern Quintana Roo. The area is distributed in ejidos (common-property lands), where people have a tradition of exploitation of natural products like the chicle (*Manilkara zapota*), a tree used by the Mayan Indians for various purposes. Approximately 23-years ago, a group of 12 ejidos (with areas between 1000 to 70 000 ha) decided to join a tropical forestry project, technically supported by foreign financial aid through the German GTZ. Forest management is done by selective logging of nearly 15 species; the principal harvested species are Mahogany and Cedar. The activities related to logging in these forests are basically small-scale clearcutting (1–10 ha clearcutting areas called "vacadillas"), road construction and plantation of some species. Many of the ejidos have maintained a large proportion of forest (ca 50%). Although the original structure of the forest is being altered, (the "vacadillas" are managed on projected cycles of 25–50 years and after clearcutting they are replanted with the commercial species), plots have a very significant recruitment of other tree species due to the presence of birds and bats in the nearby forest.

The harvesting of Mahogany and other commercial trees in Quintana Roo, as in the Mahogany case of Bolivia, seems to be sustainable at the community and ecosystem levels. Accordingly, most of the indicators of landscape pattern, habitat structure, guild structure and taxic richness and composition, proposed by Stork et al. (2), fulfil the criteria of sustainability (Table 3). However, the forest activity performed in Quintana Roo, particularly the Mahogany (*Swietenia macrophyla*) exploitation is, presumably, unsustainable at the population structure level. That is, current levels and methods of harvesting could eventually lead to a level of regeneration and repopulation that will not allow the replacement of the volume of Mahogany being harvested during the actual cutting cycle. Some indicators at the population level show that *S. macrophyla* is sensitive to the selective logging promoted by the Plan Piloto Forestal.

An important difference between the logging of this species in Bolivia and Quintana Roo is the actual perception of the Mahogany system by the forest owners. Whereas the Bolivian logging company is exclusively interested in the commercial species, the ejidatarios visualize the whole forest as the system. This contrasting perception translates into some important discrepancies in the way the owners face the system: the diversification of the exploited resources of the Quintana Roo ejidatarios *versus* the dominant monoexploitation of the forest practiced by the Bolivian company.

CONCLUSIONS

Regardless of the level considered, the adequacy of indicators depends strongly on the characteristics of every particular system. They must take into account the complexity of processes and variables that are involved in the different biological levels and human components. Consequently, indicators should be developed from an understanding of the different hierarchical levels of biodiversity and the processes that link them to human activities and economic and social factors.

A new view of the evaluation of sustainability should consider indicators, rather than providing theoretically satisfying measures of all relevant variables, as having the advantage of highlighting possible contradictions and conflicts. The Mahogany example was developed to illustrate that to a certain extent the "quality" of a system is in the eyes of the beholder and, therefore, what is to be sustained should be a matter of agreement between the principal stakeholders of a project. Since there are different stakeholders at different levels, conflicts of perception are to be expected and a variety of indicators will be required to display the contrasting views of the different participants.

Of course, since any ecological system has dynamics determined by biophysical and economical laws and constraints of the processes, stakeholders may sometimes attempt to maintain qualities that are incompatible with either the natural or the anthropogenic dynamics of the system. Because scientists, econo-

Table 3. Evaluation of the sustainability of the Plan Piloto Forestal (Quintana Roo, Mexico) applying the method proposal by Stork et al. (2).

Indicators of process	Primary verifiers	Plan Piloto
Landscape is maintained	1. Area Extent of each vegetation type	1. 5–10% of the original forest cover has been opened (roads, harvest) in the Permanent Forest Areas (PFA)[1]
	2. Number of patches per unit area	2. Except the PFA, forest cover has been maintained[*1]
	3. Contagion	3. Patches are linked by natural vegetation[1]
	4. Dominance	4. No significant changes in the dominance of vegetation type[1]
Changes in habitat diversity which have critical limits	1. Vertical structure	1. Canopy height (stem diameter) has been maintained[1]
	2. Size class structure (SCS)	2. Tree stem diameters at breast height is managed in the PFA. After a complete cutting cycle (75 years) the forest structure is recovered[1]
	3. Canopy openness	3. Openness in the canopy has been large enough to prevent mahogany trees reaching the canopy[1]
	4. Standing and fallen dead wood	4. Much more standing than fallen dead wood in PFA
Community guild structure do not show significant changes	1. Relative abundance of tree species of different guilds	1. Abundance of mahogany and cedar are decreasing, compared to rare and not harvested species, specially in the PFA[6]
	2. The abundance of selected avian guilds	2. No significant changes[2]
Richness/Diversity show no significant changes	1. Species richness reported by local people	1. No significant changes[1]
	2. Number of large butterfly species	2. No significant changes[3]
Population size/structure do not show significant changes	1. Measures of the population size of selected species	1. Mahogany and cedar are regenerating slower than expected, specially in the PFA[4, 5].
	2. Age or size structure	2. Growth rates are slower that expected[2]
Decomposition and nutrient cycling show no significant change	1. Diameter and high/length of all standing and lying dead wood	1. Diameters of mahogany and cedar are narrower than expected
	2. Depth of litter	2. No significant changes

*The evaluation of these verifiers is only qualitative.
[1] Kiernan & Freese (51); [2] Snook (52); [3] de la Maza pers. comm.; [4] Snook (53); [5] Snook (54);
[6] Lynch and Whigham (55)

mists and managers normally do not fully understand the dynamics of managed natural systems, and cannot obtain measures of all the relevant variables, indicators have to be selected and interpreted with great care.

The scarcity of scientific and technical information about natural systems, particularly those in the developing countries where the most diverse and threatened habitats and organisms are found, makes the task of selecting and using indicators difficult. The selection of the correct set of sustainable-use indicators should be guided by a realistic acceptance that simple and easy to obtain indicators are the ones most likely to be regularly obtained. However, simple indicators can never be expected to provide the depth and richness of information that direct measures of the relevant variables would do.

Since the use of simple indicators is unavoidable, it would be of the utmost importance to find, perhaps under guidance of the Biodiversity Convention, at least some long-term projects of sustainable use, in which a suite of ecological and social variables was measured as extensively as possible, together with the kind of rough and simple indicators more likely to be of practical use by nonecologists. This would provide very valuable information about their calibration and assessment. Without this kind of study, the use of indicators will never be more than a sibylline exercise.

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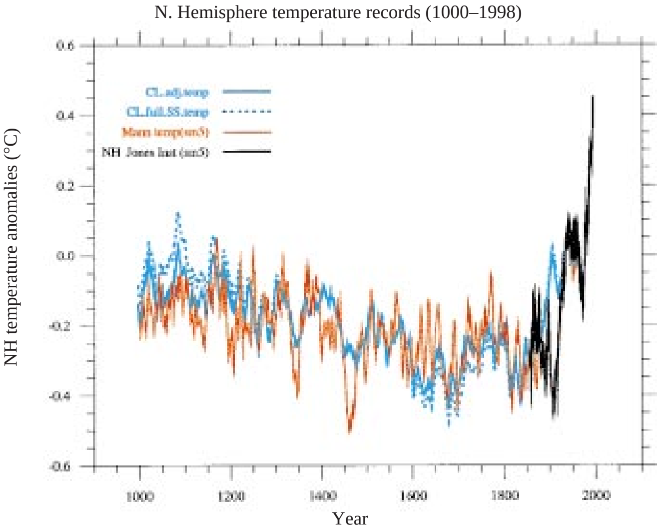
Errata

Ambio XXIX, No.1, 2000, pp 51-54.
The temperature scale on the y axis of Figure 4, page 53 was inadvertently omitted from the Figure in the article by Crowley, T.J. and Lowery, T.S.

Figure 4. Comparison of mean annual temperature records (Fig. 2) from this study with 5-pt. Smoothed Mann et al. (10) reconstruction and the Jones et al. (31) Northern Hemispheric instrumental temperature record. CL.adj.temp refers to the baseline composite adjusted to the Jones et al. record (see text); CL.full.SS.temp refers to all time series in the CL composite, with the Sargasso Sea (SS) record adjusted slightly in chronology to agree better with maximum warming in the hemispheric composite (again see text for details).



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