Tropical forest resources and biodiversity the risks of forest loss and degradation

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In an analysis of current approaches to assessing the effects of deforestation on biodiversity, this article re-examine's the concept of biodiversity in the light of recent advances in ecological theory and outlines a rational framework for applying the concept of risk analysis to the assessment and reduction of the negative impacts of tropical deforestation on biodiversity. A broader perspective is suggested which stresses ecosystem function as well as biodiversity, the need to integrate ecological, economic and social values when assessing the impacts of deforestation and the prospects for conservation and sustainable use.

Much of the emphasis in biodiversity conservation is placed on species (often particular, charismatic, endangered species), especially when projecting losses and taking protective measures; however, the species category represents just one level of diversity. Biodiversity also consists of variety and variability at higher and lower levels of biological organization among ecosystems or habitats and within species.

Yet only a very general characterization of the types and variety of ecosystems and organisms that exist in forests is possible at present (World Conservation Monitoring Centre [WCMC], 1992). At the genetic level, despite an impressive increase in knowledge of forest genetics (Namkoong, 1986), characterization of genetic variability within species has been carried out for only a few hundred of the hundreds of thousands of species that exist. The geographic distribution of ecosystem or habitat types, species and genetic diversity is only known in terms of very broad patterns for the tropics as a whole, with detailed survey information on any of these levels existing for a relatively small number of forest sites.

Scientific knowledge of patterns and processes in tropical forest biodiversity has advanced significantly in recent years. The results of the Forest Resources Assessment 1990 Project for tropical countries (FAO, 1993), for instance, added significantly to our knowledge of the status of the world's tropical forests. Benefiting from the experience of the previous global assessment (FAO, 1982), the 1990 assessment used refined methodologies that allowed a revision of the 1980 estimates as well as providing estimates of the 1990 status and rates of change in forest cover for 90 countries within the tropical forest zone. The assessment also took advantage of the increasing availability and the improved scale of resolution of satellite imagery and applied new analytical tools for estimating biomass, fragmentation and risks to biodiversity in order to better our understanding of the implications of degradation and forest cover loss.

However, very large information gaps remain in the geographic distribution of elements and their correspondence to forest impacts, thus preventing a reliable estimation of biodiversity losses. Even if such spatial information were known, the highly variable responses of species to habitat loss and degradation cannot be accurately calculated on even a relatively small scale, let alone globally. The use of mathematical expressions relating the number of species supported to the amount of habitat area, while employing species area models of proven generality, fails to reduce this uncertainty (Lugo, Parrotta and Brown, 1993). The resulting estimates, which are in the range of 3 to 10 percent of total species loss based on tropical deforestation projections to the year 2000, require numerous assumptions whose validity is essentially untestable (Whitmore and Sayer, 1992). Nor do these models account for the loss of biodiversity at either the habitat or genetic levels, which means there is a risk of underestimating the negative impact of forest habitat loss on element diversity in general. Moreover, the information obtained provides little guidance *per se* on conservation or sustainable use strategies.

There is no doubt that deforestation in tropical regions is threatening or eliminating numerous tropical forest ecosystems, species and genetically unique populations (WCMC, 1992), including valuable tropical forest genetic resources (FAO, 1990). The priority identification and programmatic focus of numerous international agencies and non-governmental organizations (NGOs) include a long and growing list of threatened habitats and species in the tropics. However, the meaning and value of biodiversity extends well beyond threatened elements to include its functional role and perceived value on all geographic and institutional scales, regardless of degree of uniqueness, rarity or present-level threat.

New perspectives on complexity and biodiversity

Forest ecologists have long recognized the mutual interaction between geometric structures of organisms, habitats and their functions. Al so referred to as "pattern and process", such relationships considered on different spatial and temporal scales are deemed essential in the determination of the importance of different factors in vegetation change (Soloman and Shugart, 1993). A three-way interaction between the components (elements), structure and function is necessary for developing biodiversity assessment indicators. Dominant features and important factors can be defined according to different spatial scales (regional landscapes, ecological communities, local sites) and levels (ecosystem, species, population and genetic) of bio-diversity (Noss, 1990). Different institutional or management scales (international, national, district, community) can be added to this scheme as a third dimension (FAO, 1994).

An element-focused perspective, particularly one based solely on the species category, presents major data limitations and also ignores a large and growing body of information, especially regarding indirect effects on element diversity resulting from changes in ecosystem structure and function brought about by forest loss and degradation. In general, recent scientific findings call for a broader view of biodiversity that considers variety and variability of elements in terms of their interaction with "pattern and process" on different spatial and temporal scales. It has become apparent, for example, that the remarkably high diversity of tropical rain forest trees is the consequence of the continuous disturbance of non-contiguous areas resulting in a mosaic pattern. Likewise, the ecotypic variation that underlies many of the most important forest tree gene resources is maintained by, and represents, patterns of environmental variation throughout a forest landscape or region. Patterns of variation in environment and landscape may be good measures of biodiversity and are practically and efficiently measurable using ground survey or remote sensing techniques.

Biodiversity and end-use values

Forest resources, like all resources produced by living systems, are renewable provided their "biological capital" remains intact. This capital includes goods and services provided by the growing stock, for example timber or watershed protection, and also overall variety and variability. Although there is a danger of reducing the complexity of the human-forest codependency to a purely economic or production perspective, the consequences of deforestation and human dependency on forest ecosystems can be most clearly assessed and presented using the concepts of risk, cost and benefit. Using a production system view of forest ecosystems (Fig. 1), the risks, costs and benefits of forest conversion or conservation can be related on the basis of the "use" and "non-use" values of biodiversity. Use values consist of direct productive benefits, such as wood and non-wood products, and indirect functional benefits. The latter include a positive impact on the biosphere, the maintenance and regulation of hydrological functions affecting local climate, hydroelectric energy and water resources and transportation as well as crop protection, nutrient cycling, in situ conservation of genetic resources and others. Non-use values are "intrinsic" to a species or habitat, based on cultural, aesthetic and spiritual perspectives. The monetary value of many of these benefits can be estimated and, when it is, the contribution of such benefits to local and national economies can usually be shown to be far greater than other forest land uses (Pearce, Moran and Fripp, 1994).

Notwithstanding the previous discussion, the real value of biodiversity eludes quantification in monetary or other terms, as difficulties of measurement and unrecognizable benefits, such as indirect productive benefits or the biodiversity attributes and elements on which species of productive and functional value depend for growth and reproduction are not taken into account. In tropical forests, such elements include birds and mammals responsible for the pollination and seed dispersal of many of the highly valued hardwood species, as well as other plant species serving as their source of food and protection. Moreover, quantification criteria do not consider the changing needs or wants of future generations.

More difficult to measure yet are the attributes of variety and variability that contribute to the ecological resilience, evolutionary potential and, consequently, the sustainability of forest ecosystems. These "indirect contributory benefits" are represented by attributes of biodiversity that enhance or are responsible for processes operating at every level (Wilcox, 1994). The heterogeneous forest landscape mosaic buffers against the effects of natural threats such as inclement weather and pest outbreaks. Species competition and redundancy within ecosystems enhances species fitness and helps ensure the resilience and genetic survival of a species in the face of environmental stresses of human and natural origin.

Although it is not certain how much variety and variability is necessary to provide specific goods and services, methods do exist to estimate requirements for maintaining the viability of valued plant and animal populations (Soulé, 1987) as well as the integrity of the underlying natural ecosystem (Karr, 1994). Recent research findings suggest that a high degree of redundancy exists in the functional assemblages of species-rich ecosystems (Schulze and Mooney, 1993). However, some functional groups consist of only one species which thereby acts as a "keystone", often supporting a web of numerous other species within an ecological community.

FIGURE 1 Production system view of biodiversity

[1] Attributes include ecological complexity and diversity (including functional redundancy) at the species and genetic levels, constituting the "variety and variability" necessary for sustaining production inputs and valued outputs.
[2] Basic requirements include food webs, trophic relationships, fixation of energy and nutrients and biogeochemical cycles.
[3] Outputs include "direct output benefits" (goods), "indirect functional benefits" (services) and species of intrinsic value.

> *Note:* Nearly all the biological diversity in an ecosystem plays an indirect contributory role by buffering the system from anthropic or natural stress (maintenance inputs) or by providing the immediate energy and material requirements. These maintenance and production inputs are the basis for providing valued outputs on a sustained basis.

In terms of assessment and management, it is obvious that a few "structuring" species and processes are critical for the maintenance of both direct and indirect use as well as non-use values of forest biodiversity. These structuring factors include, for example, the physical structure provided by dominant canopy trees, or "structure" in the sense of food webs or mutualistic interactions involving animals and fruit bearing trees or nectar-bearing plants. Keystone structuring factors also include animals such as elephants or beavers or physical agents such as fire which significantly disturb or restructure the environment (Bond, 1993).

Particularly significant is the relationship of the tropical forest fauna on tree diversity. Changes in the composition or diversity of fruit- and seed-eating species can influence tree species diversity, even affecting the regeneration of commercially valuable hardwoods (Bawa et al., 1989). The effects of depressed mammalian diversity on fruit fall is directly observable (Dirzo and Miranda, 1990) and the reduction of large predators, typically the most vulnerable to large-scale habitat losses, differentially influences the densities of fruit- and seedeating mammals and, consequently, the regeneration of large seeded canopy trees (Terborgh, 1992). Therefore, the general decline in faunal diversity of tropical forests is likely to have broad although delayed impacts, of which the consequences for overall biodiversity in tropical forests could be dramatic. A strong argument can also be made for the importance of maintaining the diversity of plant-eating insects, as well as invertebrates in general, to ensure the continued evolution and diversification of plant species, including the maintenance of genetic resources (Brown, 1987).

Tropical deforestation and biodiversity loss

As already emphasized, the biodiversity risks associated with deforestation are often approached from the standpoint of species loss. Of equal relevance are deforestation effects on ecosystem function, affecting both the biological and utility values requiring the maintenance of ecological integrity. As discussed, estimating the effects of deforestation on species loss is problematical for a variety of reasons. For example, models relating species extinction to habitat loss show a sharply increasing rate of species loss only after about two-thirds of the original habitat is lost (FAO, 1994; Tilman, May and Nowak, 1994). However, these models fail to consider the effects of deforestation on ecosystem function, which may come into play on a more significant level well before two-thirds of original forest cover of an ecosystem is lost. Moreover, an analysis of forest cover indicates that most regions have already lost over two-thirds of their original cover (Table l). In this regard, more significant than species loss *per se* is the general "biotic impoverishment" that accompanies forest ecosystem degradation (Fig. 2).

Biodiversity and the risks, costs and benefits associated with the state of and change in forest cover are most meaningfully assessed in the context of maintaining biotic integrity or ecosystem health and avoiding biotic impoverishment. A healthy forest ecosystem - where biotic integrity is maintained -can be characterized as a system that: has realized its inherent potential: is in a stable condition and its capacity for self-repair when perturbed (stressed) is preserved; and requires minimal external management "inputs". Biodiversity and biotic integrity are mutually interdependent and both are placed at risk or diminished by deforestation (Rapport, Regier and Hutchison, 1985). Stress and the response to stress have a potential negative impact on biotic integrity and biodiversity, resulting in a syndrome of effects associated with ecosystem degradation and leading to biotic impoverishment (Fig. 2).

Stress, response, impact and the degree of biotic impoverishment are all detectable with appropriate indicators.

TABLE. Regional comparison of percentage of original forest remaining in 1990

Region	Original forest[1]	1990 forest[2]	Original forest remaining in 1990
	('000 ha)		*(%)*
Asia			
South Asia	311722	61150	20
Continental			
Southeast			
Asia	189609	75 197	40
Insular			
Southeast			
Asia	244140	135349	60
Latin America			
Central America	176744	66673	40
South America	1 278371	802716	60
Africa			
West Sahelian Africa	145667	40750	30
East Sahelian Africa	251 973	64631	30
West Africa	200566	55607	30
Central Africa	394 837	204112	50
Tropical Africa	457249	143297	30
Insular Africa	116508	15782	10

[1] Olson, Watts and Allison 11955).

[2] FAO data.

Note: Original forest" area estimates are based on the digital map of Olson, Watts and Allison (1985). These were checked against other estimates, based on a combination of bioclimatic mapping, remote sensing and ground truthing, and were found to be the most conservative and accurate, despite the general inadequacies of all existing global vegetation data sets Original forest cover is a hypothetical concept which attempts to approximate prehistoric conditions but assumes that climate and other physical and biotic conditions that prevailed prehistorically are the same today. Data quality, resolution and interpretation of digital map data in terms of vegetation and geopolitical boundaries make the numerical estimates unreliable within plus or minus 20 percent. However, the values or "Original forest remaining . which have been rounded to the scares' 10 percent, are highly likely to reflect the true level of forest area relative to that which would exist in the absence of humans.

Response by or change in the structure or composition of ecosystems (species composition) tend to be more useful as early warning indicators of stress than functional changes (e.g. nutrient cycling).

In the strict analytical sense, risk assessment involves the identification of risks or hazards and the estimation of their probability of occurrence. Thus, biodiversity risk assessment requires the specification of an undesired consequence or end-point. Typical undesirable end-points in this sense are the loss of valued components or outputs of biodiversity. Therefore, biodiversity risk may be defined as a situation with potentially undesirable consequences causing a change in the variety or variability among and within ecosystems, species, populations and individual organisms.

Whether a particular level of forest degradation and biotic impoverishment represents risk in a societal sense depends to a certain degree on the values and preferences held by the particular users of a forest or by the beneficiaries of the flow of forest goods and services. Thus, the assessment of biodiversity risk actually involves two distinct levels. One is the determination of the effect of anthropic stress on biotic integrity. The other is the determination of the effect on society of biotic impoverishment, and the long-term diminution of the use and non-use values flowing from ecosystems.

Risk management and mitigation

Consideration of the causal relationships between deforestation, ecosystem function and biodiversity reveals that a number of factors are involved in ecosystem degradation and biotic impoverishment. Some of these are dependent as much on the patterns of deforestation and modes of forest utilization as on the total amount of forest habitat loss. Thus, opportunities may often exist to mitigate the worst effects of forest loss through the maintenance of buffers' corridors and large blocks of natural forest as well as through ecological restoration and reforestation. Specific mitigation measures can be described to conserve local, landscape or regional-level structural or functional attributes that are disrupted by forest habitat loss and fragmentation.

FIGURE 2 Model of forest ecosystem degradation

Sources of stress on a forest ecosystem may include:

- overharvesting of renewable resources
- pollution
- physical restructuring
- exotic species
- natural variation

Source: Rapport, Regier and Hutchison (1985).
Source of graphic: Modified from Jordan (1985).

The general process of forest ecosystem degradation, also termed ecological retrogression by some ecologists, is accompanied by:

- reduction in species diversity
- depletion in the nutrient pool
- change in structure from forest towards hardy shrubs and herbs
- decrease in complexity of relationships between species
- decrease in primary productivity Source: Woodwell (1967; 1970).

There is always a danger in the reductionism that attends risk assessment. An excessive focus on detailed mechanisms and direct causal links can result in losing sight of facts that are obvious and can be known with certainty. During the past two to three decades, forest cover in tropical countries has been lost at an unprecedented rate. Although comparable rates of deforestation have occurred locally and regionally in the past (Williams, 1990), the large geographical scale and short time frame are unparalleled. Moreover, the greater rainfall, solar radiation and direct dependence of local people for sustenance heightens the ecological, social and economic consequences of deforestation in tropical countries. In combination with equally unparalleled historic increases in carbon dioxide emissions in the industrialized countries, tropical deforestation aggravates the risk of global climate change (both through the release of carbon dioxide through the burning of forest vegetation and increased albedo or solar reflectance). The latter has the additional effect of producing local and regional drying and warming trends, making the natural and even human-assisted recovery of forest land problematic.

Many forms of human activity and production are compatible with and based on the maintenance of forests, including its indigenous biodiversity. The sustainable exploitation of renewable forest resources and the rearrangement of stocks and their underlying variety and variability does not necessarily diminish their biological capital. In fact, accelerating the sustainable development of forest resources in developing countries. including the conversion of previously undisturbed forest to managed productive forest, in order to raise living standards and break the cycle of poverty and environmental degradation may be the best way to maximize biodiversity conservation in many developing countries. The total amount of natural forest required to "capture" areas with the highest indigenous species richness, endemism and forest genetic resources is probably relatively small, as long as the total forest cover remains adequate to maintain functional and structural properties of a regional forest ecosystem or landscape.

An appraisal of our current experience suggests the maintenance of 75 to 90 percent of current forest cover is probably necessary to maintain the stability of local and global ecological functions (Woodwell, 1993). This requirement could be met with well-managed forest landscape mosaics of natural forest, plantation, agroforestry, shelterbelts and other formations. However, even retaining this amount of forest cover does not guarantee the health and sustainability of a regional forest ecosystem, including the maintenance of resilience and adaptability. This requires specific attention to the conditions required for maintaining biodiversity attributes with a contributory value in managed and unmanaged forest. This, in turn, requires a rational framework for forest land-use policy and planning, based on a full accounting of the use and non-use values of forests.

Although the rapidly increasing knowledge of ecosystem function and biodiversity affords a greater opportunity to achieve sustainable forest resource use, this same knowledge reveals that the current trends and patterns of deforestation are unequivocally negative. Quantitative rules of thumb relating forest cover to ecosystem function and biodiversity are too general to predict specific levels of degradation or impoverishment reliably when applied on a large scale (e.g. regionally), but they are adequate to indicate that the reduction of forest loss in all but a minority of tropical forest countries is severe and, in some, even catastrophic.

However, a corresponding disastrous loss of tropical forest biodiversity - at a level jeopardizing the essential role of forests in society - is not a foregone conclusion. Ecological theory also suggests that the erosion of biodiversity lags behind forest loss and fragmentation, and the possibility exists for a reversal of conditions that have previously led to unsustainable forest use. These trends could grow rapidly enough to result in a stabilization and, conceivably, a net increase in forest cover in some tropical forest countries within one or two decades.

Conclusion

The concern for tropical forest biodiversity and its assessment in the light of the current high rates of tropical forest loss requires a broad-based, rational approach to direct strategic priorities for conservation and sustainable development. This approach should stress what is scientifically known about biodiversity, including the important role of its structural and functional attributes, but it should also take into account what is not known and what may take too long and be too costly to find out. Despite the large information gaps, an impressive amount of knowledge exists to form a basis for such rational action. Much of this knowledge has been accumulated and synthesized quite recently and this consists of conceptual and methodological approaches to assessing: i) the relative values and benefits of different attributes and elements of biodiversity; ii) the role of biodiversity in ecosystem function; iii) relationships between elements and critical structural and functional aspects of biodiversity; iv) ecosystem patterns and processes at different spatial and temporal scales that influence biodiversity; and v) modes and patterns of land and forest use consistent with the conservation and sustainable management of tropical forest biodiversity. Taken together, this information is adequate to provide a basic framework for assessing the potential risks associated with deforestation and to indicate approaches to their mitigation.

For many countries, however, the demands on forests for fuelwood consumption and cropland are such that policy-makers and forest managers alike face the unprecedented challenge of stabilizing forest area before nearly all original forest is lost and significant amounts of indigenous biodiversity are extinguished.

Bibliography

Bawa, K.S., Ashton, P.S., Primack, RB. Terborgh, J., Salleh, M.N., Ng, F.S.P. & Hadley, M. 1989. *Reproductive ecology of tropical forest plants: research insights and management implications*. Paris, IUBS.

Bond, W.J. 1993. Keystone species. In E.-D. Schulze & H.A. Mooney. eds. *Biodiversity and ecosystem function*, p. 237-253. New York Springer.

Brown Jr, K.S. 1987. O paper dos consumidores na conservacão e no manejo de recursos genéticos florestais in situ. *IPEF*, 35: 61 -69.

Dirzo, R. & Miranda, A. 1990 Contemporary neotropical defaunation and forest structure function, and diversity - a sequel to John Terborgh. *Conserv, Biol*., 4(4): 444-447.

FAO. 1982. *Tropical forest resources.* FAO Forestry Paper No. 30 Rome, FAO/UNEP

FAO. 1990. *Report of the FAO Panel of Experts on Forest Gene Resources. Seventh Session*, 4-6 December 1989, Rome.

FAO. 1993. *Forest resources assessment 1990: tropical countries*. FAO Forestry Paper No. 112. Rome.

FAO. 1994. *Tropical deforestation and the loss of biological diversity: assessing the risks*. Rome.

Franklin, J.F. 1992. Scientific basis for new perspectives in forests and streams. In R.J. Naiman. ed. *Watershed management: balancing sustainability and environmental change,.* p. 25-72. New York, Springer.

Jordan, C.F. 1985. *Nutrient cycling in tropical forest ecosystems.* Chichester, UK Wiley

Karr, J.R. 1992. Ecological integrity: protecting earth's life support systems. In R. Costanza, B.G. Norton & B.D. Haskell, eds. *Ecosystem health: new goals for environmental management.* Washington, DC, Island Press.

Karr, J.R. 1994. Landscapes and management for ecological integrity. In K.C Kim & R.D. Weaver, eds. *Biodiversity and landscape: a paradox for humanity.* New York, Cambridge University Press.

Lugo, A.E., Parrotta, J.A. & Brown, S. 1993. Loss in species caused by tropical deforestation and their recovery through management *Ambio,* 22(2-3): 106-109.

Namkoong, G. 1986. Genetics and the forests of the future. *Unasylva*, 381152): 2-18.

Nepstad, D.C. & Schwartzman, S., eds. 1992. *Non-timber products from tropical forests: evaluation of a conservation and development strategy. Advances in economic botany*, Vol. 9. New York, New York Botanical Garden.

Nepstad, D.C., de Carvalho, C.R., Davidson, P., Jipp, H., Lefebvre, P.A., Hebreiros, G.H. & da Silva, E.D. *The deep-soil link between water and carbon cycles of Amazonian forests and pastures.* Woods Hole Research Center/EMBRAPA-CPATU, University of California, Irvine, USA. (in press)

Noss, R.F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. *Conserv. Biol*., 4(4): 355-364.

Olson, J., Watts, J.A. & Allison, L.J. 1985. *Major world ecosystem complexes ranked by carbon in live vegetation: a database, NDP-017* Oak Ridge, Tenn., USA. Oak Ridge National Laboratory.

Pearce, D., Moran, D. & Fripp, E. 1994. *The economic value of biological and cultural diversity.* Gland, Switzerland, IUCN.

Rapport, D.J., Regier, H.A. & Hutchison, T.C. 1985. Ecosystem behavior under stress. *Am. Nat*., 125(5): 429-433.

Schulze, E.-D. & Mooney, H.A., eds 1993. *Biodiversity and ecosystem function.. Ecological Studies*. New York, Springer.

Singh, K.D. 1993. The 1990 tropical forest resources assessment. *Unasylva*, 44(174).

Solbrig, O.T. & Nicolis, G., eds. 1991. *Perspectives on biological complexity*. Paris, IUBS.

Solomon, A.M. & Shugart, H.H., eds. 1993. *Vegetation dynamics and global change*. New York, Chapman and Hall.

Soulé, M.E., ed. 1987. *Viable populations for conservation.* Cambridge, UK, Cambridge University Press.

Terborgh, J.T. 1992. Maintenance of diversity in tropical forests. *Biotropica*, 24(2b): 283-292.

Thomas, C.D. 1990. Fewer species. *Nature*, 347:237.

Tilman, D., May, R.M. & Nowak, M.A. 1994. Habitat destruction and the extinction debt. *Nature*, 371: 65-66.

WCMC. 1992. *Global biodiversity: status of the earth's living resources*. London, Chapman and Hall.

Whitmore, T.C. & Sayer, J.A., eds. 1992. *Tropical deforestation and species extinction*. London, Chapman and Hall.

Wilcox, B.A. 1994. *Ecosystem goods and services: an operational framework*. Working Paper of the 2050 Project. Washington. DC. WRI.

Williams, M. 1990 Forests. In B.L. Turner II. W.C. Clark & R.W Kates, eds. *The earth as transformed by human action*, p. 179-202 Cambridge, UK, Cambridge University Press

Woodwell, G.M. 1967. Radiation and the patterns of nature *Science*, 156: 461-470.

Woodwell, G.M. 1970. Effects of pollution on the structure and physiology of ecosystems *Science*, 168: 429-433.

Woodwell, G.M. 1993. Forests: what in the world are they for? In K. Ramakrishna & G.M. Woodwell, eds. *World forests for the future:: their use and conservation*, p. 1-20. New Haven and London, Yale University Press

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