The functional integrity of normally forested landscapes: A proposal for an index of environmental capital

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The report of the World Commission on Forests and Sustainable Development [(1999) *Our Forests, Our Future: Report of the World Commission on Forests and Sustainable Development* (Cambridge Univ. Press, Cambridge, U.K.)] has called attention to a global need to restore the functional integrity of nature. The assumption that the biophysical world is capable of supporting any intensity of economic and political activity is now obviously wrong. The failures are seen as global changes such as the global climatic disruption now underway. The global disruptions are the product of cumulative local disruptions. Despite a conspicuous need, the scientific community has been slow in developing tools to appraise the functional integrity of landscapes. The proposal is advanced that the first steps deal with forests because they are so large in their influences on global biophysics. Analyses carried out by the commission are elaborated here as an index of functional integrity in the forest zone. The proposal is based on a simple, transparent approach. The scale is 0–100 with 100 as the nominal climax. Decrements and increments are applied as the structural and functional integrity of the landscape varies with whatever cause. The unit of area for these trials has been 10,000 hectares. The index has been applied to extremes such as the large extractive reserves in Acre, Brazil (100), the once-forested landscape of Haiti (0), and a managed forest stand in Maine. The analyses offer a scalar system for defining how well landowners and governments are protecting the public's interests in the integrity of the habitat of all.

A Practical World View

During the latter decades of the 20th century the realization spread that not only is the world "full" as suggested by Herman Daly (1), but because it is full and callously used, it is being rapidly degraded as a human habitat. Four billion years of biotic evolution that produced a fauna and flora capable of renewing both itself and its habitat virtually infinitely is, in a few decades, being displaced by one runaway species that has named itself *sapiens* despite its obvious limitations. The difficulty is a failure to recognize early that the resilience of the world in response to the human onslaught is only apparent, a temporary hysteresis that has masked for a time the full effects of the human intrusion into nature. Those effects are now being recognized for what they are, a failure of biotic function in maintaining the whole Earth. The cost is a surge of biotic impoverishment that is engulfing civilization in a downward spiral of environmental disruption that is now conspicuously global. The climatic disruption now underway is but one such change. The critical issue is the emergence of a view of the world as a biotic system that is rapidly losing its essential functions because of the intensity of unregulated human activity. Restoring the stability of the biosphere is an immediate challenge. It has been formulated officially for global climate at the behest of the scientific community as the Framework Convention on Climate Change, now ratified by virtually all nations including the United States.

Objective: Measurement of How Well the World Is Working

Intensified management of landscapes is part of the cost of growth in the size and influence of the human undertaking. Management requires an objective appraisal of the status, and therefore the value, of the landscape, not simply in monetary units for its contributions to commerce, but even more importantly, to the public as a whole for its functional integrity as an essential unit of the global environment (2–4). The objective is to explore the potential of ecology and the experience of ecologists in developing an index defining the degree of integrity of the functional attributes (environmental services) retained by units of landscape in the normally naturally forested segments of the Earth. Although this index has been referred to as an "index of forest capital" (5), placing the emphasis on function seems more appropriate in that it offers one potential answer to the question of how well the landscape is functioning in support of the biosphere as a whole. In a very broad sense earlier ecologists, in attempting to define developmental patterns of vegetation, were engaged in such appraisals. Schimper (6), for example, and later others such as Clements and Shelford (7) developed approaches that were descriptive of structure as opposed to function and tended toward a local as opposed to a regional or global emphasis. The work reported here is focused on current needs, especially the need to define national and regional contributions to global climatic stability.

Forests: A Major Global Influence

Forests are a central issue because they are so large in the world and control so much of the land surface, so much of the water, the energy, the reflectivity, the habitat of plants and animals, and the habitat of *Homo sapiens*. The topic has been explored in detail recently in substantial reviews (5, 8). Despite their role in determining essential qualities of habitat regionally and globally, forests are normally seen primarily as a potential source of timber or fiber, and management has commonly favored commercial uses as opposed to public uses. The result has been the progressive destruction of primary forests globally, leaving a residue of landscapes in varying stages of succession, agricultural development, urbanization, or impoverishment. A corollary of that massive change is a change in land use, from a total land area 44% forested globally with primary forests to a land area 28% forested with largely successional or otherwise impoverished stands (9, 10). The changes have been several and have involved a major net transfer of carbon, once stored in plants and soil, to the atmosphere, supplementing the continuously increasing release from burning fossil fuels. The total release from combustion of fossil fuels over two centuries is larger, estimated by Fung *et al.* (11) as 250 billion tonnes of carbon and continuing at about 6.5 billion tonnes annually. Recent estimates by DeFries *et al.* (12) and Houghton (13) suggest that the total net release from changes in land use exceeds half of the total from fossil fuels. The release is continuing at about 1.6 billion tonnes annually with profound consequences (8, 14).

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Abbreviation: ha, hectare.

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Forests as Environmental Capital

The ecological changes associated with commercial exploitation of forests have not been incorporated into the formal calculations of profits and losses but they, too, are large and real. Economist Robert Solow (15) formulated earlier discussions (16–18) as "... it may be possible to treat environmental quality as a stock, a kind of capital that is 'depreciated' by the addition of pollutants and 'invested in' by abatement activities. In such cases the same general principles apply as for other forms of capital. The same intellectual framework will cover reproducible capital, renewable and nonrenewable resources, and environmental capital." Although such issues are usually thought of in contemporary terms, Columbus, and before him, the ancient Greeks, understood the importance of forests in maintaining the integrity of landscapes. The value of those functions becomes conspicuous only when lost in massive changes that are impossible to reverse in a short time.

The objective is measurement of the ecological value of forests quite separately from their commercial value. The ecological value as envisioned here lies in the integrity of the functional attributes of environment, both those of the local landscape and those of the regional and global environment. The basic assumption is simple enough: in the normally naturally forested regions the late successional, old growth, or "climax" forest provides the greatest stability and diversity of services in maintaining life. The decline of those functions with reductions in the structure of forests has been defined in detail in the literature of ecology over all of history. They have been summarized recently in the report of the World Commission on Forests and Sustainable Development (5) and by me (8). The individual changes are not necessarily linearly related to the structural impoverishment of the forest, nor are they necessarily equivalent to one another on a relative basis except at the extremes. Major increases in water run-off and nutrient losses, for example, may occur after minor disruption of the forest, whereas changes in albedo may require much greater disturbance. Simplicity, at least in this first appraisal, requires that the index be a single number that integrates the spectrum of changes. Experience will define what occurs in fact in different regions at various stages of the index.

Methods: How Can We Measure Integrity of Function at Landscape Levels?

It might seem attractive to follow the example of Costanza *et al.* (19) and apply a dollar value directly to the environmental services discussed here. A dollar value, however, moves the emphasis away from ecological functions that are not normally evaluated either by the market or in dollars and toward the familiar, but probably inappropriate, economic realm.† The immediate interest is the former. The approach is to define the services and their relative values, focusing first on the functionality of the landscape. Is the landscape stable in the context of human needs and expectations? Or is it losing its essential characteristics, becoming progressively biotically impoverished (20–22) (Fig. 1), and contributing in the process to the destabilization of other ecosystems elsewhere, including the biosphere as a whole?

Simplicity and clarity seem essential. Data and experience in ecology are extensive and there have been many attempts at offering criteria for appraising the relative values and status of forest and other types of vegetation. Earlier descriptive efforts in ecology such as those of Clements (23) were focused on that purpose with a collateral interest in agricultural potential. Foresters have used a "site index" based on growth rates of trees

†What is a functional environment worth? The question comes close to what is health, or the right to live, worth. There is no answer except in the abstract. The value of life is infinite to the owner of the life. We do not, and cannot, place dollar values on all aspects or attributes of life.

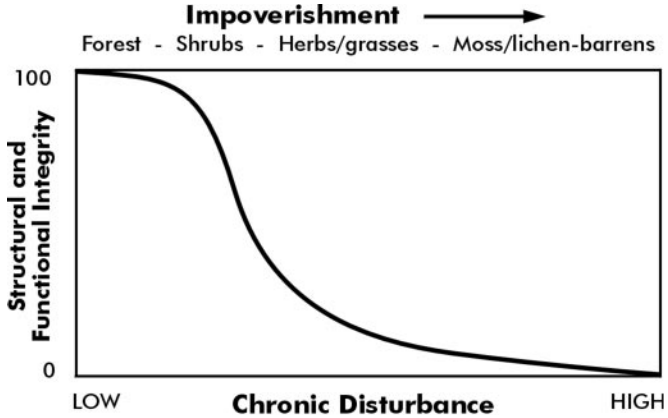

Fig. 1. The systematic impoverishment of forests occurs with chronic disturbance. The disturbance ranges from fire or mechanical disruption to pollution and progressive climatic disruption such as the general, rapid warming now underway.

(24). The World Resources Institute of Washington, DC, and Greenpeace both have addressed the suggestion of the World Commission on Forests and Sustainable Development that there be a "global forest watch" defining the status of forests nation by nation. Various other approaches offer appraisals of the quality of environment based on the assumption that the diversity of species (biodiversity) is related to the functional integrity of environment (25). The concept has drawn much attention to extinction of species (14, 26), but extinctions occur late in the chain of impoverishment discussed here, and biodiversity *per se* cannot offer an especially sensitive index of the functional integrity of a landscape or even of local plant communities.

On the other hand, a species list in the hands of one familiar with the details of the ecology of species offers substantial insight into the status of a site (27). The approach is instructive, but it requires a substantial body of field data. None of these approaches, informative as each is, offers a simple index or standard useful in the objectives set forth here.

Consideration here has been restricted to the potentially forested regions. Functional integrity has been assumed to be related to structural integrity, the presence or absence of forest, and the condition of the forest, especially its successional status.

Two sets of data are available: one is the wealth of information from plant geography on the distribution and qualities of forests, enhanced of course by the new data from satellite and other remotely sensed imagery. The second is the rich array of ecological/physiological information accumulated in recent years. Neither is simple, but the former offers an early and useful set of criteria for appraising the current status of land use. The area of forest is the first criterion and the obvious point of departure.

One Basis for an Index

The key assumption is that the greatest success in maintaining a landscape has been achieved by the plants and animals of the communities that existed before the great human expansion of the past two centuries. If we can define the details of that virtually infinitely self-renewing world, we shall have the detailed standard sought above. Deviations from it can be measured as decrements. An index might start at 100. After the removal of decrements, the residual would be the appraisal of that site. An intact primary forest would appear as 100. If the forest were degraded in some degree by pollution, as the forests on the western slopes of the Appalachian Mountains of Eastern North America, the scale would drop by some amount determined by the severity of damage. There would have to be a provision for incremental improvements in the landscape as succession progresses and as human influences turn beneficial.

Whatever the approach to the use of the land, the area must enter the calculation. Although a 10-hectare (ha) tract of intact forest may preserve certain qualities of water including stream flow and water chemistry in a small drainage basin, a 10,000-ha tract is required to preserve indigenous bird populations and other animals in a moist tropical forest (28). The analysis becomes immediately complex and the shortcomings of a single index emerge. The minimal area for recognition of a plant community may be as small as 1 ha. Practicality sets a minimal area for these considerations, at least initially, much higher, of the order of 1–100 square km (100–10,000 ha). The purpose is to provide an early, systematic analysis that integrates costs of human activities that are now ignored until they accrue, far too late for easy correction, as obvious local, regional, or global disasters.

An effective index is likely to be developed in stages. The process initiated here may be expected to encourage a new intensity of research on landscapes and to lead to new directions in economic and political as well as scientific thinking. The first product, however, will be a simplified basis for appraising the status of large regions, including the world as a whole, using comparisons between the self-renewing natural communities and the current land use. This approach is not intended to deny the possibility of developing human dominated or constructed landscapes that mimic the natural functions of the systems displaced, but such wisdom in landscape architecture is rare and the formulation of appropriate details is not yet mature. For the moment the focus is on recognizing and preserving the normal natural functions of nature.

The Elements of an Index: Plant Geography and Area

The basic assumption is pragmatic: the most stable and resilient vegetation in the normally forested regions is the primary forest, which is by definition late successional. One is inclined here for simplicity to invoke the concept of "climax" as elaborated by Clements (29, 30) or the "potential natural vegetation" of Küchler (31). Both these concepts transcend "late successional," which is interpreted here, again, pragmatically, as 100 years. At that point in succession it seems reasonable to assume that a landscape has achieved maturity of function. I simply assert that forests pass through succession into highly stable later phases that are long lasting and self-renewing. This late successional forest is taken as the potential for the region and is used in comparisons with the present distribution and status of forest to provide an appraisal of the functional integrity of the landscape.

The approach requires basic data that are easily and virtually universally available:

- A definition of forest: a leaf area index of 2.5 or more in woody plants.
- A map defining the potentially forested zone according to objective criteria such as soil structure and climatic diagrams.
- A further map defining the landscape units being considered, presumably based on minimal areas of 10,000 ha (10 km $\times$ 10 km), indicating within such areas, the fraction of land and water and the fraction of land currently forested.
- Area of primary forest remaining ($>$100 years).
- Area of secondary forest ($<$100 years)/plantations.
- Successional age.
- Fragmentation of the landscape.

There are many additional features of forest stands that have been used to describe details of forest structure, biochemistry, biophysics, hydrology, productivity, and energy fluxes. Each has nominal potential in developing an index or series of indices of forest capital, but experience led in this instance to a focus on the structure and age of the stands in the interest of simplicity.

Constructing an Index: Structural and Functional Integrity

Structural and functional integrity seem obviously related. The relationship is less obvious, however, when large areas and rare species are involved. It is, for instance, difficult to measure the effect of removing the jaguar from a 10,000-ha forest on the nutrient content of the streams or the evapo-transpiration of the forest. On the other hand, the removal of the large individuals of a single species of tree of the genus *Swietenia* (mahogany) from the forests of the Brazilian state of Pará constitutes, at least initially, a major transition in the structure of the forest and a major transition in virtually every functional aspect of the forest. The transition reaches to vulnerability to fire and the potential for serial burning of normally moist tropical forests and their destruction over large areas (32).

Emphasis here is on measurements of structure as an index of functional integrity. The relationships are a continuum and can be described in graphs for varying degrees of disturbance (Fig. 1) as described by Bormann (20) and me (21, 22). They are not necessarily linear relationships. To the extent that they are not linear, accommodations may be possible in the scaling of effects. In the end an arbitrary decision may be necessary to assure that the forested fraction of a landscape that is to preserve its functional integrity be maintained at some high fraction of the area. In considering this question for the World Commission on Forests and Sustainable Development, I chose 85% of the land area as an objective for the normally forested regions globally. The decision was arbitrary, designed to protect functional integrity everywhere, although there are clearly places where landscapes remain stable and productive with much less forest. There are also regions, such as steep slopes, that require more.

Following the plant geographical route we can, using a top-down approach, compare the forest area before the great expansion of human influence to the forest area now. Details of those comparisons such as the fraction of primary forests remaining and the distribution and fractionation of both primary and secondary (less than 100 years) forests offer a series of bases for evaluations of the function of landscapes. The topic has been pursued extensively throughout much of the history of ecology with pragmatic purpose and considerable effectiveness (29). That progress has been largely overlooked in recent years, but is, in fact, enjoying a revival in certain quarters under the rubric of "ecosystem health" (33). Russian scientists, moreover, have for decades focused on applications of allied approaches to the forests of the former Soviet Union from Europe to Kamchatka. The new application involves the invention of a set of indices that will take advantage of remotely sensed imagery from satellites.

Following the still more complicated eco-physiological route opens various additional objective, quantitative criteria developed previously for allied, but different, appraisals of nature. Such data include primary productivity and its relationships to ecosystem production and respiration of the landscape. Costanza *et al.* (34) used primary productivity (net primary production) as a criterion for appraising the dollar value of "ecosystem services" among different ecosystems. The approach was useful in the context of their analyses. It may be misleading in the context of the objective defined here, functional integrity of the landscape. A sugar cane field replacing a forest may have very high net primary productivity but a fractional and temporary storage of carbon by comparison with the forest it replaced. And the sugar cane, while having many attractive and valuable features that might be considered an "improvement on nature" from a human-interest standpoint, requires substantial management without providing the full range of "services" of the forest. Such considerations led to avoiding net primary production as the basis of comparison.

Table 1. Adjustment for fragmentation

Number of patches	Decrement
0–5	1.0
6–10	0.9
11–15	0.8
16–20	0.7
>20	0.5

Table 2. Adjustment for morbidity/mortality

% Morbidity/mortality	Decrement
0	0
1–5	0.95
6–10	0.90
11–20	0.80
>20	0.50

Similar considerations led to avoiding reliance on other common data of forestry such as basal area by species, leaf-area index, dominance/diversity curves, and the chemical structure of run-off with a special emphasis on nitrogen. Here, again, much about the function of landscapes has been learned through disruption, especially through the systematic biotic impoverishment of forests (21, 22). The causes of impoverishment examined have been exposure to toxins such as heavy metals, oxides of sulfur, smelter pollution, and ionizing radiation, as well as chronic disruption of the nutrient balance and chronic mechanical disturbance. All produce similar patterns of impoverishment of forests and other vegetation types. Efforts have been made to codify the patterns. The classes of impoverishment can be reviewed and new efforts made to apply them directly to an index of forest capital.

A simple, integrated index might be drawn from the suggestion above that the intact, late successional, forest of the region be assigned a value of 100 and decrements and increments be assigned for each influence identified. In keeping with Solow's suggestion (15), increments can be assigned for reconstructive influences. Because there are several ways of disrupting a landscape and driving it into advanced stages of biotic impoverishment, the sum of the decrements can exceed 100. So, too, there is no reason that the sum of increments could not exceed 100. As a practical matter is it unlikely that all decrements or all increments would apply to one place at one time and the index has been restricted to 0–100. Zero would represent the extreme case of deforestation with no indication of restoration underway. One hundred would be either an undisturbed forested landscape or the functional equivalent.

The question invariably arises as to whether human activities ever improve on nature. From the standpoint of local human value, agriculture is usually thought to be an improvement on forest. Why not recognize that possibility as part of the index and allow the index to exceed 100? The fact is that while agriculture is a necessary and obviously common modification of the landscape to accommodate human needs, the modified landscape does not provide the same biophysical functions that the forested landscape once performed. The local advantage to human welfare accrues as an increment of regional and global impoverishment that we assume is either small enough to be insignificant and overlooked, or restored by the functions of other, presumably intact and fully functional, natural ecosystems elsewhere. The index is being explored because the expansion of human influences has reached the point where we have a series of global changes that have overwhelmed the normally restorative powers of the biosphere. An appraisal of the extent of that change and how to reverse it is needed. Restricting the index to a scale of 0–100 based strictly on an appraisal of the functional integrity of the natural landscape seems to be the most straightforward course.

Increments of Change in Forested Landscapes

Primary Forest Subindex. The definition of primary forest for this purpose is a forest undisturbed for more than 100 years. The subindex would be calculated as:

$$\frac{\text{Present area of residual primary forest} \times 100}{\text{Potential total forest area}}.$$

The range of values is from 0 to 100. If 100, the further subindex outlined below does not apply.

Secondary Forest Subindex. The definition of secondary forest is land originally forested, committed to forest, whether it supports forest or not at present. It is added to the primary forest subindex above after the adjustments below have been applied to this successional index. This subindex would be calculated as:

$$\frac{\text{Present area of secondary forest} \times 100}{\text{Potential total forest area}}.$$

The range of possible values is 0 to 100.

Adjustments to the secondary forest subindex would include:

Stage of succession or age. This stage is a subindex used to modify the secondary forest subindex as follows.

The assumption is that functional integrity is restored in one century of successional development. Presumably functional integrity accumulates as succession proceeds from the earliest stages through late succession. After 100 years of succession there is probably little functional difference between a climax forest and the successional forest, whereas the early stages of a successional stand are quite different in functional integrity. To accommodate those differences the successional subindex is modified by the age of the succession, counting each year as 0.01. The range is 0.01 to 1.0. If the entire 10 km $\times$ 10 km plot is a fresh clear cut with a change in land use to agriculture, for instance, it would not be counted as forest at all. If the land is destined to remain in forest, it will be treated as secondary forest.

If the stand is not even-aged, or if the age is uncertain, 0.5 is the factor representing successional development of 50 years. If the ages are known and an average is possible, it will be used.

Fragmentation. Functional integrity of a landscape is compromised by dissection by roads and other fragmentation. An index of functional integrity should reflect such dissection of the landscape as a decrement in functional value. The decrement is to be applied as a factor to the successional subindex based on the number of patches of forest larger than 1 ha in each 10,000-ha tract (Table 1).

Morbidity/mortality. Morbidity is an appraisal of defoliation of the canopy dominants as a percentage of the canopy. Mortality is the fraction of the canopy dominants that are dead. In practice these two characteristics are difficult to separate and the adjustment is fused to one (Table 2).

Erosion. Deforestation often leads to active erosion. No index focused on functional aspects of the landscape can ignore such

Table 3. Adjustment for erosion

Number of sites	Decrement (X)
1	0.9
2–5	0.75
>5	0.5

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Table 4. Calculation of the index for a hypothetical township in Maine

Stand	Adjustment	Index
Primary forest		0
Secondary forest:		100
	Succession	
(1)	50% × 0.05	2.5
(2)	25% × 0.40	10.0
(3)	25% × 1.00	25.0
	Fragmentation	
(1)	2.5 × 1.00	2.5
(2)	10.0 × 1.00	10.0
(3)	25.0 × 1.00	25.0
	Morbidity/mortality	
(1)	2.5 × 0.9	2.25
(2)	10.0 × 0.90	9.0
(3)	25.0 × 1.00	25.0
	Erosion	
(1)	2.3 × 0.75	1.7
(2)	9.0 × 0.75	6.7
(3)	25.0 × 1.00	25.0
Sum		33.4
Index of landscape integrity		33.0

a transition. The incidence of erosion within each 10,000-ha tract might be incorporated as a significant decrement (Table 3).

Applications: Testing the Extremes. The operation of the index at the extremes is obvious. A forested region such as the Chico Mendes Extractive Reserve in the Brazilian Amazonian state of Acre, where deforestation is limited to a small number of clearings for dwellings covering a total area far below 5% of the total area and none of the other decrements applies, would have an overall index of 100. At the other extreme we might consider the landscape of Haiti where there is no forest remaining in the naturally forested region. There the index is zero.

A Township in Maine. For a different test we might try an "unorganized township" in the state of Maine. The townships were marked out in the original land surveys as tracts ≈6 miles by 6 miles (10 km × 10 km = 10,000 ha). They have no municipal government and are therefore unorganized and are forest land. For this hypothetical township we are assuming that the land has been owned by a paper company for the past century and the forest has been cut for pulpwood more or less continuously over that time. About 3/4 of the total area is lowland where the late successional forest would be red spruce (*Picea rubens)* and balsam fir (*Abies balsamea*) interspersed with large white pines (*Pinus strobus*). The uplands support the northern hardwoods, birch, beech, and maple interspersed normally with spruce and pine. Recent cutting for pulp has been heavy, and about 50% of the total land area is dominated by shrubs and small trees less than 2 m tall. Carelessly built logging roads are eroding in three areas in this heavily cut region. The remainder in the lowlands, about 1/4 of the total area, is balsam fir 6–18 m in height and with a leaf area index of 5+ as is common with conifers. The fir is about 40 years old, the result of a previous cut of spruce. The uplands, which constitute 25% of the area of the township, support a closed-canopy late successional northern hardwoods stand from which the once giant spruce and pine have been removed. There is no primary forest remaining although many of the maple and beech of the uplands are residual trees. The spruce budworm has deformed many of the balsam firs and killed enough that a person on the ground might estimate that the canopy was reflecting a 5–10% reduction in density. The forest capital index might be calculated as shown in Table 4.

The index as formulated is designed to address the functional integrity of the landscape, not the forest type or details of topography. In a Maine township 6 miles by 6 miles there is substantial variation in topography and in forest types. No attempt is made and none is required for our purposes to distinguish the lowland spruce-fir forest, or even bog forest, from the upland forests. We are appraising the integrity of function of the landscape on the basis of what it normally supports. It is a thoroughly disturbed landscape dominated by early successional forests.

We could follow this township over time. Assuming no further disturbance the index would rise toward 100 year by year. If, however, the remainder of the 40-year-old fir was cut this year, as is common practice in those forests, the index would drop immediately to 26. To the extent that erosion became conspicuous, the index would fall rapidly.

Examining Changes in Land Use in the Amazon Basin. For contrast we might consider a series of satellite images of Marabá in the Brazilian Amazonian state of Pará (Fig. 2). The image of Marabá contains approximately four 10,000-ha tracts. Here the principal transition is from primary forest to grazing land and the primary forest subindex dominates. The appraisal can be made initially from the imagery alone. With higher resolution and experience gleaned from other imagery or experience on the ground the index can be improved. An initial appraisal of the four 10,000-ha plots by using a black and white transformation and computer counting of pixels yielded indices as shown in Table 5.

The analysis, entirely based on the imagery shown, reveals the extraordinary rate of expansion of agriculture into primary forest in that region.

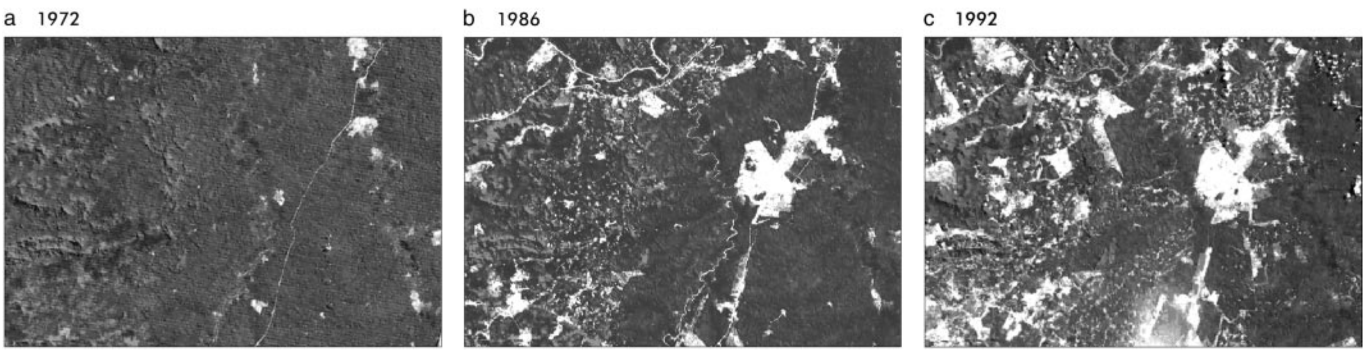

Fig. 2. Landsat images of Marabá in the Brazilian Amazonian state of Pará obtained in 1972 (*a*), 1986 (*b*), and 1992 (*c*). The lighter areas are deforested for agriculture, usually for pasture. The forests are all primary forests by the definition used here. Appraisals of area can be done by counting pixels or by counting squares in a grid. Process and design by T. A. Stone and M. Ernst, Woods Hole Research Center.

Table 5. Means of four plots in Brazil

Year	Index
1972	99
1986	88
1992	68

Discussion: Simple Enough to Be Useful

This approach is little more than a formalization of an appraisal of the area of forests of a landscape. In arriving at the approach it became clear that more detailed descriptions based on more detailed data quickly become obscure and run the risk of introducing less, rather than more, objectivity. That conclusion virtually closes any further consideration here of a more detailed analytical approach incorporating specific functional attributes of forests such as primary productivity or even biomass, at least for the moment. But there is an obvious need for greater resolution. In the case of the forests of the Chico Mendes Extractive Reserve of Acre, for example, the index as applied does not have the sensitivity to detect or define the trends underway there where the indigenous dwellers have, at least in the past, found it attractive to expand their pastures to accommodate more cattle within the forest than to rely further on forest products such as rubber, Brazil nuts, and less durable products such as many tree fruits.

In Haiti the instability and poverty of the landscape escapes any such definition.

This formulation does have the advantage that much of the data required can be obtained from remote sensing. Although the approach obviously requires much further development and refinement, it has a core of simplicity that seems essential and seems, at least initially, to codify and systematize the judgements that are, in the final analysis, arbitrary.

If the objective is protection of the functional integrity of the landscape, we would probably seek an index in excess of 75, possibly as much as 85 or higher. We might codify the changes that occur along the continuum of change toward lower indices as I have done previously (22), using simple descriptions of well-known gradients of impoverishment (Fig. 2) to enrich the details of the transitions reflected in the numerical index.

Conclusion

This simple preliminary exploration, performed as background for further discussions, has led back to a recognition that the area of forest as a fraction of the total potentially forested area is the key to the integrity of function of landscapes in naturally forested regions. Although there is little new in this observation, it emphasizes the need for formality in defining the relationships between the functionality of the landscape and forest structure and extent. The purpose is not to enable human interests to push the intensity of use of the landscape to the ultimate in risk or the limits of cost, but to assure that the sum of human activities remains within the limits required for long-term stability of the habitat. It also has the advantage of offering a continuing emphasis on the importance of changes in land use from forest to other purposes, even though that change may have occurred long ago and may have been largely overlooked in recent decades or longer. The scale of such changes globally is now at a point where we cannot longer ignore them. The route to systematic measurement seems clearly through an emphasis on area and structure of the vegetation and the relationships to the functional integrity of the landscape. In the end localities, regions, and nations must keep score on the environment to show how each is doing in contributing to its share of a global responsibility in maintaining a global human habitat that remains functional and wholesome for all. The rudiments of that responsibility exist already in the Framework Convention on Climate Change, now universally accepted. It presents a major challenge to the scientific community to provide tools to implement it in full.

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