13. Managing for sustainability: ecological footprints, ecosystem health and the Forest Capital Index

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ECOSYSTEM CHANGE

We may define ecosystems most simply as the interactions of plants and animals with their abiotic environment. As such, we may identify their ecological character in terms of species dominance (plant or animal), energy flux, nutrient flows and the like. Humans are part of these systems, and we may thus also identify ecosystems in terms of their socio-cultural characteristics. Indeed, increasingly, humans have so modified nature, that the socio-economic (and hence culturally determined) impacts are now the dominant force in ecosystem dynamics (Vitousek et al., 1997). Further, increasingly the landscape has been transformed by wholly human-constructed and maintained ecosystems: e.g. agro-ecosystems, agro-forestry, aquaculture, dams (creating mammoth lakes), diversions for rivers (for irrigation, and/or energy) and so forth.

Even without human influence, in the time before *Homosapiens* and our immediate progenitors, two to three million years ago, ecosystems were anything but static. Over various time scales, from geological to ecological, ecosystems undergo change, owing to geological, ecological and evolutionary forces. Large inland seas, which once covered two-thirds of what is now North America, transformed into fertile plains and grasslands. Continents have formed, and migrated over the Earth's surface – propelled by the geological forces of plate tectonics. In these migrations, tropical ecosystems have become arctic, or sub-arctic. Forests have been gained and lost, lakes appear and disappear, and sometimes connect with and disconnect from the sea – as is the history of the great expanse of waters now known as the Baltic Sea.

Today, there is no evidence that these 'larger forces' have been quieted. No doubt they continue to come into play, at gigantic spatial and temporal scales. However, it is evident that at infinitely smaller ecological time scales, humans have become the major influence (and some might say, the major scourge) of the planet's near-term history. It is also evident that the process of human transformation of the Earth's ecosystems is fraught with risks for the future of humanity. There is accumulating evidence that as human populations are swelling to historic highs, the vitality and health of the Earth's ecosystems is sinking to historic lows (Rapport et al., 2003). We are most likely in the early phase of the sixth mass extinction of life on Earth – this one largely triggered by the rapacious use of planetary resources by humans. Healthy ecosystems, which are the very basis of subsistence for rural populations (*World Conservation*, 2004) are not only at risk, but many, including very large ecosystems such as the Mesopotamian Wetlands, are virtually dead. Many others (including the Aral Sea, tropical forests and coral reefs) appear to be in increasingly dire straits.

COGNITION AND HUMAN VALUES

It would seem a natural response in view of these unfolding transformations, to take corrective action as a society, globally, regionally and locally. Indeed, that is the goal of public policy on the environment. And progress has been registered. The Montreal Protocol appears as the Gold Standard for effective international action – resulting in a strong and sustained commitment by the global community to stem the thinning of the Earth's protective troposphere ozone layer by phasing out the use of sources of chlorofluorocarbons, the primary cause of the deterioration in the ozone layer. The Kyoto Accord has, after long delays, been ratified – and constitutes a commitment by a majority of nations to stem the release of so-called 'greenhouse' emissions (particularly carbon dioxide). Add to these the Ramsar Convention, Agenda 21, the Law of the Sea, and the work of various regulatory bodies at national and international levels, and there is at our disposal a virtual armada of policies and control mechanisms designed to modify and alleviate human pressures on the Earth's ecosystems.

At the same time, we remain cognisant that these policies, while mostly pointing in the right direction, are thus far insufficient to stem the global tide of ecosystem collapse. It is not the lack of knowledge, per se, that is the issue: there are any number of authoritative reports that document the changing state of the environment and clearly give cause for concern. Rather, it is the lack of political will that appears to be the major barrier to a more concerted effort to bring humankind into balance with their ecosystems. At root, it is human values that need massive transformation – to be an effective counter-balance to the ongoing transformation and degradation of the Earth's ecosystems.

While information on the state of the environment is ever more abundant, very little is in a form readily communicated to the public and decision makers. What is needed is the development of summary trends on the state of the Earth's ecosystems, much as we have summary trends on the state of health of the economy.

This is also the principal motivation behind the proposed Forest Capital Index (FCI). The FCI would assess the environmental sustainability of forest ecosystems. The development of an index, as a summary of trends in the health and vitality of forest ecosystems, has been recommended by the World Commission on Forests and Sustainable Development (Salim and Ullsten, 1999). The FCI is to serve as a composite measurement of the quality of stewardship of the forest capital, and signal its progress or lack thereof to policymakers and the public at large. Since monitoring conditions in the forest and woodland ecosystems are well established, the development of an FCI represents a unique opportunity to communicate, in a synthetic manner, the results of forest monitoring to both decision makers and the public. Before turning to the description of the FCI, we discuss two complementary concepts, namely that of 'ecological footprint', and that of 'ecosystem health'. These notions provide a conceptual underpinning for the choice of indicators of the FCI.

ECOLOGICAL FOOTPRINTS AND ECOSYSTEM HEALTH

Ever since the publication of *An Essay on the Principle of Population* by Thomas Malthus (Malthus, 1803) there have been concerns that the human population might increase beyond the Earth's carrying capacity (Hardin, 1968; Catton, 1982). While it has long been recognized that humans are part of the ecology of nature (Hawley, 1950), far too little attention has been given to the fact that humans are fully dependent on the well-functioning of the Earth's ecosystems, and thus that, in order to achieve a reasonable quality of life, it is as essential to protect the health of ecosystems as it is to achieve economic viability.

There are various ways to portray pressures on and changes in the environment. Pressures can be measured in terms of the 'ecological footprint', a concept that measures the per capita dependence on natural resources. The response of ecosystems to these pressures can be measured in terms of the degree of 'ecological integrity' – the degree to which ecosystems are transformed from a 'pristine' state, or in terms of ecosystem health – that is in terms of the ecosystem's capacity to maintain its structure and function. These three concepts are closely interrelated (Rapport, 2000). Yet each has its unique focus and its particular strengths and weaknesses. All three, however, reach common ground in drawing attention in various ways to the growing loss of harmony between humans and the ecosystems in which they live.

The notion of 'ecological footprint' (EF) adds a special contribution in efforts to come to grips with the Earth's carrying capacity by drawing attention to the land area required per capita to support current consumption levels. In most cases, populations require for more land to sustain their consumption than they physically occupy.

The EF can be measured in a variety of ways: e.g. in terms of the net carbon released for a per capita increase in population in a particular area (Rees, 1999), or in terms of the hectares of land required to sustain a given geographical unit. In essence, the EF is an '. . . accounting tool that enables us to estimate the resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area' (Wackernagel and Rees, 1996).

Thus the EF portrays the degree to which human societies are parasitic on nature (Peacock, 1999). For example, the ecological support for the human population in the geographical unit of the city of Vancouver (British Columbia, Canada), which is contained in an area of 11 420 hectares, draws upon a productive land area of 2 360 600 hectares (Rees, 1999). Thus the ecological footprint of Vancouver is 207 times the area occupied by its citizens. Rees terms this ratio the 'overshoot factor'. For the lower Fraser Basin as a whole (the ecological region in which Vancouver is situated), the land area occupied is 830 000 hectares, while the ecological footprint is estimated to be 10 000 000 hectares, or an overshoot factor of 12. At the very least, such calculations provide a picture of the relative degree of exploitation amongst different communities and regions.

The ecological footprint of North America is at least an order of magnitude greater than the footprint of India. There is no iron-clad rule that this need be the case, since with wealth comes the capacity to design 'smart' systems that conserve resources while furthering economic objectives. And to some degree, this has taken place (for example, hybrid cars, harnessing wind power, 'smart' houses, and so on) but overall, any gains made in this respect have been overridden by increased per capita consumption. In fact, very few nations have a footprint small enough to ensure sustainability (Wackernagel and Rees, 1996; Chapter 12). Further, the EF calculations suggest that if all countries were to live at the level of consumption of North Americans (as many aspire), it would take 3 or 4 Planet Earths to accommodate this on a sustainable basis.

Calculations on a nation-wide basis are equally revealing of vast inequalities. The economically privileged nations have a far larger ecological footprint than economically disadvantaged nations do. The rich nations can only sustain their lavish life-styles (relative to the rest of the world) by drawing down the natural capital of the poor countries.

The concept of 'ecological integrity' is another means to reflect the degree of harmony or balance between humans and their ecosystems. Instead of focusing on resource consumption per capita, this concept focuses on the degree to which any given ecosystem can said to be in its 'natural' state – a state taken as that which would exist in the absence of humans, or human influences. Given that humans are part of ecosystems, the notion of a 'natural state' as one only existing with the exclusion of humans, constructs an artificial reality. Yet the purpose of such a construct is clear enough. The issue is, essentially, how far has the condition of nature been transformed by humans and, in the process, deformed through human activity? Indices of ecological integrity have been constructed, particularly for aquatic ecosystems, based upon a dozen or so metrics, each of which relates to some aspect of the structure or function of these complex systems (Karr and Chu, 1999). Commonly used metrics include biodiversity, nutrients, toxic substances, community structure, disease prevalence and the health of key species. An index of biotic integrity allows policy makers to assess the degree to which aquatic and terrestrial ecosystems have been altered through human use.

This works best in those cases where one may safely presume that the more the system departs from 'natural' the less suitable it is for human occupation. In essence this perspective measures any departure from 'natural conditions' as degradation. While this may be useful in monitoring wilderness reserves or other protected areas, it is less relevant to human-dominated ecosystems, which by their very nature are generally greatly transformed from their condition before human colonization. For these situations, which in fact now envelope most of the Earth's ecosystems, the key environmental question is not the degree to which these systems have departed from a 'natural' state, but rather the degree to which these systems maintain their full capacity to function. Such considerations lead us directly to the notion of ecosystem health.

It has been recently reaffirmed by many international organizations (for example the World Bank, the World Resources Institute and the United Nations Environment Programme) that the vitality of the Earth's ecosystems ought to be a key priority for the 21st century (United Nations Development Programme et al., 2001), and further, that healthy ecosystems are essential to ensure food security for rural peoples (World Conservation, 2004). The notion of ecosystem health forms the third underlying concept that has stimulated the development of the forest capital index.

Healthy ecosystems may be defined as those that are free from ecosystem 'distress syndrome' (Rapport et al., 1985) and maintain their resilience, organization, and vitality (Rapport et al., 1998a, 1998b; Rapport and Whitford, 1999). Ecosystem distress syndrome is characterized by declines in biodiversity, declines in long-lived native species, the leaching of nutrients from terrestrial ecosystems, the accumulation of nutrients in aquatic ecosystems, reduced counter-active capacity (or resilience) that is, the capacity to recover from disturbance, and increased disease susceptibility (in both humans and other biotic components of the system).

The notion of 'resilience' is particularly important, as it measures the capacity of ecosystems to recover from perturbations such as fire, flood, drought and so on. Such perturbations are a key mechanism by which ecosystems adapt to changing environments (Whitford et al., 1999). However, ecosystems altered by anthropogenic stress invariably exhibit the loss of resilience (Whitford et al., 1999) and this loss results in a permanent loss of ecosystem function. The loss of ecosystem functions has negative consequences for human well-being in terms of human health, sustainable livelihoods and socio-cultural well-being (Rapport et al., 1998a, 1998b; Costanza et al., 1997; Maffi 2001).

In short, ecosystem health can be broadly defined as the 'capacity for maintaining biological and social organization on the one hand and the ability to achieve reasonable and sustainable human goals on the other' (Nielsen, 1999, p. 66). Quantitative measures may be found, not only in the biophysical attributes, but as well in social, economic, cultural and human health indicators (Rapport, 1995; Rapport et al., 2003).

With respect to human health, degraded ecosystems often increase health vulnerabilities (Rapport and Lee, 2003). For example, outbreaks of cholera in coastal communities, have been associated with eutrophication of coastal marine waters. Eutrophication favours the proliferation of the pathogen, *Vibrio cholerae*, commonly found in coastal marine systems associated with phytoplankton and zooplankton communities (Huq and Colwell, 1996). In nutrient enriched waters (for example, as a result of fertilizer run-off from agricultural practices) and under suitable temperature and salinity conditions, non-virulent (dormant) forms of the bacteria become virulent (actively reproductive). Thus, as coastal marine ecosystems become nutrient-enriched as a result of agricultural runoff as well as from urban and industrial inputs, conditions become more favourable for the transformation of *Vibrio cholerae* to a virulent reproductive state, which in turn increases the likelihood of contracting the disease due to more humans coming into contact with the pathogen through contaminated water and/or food supplies. Many other human pathogens are similarly traceable to ecological imbalances. These include outbreaks of Lyme disease, dengue fever and swine flu (McMichael, 1997; Patz, 1996; Rapport and Lee, 2003).

SUSTAINING HUMAN FUTURES

Once ecosystem health has become severely compromised, recovery may become impossible, at least in ecological time, even if the initial causes of ecosystem pathology have been removed (Rapport and Whitford, 1999). Overgrazing by cattle transformed a once healthy arid grassland in SW New Mexico (USA) into a shrub land dominated by creosote bush and mesquite (Whitford, 1995). Once these shrubs become dominant they cause further depletion of soil nutrients and thus entrain a process of desertification.

Thus information on conditions and trends within ecosystems ought to take into account not only indicators of the per capita utilization of the Earth's resources (the ecological footprint), but also indicators of the viability of human-dominated ecosystems (i.e. indicators of ecological integrity and ecosystem health). Thus, there appears to be a dual policy challenge: both to reduce the size of the ecological footprint and to improve the health of ecosystems. These twin objectives appear to be complementary and interdependent. To meet this challenge requires public information that summarizes in some reasonable way, the overall situation with respect to the changes in the viability of the world's ecosystems. One ambitious plan to do just that for one of the world's most prominent and threatened ecosystems, namely forest ecosystems, is the construction of an index of forest sustainability, known as the Forest Capital Index.

THE FOREST CAPITAL INDEX

The Forest Capital Index (FCI) was proposed as a broad measure of the sustainability and health of forest-dominated ecosystems. In recommending the development of such an index, the World Commission on Forests and Sustainable Development (WCFSD) took into account the many complex manifestations of change, from the biophysical to the socio-economic and cultural (Salim and Ullsten, 1999). The Commission recognized that, for policy purposes, it would be highly desirable to condense these various indicators into an index that represents trends in the state of the global and regional forest ecosystems. Here we present an abbreviated description of the FCI, adapted from Ullsten et al. (2004).

In economic discourse, 'capital' refers to a stock of productive resources. Thus a literal translation of the term 'capital' in the forest context might refer to the stock of standing timber, or biomass, or some such equivalent. However the WCFSD, as indicated above, adopted a broader perspective. They not only included a measure of the stock of standing timber (or forest cover) but also took account of the degree to which the functions of forest ecosystems are maintained. This requires the assessment of productivity, nutrient cycling, the maintenance of cultural values, practices and uses and so on.

A major challenge is how to incorporate all of these dimensions in a way in which policy makers and the public will readily understand the changes in conditions and trends in the health of forest ecosystems. One way of meeting this challenge is to construct an index, i.e. the FCI, by which a single number would take into account ecological, socio-economic, and cultural aspects of forest ecosystems.

There are many potential ways to do this, but all run into one fundamental problem – namely, that the various indicators that comprise the FCI lack a common denominator.

However this remains an issue for the construction of most indices in which disparate information is brought together. The key here is that whatever index is produced, there is a need for transparency – that is, the calculation of the index based on various indicators needs to be explicit and the trends in the individual metrics that go into the index should also be displayed.

For many decades, a growing number of experts, policy makers, NGOs, and intergovernmental organizations have called for the sustainable use of natural resources including forests, and ways to measure the components of sustainability (ITTO, 1992; UNCED, 1992; Anonymous, 1994, 1995; Salim and Ullsten, 1999; Rapport et al., 2003). In 1987, the World Commission on Environment and Development (WCED) popularized the term 'sustainable development', which means satisfying needs for livelihoods without eroding the natural capital. In economic terms, this translates as living off the 'interest', not the 'capital'.

In 1992, the United Nations Conference on Environment and Development (UNCED, the Earth Summit) called for development of indicators of sustainable development, as means for monitoring progress (UNCED, 1992). The Intergovernmental Forum on Forests (IFF), established in 1994, and its successor, the UN Forest Forum (UNFF), discussed the need for the systematic evaluation of global forests.

Many agencies and programs carry out the monitoring of the extent and incremental gain or loss of forests, and publish periodic measures of the extent of the world's forest cover. The Helsinki Processes (Anonymous, 1994) and Montreal Processes (Anonymous, 1995) have identified a number of indicators of forest condition based on prior work by the UNCED (1992) and ITTO (1992). A number of other initiatives related to forests and forestry indicators have arisen – notably, UNEP's Global Environment Outlook program (UNEP, 2003), the Food and Agriculture Organization's

State of the World's Forests (FAO, 2003), the Canadian Forest Service's Criteria and Indicators program, the World Resource Institute's Pilot Analysis of Global Ecosystems (Matthews et al., 2000), NASA, the USEPA forest monitoring programs, and State of the Environment reporting in a number of countries. Agencies such as the World Bank, FAO, OECD and NASA also compile and list hundreds of indicators on forest condition and associated socio-economic variables. A number of initiatives in forest certification have emerged to encourage sustainable use of forest resources, such as the Forest Stewardship Council (http://www.fscoax.org) and the Pan European Forest Certification (http://www.pefc.org).

The construction of a Forest Capital Index (FCI) is a logical next step in support of sustainable utilization and conservation of the world's forest resources. The FCI is a way of combining relevant but complicated data related to the trends and condition of forest ecosystems composed of individual indicators which, when considered individually, provide only partial answers to forest sustainability questions. Large sets of indicators, while they may be of enormous benefit to scientific research, generally confuse the public and decision makers. What they need to know is simply whether forests are moving towards or away from sustainability. An FCI designed as a performance index based on sub-indices ought to be capable of providing this assessment. The FCI captures aggregate or overall trends understandable to both decision makers and the public.

The FCI is thus directed towards aggregating and communicating important information on the state of the world's forest-dominated ecosystems. The FCI provides a single number, based upon selected indicators that measure various aspects of forested landscapes. Trends in the FCI will reveal the degree to which the health of forested ecosystems is being compromised or improved through human activity. Ideally, the FCI would apply to all forests, natural and managed, regardless of size and type, and go beyond giving guidance for forestry practices alone.

Andreasen et al. (2001) discuss the general criteria for a useful index of integrity (and health) of terrestrial ecosystems: it must be multi-scaled, grounded in natural history, relevant and helpful, flexible, measurable and comprehensive (i.e. it must incorporate components of ecosystem composition, structure and function). The FCI takes these same considerations into account and might proceed by:

1. selecting a limited number of indicators that measure the status of forest resources and services of forest-dominated ecosystems;
2. aggregating the chosen indicators and targets into a regularly updated Index;

3. applying the chosen FCI methodology in a series of pilot studies in countries with different types of forest dominated landscapes and phases in the development of the use and exploitation of forests, using the same measurement protocol at all sites;
4. studying the institutional arrangements needed for gathering, keeping and updating data over time and facilitating their application in national forest policies; and
5. assessing changes in the FCI over time.

Selecting Indicators

The development of the FCI would build upon a range of existing forest ecosystem monitoring and measurement efforts and make use of indicators that have been developed from processes such as the Criteria and Indicators (C&I) reporting developed under the Montreal and Helsinki Processes (Anonymous, 1994, 1995), which serve as measures of sustainable forestry.

The individual components ought to satisfy the following conditions: they should be sensitive to change; respond to stress in a predictable and unambiguous manner; be supported by precise, accurate, reliable and, if possible, readily available data for all nations; be verifiable and reproducible; and be understood and accepted by intended users. A good indicator will have a direct link from environmental measurement to practical policy options (Dale and Beyeler, 2001). The indicator data must also be objectively collected, and representative of a wide range of forest types.

Aggregating Indicators into a Forest Capital Index

Once selected, the indicators need to be aggregated into an index reflecting the overall health of forest dominated ecosystems (Rapport et al., 1985, 1998a, 1998b; Rapport and Whitford, 1999). This FCI, when regularly updated, should permit evaluation of progress, or lack thereof, in sustaining the health of forest dominated ecosystems.

Aggregation of indicators into an index involves the construction of a mathematical model that defines the relationships of the component indicators. Aggregation can be complicated, partly because different indicators are reported in different units of measure on different time and spatial scales. Also, various components may be given different relative weights (e.g. would forest cover changes have the same significance (weight) as changes in diversity of trees or bird species or overall biodiversity?). Further, one must account for non-linear behaviour, in that changes in some components of the index, beyond a threshold, may have a more dramatic impact on ecosystem health than changes in other components.

Thus weighting the importance of the indicators is a significant issue. Weighting the index, as well as indicator choice, is ultimately a subjective decision and open to criticism (Andreasen et al., 2001). However, if the process of aggregation and weighting of the index is carried out by means of a careful, scientific, and thorough consultation process, the index will be accepted by a reasonable majority of stakeholders. Whatever system is chosen, it should be constructed such that it can apply equally across all regions, ensuring the validity of making comparisons between countries.

One of the dangers in any weighting scheme is that there is the potential for eclipsing the value of a particularly critical component of an index (Ott, 1978). For example, suppose that in constructing the FCI, particular soil ions, such as calcium ($Ca+$), are taken into account. $Ca+$ is a critical indicator of forest health and its decline may signal the onset of a potentially serious risk to forest ecosystems. Yet if the concentration of this particular ion is only one small component of the FCI, this decline could easily be overlooked. This is especially likely if other indicators of forest ecosystem health, such as productivity, have not yet responded to this change. In cases like this it is likely that the value of an FCI would fail to signal an important change in the health of the forests since the impact on the FCI, owing to declining levels of soil Ca, would be buried or 'eclipsed' by the lack of change in other variables.

Another example of 'eclipsing' would be the sudden disappearance of a 'sentinel' species, for example, an interior forest bird species, while other indicators of forest health, such as primary productivity, forest cover, soil nutrients and so on remain unchanged. Here too, an FCI would fail to register the loss of a potential 'miner's canary' of the health of forested ecosystems.

The only way to avoid such pitfalls, which are inherent in any index of 'health' status, would be to also examine the trends in the various indicators comprising the index, in order to be sure that such vital information is not overlooked. In essence, both the index and its constituent indicators must be examined simultaneously, as part of the same information system. For decision makers, this might be accomplished by using a diagrammatic approach, such as taken in the 2002 Environmental Sustainability Index (World Economic Forum et al., 2002). This approach would serve to highlight worrisome changes in any critical component of an index. At the same time, the index provides the overall trends in forest health in a format that is more readily understood by decision makers and the public at large.

To clarify this further, we draw an analogy to commonly used environmental indices such as air pollution or water quality. The public (and decision makers) are of course interested mainly in the general trends, and in particular, whether critical thresholds which might endanger public health have been reached. With air pollution, for example, certain levels of pollution trigger public response such as reducing industrial activity that emits significant amounts of air pollution, or restricting the use of automobiles in the impacted areas. At the same time it is understood that an overall air quality index does not fully reflect all risks. For example, if there was a surge in 'small particulates', which can be a serious respiratory health risk, this might be eclipsed by the broad spectrum of other indicators that comprise the air pollution index. In such a case, it would be essential to provide the public and policy makers with supplementary information to the effect that a particularly worrisome component of air quality has been observed to be on the increase, even if the overall index has been little changed.

Studying Institutional Arrangements for Collection and Upkeep of Data

An important prerequisite for implementing the FCI is an understanding of the institutional arrangements needed for gathering, keeping and updating data over time and thus making the index operational for the adoption of appropriate policies and as a tool for informing the public. A clear understanding is required of who will produce the FCI, and how, and who will use it. Governmental, business, and NGO and community audiences have different needs, capacities and perspectives that may need to be considered. They may also be wedded to particular performance measurement tools and systems into which the FCI might need to be integrated. Should the FCI be calculated by independent parties in various parts of the world, it would need to conform to certain criteria. One would need to understand the type of capacities needed, capacity gaps, and offer strategies for addressing them. A key purpose for the FCI is to improve forest ecosystem-related decision making. Use of the FCI under different institutional conditions must be demonstrated so that actual benefits can occur.

Calculating the index will be computation-intensive and require specialized software. The software will be needed to perform the required calculations, to serve as a data storage facility and to present the results of the index in a visually attractive format. Because the FCI is likely to use spatially referenced data, a platform with Geographic Information System capabilities should be used.

Assessing Changes in the Forest Capital Index Over Time

A key function of the FCI would be to assess changes over time in the sustainable use of forest resources. Changes in forest ecosystem conditions and use will be measured against some initial period – ideally that period should be chosen as one in which forest ecosystems were minimally impacted by human activity (Woodwell, 2002). However the question remains, for forest ecosystems, should the standard (or benchmark period) be the condition and forest cover that pertained 8,000 years ago – a period prior to significant human influences on forest ecosystems? If this benchmark were to be chosen, the value of the index today for many regions of the world would be rather low (on average less than 50 per cent of the benchmark value). Even if a more recent period were taken to be the benchmark, for example, the condition of forests at the beginning of the 20th century, the current value in many areas would also be rather depressed as large scale clearing of forests have taken place in the 20th century. Some argue on pragmatic grounds, that for policy purposes, one could adopt the value of the index in the first year of calculation as the standard (Matthews et al., 2000).

Since the policy implication of the FCI is to portray trends, it may well be that the year of the first calculation is as suitable as any to show the direction of change. However, at the same time, some historical reference points would be useful to indicate the recent history of forest transformation and serve to motivate policies to restore forest health to its full potential.

DISCUSSION

The construction of overall measures of ecosystem health designed to inform decision makers and the public on overall conditions and trends poses a great many challenges. The proposed FCI is an attempt to meet these challenges for one of the world's most critical ecosystems. Currently, in the monitoring of conditions and trends in forest ecosystems there are myriad indicators, often motivated more by what can be measured, than by the utility of the measurements in informing decision makers and the public about the sustainability of forested ecosystems. In proposing the construction of an FCI, we recognize both the dangers of oversimplifying the available information as well as the dangers of having a bewildering number of indicators from which no clear picture emerges.

In effect, the FCI seeks middle ground between the two extremes: complexity which fails to communicate, and simplicity which devolves into being overly simplistic. Ultimately, what is sought is a measure with a solid footing in our understanding of the complex dynamics of the forest–human interactions, and with a strong capacity to communicate that understanding to decision makers and the public.

Potential Audiences and Users of the FCI

There is a wide range of important audiences, including governments, corporations, non-governmental organizations, academe, think tanks and research organizations, intergovernmental organizations (including the UN system), financial institutions from national to global and the news media. It is also vital to reach the public – the benefactors of services provided by healthy forest ecosystems – in order to build support for such a measuring system. Public support is essential to build political will and to encourage business to use the index. The development of an FCI will take into consideration that different actors have different needs in terms of level of detail of information. An FCI should be seen as an information system, and the FCI and the components it builds on should be published simultaneously, so that both the larger picture and the details are available to index users with full transparency.

The development of an FCI is likely to provide benefits to society in many different ways. It will permit evaluation of progress in sustaining forest capital in a country, serve as a benchmark for assessing whether forest capital is increasing or declining and create a global framework for valuation of forest ecosystem services. The introduction and use of an FCI would make available a kind of 'score card' or 'report card' that attributes a numerical value to various forest functions, including a 'GDP-like' one-dimensional index of the total (Salim and Ullsten, 1999). This may serve as a helpful tool in debt-for-nature swap agreements, and in designing tradable permits involving forests within the Kyoto Protocol and otherwise.

Human activities have eroded global forest capital and other natural resources over many centuries, and are undermining the ability of future generations to meet their own needs from the natural resource base (Dasgupta, 1982; Pearse, 1990). This applies not only to forests, but also to other major global ecosystems (for example, coral reefs, wetlands, grasslands, fresh water bodies (lakes, rivers), as well as marine systems). Current indices, such as the GDP, do not take into account the necessity for the sustainability of nature (Tietenberg, 1992). By expressing the values of forests, which often lie outside the domain of routine economic calculus, the FCI would increase awareness about the degree to which current use of the world's resources is taking account of future generations by safeguarding the natural capital of forests. The same sort of consideration would apply to all of the world's major ecosystems.

Information Gaps Concerning the Natural Capital

The very process of formulating an FCI would identify gaps in our knowledge of forests and would lead to additional research focused on filling those gaps. Data gaps should be analysed with regard to their significance for creating a robust and reliable index. Other data gaps may become apparent in the course of development of the index. The programme of activities to formulate an FCI will necessitate a pooling of resources, expertise, resources and outputs from established monitoring activities that could lead to far more incremental value than if researchers were to continue to operate independently of and sometimes at cross purposes with one another.

Spatial Scales for the Forest Capital Index

An important consideration for construction of an FCI is the spatial scale to which is applies. Are we thinking of the global picture, a country level perspective, a particular region (say a watershed or biome), or some other defined area? In principle, the FCI could be applied to any defined region, provided the data are obtained that relate to that particular domain. The concept of biomes, eco-zones, regions, districts and sites, as well as basins, watersheds and sub-watersheds have found various applications in reporting on the changing state of environments (e.g. Bird and Rapport, 1986). We envision a nested hierarchy of such regions for purposes of constructing an FCI. Ideally, there will be ways of aggregating such ecologically-based constructs to merge with political boundaries at state and federal levels. Within the European Community, the EC Water Framework Directive provides strong support for such an approach.

The FCI can be viewed as a 'top down' approach to management of the forest. However, it is not intended to be biased in that direction. It should equally serve 'bottom-up' processes – that is, community-driven processes to change the management of local forests which are the ecosystem in which that community thrives. This would particularly be the case if it were the community that suggested the parameters which are most meaningful to the health of their forest ecosystems, including not only the bio-physical aspects, but as well the socio-economic and cultural dimensions. The main goal of the FCI is to provide information as to the changes in the health/condition of forest-dominated ecosystems. That information should be of equal value to local communities and the various levels of governance.

Linking the Forest Capital Index to Economic and Social Indices

During the last decades of the twentieth century, environmental issues have gained increasing prominence. Indeed, sustainable development has become one of the core organising concepts of environmental policy and can be defined as the maintenance of important environmental functions into the indefinite future (Ekins and Simon, 2001). However, sustainability is also an inherently vague concept whose scientific definition and measurement still lacks wide acceptance. If measurement methods indicating both short- and long-term targets are developed (Mills and Clark, 2001), the concept can be made much more concrete, and it should become possible to assess needs in order to achieve healthy ecosystems at various spatial scales.

To become policy relevant the FCI must have the potential of being linked to existing and planned broader indices for sustainable development at the national and international level if it is to be widely used. Two prominent examples of forest-based criteria and indicator sets are the Montreal Process (Anonymous, 1995; used by the United States and 13 other temperate and boreal forest countries) and the Helsinki Process used by European countries. These sets of criteria and indicators allow for standardized measurements of agreed-upon variables including biodiversity, productive capacity of forests, protection of soil and water, contributions to the global carbon cycles, economic factors and contributions and legal and institutional issues pertinent to forest management. These well-established systems offer us two helpful assets. First, the rich data sets they provide give us starting points for the selection of indicators and yield useful data to populate them. Second, because these sets of indicators have already been agreed upon by large constituencies, we can capitalize on the investment of time, money and other resources that have moved diverse stakeholder sets from dispute to dialogue to data. This will be important, as the FCI will be subject to scrutiny by many groups.

CONCLUSION

Managing sustainability is about trying to reduce the ecological footprint of humans that has, over time, resulted in a serious erosion of the viability of the world's major ecosystems. Indeed, as a consequence of human domination of most of the Earth's ecosystems, their vitality and health is now at a historic low. Thus far, policy responses triggered by observations that the environment has become seriously compromised have failed to stem the continued degradation.

There are many reasons why that is the case. One of them is the inability of political systems to handle issues that are, by definition, long-term in character and involve the perspective of planetary survival. This, however, does not mitigate the role and responsibility of science to provide better and more comprehensible information about the unfolding transformation of the Earth's ecosystems. Concepts such as the ecological footprint, ecological integrity and ecosystem health have an important role to play in structuring new and comprehensive information systems on the environment.

The increasing availability of indicator data on a broad scale (particularly from the use of remote sensing technologies) makes comprehensive assessments of the vitality of the Earth's ecosystems more feasible than ever before. In many cases, however, improved technologies for monitoring conditions and trends in the Earth's ecosystems have only led to 'information overload'. With intergovernmental agencies and other institutions reporting hundreds of indicators, scientists, decision makers, and the public, are hard pressed to answer the simple question: what are the trends in the health, viability, sustainability of ecosystems for particular regions or countries as a whole?

In the forest sector, the situation motivated the proposal for constructing an index of forest capital. The FCI is intended to serve as a vehicle for communicating to decision makers and the general public, the overall trends of forest ecosystem health. Its focus is on ecosystem viability, including (at least eventually), the socio-economic, cultural, governance and human health aspects, as well as the biophysical aspects of forest-dominated ecosystems.

Much attention has been rightly placed on the size of our ecological footprint. But this alone is insufficient. Information on footprints suggests the degree of stress to which regional ecosystems are subjected. But, by itself, this information does not tell us whether or not the regional ecosystem can sustain these levels of stress. To address this question, and to provide an overall picture of whether forests are improving or declining, one needs an overall measure of ecosystem health and its changes over time. This is the central motivation governing the construction of the FCI. While there is certainly no unanimous agreement among scientists or decision makers on indicators for use in indices of sustainability, or on methods of aggregation or weighting, there is agreement that one needs, urgently, a mechanism for making sense of large amounts of conflicting data.

A transparent protocol for constructing an FCI would represent an important step in this direction. It also represents an opportunity, based on this approach, to develop indices for communicating the status and trend of all of the world's ecosystems, as efforts to ensure their viability intensifies in the 21st century.

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