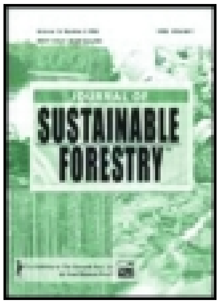

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Sustainability of Forests

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INTRODUCTION

Forests are the most awesome and overpowering entity constructed by nature. They tower majestically into the biosphere and comprise over 90% of the terrestrial biomass of the earth. They are the main repository of the planetary carbon in their immense expanse of woody tissue. As they are destroyed this repository is lost and gaseous carbon is emitted into the atmosphere as a greenhouse gas. They are also habitats for a multitude of other organisms and can even clean the air of anthropogenic pollutants when planted in our cities. A paradox of forests is why is there so much wood in the world when allocation of carbon to wood is the lowest priority of the plants after leaves, roots, reproductive structures, and elongation of stems? The reasons lie in the tremendous productivity of forests (forests occupy only about one third of the land surface but account for two thirds of the net annual photosynthesis) and in the longevity of wood (secondary xylem) by virtue of its amazing resistance to the forces of destruction. A key to this is the fact that it is largely stored CO_2 and water, cleverly combined for strength (cellulose) and rigidity/endurance (lignin). In addition, most of this tissue

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is dead shortly after formation (apoptosis) and therefore functions, in strength, conduction and resistance to wind, insects, and decay with minimal carbon cost in respiration. These properties of forests make them all the more critical for the survival of the biota of this planet. Consequently, we foresters have a special responsibility to insure the continuity of the forests that are left in the world and to create and renew forests wherever and whenever physical, economic and social factors permit such action. We are convinced that the continued development and practice of forestry is a step in this direction.

Initially humans cut down trees as needed without any management plan or thought of consequences. Forests gradually receded from human settlements and the tasks of providing fuel and construction materials became more difficult. This led to the development of forest products harvesting and processing as a vocation and eventually provided the basis for the development of the profession of forestry. Numerous catastrophes such as mud flows, erosion, landslides, fires, and other disasters provided added incentive for this development. In an historical context exploitation led to conservation, preservation, multiple use and, most recently, sustainability. Exploitation preceded the profession of forestry and unfortunately has continued after its advent. Conservation means wise use, but in the United States it was, at least initially, associated with management for the sustained yield of forests for timber production. Preservation has come to signify the exclusion (or near exclusion) of non-recreational human use and with single species management as for grizzly bears or spotted owls. The principal objective of multiple use forestry, as currently conceived, is management for sustainability of growth and yield of generally more than one "product" (fish, bears, timber, wild and domestic grazing animals, birds, water, recreation). The founder of multiple use forestry in United States was Gifford Pinchot, the first Chief Forester of the Forest Service, who coined the aphorism, "the greatest good for the greatest number in the long run" (Pinchot, 1947). Sustainability is a further progression and requires management of forests such that the crucial natural processes of inorganic and organic matter cycling necessary for the continuity of the life of the forest over the foreseeable span of time are not curtailed or eliminated.

BASIC DETERMINANTS OF SUSTAINABILITY

Sustainability is based on continued functionality of the parameters that drive ecosystems, namely: (1) the physical and chemical which consists largely of solar energy, water, meteorological, and geological inputs; (2) food chains and trophic levels that are an organismic reflection of the physical and chemical set of parameters; and (3) resiliency which is a composite of the first two sets of parameters (Berlyn and Ashton, 1995). To this framework a concept from chaos theory must be added, namely that changes at smaller scales (cellular to organismal) may be amplified into larger changes at the ecosystem and landscape level. Or as Levy states (1995) "In ignorance of the details of beginnings, no valid predictions are possible." For this reason management policies based on averages may be doomed to failure in heterogeneous and complex systems like forests.

Thus, we believe that sustainability is more than a purely human concept or a mere change in human philosophy (for some opposing views see volume edited by Aplet et al., 1993). It may be that in many, if not most cases, multiple use and sustainable use will arrive at identical practice, but the priorities are different and in crucial situations the practice will also differ. Output of goods and services will give way to process continuity–insofar as we are able to perceive it.

Sustainability implies treatment of causes of problems like forest declines (increased mortality and lowered resistance to stress) and not merely symptoms. For example, if one assumes that a consequence of acidic pollution in a given forest decline situation is due to leaching of micronutrients out of foliage and soil, it would be theoretically possible to alleviate these symptoms by fertilizing the forest with suitable amounts of the requisite nutrients and chelators. In this case you are treating the symptoms, but not the cause; the treatment is not really sustainable and a cascade of effects in the rhizosphere may eventually require more and more treatments until finally nothing works. While this is not really a sustainable approach, it may be a practical necessity to at least keep the forest alive until the underlying causes, physical as well as social and economic, of the acid rain are abated.

The biosphere is attuned to the life cycle processes of birth, life, senescence, death, and renewal. These life processes have been subjected to intensive selection over time such that the functioning of the biosphere, and its ecosystems, is dependent on the means by which this turnover is attained. Death is not simply an unavoidable evil, it is also a requirement for the reprocessing necessary for renewal. When litter raking is permitted in the forest it initiates an unsustainable cycle as the nutrient capital of the forest is gradually drained away to agricultural lands. The malnourished forest is then rendered more susceptible to a host of secondary stressors such as insects, fungi, drought, frost, and even pollution.

Another example of the power of sustainability can be found in the apparent paradox of some tropical rain forests. How can such rapid growth, tall trees and high leaf area indices occur on soils that are so leached and infertile? The answer is of course that they have a long growing season with mild temperatures and low water stress that optimize photosynthesis. Additionally, there is enormous genetic wealth represented by species, and their varieties and provenances, with physiomorphological adaptations that can take good advantage of the great diversity of rain forest habitats. But this is only part of the story. The warm temperatures lead to high microbial metabolism in the soil with high turnover of nutrients cycled down to the forest floor and in organic debris and in root turnover. The nutrients are concentrated in the upper levels of the soil in the litter, organic matter and humus. It is no accident that tropical trees tend to have superficial and even surface roots where they are in position to rapidly take up the concentration of the nutrients released by the soil microflora and fauna before they are leached out of the soil. A high proportion of the trees also have mycorrhizal symbioses as well as phytochelators and there is a plethora of nitrogen fixing trees, all of which reduce the nutrient cycle time. The rapid and surficial cycling contributes to the vulnerability of these tropical rain forests. In this telescoped system the importance of the biological cycles are amplified, but they are critically important in all forest ecosystems.

CRITERIA FOR SUSTAINABILITY

The main source of resilience and adaptation of the forest is the meristematic mode of growth whereby the plant leaves, the primary basis of life on earth, are developed in continuous harmony with the environment as a consequence of their phenotypic plasticity–the ability to modify their structure and function in response to the environmental factors. Plant leaves are in direct contact with the aerial environment and the most sensitive to changes in it, and the most easily damaged by debilitating forces such as pollution, insects, and disease. Since leaves are the main source of energy for the forest their health is a critical factor in attaining sustainability of forests.

As the key organ for the energy cycle of the earth the plant leaf is responsible for the domination of the terrestrial portion of the biosphere by forests. This function if facilitated by the evolution of canopies. The aggregate of the leaves of a tree comprise the crown and the aggregate of the tree crowns comprise the canopy of the forest. Canopies may be displayed in a single layer or stratified into several layers depending on the number and kinds of trees that make up the forest. Complex canopies may form a kind of ecosystem of their own, with each layer of the canopy consisting of species adapted to their particular habitat and supporting a myriad of animal (insects, birds, mammals) as well as other plant life (lianas, epiphytes). Plant canopies may vary in: (1) layering; (2) spatial continuity, orientation and density; (3) amount and types of pigments such as chlorophyll, carotenoids and anthocyanins; and (4) the degree of deciduousness and/or other seasonal changes (temporal continuity). Canopy and leaf structure encode information on the health and vigor of the forest as does the changes in the amount of foliage per unit ground area (leaf area index). More base line data on these properties is needed in order to monitor the status of forests in relation to sustainability.

In the Oliver-Larson (1990) concept forest stands progress through four ontogenetic stages: stand initiation, stem exclusion, understory reinitiation, and old growth. The understory reinitiation stage may be likened to loss of a critical level of adaptation energy. When a cell is formed in the meristematic zones of a tree it is thought to be totipotent–capable, under the proper environment, of giving rise to a whole organism. This morphogenetic potential diminishes over time as does that of the whole tree. Something is lost and it is not clear what although Selye (1976) has termed it adaptation energy (not related to caloric energy), i.e., the capacity to respond to and recover from stress. The trees are no longer able to exploit openings in the canopy, as they could during the stem exclusion stage, by filling them with photosynthetic tissue. This, of course, is not an ontogenetic accident, but a feature of the life cycle of the forests that facilitates its sustainability over the generations.

The primary motivation of sustainable forest management is process continuity with secondary focus on growth, yield and multiple uses. Only through continuity of these critical processes of organic and mineral matter recycling can forests be sustainable in the long run. However, processes and their intensities change in time and space and thus sustainable management must change in time and space in a coordinate way. Forestry therefore requires new technologies, new economics and new cultural practices. As Aldo Leopold said almost a half century ago, "Health is the capacity of the land for self-renewal" (Leopold, 1949). Thus, a healthy ecosystem is a sustainable one and sustainable forest management requires that we first understand this capacity and then that we maintain its continuity. This is not to say that multiple use objectives are excluded in sustainable forestry; only that they are subordinate to ecosystem health and therefore sustainability. In particular single species management of a forest containing multiple species is generally incompatible with sustainability. In practice sustainable forestry may in many cases not differ from multiple use management. Sustainability thus represents a change in the prioritization of management objectives.

It must be acknowledged that unequivocal standards of proof for the concept of sustainability are difficult. However, an exception may be the recent catastrophic fires in eastern Washington State in the United States. About 70 years ago fire exclusion was initiated in the ponderosa pine-grass ecosystem. Normally, the fire frequency in this area was about every 10-12 years. Most of these fires were ground fires and the ponderosa pine would survive these fires and prosper because of them. When fire was excluded grand fir and Douglas fir began to encroach upon the area. These would normally have been excluded by the ground fires. Along with these exotic species came a host of insects and diseases that afflicted the forest, causing considerable mortality. Spotted owls also entered this ecosystem despite its youth. The owls were not there before fire exclusion, but prosper in a layered forest even if it is not "old growth" or "ancient." The buildup of fuels (an essential component of the fire triangle of fuel, heat, oxygen) on the forest floor due to the accumulation of dead and dying trees is generally a guarantee that when fires do start they will be catastrophic and this is precisely what happened in the summer of 1994 (see acknowledgments).

The pattern and effects of land use are affected by population pressure. If the intensity and duration of use is very low, the results of exploitive land use may be little different from that of sustainable land use. Many lands have been under agricultural use from hundreds to thousands of years with little or no loss of productivity, i.e., home gardens in Sri Lanka, Lower Euphrates river valley, swidden agriculture with long fallow periods in East Kalimantan, Indonesia. Some Iowa cornfields have shown increasing production over the last century; this being largely due to increased fertilizer and pesticide use and the development of high yielding genetic varieties. Whether this latter type of increase is sustainable is open to question. Short term increases may result in long term decreases if cultural practices lead to soil deterioration or contamination. The time scale is critical and short term prophecies of doom have not materialized into reality (c.f. Erhlich, 1970; Helfrich, 1970).

OLD GROWTH AND SUSTAINABILITY

A common but inaccurate assumption is that old growth forests represent the "optimum" condition of the forest and that anything else is less than "optimum." Forests like other ecosystems are continually changing and responding to disturbance, both natural and anthropogenic. Forests are mortal and have a time to be born, mature, die and be recycled into the succeeding forest. They are not static and the life associated with them ebbs and flows along with the life cycles of the forest. Both climate and species change over time and succeeding cycles of the forest may have different endpoints even without human intervention. Thus, it is important that the world's forests have a diversity of age structures and that old growth forests are continued to be represented in the forest flora of every forest region. Sustainability must be considered in the light of these complexities and in the human context. Our human population is now so large, diverse and pervasive in its resource use and impact that it influences all of the other life forms on earth. A middle ground between preservation and consumption must be sought. Preservationists are, like everyone else, consumers of forest products even if they do not realize it or when their actions cause the use/misuse of someone else's forests somewhere else. While conservation of natural products use is important for everyone, environmental justice requires that all countries contribute their fair, sustainable share of forest products to meet the needs of humankind in the world. The earth must be managed for the closest approach to sustainability because sustainability is necessary for its survival. Of course in the long run nothing, not even our sun is entirely sustainable, i.e., "the entropy of the world strives to a maximum." Nothing and none of us can escape the second law of thermodynamics; we can only strive to attain a sustainable state of nature and to minimize unsustainable land use.

History tells us that in recent as well as historical times nations fail when the natural resources that support them are degraded by overuse, pollution, and mismanagement. Eastern European communist regimes were convinced that environmental protection was unnecessary and as their natural resources failed so did they. However, preservation is not a viable policy for biological as well as sociological reasons because it does not consider the natural cycles of ecosystems or the pervasive influence of human populations on process continuity. For example, when fire is excluded from an ecosystem whose natural disturbance pattern includes fire you stifle process continuity and therefore sustainability. It is also not possible to induce or artificially simulate hot wild fires in forest areas interspersed with or bordering on human habitation.

As the population of the earth increases there is a concomitant increase in stress to the earth's environment. Vernadsky noted more than 50 years ago in "The Biosphere" that the living world occupies a rather thin film on and near the surface of the planet. Within this film almost all the matter is biologically processed. The system is based on the recycling of organic matter, of which 90% is of plant origin. The earth's ecosystems have tremendous buffering capacity and in the past the effect of human activities was relatively minor.

Increased populations and technologies that utilize more resources per capita have changed this situation. It is apparent that we have reached a critical point in the environmental history of the earth, since we can already observe localized environmental catastrophes like the dead forests of eastern Europe and mass killings of people due to pollution such as in Donora, Pennsylvania, U. S. A. (1948, 20 deaths), London, England (4000 deaths, 1952; 1000 deaths, 1956; 400 deaths, 1962), and New York, U.S.A. (200 deaths, 1953; 400 deaths, 1963) (see Bhatti, 1986; Kupchella and Hyland, 1989; Miller, 1994). The danger is that these localized events will become more frequent and achieve confluence. Responsible land stewardship requires that we heal the damages inflicted on our biosphere and provide holistic management systems for a sustainable planet into the 21st century and beyond.

Any forest policy must have the support of the people who live on or near the forest if it is to be successfully implemented (see Pinchot, 1947). However, the advent of rapid travel by airplane and automobiles has brought additional people to the forest for recreational reasons and their wants must also be part of management plans for the forest. Sustainable forestry, especially in developing countries, should, insofar as possible, be based on local species that local people value and know how to use. Brandis (1897) advocated this policy long ago, but its implementation has been lacking to say the least. Nitrogen fixing trees with edible beans can be a useful choice for reforestation or aforestation, especially for marginal lands, but their success will depend on local familiarity or acceptance (Bryan, 1994).

Ecosystem-based sustainable management is not a universal set of operations because ecosystems differ in their physical and biological processes and in their resiliency to different types of disturbance. Ecosystems have adapted to specific disturbance regimes and generally require these disturbances for process continuity. Ecosystem state variables change as ecosystems move from one state to another as in succession; resiliency may vary in different states. In general, most temperate ecosystems are more resilient with respect to forest sustainability than tropical ecosystems, especially in lateritic soils where reforestation may be difficult if not impossible. Boreal and high elevation forests are also areas of limited resilience. These different and changing vulnerabilities impose a set of restraints and challenges for management. Meeting these challenges within the restraints imposed by the need for process continuity is the role of sustainable forestry. Process continuity requires that the flora and fauna of the forest that are essential to these recycling processes (such as the decay fungi that convert green litter like leaves and twigs on the forest floor to humus) must not be reduced or eliminated by such things as acid rain, pollution, and indiscriminate or overuse of pesticides and herbicides. Good cultural practices that maintain or promote process continuity are essential to sustainability. New technologies that support process continuity are needed and some are currently available or under development, but few have been implemented. The litigious nature of our society may limit ability to experiment because of fear of the consequences of failure. Over the long run this is a deterrent to progress.

Sustainable management must be based on ecosystem management which in turn must be based on ecosystem science. But this implies that ecosystem science provides unbiased ("value-free") data upon which to base management decisions and policy. Unfortunately, this is not always the case and ecosystem scientists have often intruded their various values of and about human society into their results (Bocking, 1994; Berlyn and Ashton, 1995). Few biophysically trained ecosystem scientists are knowledgeable enough, appreciative enough or sensitive enough of the social sciences to provide much of value in the way of input to forest managers. Thus, the forester in the field faces the task of interpreting the often conflicting results of ecosystem science. He or she, unlike the scientists, is faced with the task of answering directly to the public (Pastor, 1995) for policies that must insure the sustainability of both the entire ecosystem including the humans and their culture. Uncertainty and risk thus become a major problem for managers to address. Fortunately, their tool box is increasing at an exponential rate, but high technologies can carry the risk that policies will be too dependent on them. For example geographic information systems and computer models have many implicit assumptions that are based on scant empirical evidence or only on the cursory understanding of the biological processes of ecosystems.

Forestry therefore requires realistic sustainable objectives and silviculture is the means by which these objectives are realized (cf. Smith, 1986). For example silviculture may be directed to produce some level of wood or habitat manipulation. To do this it must introduce some level of disturbance. The stand initiation period immediately after disturbance usually determines the species composition of the future forest. Thus, it is essential that we understand the responses of the species of a particular forest to the scale, frequency, intensity and type of disturbance whether natural or anthropogenic. However, the response of a forest to disturbance is also a function of the developmental state of the stand which in turn is influenced by the developmental state of the individual trees comprising the stand. That is to say that disturbances to young stands undergoing stem exclusion may result in a forest composition that is quite different from disturbance applied to a stand in the old growth stage (see Oliver and Larson, 1990). However, even a small change in species frequency can alter canopy structure, texture, and density such that the forest will appear different at each stage during a given round of forest succession even if climate remains static during this interval.

At the end of the stem exclusion stage, the canopy trees begin to lose their monopoly on the site and the crowns can begin to separate. Species differences in abrasion resistance and resource use efficiency will affect such crown separation. The degree of separation will in turn affect the nature, density and character of the understory renewal stage. Variations among species and individuals in canopy tree senescence drives pattern in gap opening. As openings increase in number and size the amount of evapotranspiration will vary and change the soil moisture profile. Soil fungi release ethylene and this is thought to affect germination and subsequent seedling growth (Salisbury and Ross, 1992), an example of process continuity that can be affected by anthropogenic use of fungicides and pesticides. In this sense no homologous replication of a forest is to be expected, but under sustainable management a spruce-fir ecosystem should retain both of its namesake species although the specific mix and the understory and below ground life may vary as well.

Forestry started with the spirit of adventure in exploring the unknown and the ideal of providing the benefit of forests to future generations. It must retain its willingness to try new approaches and to take responsibility for its mistakes and to learn from them. It is important to accept the fact that mistakes will be made, but moving forward is essential for humanity as well as the environment of which it is a part. This is what should separate foresters from those doomsday ecologists and conservation biologists whose main motivation is to do nothing or manage for a single species and to eschew all social responsibility. In the long run we believe that such a policy will cause more destruction of the environment than sustainable management. Parks and forests cannot be maintained if people are cold and hungry. Doing nothing in our anthropogenically influenced biosphere has consequences and by itself may not be sustainable.

Aldo Leopold who always defined himself as a forester said in Sand County Almanac (1949, p. 259) that, "in my own field, forestry," there are two kinds of foresters, one commodity (viz., cellulose) oriented and the other that prefers natural regeneration and considers the totality of forest values. We have to encourage more of the latter if foresters are indeed going to be the catalysts for sustainable forest management in the next century.

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