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An Overview of Sustainable Forestry

By David A. Perry

With the population of the globe accelerating past 5 billion, increasing deterioration of ecosystems throughout much of the world, and mounting evidence that we are entering a period of significant change in global climate, it seems clear that if we are to survive, we humans must change our relationship with nature from one dominated by exploitation and indifference to one of respect and sustainable balance. One of the first steps on the road to sustainability is to ask how various resource management practices influence the long-term health and productivity of ecosystems, which in turn requires that we know something about what keeps ecosystems stable and productive. With this knowledge, we humans can turn our often misplaced genius to the task of developing appropriate "ecotechnologies," i.e., resource management systems designed with the future in mind as well as the present. In doing so we buy insurance for our children.

This paper deals with sustainable forestry, although the basic principles discussed here should apply to any renewable resource. I first discuss the concept of "long-term" productivity, what it means and what it doesn't mean. I then outline the important factors contributing to ecosystem stability, the system components that management must strive to protect, and how these are impacted by current management practices. Finally, I close with some discussion of current research directions. Throughout it is important to realize that scientists have a rather poor understanding of how ecosystems function, and in particular what keeps them stable. Some of the ideas I will discuss are controversial; all need much more study.

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A few words on terminology. The terms "sustainability" and "maintenance of long-term productivity" mean the same thing and I will use one or the other at various times. Throughout, the term "forest" refers to the community of plants and animals occupying a piece of ground at any one point in time, while "forest ecosystem" denotes a much broader set which includes the physical environment (e.g. soil minerals and water) and, in particular, extension in time, i.e., not only the present forest on a piece of ground, but past and future forests as well. This is an important distinction, because forests, like people, grow and die; it is the integrity of the forest ecosystem, the dynamic extension of the forest in time, that we must learn to protect.

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What Is Long-term Productivity?

Sustainability, or maintenance of long-term productivity, is a very old concept in forestry that simply means adopting a level of harvest and management activity that can be sustained indefinitely. The concept of sustainable forestry is straightforward but often misunderstood. I recently reviewed a management plan in which it was argued that removing land from the harvest base would decrease long-term productivity. This is not the sense in which the term "long-term productivity" will be used here. Long-term productivity refers to a potential only, the productive *capacity* of the land and the ecosystem. How much of that capacity is actually realized by removal in harvest is a management decision and has no direct connection with the kind of productivity we are discussing here (although it can have an indirect impact through effects on factors such as nutrient loss).

Moreover, the concept of sustainability recognizes that forest values not traded in the market place are nonetheless valuable, and in some cases more so than wood fiber (e.g. watershed protection, climate moderation). So, although the *capacity* of a site to grow trees is probably our best measure of sustainability and of ecosystem health, in no sense can reduced timber harvest be directly translated into lowered long-term productivity.

In the same vein, maintaining long-term productivity is not the same thing as maximizing the production of wood fiber in a single rotation (the period from harvest of one stand to harvest of the following stand). In fact, as we shall discuss in more detail later in the paper, harvesting stands so that productivity is maximized in one rotation often reduces productivity over the long-term.

Although the concept of sustainability is straightforward, defining the kind of management practices that ensure sustainability is not always so simple. Nature is full of surprises; what on the surface may appear to be highly destructive may in fact be beneficent, while measures designed to "protect" ecosystems have sometimes turned out to be quite harmful.

A classic example of the latter is fire control in parts of western North America. Before fire control was instituted in the early part of this century, ponderosa pine forests experienced frequent, rather gentle fires that left most mature trees unharmed but cycled nutrients and retarded the invasion of other tree and brush species. Following fire control, which originally must have seemed to be a practice that benefited the ecosystem, the character of these forests changed in such a way that today they are more vulnerable to catastrophic, stand destroying fires. Entomologists believe they may serve as foci for regional-scale insect outbreaks.

Virtually all forest ecosystems

evolved within a milieu of periodic disturbances, some of which were highly destructive. Natural forest ecosystems were well adapted to cope with, and in fact were shaped and often renewed by, the disturbances that characterized their environment. Even when stands were completely destroyed, as certainly happened from time to time in some forest types, mechanisms were in place to maintain soil fertility, facilitate recovery, and keep the system on track. On the other hand, forest ecosystems may be quite vulnerable to "foreign" disturbances, those against which they have evolved no defenses.

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The point that I wish to make is that sweeping generalizations about what is "good" or "bad" management, while in some cases correct, can also be pitfalls because they do not account for the highly individualistic nature of ecosystems. Clearcutting is widely viewed by environmentalists as a "bad" management practice, and this is certainly true in some cases. On the other hand, clearcutting and slashburning may have relatively minor long-term implications for forests that have evolved in a regime of periodic stand-destroying wildfire. However, herbiciding early successional nitrogen-fixing shrubs following a clearcut and burn introduces a "foreign" disturbance that disrupts the normal recovery process and reduces site fertility. In this example, and in resource management in general, "good" or "bad" management can no more be defined without understanding the way the ecosystem works than proper medicine can be prescribed without understanding the way the body works. The key to sustainable forest management is understanding and protecting the mechanisms that allow ecosystems to "roll with the punches." Fortunately, these can be generalized to some degree.

Factors Contributing to Sustainability

The healthy, resilient forest is much like a healthy human, able to weather the vagaries of life and keep them from turning into catastrophe. In the forest this means absorbing climatic fluctuations and low levels of insect and pathogen activity without long-term effects on ecosystem health. The stable forest ecosystem, the extension of the forest in time, is more analogous to a vibrant human culture, able to retain its basic character throughout many generations of individual births and deaths. Sustainability requires that both conditions, resilience against environmental fluctuations and ability to recover from larger-scale disturbances, be met.

The factors responsible for ecosystem stability and resilience can be divided into three broad groups: (a) those associated with soils; (b) ecological diversity; and (c) genetic diversity within populations of single species (see Figure 1). These three "legs" of sustainability are like the three legs of an old-fashioned milking stool. No one can be said to be more important than the others; the stool stands because all three work together to make it stable.

Soil

Soil is a complex, dynamic, living "organ" of the ecosystem whose importance to forest health and productivity cannot be overemphasized. Of the sixteen chemical elements required by life, all but two (carbon and oxygen) are obtained by plants from soil. Soil organic matter is not only a reservoir of nutrients, it is an energy source for soil microbes and animals and provides the structure that gives soil good water-retention characteristics and adequate aeration. Soil has much more than an immediate influence on tree growth, it is the connecting link between a forest that is destroyed by harvest or natural processes (e.g. fire) and the succeeding stand of trees.

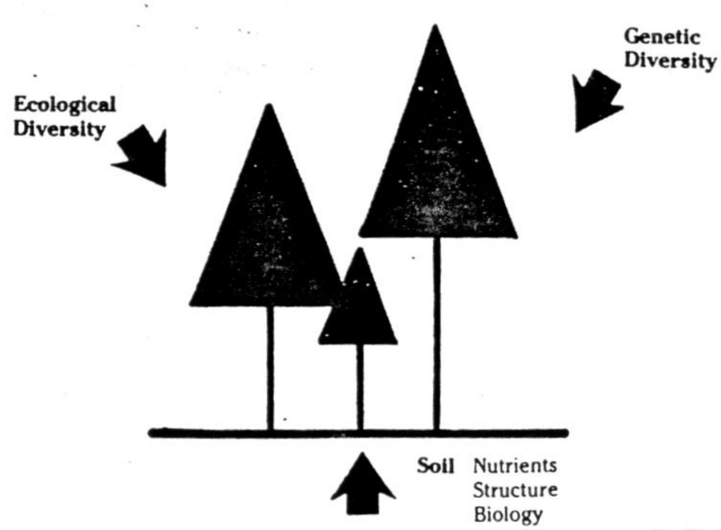
Excessive loss of nutrients or organic matter during harvest will reduce future productivity. What constitutes "excessive" depends on how much is lost from the site during harvest and the degree to which losses are replaced (either by natural processes or fertilization) before the next harvest. It is a simple matter of arithmetic; if more is removed than is replaced, the soil, like a bank account, eventually runs out of "funds," and as the level of "funds" drops so do the dividends.

The quantity of nutrients and organic matter lost during clearcutting and associated site preparation depends on three things:

• **The amount and type of biomass removed**. Nutrient concentration of tree boles is quite low, while that of small branches and foliage is relatively high. "Whole-tree" harvest, in which crowns as well as boles are removed in the interest of efficiency and "complete utilization," removes far

Figure 1

The Three Legs Of Sustainable Forestry



more nutrients than simply harvesting the boles.[1,2] Recent studies of various areas in the eastern United States have shown particularly high calcium losses in whole-tree harvest.[3] Removing old, unmerchantable logs, a practice called "yumming" ("yarding unmerchantable material") eliminates what in some forest ecosystems is an important source of future soil organic matter.

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• **Site-preparation techniques**. Clearcutting frequently leaves behind a residue of tree crowns and other unmerchantable material. In order to reduce the chance of wildfire and to prepare sites for planting, these are frequently disposed of by controlled burning where they lie ("broadcast" burning), or by using bulldozers to push them into piles which may or may not be burned (variously called "windrowing," "pile-and-burning," or "root-raking"). Windrowing is a highly destructive practice that has been shown in numerous studies to reduce site fertility [4,5,6]. In windrowing, nutrients and organic matter contained in residues are concentrated on a relatively small proportion of the site (leaving the rest of the site depleted). Top soil layers, rich in nutrients and organic matter, are often "piled" as well, and soils are almost always compacted.

The effect of broadcast burning on soil fertility depends on how hot the burn is. While many nutrients are returned to the soil in the form of ash, nitrogen and sulfur are volatilized and lost from the site as gases. Very hot fires consume most carbon and nitrogen in residues (sulfur is volatilized less readily), and may cook these elements out of upper soil layers as well. Unless nitrogen is replaced by fertilization or, where they occur, through nitrogen-fixing plants, this type of fire is likely to reduce site fertility. If soil structure is altered (possible in very hot fires), fertilization may not be sufficient to restore productivity. Relatively cool broadcast burns have much less impact, and are probably consistent with maintaining site productivity.

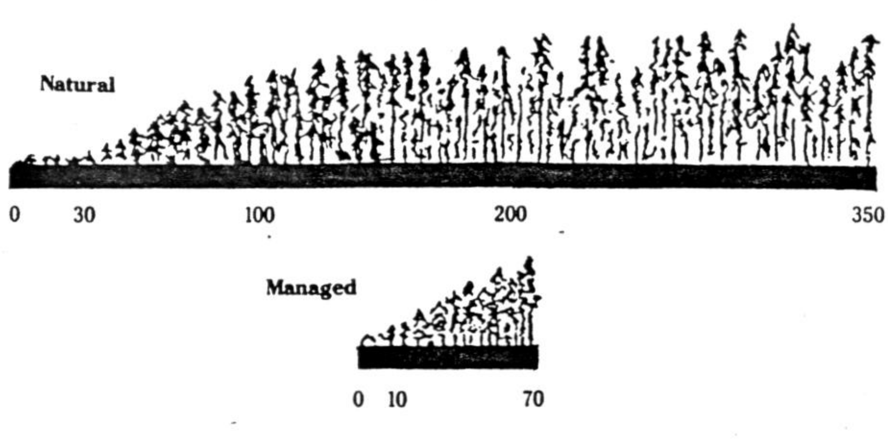
• **Rate of vegetation recovery**. The so-called "pioneering" vegetation, species specialized to occupy newly disturbed sites, plays an important role in retaining nutrients and key soil organisms during the period that trees are re-establishing. Some pioneers, the "nitrogen-fixers," have bacteria in their roots that are capable of converting atmospheric nitrogen, which in its gaseous form is unusable by all organisms but a few microbial groups, into a form that is suitable for life. Practices that reduce cover of these pioneering plants can lead to nutrient loss (through leaching to streams) and eliminate an important source of natural nitrogen fertilization. Nutrient losses resulting from control of pioneering vegetation vary widely depending on forest type. Leaching losses are much higher in eastern deciduous forests [3,7] than in western coniferous forests.[8] On the other hand, nitrogen-fixing plants are generally a more important source of ecosystem nitrogen in western than in eastern forests, and their elimination has long-term adverse implications.

In order to balance the soil "bank account" we must know how much is going in as well as how much is taken out. Nutrient inputs to ecosystems vary widely depending on chemistry of the soil-forming rocks and precipitation inputs. Nitrogen is generally the element of most concern, because it is not input by rock weathering and, in areas not impacted by acid rain, precipitation inputs are often quite low. (This is the case throughout much of western North America.) The recent work cited above also raises a red flag about calcium.[3]

One of the more serious threats to soil nutrient stores is short-rotation forestry. Short rotations are very appealing economically, because return on investment comes faster, and also because trees tend to attain maximum growth rate at a relatively young age. In the long view, however, short rotations are generally undesirable because they do not allow sufficient time between harvests for depleted nutrient stores to be replaced.

A classic example of the adverse effects of shortened rotations comes from the moist tropical forests (MTF). For millennia, native people in MTF practiced a form of shifting agriculture called "slash-and-burn," in which they would move periodically from one cleared plot to clear and plant another, eventually returning (usually after decades) to begin the cycle again. This stable, sustainable form of resource utilization went awry in the latter half of this century, when growing populations and shrinking MTF forced native cultivators to stay on one piece of

Figure 2



Contrast in duration of successional stages under natural and human disturbance regimes. Typical frequency for fire return under natural conditions is 350 to 450 years in northern Oregon and Washington. Normal rotation for managed stands is 70 to 90 years. Managed rotations eliminate the mature and old-growth stages of stand development and abbreviate the open, preforest canopy stage.

ground longer and return to it more frequently. Ecosystems did not have time to recover under this intensified regime, and slash-and-burn agriculture now accounts for a high proportion of degraded land in the moist tropics. Although not forestry in the strict sense of the word, the example of intensified slash-and-burn agriculture is applicable to any management system that is based on "deficit spending" from the soil bank account.

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Ecological Diversity

The second leg of sustainability is ecological diversity, a catchall term that includes: diversity of plant and animal species; structural diversity such as the number of canopy layers in the forest or the presence of old dead trees (important animal habitat); and diversity at the level of landscapes. In general, plant and animal diversity increases with structural and landscape diversity.[9] R. Rickleffs has recent discussed this concept.[9]

Management can impact diversity in various ways.[10] Even-aged forestry generally aims at (a) rapid site capture by crop trees, and (b) harvest when trees attain their maximum growth rate. At one end of the rotation, this reduces the time spent in the relatively diverse "shrub-forb-sapling" stage following the previous clearcut, and, at the other end, the diverse "old-growth" forest is completely eliminated, along with old logs and snags that provide unique habitat for various animal species (Figure 2). Note that these two impacts are not a necessary consequence of even-aged forestry, which can easily be designed to incorporate both the shrub-forb-sapling and old-growth stages, rather they result from the attempt to maximize the production of wood fiber. (I stress the word "fiber," because such rapidly grown trees have been found to produce wood of poor structural quality.[11])

Will reduced ecological diversity affect sustainability? Ecologists have long argued about the role of diversity in stabilizing ecosystems, the dogma swinging over the last 30 years from "diverse systems are more stable", to "diverse systems are less stable" to its current position which seems to be somewhere in between.[12] My answer to this question is a qualified yes and I have recently written a more detailed discussion.[13] It seems clear that a genetically homogeneous, intensively managed tree farm is less stable than a natural forest. Most managed forests fall somewhere between these two extremes, however, and the information simply isn't available that allows for hard and fast statements.

Nevertheless, given the very high level of environmental uncertainty we are currently facing in the form of climate change, pollution, and loss of the atmospheric ozone shield, the prudent thing to do is to reduce risk by maintaining as much ecological diversity as possible. There isn't time to wait for definitive studies of what is and what isn't important to ecosystem stability. As Aldo Leopold pointed out many years ago, the first rule of intelligent tinkering is to save all the pieces. Human substitutes for natural stabilizing mechanisms often have a short lifetime and a disconcerting tendency to produce unwanted side effects (e.g. pesticides selecting for increasingly pesticide-resistant insects).

In some cases there simply are no human substitutes for natural stabilizing mechanisms. Resistance to catastrophic fire is a case in point. Catastrophic wildfire may be the most serious threat to sustainability that we face, particularly in areas where the climate is going to become drier. It is clear that humans have increased the susceptibility of moist tropical forests to fire, and the weight of evidence in the Pacific Northwest suggests that conversion of structurally heterogeneous old growth forests to structurally homogeneous plantations increases the severity of wildfires. In the 1987 fires of southwest Oregon, for example, plantations and young stands established by wildfires in the 1930's were much more heavily impacted than old growth forests.

In thinking about diversity and stability it is important to remember it is *relationship*, or pattern, rather than numbers, that confers stability on systems. To understand this point it is helpful to think of ecosystems as somewhat analogous to human languages. Languages are composed of words, but these are only raw materials; the richness of language is imparted by syntax and context, the way words are arranged into sentences and sentences into phrases. In ecosystems, stability flows from the patterns of relationship that have evolved among the various species. Creating a stable artificial system, even a very diverse one, that does not attend to these co-evolved relationships has about as much chance of succeeding as creating a viable sentence out of randomly selected words. However, creating a partly artificial managed system, one that is grounded within and takes advantage of naturally occurring patterns, has a good chance of being sustainable.

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Genetic Diversity

Most tree species are extremely diverse genetically, much of this occurring within individual stands.[14,15] (For a recent discussion of genetics and conservation, see various papers in the recent book edited by Schonewald-Cox and others.[16]) There is no general agreement about how much of this local diversity is "adaptive," i.e. contributes to the resilience and stability of forests, and how much is due to random, adaptively insignificant mutations. As with ecological diversity, the prudent thing to do at this juncture is to keep as much as possible. This probably does not exclude the relatively low level genetic selection programs that are most common in forestry; these are unlikely to significantly reduce genetic variation. (More research is needed on this point however.) Clonal forestry is another matter, and in my opinion should be avoided.

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Current Research and Future Directions

During the last five years interest in the issue of maintaining long-term productivity has dramatically increased among the public and both government and private land managers. Even the World Bank, long a force for wrong-headed development in the tropics, has developed an ecological consciousness and now pays some attention to the sustainability and environmental impacts of the development projects that it funds. Translation of this interest into the money necessary to do key research has been slower, but some things are beginning to happen.

In the United States, the National Science Foundation (NSF), through its Long Term Ecological Research Program (LTER), is a principal funding source for research related to ecosystem stability and implications for sustainable resource management. A primary objective of the LTER program, which encompasses 17 intensive research sites representing virtually all significant ecosystem types from Puerto Rico to Alaska and Oregon to New Hampshire, is to search for commonalties in the way ecosystems are put together and in how they work, including how they are stabilized. The first of the LTER studies directly dealing with the influence of forest management practices on long-term productivity of forest ecosystems is now being installed on the H.J. Andrews Experimental Forest in western Oregon.

The transition from exploitation to balance and sustainability will not be easy. Human interaction with nature is characterized by a complex blend of social, psychological, economic, historical, and ecological factors, and all of these must be accounted for if we are to succeed. Moreover, the effort must be global; sustainable management practices at the local level will buy little if managed ecosystems are stressed by climate change and pollution. Much more than scientific understanding is required. We need economists who are willing to abandon outdated models and face the realities of the modern world,[17] and politicians with the courage to lead the transition away from the old sacred cow of growth toward economic and social balance with our life support systems. Most importantly, perhaps, we humans must abandon the hubris and alienation that have characterized recent history and see ourselves for what we are: part of a marvelously complex and beautiful global ecosystem. This process is what M. Berman calls the 'Re-enchantment of the World."[18] In a recent paper, Jumanne Maghembe and I put it this way:[13]

"*. . . the old Cartesian view of humans standing outside and manipulating systems like puppeteers is no longer valid. We react to nature, nature reacts to us, and the ultimate outcome may not be predictable. The technology of reductionism is not sufficient to cope with the 'certain uncertainty' that, paradoxically, has been magnified by our own power to manipulate. We must also invoke a technology of holism that draws on and learns from the robustness of nature. In doing so, we in a sense return to the ancient notion that the variety of ways in which humans interact with nature cannot be compartmentalized, but represent a whole that gives humankind vitality and balance.*"

Time is short. ■

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