LESSONS FROM THE PAST: FORESTS AND BIODIVERSITY

By
Jeffrey A. McNeely
Chief Biodiversity Officer
IUCN
1196 Gland, Switzerland

ABSTRACT

The biodiversity of forested regions today is the result of complex historical interactions among physical, biological, and social forces over time, often heavily influenced by cycles of various sorts. Fire, agriculture, technology, and trade have been particularly powerful human influences on forests. Virtually all of our planet's forests have been affected by the cultural patterns of human use, and the resulting landscape is an ever-changing mosaic of unmanaged and managed patches of habitat, which vary in size, shape, and arrangement. Because chance factors, human influence and small climatic variation can cause very substantial changes in vegetation, the biodiversity for any given landscape will vary substantially over any significant time period -- and no one variant is necessarily more "natural" than the others. This implies that biodiversity conservation efforts may need to give greater attention to ecosystem processes than to ecosystem products. A review of historical evidence shows that past civilizations have tended to over-exploit their forests, and that such abuse of important resources has been a significant factor in the decline of the over-exploiting society. It appears that the best way to maintain biodiversity in forest ecosystems in the late 20th century is through a combination of strictly-protected areas (carefully selected on the basis of clearly-defined criteria), multiple-use areas managed by local people, natural forests extensively managed for sustainable yield of logs and other products and services, and forest plantations intensively managed for the wood products needed by society. This diversity of approaches and uses will provide humanity with the widest range of options -- the greatest diversity of opportunities -- for adapting to the cyclical changes which are certain to continue.

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1. INTRODUCTION

Throughout history, forests have been a basic support system for society, providing goods such as timber, game meat, fodder, and medicinal plants, and services such as soil formation, watershed protection, and climate amelioration. People have often sought to enhance one or another attribute of forests at the expense of others, thereby providing -- in the judgement of those making the decisions -- the "optimum" mix of forest benefits to society. In retrospect, these judgements have not always been "correct," in the sense of supporting a sustainable society; but irrespective of their wisdom, the choices about the use of forest resources have had a profound influence on the structure and composition of the forest system.

What historical factors have led to choices which have reduced or increased the biological diversity of forests? What can historical experience tell us about the way forests are being used today? And how can a historical perspective help us use forests better in the future? Answering these questions requires an objective consideration of the influences people have had on forests throughout history.

In western culture, "nature" is often considered to be that which operates independently of people (Hoerr, 1993), and a major focus of development has been to bring nature under greater human control. In fact, "progress" is often measured by technological innovations which have enabled humans to gain a greater share of the planet's productivity. Conservation, on the other hand, has been based on the idea of sequestering the largest possible tracts of nature in a state of imagined innocence as national parks and other kinds of protected areas. Forests which are "pristine" or "virgin" or "primary" are thus given particularly high value for conservation, and considered likely to have particularly high diversity.

Despite the dominance of this view of nature, recent work in ecology (Sprugel, 1991), paleontology (Martin and Klein, 1984), forestry (Poffenberger, 1990), history (Boyden, 1992; Ponting, 1992), archaeology (Audric, 1972; Raven-Hart, 1981), anthropology (Denevan, 1992a), and ethics (Taylor, 1986) is calling into question the separation of people from nature, supporting instead the age-old view of many cultures that people are part of nature and that the biodiversity -- that is, the variety of genes, species, and ecosystems -- found in today's forests result from a combination of cyclical ecological and climatic processes and past human action. Evidence is building to support the view that very few of today's forests anywhere in the world can be considered "pristine," "virgin," or even "primary", and that conserving biological diversity requires a far more subtle appreciation of both human and natural influences. This paper will draw from a number of these studies to suggest four basic conclusions about the history of forests and biodiversity:

- humans have been a dominant force in the evolution of today's forests;

- as humans have developed more sophisticated technology throughout history, the impact they have had on forests has tended to increase to the level where forests are degraded to the long-term detriment of the over-exploiting society;

- over-exploitation is usually followed by a culture change which may reduce human pressure, after which some forests may return to a highly productive and diverse, albeit altered, condition, and others may be permanently altered to much less productive and diverse conditions; and

- the best approach to conserving forests and their biodiversity is through a variety of forms of management ranging from strict protection through intensive use, with a careful consideration of the distribution of costs and benefits of each management approach.

2. CYCLES, FORESTS, AND BIODIVERSITY

Cycles provide an essential framework for understanding the history of forest habitats, changing the perception of forests from static standing resources to dynamic processes. The daily passage of the sun and moon, and the longer cycles of the lunar months, the monsoon system, and solar years, are related to the rhythms of deciduous forests and the shedding of leaves from trees in evergreen forests, population cycles of insects which affect forests, and movements of birds, elephants, wildebeest, caribou, and other migratory species. The distribution and numbers of species are also affected by long climatic cycles which can bring periodic drought and fire to even ever-wet tropical forests (as El Niño did to Kalimantan in 1983), or by cyclical changes in sunspots. Changing sea levels are correlated with glacial and interglacial episodes in the temperate world and have caused alternating connections and disconnections between Indonesian islands and the mainlands of Asia and Australia, helping to contribute to the great biodiversity seen in tropical Asia, as well as to extinctions of a number of large mammals (McNeely, 1978). Biogeochemical cycles operating at a variety of speeds govern the transfer of chemical elements such as carbon, nitrogen, sulphur, calcium, and phosphorus between the biotic and abiotic parts of the biosphere (Jordan, 1985).

Different cycles affect biodiversity at different levels and at different speeds, from hours for some insects, to months for leaves, to years for small vertebrates, to decades for larger species, to centuries for forests, and to millennia for continental landscapes. Plant and biogeochemical processes dominate at small scales and climatic and geophysical processes dominate at large scales (Schindler and Holling, in press). Irrespective of the scale, the critical processes at each of the levels from the scale of the leaf or individual insect to an island or continent can be seen as a cycle of birth, growth, death and renewal.

Forest cycles are well known to foresters (e.g., Jordan, 1985; Holling, 1986). Birth (or reproduction) occurs when mature plants produce seeds which rapidly convert nutrients into energy to support growth. Growth is characterized by the slow accumulation and storage of nutrients and biomass. As the natural capital becomes more and more tightly bound and growth slows, other competitors are prevented from utilizing the accumulated capital until the system eventually becomes so over-connected (foresters might call this "over-mature") that rapid change -- death, or "creative destruction" -- is triggered by natural agents such as forest fires, insect pests, or intense episodes of grazing (Holling, 1986). The stored capital is suddenly released, the tight organization is lost, the "binding" loosens, and the released nutrients are reorganized to initiate the same or a very different cycle again. In short, chaos emerges from order, and order emerges from chaos (Schindler and Holling, in press).

Foresters have often tended to give most attention to the processes of regeneration and growth, seeking to enhance productivity, the results of which can then be harvested. But in terms of the sustainability of cycles, the processes of death and renewal may be even more important, because these affect the capacity of the forest ecosystem to renew itself after disturbance and enable the cycle to continue. Renewal of a forest ecosystem following harvesting, fire or other form of disturbance, depends on the nature and intensity of disturbance and the diversity and mode of reproduction of species located on the site (Maini, 1992).

While disturbance is part of the internal dynamics of any forested ecosystem, some disturbances can convert a diverse system into a much less diverse type of vegetation, through linkages with climate cycles, nutrient cycles, and hydrological cycles. Clark (1992), from a detailed study of "natural experiments", concluded, for example, that tropical deforestation could bring about essentially different ecosystems through its impact on local climate. If large areas of tropical forest are replaced by grassland, he found, annual evapotranspiration is likely to be reduced by about 300 mm and rainfall by 650-800 mm in these areas. Lower rates of evapotranspiration, he concluded, would lead to an increase in surface air temperatures of about 3°C, and reduced cloud cover would also lead to even higher temperatures, so the overall effect could be a rise in temperature of 4 to 5°C. While these observations are controversial (Bruijnzell, 1990; Bosch and Hewlett, 1982) and may apply only to the Amazon, it is apparent that in places where human influence has been intensive and long-standing and where soils are poor in nutrients, forests can be replaced by degraded savanna vegetation. In what is now Pakistan, the people of the Indus Valley in the fourth millenium B.C. destroyed the forested basis of their own livelihood. "The forests which had moistened their climate and restrained their floods had now been felled. Grazing had now extended the desert of Sindh and perhaps already absorbed the seasonal flow of many disappearing rivers" (Darlington, 1969). Similarly, what is now the Thar Desert in Rajastan and Punjab, India, was still tall forest 2,000 years ago, and the great stone faces which dot the grasslands of Easter Island bear silent witness to the forests that covered the remote island when humans first arrived some 1500 years ago (Ponting, 1992). More recently, the forest in some parts of tropical Asia has been so disrupted that it remains in a disclimax of *Imperata* grasslands and bamboo which supports a very low biomass and diversity of vertebrates, and is very resistant to reforestation efforts (Sayer, McNeely, and Stuart, 1990).

Ecology has not always had such a dynamic view of ecosystems. The great pioneer ecologists (Clements, 1916; Tansley, 1935) thought that for any site, a single "climax community" would be reached after a long period without large-scale disturbance (fire, wind storm, human clearance, etc.). It would then remain in equilibrium during which species composition, biomass, net primary productivity, and so forth were roughly constant from year to year, and opposing processes (such as gross primary production versus total respiration, or nutrient input versus nutrient loss) would be approximately balanced on a landscape scale (Sprugel, 1991). But now the venerable ecological principle of a single "climax vegetation" is being modified by a greater appreciation of the critical role disturbance plays in ecosystem dynamics. More ecologists are coming to the view that the possibilities for community organization within any one landscape are effectively infinite, especially in the tropics where species numbers are very high and food webs are very complex. The specific mix of species found at any site at any time is an accident of history, depending on what was there before, the way the habitat was disturbed, the order in which the various species arrived, and the influence of fires, diseases, humans, and so on during the process.

Sprugel (1991) concludes that at any specific point in time, the vegetation of any area has some special characteristics that make it different from other times in history. Because chance factors, human influence and small climatic variation can cause very substantial changes in vegetation, the biodiversity for any given landscape will vary substantially over any significant time period -- and no one variant is necessarily more "natural" than the others. This implies that biodiversity conservation efforts may need to give greater attention to ecosystem processes than to ecosystem products.

But this perspective should not be carried too far. Not all possible biotic assemblages are "natural"; a planted, fertilized, pesticide-saturated pasture dotted with cows, or a forest of genetically identical rubber trees planted in formations like a training regiment of army recruits is not a natural ecosystem by any reasonable definition. Further, it is clear that certain species of flora and fauna that may be of special concern to people are very susceptible to human activities and rapidly disappear from areas of heavy usage of forests. For example, large-bodied primates are easily hunted and decline rapidly in exploited habitats, so high densities of many of the large primates are now restricted to protected areas in many parts of the tropics (Bodmer and Ayres, 1991).

Different systems of forest management, and of the understanding of the forest dynamics on which they are based, may enhance or reduce their diversity. The most species-rich communities are likely to be found in high-rainfall areas covered by a wide range of different formations, including secondary forest in various stages of recovery interspersed with patches of old-growth forest. Completely excluding human intervention may reduce both genetic and species diversity by changing the mix of successional stages, although in other circumstances strictly limiting human impact may be necessary for conserving certain species. Nor is the sheer number of species necessarily a useful measure; Hawaii, for example, no doubt has more species than ever before in its history, though most of them are introduced and maintained by human action. The notion of "natural" vegetation or ecosystem processes, therefore, is still useful as a goal for forest management, though it must be revised to recognize that a range of ecosystems can legitimately be considered "natural" (Sprugel, 1991), and almost all of them will have been significantly influenced by people. The crucial point is that governments, and people, must consider what kind of ecosystem they actually want. It is not enough simply to preserve the existing landscape, or seek to re-create one from the past. Ecosystems are dynamic. They must evolve. But what should any ecosystem be allowed, or managed, to evolve into? Answering this question moves from ecological issues to those of human values, and may be illuminated by an historical perspective.

3. CONNECTIONS: THE HISTORY OF PEOPLE, FORESTS, AND BIODIVERSITY

The western vision of an untouched wilderness has permeated global policies and politics in resource management (Gomez-Pompa and Kaus, 1992). But this view of forests is based not only on an out-moded ecological perspective, but also on a misunderstanding of the historical relationship between people and forests, and the role people have played in maintaining biodiversity in forested habitats. A brief review of certain episodes in the history of people, forests, and biodiversity will show how humans have affected the birth, growth, death, and renewal cycle in a variety of ways, with a variety of outcomes in different parts of the world. The conclusion that the world has few, if any, forests which have not been significantly influenced by cycles driven by people is supported by evidence from three parts of the world:

Asia. Tropical Asia was one of the heartlands of shifting cultivation (Solheim, 1972), a prototypical cycle which has had a profound influence of habitats throughout the region over the past 10,000 years. Spencer (1966), on the basis of a detailed study of the impact of shifting cultivation in Asia, concluded that "most of the mature forests of the Orient today are not virgin forests in the proper sense, but merely old forests that have reached a fairly stable equilibrium of ecological succession after some earlier clearing by human or natural means. In some areas it is possible that old forests are not secondary forests or even tertiary forests, but forests of some number well above three."

Shifting cultivators plan their lives on the basis of the cycle of clearing and tilling the land, planting, harvesting, and regenerating vegetation in the fallow fields to recover nutrients over the subsequent decade or two before the cycle begins anew. A wide range of crops can be grown in forest fields, transforming a natural forest into a harvestable one which does not necessarily lose diversity on a landscape scale. Among the Lua of northern Thailand, about 120 crops are grown; the fallow swiddens continue to be productive for grazing or collecting, with well over 300 species utilized (Kunstadter, 1970). The Hanunoo of the Philippines may plant 150 species of crops at one time or another in the same swidden (Conklin, 1954). Among the Tsembaga Mareng of Papua New Guinea, each field contains some 15 to 20 major crops, plus dozens of minor crops, spread seemingly at random through the field (Rappaport, 1971).

Under traditional systems of shifting cultivation, wildlife flourishes, with elephants, wild cattle, deer, and wild pigs all feeding in the abandoned fields; tigers, leopards, and other predators are in turn attracted by the herbivores. The older fields contain a high proportion of fruit trees which are attractive to primates, squirrels, hornbills, and a variety of other animals. Wharton (1968) has provided convincing evidence that the distribution of the major large mammals of southeast Asia is highly dependent on shifting cultivation, because mature tropical forests conceal most of their edible products high in the canopy beyond the reach of the terrestrial herbivores, while forest clearings bring the forest's productivity down to where it can be reached by hungry browsers. The earlier successional stages are also faster-growing, and therefore more productive, than the later stages of the cycle as the forest becomes more mature.

However, the conclusion that shifting cultivation has benefitted both man and forest is dependent on it being carried out in a sustainable manner, which today is becoming an extremely rare phenomenon. Shifting cultivation can become maladaptive in at least three main ways: by an increase in human population which causes old plots to be recultivated too soon; by inept agricultural practices such as cultivating the land for so long that productivity declines and persistent weeds such as *Imperata cylindrica* become established; and by attempting to cultivate forests which are too dry, so recovery is too slow and the danger of cataclysmic fire is too great (Geertz, 1963). Sometimes the three factors work together to destroy wide areas of tropical forest.

Most shifting cultivation has taken place in the hills, where the vegetation dries out more quickly and up-drafts help fan the flames among the cut vegetation. The lowlands, many of which were seasonally flooded or otherwise difficult to burn, remained relatively intact during the early years of agriculture and were used mostly for hunting, fishing, and gathering of tubers and other plants. With the development of irrigation and agricultural surpluses, all that changed, and new civilizations flourished in lowlands where wet rice could be grown, often leading to substantial forest clearance.

Sumatra, for example, was the centre of the rice-growing Sriwijaya civilization which spread its influence from what is now Palembang throughout southeast Asia, even sending an army to Cambodia in the 8th century A.D. Following its collapse in the 14th century, forests quickly reclaimed much of the landscape which had been transformed by Sriwijaya (Schnitger, 1964) and parts of their ancient farmlands are now so important for biodiversity that they are included in Indonesia's protected area system. Even some of Indonesia's most remote protected areas are proving to contain important Sriwijanan archaeological sites, as in Kalimantan's recently-established Kayan Mentarang Nature Reserve, an indication of substantial historical human activity in forests noted today for their high biodiversity.

In Sri Lanka's remote and well-forested Mahaweli Basin, engineers digging the first survey ditches twenty years ago for a major water resources development programme were surprised to uncover ancient irrigation works two metres or so below the surface, but precisely where hydraulics experts advised building irrigation channels. Subsequent investigation revealed that these channels were built some 800 years ago, when Sinhalese civilization flourished in the Mahaweli. It soon became apparent that today's forests were yesterday's rice fields, and that modern development was following in the footsteps of the ancients.

But why were these ancient systems not still in use? Historians say that the hydraulic civilizations of Sri Lanka's Mahaweli region had a tumultuous past, with military adventures, social unrest, major investments in religious monuments and irrigation projects, political intrigue, and eventual collapse (Raven-Hart, 1981). The depth of the sediments found by the modern surveyors suggests that an increasing population might have spread into the surrounding hills and cleared the forested uplands for shifting cultivation; this would have led to the increasing levels of siltation that eventually smothered the irrigation systems. Social unrest and political intrigue no doubt accelerated the deterioration of the irrigation systems, and the Mahaweli Basin was abandoned some 600 years ago by the irrigators. Forests reclaimed the abandoned rice fields, the irrigation tanks began to resemble lakes, civilization moved to the northern and western parts of the island, and the aboriginal Vedda inhabitants of the region reclaimed their use rights. Today's developments are beginning the cycle anew, though a system of national parks is being established to help protect the forests and avoid repeating history's mistakes (McNeely, 1987).

Similarly, in what is now Cambodia the civilization centred around Ankor Wat in the 10th to the 12th centuries was based on a sophisticated irrigation system which enabled growing populations to be supported. But the cost of development was the depletion of the forests, leading to disastrous silt loads that came with the floods of the rainy season. The canals became clogged and epidemics of malaria swept through the city, caused by the mosquitoes which bred profusely in the now stagnant swamps. This weakened the capacity of Ankor to adapt to change, and the magnificent capital city was abandoned, leaving the irrigated rice fields to return to forest and the people to return to their age-old hunting, gathering, and shifting cultivation existence (Audric, 1972).

In tropical Asia, forest management was primarily in the hands of the people who lived in the forests in pre-colonial times, but the colonial era brought forests into the global market system, leading to many forests being nationalized, forest management technology being imported from Europe, and the loss of many traditional resource management practices that had the effect of maintaining biodiversity in forests (even if they were not explicitly designed to do so). Poffenberger (1990) points out that conflicts between state land management policies and locally operating forest-use systems is a major cause of forest land mismanagement throughout southeast Asia. With colonial regimes, forest departments in India, Sri Lanka, Burma, Thailand, and Indonesia were designed to generate revenue for the State rather than provide direct benefits to rural communities. Radical changes in tenure rights and lack of clarity over ownership of tree and forest products are key factors in understanding the speed with which Asian forests have been depleted, and why so many species are threatened today.

The Western Hemisphere. Trees played a crucial role in the initial occupation of the western hemisphere. It is now believed that the critical environmental variable that enabled the first humans to move from Asia into North America was the reappearance of trees in Alaskan river valleys, which provided essential fuel sources as glaciers withdrew at the end of the Pleistocene around 11-12,000 years ago (Hoffecker, Powers, and Goebel, 1993). Human influence on forested ecosystems, therefore, began as soon as people moved into the continent.

As they moved further south, the immigrants from Asia continued to modify the American forests. In reviewing the evidence, Denevan (1992b) concluded that pre-Columbian human settlement had modified forest extent and composition, expanded grasslands, and rearranged the local landscape through countless artificial earthworks. Agricultural fields, towns, roads and trails were common, having local impacts on soil, micro-climate, hydrology, and wildlife. These early immigrants had a significant impact on biodiversity as well, with some 34 genera of large mammals becoming extinct around the time of first human occupation of the continent (Martin and Klein, 1984).

On the other hand, selective burning and other forms of forest clearance promoted a mosaic quality of North American ecosystems, creating forests in many different states of ecological succession and thereby promoting biodiversity on a landscape scale. The long-leaf pine, slash pine, and scrub oak forests of the southeast United States are an anthropogenic sub-climax created by Amerindian burning, as were many of the mid-western grasslands found by the early European explorers. By the 19th century, many Amerindian-created grasslands in Wisconsin, Illinois, Kansas, Nebraska, and elsewhere were re-invaded by forests after fire had been suppressed by the new wave of immigrants from Europe (Denevan, 1992a).

With the coming of European colonialists in the sixteenth century, the eastern forests were under renewed pressure for agricultural clearance and construction. By 1700 most of the timber within 30 km of the main rivers of New Hampshire had been felled and within another 50 years most of the eastern sides of the mountains had been cleared of timber. By 1775, the eastern part of North America had been stripped of the very tall pines needed for main masts of British ships, and the great hardwood forests of the eastern seaboard had lost over 75 percent of their area by 1880 (Ponting, 1992).

Global trade was a key factor in the loss of forests in the North American colonial period, even if the local people were not always aware of this. Mancall (1991) points out that during the 18th century in the upper Susquehanna river valley of New York and Pennsylvania, the early colonial settlers and indigenous people set about their goals of subsistence and economy in culturally defined, usually non-market-oriented ways. However, increasing availability of cash and manufactured commodities, as well as the boom and bust cycles of economic practices based on relationships with merchants and land speculators, always kept the rural populations tied to the world economy. Further, the colonial authorities manipulated the process of settlement and forest clearance, with constant collusion between the government authorities and wealthy individuals helping to transform the colonial economy (Ponting, 1992).

Following the American Civil War (1860-1865), the west was opened up by railroads and emigration from the east led to large-scale abandonment of land in New England, New York, and Pennsylvania, followed by natural revegetation which produced a re-established forest estate in these areas.

Further south, many of the tree species now dominant in the mature vegetation of Central America were and still are the same species protected, spared, or planted in the land cleared for crops as part of the practice of shifting agriculture. By A.D. 800, the Maya had modified 75 percent of the Yucatan forest, and following the collapse of the classical Mayan civilization shortly thereafter, forest recovery in the central lowlands was nearly complete when the Spaniards arrived 700 years later (Whitmore, *et al.*, 1990). The Aztecs followed a similar cycle. Examining the association between erosion and pre-Colombian population in Central Mexico, Cook (1949) concluded that: "An important cycle of erosion and deposition accompanied intensive land use by huge primitive populations in central Mexico, and had gone far toward the devastation of the country before the white man arrived." O'Hara *et al.* (1993) found three major episodes of erosion in central Mexico over the past 4,000 years, correlated to the first arrival of corn, farming of steep slopes, and a period of heavy population density, all in pre-colonial times. The current composition of the vegetation in Central America thus is the legacy of past civilizations, the heritage of cultivated fields and managed forests abandoned hundreds of years ago (Gomez-Pompa and Kaus, 1992).

Even further south, the great "pristine" forests of Amazonia supported a human population of at least 8 million people at the time of the voyage of Christopher Colombus (Denevan, 1992a). By 1492, the Amazon forests had been significantly influenced by human use, and the people were managing kinds, numbers, and distributions of useful species of trees. Modern-day tropical forest hunters with simple technology also have significant impacts on the forest, suggesting how even relatively simple technology could have affected forest biodiversity. While routinely hunting and gathering through the forest, the Kayapo Indians of Amazonia collect dozens of tubers, beans, and other food plants, carry them back to forest campsites or trails, and replant them in natural forest clearings. Such "forest fields" are often located near streams, but even in the savanna, where patches of forest are scattered, areas where collected plants have been replanted form useful food depots for the indigenous people (Posey, 1982). This age-old pattern has had profound effects on the distribution of plants in the forest and has been an important influence on the current biodiversity of Amazonia.

Many societies living in Amazonia have a detailed and sophisticated understanding of cycles. Based on long fieldwork with the Tukano of Colombian Amazonia, Reichel-Dolmatoff (1976) found a common belief that people used to be healthier, stronger, and more intelligent than they are now, and that animals and fruits were larger and more abundant. The Tukano's sense of entropy -- the tendency toward disorder and chaos -- did not seem to be a consequence of their present plight, but was rather an existential anxiety that formed part of native cosmology and philosophy, based on the close and daily observations of the biological cycles of growth and decline. However, their sense of increasing disorder is accompanied by an institutionalized resolution to recreate the world and to re-establish its order and purpose as stated in cosmological tradition. Reichel-Dolmatoff recognized this continuous cycle of ritual creation, destruction and re-creation in many tropical forest societies and considered it an important mechanism of cultural and biological survival which probably characterized many traditional cultures which occupied tropical forest habitats.

But profound changes came when European colonists brought diseases, forced labour, and the like, leading to a crash of the population of tropical Amerindians which eliminated estimated 76% of the native people of the Americas south of the present-day USA between 1492 and 1650 (Denevan, 1992a). This population crash was not compensated by new immigrants until fairly recent times, leaving wide areas of agricultural land to revert to tropical forests which today are often considered "pristine" or "natural". In short, the authentic virgin forest of the Americas was discovered over 10,000 years ago by the first Asian immigrants, who quickly set about modifying the forest to suit their ends. The "virgin forest" alleged to have been encountered by European explorers in the 16th and 17th centuries, and which has had such a profound influence on global perceptions of tropical rainforests, was in fact invented by romantic writers about nature in the late 18th and early 19th centuries (Pyne, 1982).

Europe and the Mediterranean. The case for Europe is perhaps even more dramatic. The ancient vegetation of the Mediterranean area was a mixed evergreen and deciduous forest of oaks, beech, pines, and cedars. The forest was eaten away by waves of different civilizations who used the forest and forest lands to further their development objectives, expanding and contracting as the wisdom of their policies was tested. The process of forest clearance was already well underway at the time of Homer in the 9th century B.C., who likened the noise of a battle to "the din of wood cutters in the glades of a mountain". Early in the 4th century B.C., Plato, referring to the disappearance of forests in Attica, wrote: "What now remains compared with what then existed, is like the skeleton of a sick man, all the fat and soft earth having been wasted away, and only the bare framework of the land being left" (quoted in Boyden, 1992). Civilizations from Bronze Age Crete and Knossos, Mycenaean Greece, Cyprus, Greece, and Rome rose and fell with the forests which supported them (Perlin, 1989). Subsequent overgrazing by sheep, cattle, and goats prevented the forests from ever becoming re-established.

The olive is perhaps the "flagship species" of the Mediterranean. Developed from a straggly wild relative along the coasts of Syria and Anatolia in the 6th century B.C., it became a crop of outstanding economic importance. But it also led to significant deforestation, land degradation, and loss of biodiversity. As the richer valley lands were cleared of forests to plant crops, the poorer soils of the hillsides were being planted with olives. The development of Crete between 2500 and 1500 B.C. was supported by the export of timber and olive oil to Egypt, as forest trees were felled and olive trees were planted. But as a result of deforestation, soil accumulated in a million years was being washed from the hillsides in just a few centuries, and the natural wealth of the country was eroded with the soil. The decline of the Cretan forests was mirrored by the same transformation, following in the wake of the axe, the plough, and the olive in their westward progress through all the civilized states of the Mediterranean (Darlington, 1969). As a result, much of the evergreen forest in the Mediterranean region was transformed into the low-diversity brushwood known as *maquis* which today is maintained by fire. The loss of native forests also had significant impact on biodiversity, with some 90 percent of the endemic mammalian genera of the Mediterranean becoming extinct after the development of agriculture (Sondaar, 1977).

On the Mediterranean north coast of Africa, Carthage, too, suffered from serious deforestation, over-exploiting timber for building ships of war. The soil erosion which followed prevented the restoration of forests and pastures, creating swamps which, beginning in the 3rd Century A.D., began to harbour mosquitoes which North African armies invading Europe infected with malaria. So it was that, following Crete and Greece and preceding Sriwijaya, Angkor, and the Maya, North Africa took the deforested pathway to the collapse of civilization, at a pace accelerated by war (Darlington, 1969). The forests of North Africa have never recovered, and numerous species have been lost.

Forest clearing has been a significant factor in the history of central Europe as well, where a series of internal colonization movements driven by technological change have had significant impacts on forests. The development of improved agriculture by Bronze-Age Celtic peoples 3,000 years ago, for example, enabled them to clear forests and spread over much of northern and central Europe (Rackham, 1986). The latest major internal colonization movement came when Germanic peoples developed improved iron axes to fell trees for fuel and timber, and iron ploughs to till the heavy soils on the land they cleared. This enabled them to move eastwards into Slavic lands from the 10th to the 13th centuries, following a sustained and deliberate policy of development based on clearing the northern European forests (Darlington, 1969) which had regrown after the decline of the Celts. By the time this great internal colonization came to a halt, population was probably higher than it had ever been, the climate was deteriorating, and new settlements had increasingly been pushed into areas marginal for agriculture where yields were lower. As a result, populations started to decline and the catastrophic accelerated loss of population due to bubonic plague in places led to the loss of up to a third of the people. These processes changed the ethnic map of Europe by producing a complex mixture of peoples that has bedeviled the history of the region ever since (Ponting, 1992). The 80 percent of central Europe covered by forest around 900 A.D. had been reduced to just 20 percent by the time Colombus set sail to encounter the "New World".

The rapid clearing of European forests during times of changing technology caused significant shortages of timber. When Venice exhausted local timber supplies in the Middle Ages, it had to rely on imports from its colonies along the Dalmatian coast, while imposing draconian laws in an unsuccessful attempt to protect the last of its domestic oak forests on the Italian mainland. Portugal's timber shortage may have helped stimulate its voyages of exploration along the coast of Africa and the Indian Ocean and by the 16th century nearly all Portuguese ships were built in its colonies. Spain suffered similar shortages, buying trees from Poland to build the Spanish Armada which sailed against Holland and England in the 1580s. The English navy, which ruled the seas and enabled the vast British colonies to be governed in the 18th and 19th centuries, was built only partly from British oaks; significant amounts of timber were imported from Scandinavia and Russia (including 600,000 trees a year from Russia to supply the Royal Navy in the late 1750s) (Ponting, 1992).

On the other hand, the loss of forests also challenged people to be creative. In England, for example, forests had been so reduced by the early 16th century that fuelwood was replaced by coal, stimulating new methods of manufacturing and the exploitation of new resources. The loss of forests was therefore an important stimulus to both the industrial revolution and the colonizing impulse of Europe (Nef, 1977). By the 19th century, serious shortages led to timber being considered the most important forest product, and foresters developed a value system that focused on issues of engineering and biological productivity, with relatively little attention given to questions of broader social interest and social values, including biodiversity. European (mostly German) foresters then promoted the single-use forestry model to North America, Australia, New Zealand, Japan, and India (Behan, 1975), thereby having a profound influence on forests and their biodiversity throughout the world.

These three brief histories of some aspects of forests and biodiversity lead to the general conclusion that the impact of humans is not simply a process of increasing change or degradation in response to population growth and economic expansion. History is instead interrupted by periods of reversal and ecological rehabilitation as cultures collapse, populations decline, wars occur, and cultivated habitats are abandoned to forests. Impacts may enhance or reduce biodiversity, but change has been continual at variable rates and in different directions (Denevan, 1992b). It is also instructive to compare these historical cycles with the ecological cycles described earlier. Perhaps the development of new technology is comparable to "birth," while the rapid exploitation of forests following the new technology can be seen to fuel a rapid "growth" in the human culture. As exploitation accelerates, a point of over-exploitation is reached ("death"), the human population declines, the forest recovers, and the human culture adapts to the new conditions ("renewal"). In some cases, such as Europe, the renewal leads to significant technological changes, while in others it may lead to a return to living in a new balance with the forests (as in Amazonia), while in still others it may lead to cultures which have essentially lost their links to the forest (as in Easter Island, or North Africa).

4. CONCLUSIONS: CULTURE, FORESTS AND BIODIVERSITY

Forests have been an essential basis of human prosperity, providing diverse products and services throughout the evolution of our species. The combination of cyclical ecological and historical factors goes a long way toward explaining which of the many goods and services available from forests will be given priority by a society, the means available to utilize these resources, and the impact human decisions have had on biodiversity and on sustainable productivity. Clearly, what is acceptable under one set of socio-economic and ecological conditions -- or level of understanding -- may be totally rejected under another set of conditions (Maini, 1992); but at each period in history, society may be seen to be acting in its perceived self-interest. As we have seen above, civilized society has not always been "right" in its judgement, if we equate "rightness" to sustainability. The ruins of civilizations past bear ample witness to miscalculations in the development strategies of our forebears. Nor are traditional societies always wise stewards of biodiversity, judging from the many prehistoric extinctions which appear to have accompanied early hunters and agriculturalists (Martin and Klein, 1984).

Drawing on the earlier discussion, numerous cultural innovations can be seen to have affected human impacts on forests, of which at least four have been revolutionary: fire; agriculture; technology; and trade. Each of these revolutions helped to set our species apart from the rest of the animal kingdom. Each has been supported by numerous specific innovations over time (e.g., iron, internal combustion engines, chemical fertilizers, computers, television, nuclear power), but the broad adaptations represented by fire, agriculture, technology, and trade have each brought very fundamental changes to the relationship between people and forests, drawing from cultural innovations and stimulating change in different ways in different places. The following discussion mentions just a few of the implications of these adaptations, showing how profound they have been in their implications for forests and biodiversity.

Fire. At the earliest hunting and gathering stage of human existence, people probably had little more impact on the ecosystem than did any other medium-sized generalized omnivore. Indications are that they utilized no more than 0.0001 percent of the available photosynthetic energy (Boyden, 1992). But as technology improved, the ecological niche of early man steadily expanded. Humans started having an impact on other species out of all proportion to their numbers and biomass (some ecologists consider this the defining character of a "keystone species" -- Bond, 1993) when they first learned how to control fire several hundred thousand years ago (Hough, 1926). Controlling fire enabled early hunters to burn grasslands and open forests, thereby increasing the productivity of these habitats, attracting the large species humans preferred to hunt, and facilitating the movement of hunters. Fire subsequently became an important tool for clearing land for agriculture, and for converting biomass into energy useful to humans. The use of fire (combustion) to convert fossil fuels to energy -- essentially drawing on hydrocarbons stored by living organisms long extinct -- is now elevating atmospheric carbon dioxide and is highly likely to lead to significant climate change (Schneider, 1989), thereby affecting the climate cycle and causing fundamental changes in forest types and distribution.

Agriculture. Agriculture fundamentally changed the relationship between people and the rest of nature through domestication of plants and animals, which enabled a much greater degree of human control over some ecosystems, species and their genetic composition. Traditional farmers modified species to meet their needs, leading to greatly enhanced genetic diversity among the species cultivated; India, for example, had over 25,000 varieties of rice . Based on archeological evidence and historical records, it seems certain that the early agrarian societies were highly dependent on forests as an essential supplement to their permanent fields, providing both goods (nuts, fungi, wood, fodder, firewood, medicinal plants, etc.) and services (building soils during fallow periods, protecting water sources, etc.). This pattern has continued until the present in many agrarian systems. In Nepal, for example, it is estimated that for every hectare of agricultural land, farmers need 3.4 ha of forest to provide firewood, fruits, and various other products (Sattaur, 1987), and Swiss farmers invariably have forests on part of their land or at least have access to communal forests. Agriculture supports much higher populations than hunting and gathering, and significant agricultural surpluses eventually led to great civilizations. Increasing from 2.65 million square kilometers in 1700 to 15 million sq km in 1980, agricultural land has spread at the expense of forests, but as shown above, this has often been a cyclical change and even today agricultural land covers only about 10 percent of the terrestrial surface of the planet (WRI, 1992). Further, many agricultural systems have maintained great biodiversity; Javanese farmers, for example, cultivate over 600 species in their gardens, with an overall species diversity comparable to deciduous tropical forest (Soemarwoto, 1985). But in recent times, the "green revolution" has led to a loss of genetic diversity and a reliance on energy (in the form of fertilizers, pesticides, etc.) from outside the system. Modern biotechnology will undoubtedly lead to additional changes, but limits are being reached; Vitousek *et al.* (1986) calculated that our species is now consuming or otherwise pre-empting over 40 percent of the planet's terrestrial photosynthetic productivity.

Technology. While tool use is by no means unique to our species, we have taken tool use to levels that enable us to harvest a much broader spectrum of nature's products than any other species (Gibson and Ingold, 1992; Kingdon, 1992), and indeed technology has played an important role in our evolution (Schick and Toth, 1993). Judging from both archeological and historical evidence, technology has been characterized by change. When technological change is very rapid, as it has often been when major innovations are introduced (such as ship-building), over-exploitation is to be expected as traditional controls break down and humans learn to exploit resources in new ways. Modern technological innovations -- such as plantation forests or industrial logging -- tend to favour over-exploitation of forests and the weakening of traditional approaches to forest management which had been developed in response to historical experience. Today, technology -- through processing, transport, and marketing -- enables the global consumer society to harvest resources from alternative locations when local resources are exhausted. The market-driven economy derives no particular advantage from adopting the traditions of sustainable, conservative use that may have characterized the groups which lived in balance with their resources, instead feeding most of the benefits of the forest into the global system while paying few of the local environmental costs. These costs remain with the local people, who must live with the consequences of the resource management decisions imposed upon them from outside (Gadgil, 1987).

Trade. Trade appears to be ancient in human history, judging by the distribution of flint axeheads found far from their source of raw material. Trade has been an important part of all civilizations, and enabled far greater populations to be supported. With trade, forests no longer support only the local human ecosystem, but increasingly feed the demands of distant markets; the impact of the olive on Mediterranean forests mentioned above is only one example of this phenomenon. International trade makes forests part of the international economic system rather than the national or local economic system, so costs and benefits of timber production are distributed in ways that are quite different from locally-marketed or subsistence commodities. Timber has become a major commodity in international trade, with the top ten exporters earning some US$ 70.7 billion in 1989 (FAO, 1992), of which developed countries accounted for over 81 percent. Because they are not responding to local conditions of supply and demand, traders do not experience the limits which agrarian forest managers learned to address through management systems developed over long periods. Although trade allows some countries to live beyond the ecological carrying capacity of their borders, it is impossible for all countries to do so. As Daly (1992) has pointed out, no matter how much world trade may expand, all countries cannot be net importers of raw materials and natural services. Free trade might allow the ecological burden to be spread more evenly across the globe, thereby buying time before facing up to the limits, but at the cost of eventually having to face the problem simultaneously and globally rather than sequentially and nationally (or even locally). Trade converts the world's forests from a complex set of multiple cycles operating at different speeds in different parts of the world into one massive inter-connected cycle. What were once locally self-sufficient and sustainable human systems have become part of much larger national and global systems whose higher productivity is both welcome and undeniable, but whose long-term sustainability is far from proven. Further, increased consumption facilitated by this higher prductivity is also encouraging land-use practices which are unsustainable, especially deforestation and use of land for agriculture that would be more suitable for forests or other uses. As demonstrated by the experience of previous civilizations and the seemingly inevitable cyclical changes thre automobiles. Any money yielded by such an action would be inconsequential relative to the social value of the national symbol. The controversy in the Pacific Northwest of the US and Canada between loggers and advocates for the spotted owl is simply one example of the political process of making choices about how forests are to be managed. As non-product benefits like biodiversity become more important to urban citizens, the social system (such as public interest groups) and the political system (including new legislation, environmental impact assessments, greater public involvment in decision-making, more detailed regulations and reorganization of forestry agencies) inevitably will become a more prominent part of forest management (Koch and Kennedy, 1991). The issue of whether these measures are symptoms of significant improvements or of management systems becoming "over-connected" and more brittle, and therefore approaching senility, remains to be seen.

Where the forest industry once exploited a seemingly endless timber supply, political demands for sustainability are forcing it to seek maximum benefits out of a smaller quantity of higher quality wood, or out of lower quality second growth and plantations. Foresters are increasingly seeking combinations of forest uses which are compatible. They are finding, for example, that conserving biodiversity and storing carbon for reducing atmospheric carbon dioxide are highly compatible forest services, and that such uses can also allow the production of non-timber forest products, the conservation of soil and water, and recreation and tourism. These uses are certainly incompatible with clear-felling, but perhaps may be compatible with well-managed selective logging. The trend is clearly away from single-product forestry, and back to diversity and benefits for people living in and around the forests.

The Statement of Forest Principles approved by governments at the United Nations Conference on Environment and Development in Rio de Janeiro last June clearly recognized a new political appreciation of multiple use, stating that "Forest lands should be sustainably managed to meet social, economic, ecological, cultural, and spiritual human needs of present and future generations." Ecological science supports this cyclical change away from clear-felling for chips or timber and toward a more sensitive and diverse approach to forest management. Schindler and Holling (in press) point out that since ecosystems are dynamic, with multiple futures that are uncertain and unpredictable, forest management must itself be flexible, adaptive, and experimental at scales compatible with the scales of critical ecosystem functions such as nutrient flows, hydrological flows, and evolution.

It appears that the best way to maintain biodiversity in forest ecosystems in the late 20th century is through a combination of strictly-protected areas (carefully selected on the basis of clearly-defined criteria), multiple-use areas managed by local people, natural forests extensively managed for sustainable production of commodities such as logs (but with other benefits being accommodated to the extent possible), and forest plantations intensively managed for the wood products needed by society. This diversity of approaches and uses will provide humanity with the widest range of options -- the greatest diversity of opportunities -- for adapting to the cyclical changes which are certain to continue.

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