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Coping with Change

People, Forests and Biodiversity

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 climatic improvement. People have often sought to enhance a certain attribute of forests at the expense of others, thereby providing—in the judgement of those making the decisions—the best mix of forest benefits to society. However, these judgements have not always led to sustainable use of forest products. The choices about the use of forest resources have nevertheless had a great influence on the structure and composition of the forest system.

What can historical experience tell us about the way forests are being used today? 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 setting aside large tracts of nature that are in a state of imagined innocence and converting them into 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 biological diversity.

Despite the dominance of this view of nature, studies in such areas like archaeology, history and forestry call into question the separation of people from nature, supporting instead the age-old view that people are *part* of nature and that biodiversity—that is, the variety of genes, species, and ecosystems—found in today's forests results 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.

Delving into the history of forests and biodiversity leads us to the following four conclusions:

1) humans have been a dominant force in the evolution of today's forests;
2) as humans have developed more sophisticated technology throughout history, the impact thay have had on forests has tended to increase to the level where forests are degraded to the long-term detriment of the over-exploiting sociey;
3) 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
4) 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.

These conclusions can be drawn from the following review of the changes in forest use throughout human history.

Cycles, Forests, and Biodiversity

Natural cycles provide an essential framework for understanding the history of forest habitats. The daily passage of the sun and moon, and the longer cycles of the lunar months and solar years, are related to the shedding of leaves from trees in deciduous forests, population cycles of insects which affect forests, and movements of 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. Different cycles affect biodiversity at different levels and at different speeds (from hours for some insects, to months for leaves and to millennia for continental landscapes). The critical processes at each of the levels can be seen as a cycle of birth, growth, death and renewal (Holling, 1986).

Foresters have often been inclined to give the most attention to the processes of birth and growth, trying to enhance productivity, in order to harvest the products. But 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 extent and nature of the disturbance and the diversity and mode of reproduction of species located in the forest (Maini, 1992). Disturbance is an important part of any forested ecosystem and helps set the timing of further cycles.

However, 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 moisture precipitation produced by vegetation (evapotranspir-ation) is likely to be reduced by about 300mm and rainfall by 650-800mm 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 (Bruijnzeel, 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 millennium BC destroyed the forested basis of their own livelihood. 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 1,500 years ago (Ponting, 1992). More recently, the forest in some parts of tropical Asia has been so disrupted that it now only consists of a combination 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).

The traditional ecological principle of a single steady state of vegetation is being replaced by the realization that the possibilities for community organization within any one landscape are effectively unlimited, especially in the tropics where species numbers are very high. 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.

The vegetation of any area at a specific point in time 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 (Sprugel, 1991). 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 assortments of vegetation 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 areas are likely to be found in high-rainfall areas covered by a wide range of different ecosystems, 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. The notion of "natural" vegetation or ecosystem processes 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? To answer this question we must also take into consideration human values and their impact on ecosystems thoughout history.

Learning Lessons from History

The western vision of an untouched wilderness has pervaded through 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 here by evidence from three parts of the world:

Asia. Tropical Asia was one of the

heartlands of shifting cultivation (Solheim, 1972), a repetative pattern of agriculture which has had a profound influence on habitats throughout the region over the past 10,000 years. Shifting cultivators plan their lives on the basis of the cycle of clearing and tilling the land, planting, harvesting, and regenerating vegetation in the uncultivated fields to recover nutrients over the subsequent decade or two before the cycel 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, for example, about 120 crops are grown; the uncultivated fields continue to be productive for grazing or collecting, with well over 300 species utilized (Kunstadter, 1970).

Under traditional systems of shifting cultivation, wildlife flourishes. Elephant, wild cattle, deer, and wild pigs all feed in the abandoned fields, and tiger, leopard, 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 be detrimental 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 by attemping to cultivate forests which are too dry, so recovery is too slow and the danger of large fires 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 updrafts 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 plants. With the development of irrigation and agricultural surpluses all that changed, and new civilzation 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 AD. 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, and 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 civilization 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 Angkor 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 Angkor 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 means of maintaining biodiversity in forests. Poffenberger (1990) points out that conflicts between state land management policies and locally operting forest-use systems is a major cause of forest land mismanagement throughout southeast Asia. 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. 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 Clein, 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.

With the coming of European colonialists in the sixteeth century, the eastern forests were under renewed pressure for agricultural clearance and construction. By 1700 most of the timber within 30km 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 per cent 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. The colonial authorities manipulated the process of settlement and forest clearance, with constant collusion between the government authorities and wealtlhy individuals helping to transform the colonial economy (Ponting, 1992).

Further south, many of the tree species now dominent 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 AD 800, the Maya had modified 75 per cent 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. 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 (Gomaz-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 Columbus (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 food plants, carry them back to forest campsites or trails, and replant them in natural forest 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.

But when European colonists brought diseases, forced labour, and the like, the population of tropical Amerindians crashed, with an estimated 76% of the native people of the Americas south of the present-day USA being eliminated 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 primeval 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 thei r ends. The "virgin forest" alleged to have been found 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 BC. 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 BC, 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 BC 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 per cent of the endemic species of mammals of the Mediterranean becoming extinct after the development of agriculture (Sondaar, 1977).

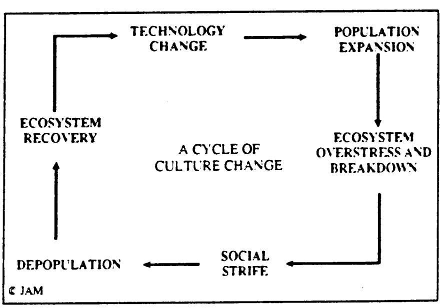
On the Mediterranean north coast of Africa, Carthage, too, suffered from serious deforestation, over-exploiting timber for building ships of war. The soil erosion which followed prevented the restoration of forests and pastures, creating swamps which, beginning in the 3rd century AD, began to harbour mosquitoes which infected North African armies invading Europe 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 eighty per cent of central Europe covered by forest around 900 AD had been reduced to just 20 per cent by the time Columbus set sail to encounter the "New World."

The rapid clearing of European forests during times of changing technology caused significant shortages of timber. 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. 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).



Four Cultural Revolutions

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 agricuturalists (Martin and Klein, 1984).

Drawing on the earlier discussion, numerous cultural innovations can be seen to have affected human impacts on forests, of which as least four have been revolutionary: fire; agriculture; technology; and trade. Each of these revolutions has been supported by numerous specific innovations over time (e.g., iron, chemical fertilizers, computers, nuclear power), but fire, agriculture, technology, and trade have each brought very fundamental changes to the relationship between people and forests, drawing from technological innovations and stimulating change in different ways.

Fire. 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 climatic cycle and causing fundamental changes in forest types and distribution.

Agriculture. Agriculture fundamentally changed the relationshiop 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 archaeological 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. Agricultural land has spread at the expense of forests but this has often been a cyclical change and even today agricultural land covers only about 10 per cent of the terrestrial surface of the planet (WRI, 1992). 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 (Socmarwoto, 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.

Technology. While tool use is not unique to our species, we have developed it in such a way that it enables 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 archaeological and historical evidence, technology has been characterized by change. When technological change is very rapid, 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. 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 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. 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 per cent. 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) (Daly, 1992). 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. Furthermore, increased consumption facilitated by this higher productivity 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 that are inherent in forest systems, this all-or-nother approach is a risky strategy.

Conclusions

The general trend is clear: human influence on forests has increased significantly over time, as those responsible for managing forests have responded to the social values of the time. Innovations for gaining more benefits for people from the planet's finite resources increase the availability of food and thus determine local growth of population, leading to migration to relieve population pressure and repeating cycle of expanding population and improving technology (Cavalli-Sforza, Menozzi, and Piazza, 1993). While local civilizations and cultures undoubtedly have gone through cycles, the global trend is still toward greater human dominance of the world's ecosystems.

What, then can we expect of the future? Changed circumstances are bringing about new perceptions and new demands. The recognition of the role of forests in climatic, nutrient and other cycles, will stimulate new approaches to forestry. Forest economists perceive the quantifiable economic value of logs from a rare old-growth forest very differently from the non-quantifiable social values reflected in political decisions. One of the challenges inherent in a multiple-use approach is that those outputs of forests that can be allocated by markets are relatively easy to quantify and exploit, while those that cannot be given a market value—such as biodiversity—tend to be undervalued and are therefore likely to be degraded over time. Utilitarian values are often in conflict with strongly-held romantic and symbolic values. To many urban people today, clearing rare old-growth forests for their commodity values is as sensible as melting down the Eiffel Tower to sell the iron to make more automobiles. The controversy in the Pacific Northwest of the USA 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, regulations and reorganization of forestry agencies) inevitably will become a more prominent part of forest management (Kock and Kennedy, 1991).,

Where the forest industry once exploited a seemingly endless timber supply, political demands for sustainability are forcing it to seek maxi.mum 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 indirectly regulating climate 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. 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. Since ecosystems are dynamic, with multiple futures that are uncertain and unpredictable, forest management must itself be flexible (Schindler and Holling, in press).

It appears that the best way to maintain biodiversity 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 habitats extensively managed for sustainable production of commodities such as forage of logs (but with other benefits being accommodated to the extent possible), and agricultural land and forest plantations intensively managed for the consumer 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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