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TECHNOLOGIES FOR SUSTAINABLE FOREST MANAGEMENT: CHALLENGES FOR THE 21ST CENTURY

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Summary

Technology will help to address the challenges for sustainable forestry in the 21st century. Some of the challenges will include the shift of production from native forest to plantations in areas of comparative advantage, more efficient processing delinking end-use products from raw wood characteristics, increased demand, better information technologies to support decision makers, and more options for conserving biodiversity. Definitions of sustainability will vary in time and space as society's expectations and aspirations change, so there can be no "silver bullet" to ensure sustainability. However, progress may be facilitated with a systematic approach to forest management embracing the usual planning cycle: formulation of objectives, preparation of a strategy, planning, implementing, monitoring, and reappraisal. This requires a good understanding of each particular situation. Managers need good resource assessment and decision support systems; they must foster stakeholder participation in decisions, costs and benefits; and ensure effective procedures to resolve conflicts. Within an appropriate system, technical advances such as better machines and new implements may help to make a difference, but will not in themselves ensure sustainability. The important technologies for sustainable forestry are those that foster better communication between stakeholders and allow informed decisions spanning scales from the gene to the ecosystem. This remains an important challenge for forest managers in their search for sustainability.

INTRODUCTION

Experience suggests that technological challenges will continue to confront foresters in the 21st century in their efforts to manage their forests sustainably, particularly if *technology* is interpreted in the broadest sense. In this paper, we try to anticipate some of these issues, and to identify the research needed to provide the tools and techniques required for effective management in a changing environment. We anticipate change in several areas:

- production shifting from native forest to plantations;
- technological developments allowing more efficient processing, less waste and more recycling;
- end-use products becoming less dependent on the specific wood characteristics of raw materials;
- demand increasing, but fluctuating according to technologies in non-forest sectors;
- better information for decision makers, through the integration of remote sensing, GIS, and other technologies into decision-support systems;
- more rapid shifts in loci of production and transformation as industries seek out areas of comparative advantage;
- more pragmatic and efficient options for conserving biodiversity.

We anticipate a significant shift in timber production from natural forests to plantations. This will be driven by several factors, including the reliability of supply, uniformity of raw material and competitive pricing. Technically, there is no reason why plantations cannot supply most of the world's wood requirements by early next century. Even if demand exceeds the most optimistic projections (ECE 1996, Solberg *et al.* 1996), requirements may increasingly be satisfied from plantations, which offer both economic and environmental advantages over natural forest production. Demand for the few specialty products that can be obtained only from natural forests may not increase greatly, and can probably be satisfied from ecologically sensitive logging operations in areas where forests are retained primarily for their environmental and amenity functions.

Technology promises many advances in processing, recycling and in other areas that may influence wood and paper consumption (e.g., office automation), but most of these will have relatively minor influences on the sustainability of forest management, other than their ability to drive demand. Technological developments in areas more closely allied to sustainable forest management (e.g., logging equipment) are also likely to advance relatively slowly and deliver modest gains.

Information systems are one area of technology that may have a big impact on forest management. Sustainable forest management relies on timely and accurate information, and the ability to obtain such information is likely to change significantly in the near future. We may expect major developments in remote sensing, in various forms of computer modelling, and in the integration of these and other components into accessible decision support systems.

Lastly, the globalisation of economies will allow producers and manufacturers of forest products to shift their operations between countries and localities in response to changing economic and regulatory environments and to concentrate in areas where production, transport and labour costs are minimal.

DEFINING SUSTAINABILITY: CRITERIA AND INDICATORS

No-one disputes that sustainability involves satisfying present needs without compromising future options, but it is not always obvious what this means in terms of forest management. It is not merely an issue of natural forests versus plantations, or clearfelling versus selection logging systems, but involves more fundamental questions about the functions and services provided by forests, and about stakeholders, equity and expectations. Clarifying these issues, and establishing criteria and indicators (C&I) of sustainability, is a small but important step towards sustainable forestry.

The original drive to develop C&I came from the eco-certification lobby, but the potential application of C&I in the numerous national and international debates on forest sustainability is now widely accepted. This has led to a fertile debate internationally, and has provided sharper focus for efforts to develop techniques to reduce harvesting impacts in tropical forests. The C&I debate has led to a general recognition that forest management needs to become increasingly effective in adapting to local ecological and socio-economic conditions. Governments and international agreements may impose limits within which forest management should take place, but decisions on product optimisation and the degree to which forest systems can be modified from their natural state will have to be taken by local stakeholders. What is defined as sustainable forestry will vary greatly over space and time as society's needs and perceptions evolve. This has led CIFOR to focus its attentions not on producing a definitive list of C&I but rather on producing a "tool box" which stakeholder groups can use to develop appropriate indicators once they have established their own management objectives and performance criteria (Prabhu *et al.* 1996).

C&I are tools which can be used to conceptualise, evaluate and implement sustainable use of all kinds of forests. In this context, CIFOR's research has assumed the broadest possible definition of sustainability. Thus sustainability has been taken to mean maintaining or enhancing the contribution of forests to human well-being, both of present and future generations, without compromising their ecosystem integrity, i.e., their resilience, function and biological diversity. This definition of sustainable forest management has allowed CIFOR researchers the flexibility to develop operational definitions in terms of C&I for selected forest sites, and in turn has enabled similarities and differences between sites to be examined.

An important objective of the C&I research is to disaggregate the sustainability goals into key components that can be measured either quantitatively or qualitatively on the ground. Taken together with the objectives of relevance and cost effectiveness, C&I are potentially powerful tools that can provide a practicable and relatively objective assessment of the sustainability of forest management. C&I are however not simply tools for the assessment of the status of the forest and the quality of forest management. Research is beginning to reveal the relative values of alternative management options in achieving sustainability. This information is helping to identify management options that will be most cost effective in achieving sustainable wood production while reducing social and environmental externalities, and thus is enabling the debate on management options to proceed on a more objective basis.

Within CIFOR's research on criteria and indicators of sustainability at the forest management unit level, the approach to deriving appropriate indicators both for biodiversity and genetic resources has been to focus on those processes that maintain adequate levels of diversity in sustainably functioning landscapes. The use of “pressure-state-response” indicators is widely accepted as being valuable in assessing sustainability. Indicators of pressure, e.g., areas deforested/logged/ burnt/grazed, are relatively simple to implement. Similar, indicators of state, e.g., current forest extent, existence of corridors, are also fairly straightforward. However, indicators of response are potentially the most valuable, as they indicate the likely future direction of the system. They are also the most difficult to develop, but CIFOR’s emphasis on indicators related to processes that maintain bio/genetic diversity offers an opportunity to assess both state and response indicators simultaneously. Examples of proposed indicators arising out of CIFOR’s work are given in Figure 1.

Genetic level:
- Spatial/temporal changes in levels of genetic variation
- Directional change in allele/genotype frequencies
- Capacity for migration among populations
- Changes in reproductive system

Population/species level:
- Temporal changes in community guild structures
- Temporal changes in selected (indicator) taxa
- Changes in population structure of key taxa
- Changes in nutrient cycling/decomposition
- Changes in water quality and quantity

Habitat level:
- Temporal changes in habitat diversity

Landscape level:
- Changes in area of each vegetation type
- Changes in landscape patterns (connectivity, dominance, edges)

Figure 1. Key indicators of forest sustainability.

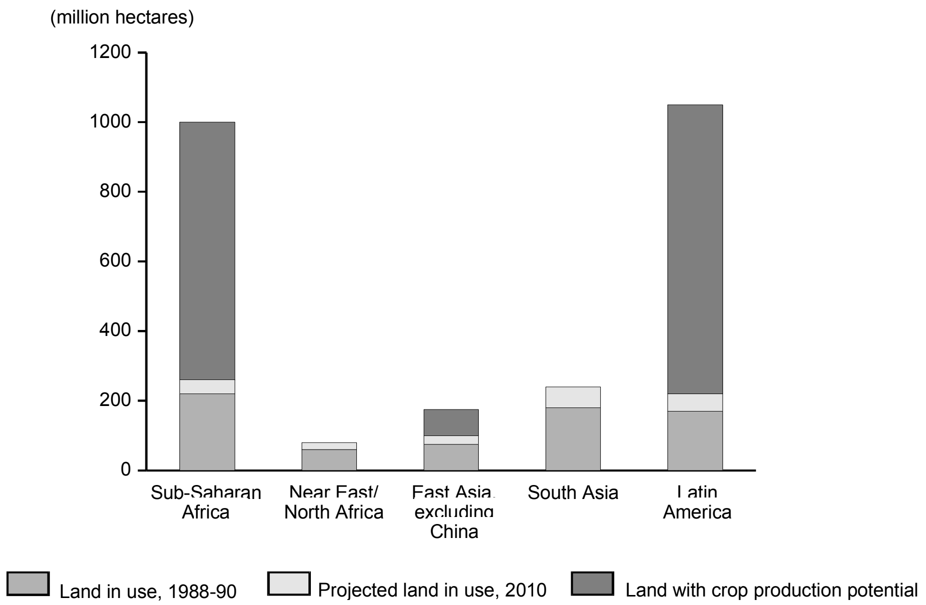
The existence of a C&I toolbox, and of a transparent process for establishing and reviewing C&I at the national and management unit level are also fundamental to progress in achieving “adaptive forest management”. Increasingly, foresters must adapt their management practices to satisfy people’s changing expectations and needs for forest goods and services. This requires sensitive indicators of changes in forest attributes and the ability to predict responses of the forest to modified management regimes. Appropriate C&I might, for example, help measure the impact on biodiversity, amenity or water yields of a decision to change the magnitude, frequency or nature of harvests. The utility of C&I lies in their efficient handling of information, notably the explicit identification of goals and definition of performance thresholds, targets and processes based on the most appropriate management practices for a given area. This makes them key tools for adaptive management. A fundamental aspect of the C&I research and development process has been the recognition that they must be transparent in application and acceptable to stakeholders, so that they form a broad and effective platform for building consensus.

OVERCOMING OBSTACLES TO SUSTAINABILITY

The international debate on C&I has promoted rigorous thought on what is meant by environmental sustainability and has encouraged people to explicitly identify the various elements that collectively comprise sustainability. One positive outcome is that the broader debate on forestry issues has become less polarised. Many of the activist NGOs that were totally opposed to logging of natural forests just a few years ago are shifting to the middle ground and conceding that environmental and amenity values of forests can be maintained when timber is harvested. Similarly, most industries and forest services are recognising that it is necessary and reasonable to modify forest harvesting practices to reconcile differences with a civil society preoccupied with environmental conservation. The important question is then, what obstacles remain, and how can they be overcome?

Competition for land

There is intense debate at present about the problem of finding enough agricultural land to meet world food needs in the 21st century (Brown 1995; CGIAR 1996; Waggoner 1996). Experts differ widely on their views as to how much new agricultural land will be needed to feed the world and on the extent to which yield increases on existing farmland will provide for the world's future food needs. Some believe that biotechnology will allow for a new "green revolution". The overall assessment of FAO is nonetheless that very significant areas of forest will have to be converted to agriculture in coming decades (Figure 2). A further problem is that the best land that sustains the highest yields is limited, and has mostly been dedicated to agriculture for some time. The key question is whether further increases in agricultural output can be achieved through increased yields from existing lands or whether they will depend on expansion onto new, lower-potential lands. Whatever the outcome, the competition for good land will be intense and forestry will inevitably be pushed into poorer areas. Fortunately, forest plantations in the tropics and subtropics can succeed on land of intermediate productivity, much of which is unsuited to permanent agriculture. There is a great deal of such land available in the tropics. In particular, there is great potential for expansion of plantation forestry in the countries of the Guyana Shield and in the less densely populated areas of coastal Africa, from Gabon to Angola and Tanzania to Mozambique.



Source: Alexandratos (1995: 162-163)

Figure 2. Projected cropland expansion in developing countries by 2010.

The observation that agriculture and plantation forestry may occupy different niches avoids two more fundamental questions: "how much agriculture do we need?", and "how much timber plantation do we need?" (e.g., Nilsson 1996). Although important, these rather obvious questions may distract from the more elusive but compelling question, "how much forest, natural or otherwise, do we need to maintain essential environmental services?" (e.g., Waggoner 1996). Currently, we have no answer to such questions, but we recognise them as important areas for research.

The increase in world demand for commodities derived from tree crops may greatly reinforce the competition for forest land. Very large areas in the humid tropics are currently being converted to oil palm plantations. Some analysts believe that this may lead to over-supply. But technologies for using palm oil to run internal combustion engines are improving and if this use becomes economically attractive the market for palm oil would be colossal. Any moves by governments to impose economic disincentives on the use of fossil fuels could make oil palm and many other renewable sources of energy and hydrocarbons much more attractive with consequent increases in demand for land upon which to cultivate them. In the face of such increased competition it would seem prudent to maximise the benefits that we can derive from forests and this must involve maximising the range of products and services, although not necessarily on the same site.

Economic impediments

Technologies that were critical to achieving sustainability in the past may become less important under some scenarios for the world's forests in the future. In recent papers (Byron and Ruiz Pérez 1996, Sayer and Byron 1996), we tried to anticipate how forestry practices may change in response to changing demands for forest products. We take a contrary view to that of the World Resources Institute (Bryant *et al.* 1997) that the major international forest issue is regulating frontier logging. We conclude that the frontier logging of relatively remote areas in the tropics, which has been a prominent feature of the timber industry in the late 20th century, may become less important in the future. We base this assessment on the fact that the technological requirement for large-diameter low-density hardwoods, common in many South-east Asian and African forests, will decline at the same time as the difficulties of exploiting the remaining stands of these forests increase. The technological problems which made the more highly diverse and higher wood-density timbers of Papua New Guinea and South America less attractive in the past have largely been solved. However, demand for the products of these forests will be limited by the cost of extraction. Once the forests in more accessible areas (close to roads, rivers and ports) have been exploited, any cost advantage that these forests might have had will be rapidly eroded. We expect them to become less able to compete with the outputs of the rapidly expanding plantation sector in the tropics and subtropics. In contrast to rising costs and declining quality of logs from natural forests, the volume and quality of plantation material will continue to improve while technological advances in plantation silviculture and wood processing continue to lower unit production costs. Some specialist products (e.g., durable timbers for marine applications) may circumvent this trend in the short term, but will in the longer term be displaced by technologies such as plato®. Even if plato®, scrimber®, valwood® and other technologies fail commercially, the search continues for technologies to make high-value products out of cheaper and more readily available fibre.

At present about 15 per cent of the world's industrial wood production comes from about 25 million hectares of fast growing plantations located in both tropical and warm temperate countries. High-yield forestry is a reality and the biological ability to shift most wood production to plantations exists and can be put into practice if prices of industrial wood rise high enough to justify it. In this context, the prime motivation for maintaining natural forests may be for amenity and environmental services in richer countries, and for non-timber forest products (NTFPs) and subsistence goods in poorer countries. However, it seems unlikely that logging of natural forest will disappear completely. Even in the most developed economies, the existence of forest industries, the cost of transporting timber products, and the desire to maintain employment in rural areas leads to continued logging of natural forests even when these are also valued highly for environmental services and amenity values. There will always be some areas of natural forests where the returns from logging are sufficiently high, and costs low enough, for them to be competitive with the plantation industry (Figure 3).

Maintaining the environmental and amenity values of natural forests will not be cheap, as significant investment and operating costs must be paid, either by the users directly, or by the public at large. In some cases, costs may be paid from timber receipts (on these or other forested lands, including plantations), but there is no inherent reason why timber revenues should pay for amenity uses. However, alternative sources of funding are often unavailable, and timber revenues represent the usual way to finance the maintenance of many other forest services.

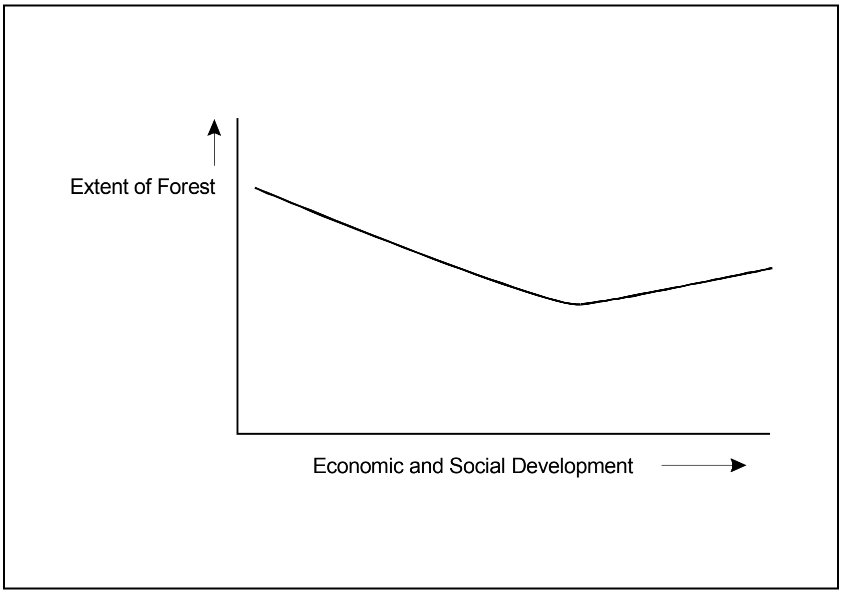


Figure 3. Schematic representation of the inflexion in the forest area curve which occurs when thresholds of economic and social development are exceeded.

Scenarios for natural forests

What will dictate the management of the remaining natural forests in the 21st century? In the past, forecasts of future timber needs have been an important consideration in determining the extent of national permanent forest estates. If timber is increasingly to come from plantations, one might expect that this would lead to a reappraisal of such policies, and to a reduction in the area of natural forest. However, few countries have responded in this way. Rather, they place renewed emphasis on the values of forest for amenity and environmental services at both the local and global levels. Thus several countries with little need to harvest timber from natural forests (e.g., New Zealand) strive to maintain extensive areas of forest in a near-natural condition. A consequence is a situation currently found in much of Europe where the mean annual increment of forests exceeds actual or predicted demand for timber (Solberg *et al.* 1996). There, forests are more valuable to society as aesthetic and amenity resources than as sources of industrial cellulose.

An interesting question is the extent to which similar trends will eventually emerge in the tropics. The answer to this question will depend on many factors originating outside the forest sector. Principal amongst these will be the rates of growth of both populations and economies, and the availability of alternative sources of employment for people who now derive their livelihoods from forests and forestry. It seems reasonable to assume that forest cover in countries whose economies are rapidly developing will in general follow a U- (or reverse-J) shaped curve, with forest areas declining until thresholds for industrial employment and the capacity to intensify agriculture and forestry are attained (Figure 3) (See for example Capistrano 1990). The World Bank predicts that four of the most important tropical forest countries (Indonesia, Brazil, India and China) will join the world's largest economies early in the 21st century. Past trends suggest that attainment of this level of development may herald the bottom of the curve, and that decline in forest area may cease. However, one difference in these and many other tropical countries is that there may still be a large proportion of the population whose per capita income remains much lower than in those industrialised countries where forest areas are now expanding.

It is difficult to determine the point at which a reversal of the deforestation trend might occur. Such predictions are complicated by the fact that conditions within countries differ so greatly. However, it seems reasonable to anticipate that the tendency to deforest should cease when countries graduate into the "middle-income category". Important issues relate not only to where the minimum occurs, but also what its value is, what the recovery rate is, what the eventual equilibrium forest area may be, and how these points may be influenced by policy and technology. One of the critical questions for biodiversity is whether the forest area has to decline almost to zero before the response is triggered.

It seems possible that within a couple of decades, the "tiger economies" of South-east Asia (and other countries with rapid economic growth) will attach a value to the biodiversity and watershed protection functions of some forests that will be higher than the potential revenues to be derived from these forests for timber production. This optimistic scenario would result in economics succeeding in achieving the objectives set out in many national forest policies where regulation has manifestly failed to do so. However, this approach examines only national trends, and it is much more difficult to assess global trends, as the timber trade may export the trend to deforest.

It is much more difficult to anticipate deforestation trends in Africa where economic growth is likely to be slower than in Asia and South America, and where most scenarios anticipate the persistence of a large population of poor subsistence farmers well into the 21st century.

Political and institutional constraints

Throughout history most forest products have been harvested for use locally. Although international trade in forest products is as old as history, it was only during the colonial period that tropical timber began to be traded in large volumes. The globalisation of trade in the mid-1960s resulted in large quantities of forest products entering the international trade from remote, sparsely populated areas in the tropics. As populations in the South increase and economies further develop we may see a reversion to the situation where an increasing proportion of forest products are consumed closer to their point of production. This will almost certainly be reflected in an increase in the proportion of world trade in forest products being South-South as opposed to South-North. ITTO foresees an acceleration in the next few years of this trend towards increasing domestic log consumption in tropical countries (ITTO 1996). If this is the case, and if the evolution of civil society in the expanding economies of the tropics parallels that in industrialised countries, we should see a situation where significant amounts of timber for local markets continue to be exploited from near-natural tropical forests.

HOW TECHNOLOGY CAN HELP

Increasing production

Wood productivity in natural forests ranges, in most cases, between one and three m^3/ha/yr. However, forest plantation productivity has increased spectacularly during the past few decades and continues to do so (Cossalter 1996). Growth rates of 20 m^3/ha/yr are now routinely achieved with some tropical and subtropical fast-growing species while some industrial plantations of the tropics and subtropics exceed 30 m^3/ha/yr operationally. These gains have been realised in part through improved genotypes, but also through better silviculture and management of plantations. The implications for the land area required to service world timber demand are obvious (Figure 4).

Spectacular though they are, these technological achievements concerned a limited number of species grown on short rotations for the production of pulpwood, chips, industrial charcoal and small-sized wood for other industrial uses. They represent a minute proportion of the tree species which can be planted in the tropics and subtropics. With few exceptions, timber species grown on medium and long rotations have not benefited from these technological advances. Long rotations have not appealed to commercial investors and tree breeding and silvicultural research has focused largely on fast-growing species for industrial uses. Some reduction in rotation length can be achieved by intensive selection and breeding for rapid growth, and promising results in this regard have been obtained with species such as *Araucaria cunninghamii, Araucaria hunsteinii, Gmelina arborea*, several central American pines and *Paraserianthes falcataria*. However there are limits to the potential of tree breeding, and it seems unlikely that timber species could exceed 40 cm dbh within 15 years. However, relatively modest increases in productivity will satisfy projected demands in the foreseeable future (Figure 5; Brooks *et al.* 1990).

Maintaining high yields from successive rotations of tree plantations while ensuring that the quality of the soil resource base and the resistance of the planting stock to pest and diseases is not declining is currently an important area of research for CIFOR.

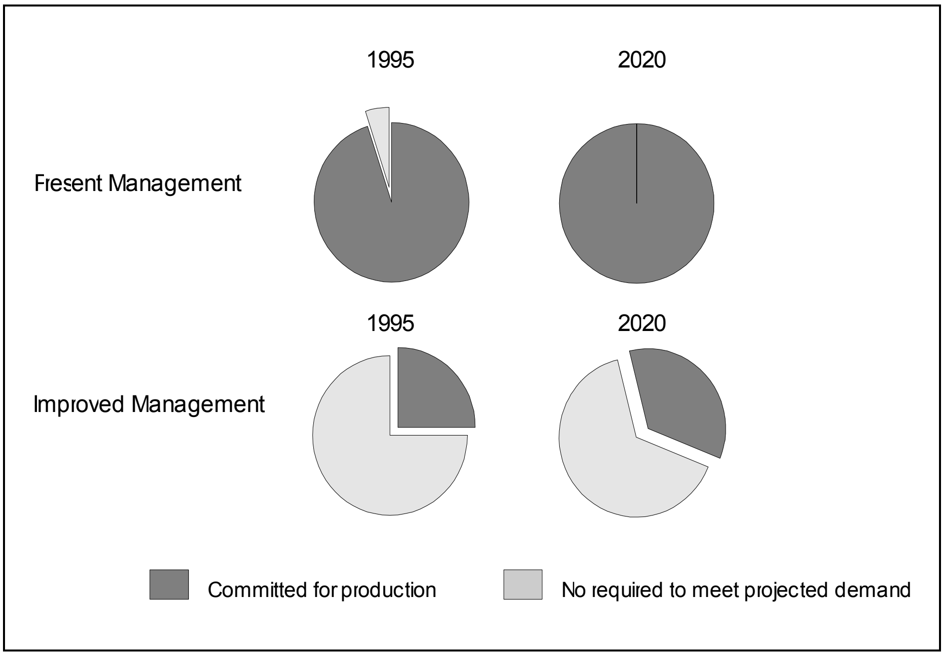


Figure 4. Much of the world's forest is over-utilised and under-managed, so that average productivity (of industrial roundwood) is 1 cu m/ha/yr. This low productivity means that most of the world's forest need to be utilised to satisfy current demands for roundwood and fuelwood. A small increase in productivity in the more accessible and productive forests would free much forest from production obligations. The increase illustrated is equivalent to average Swedish levels (4.5 cu m) in temperate-boreal regions, and to existing well-managed standards (6 cu m) in the tropics.

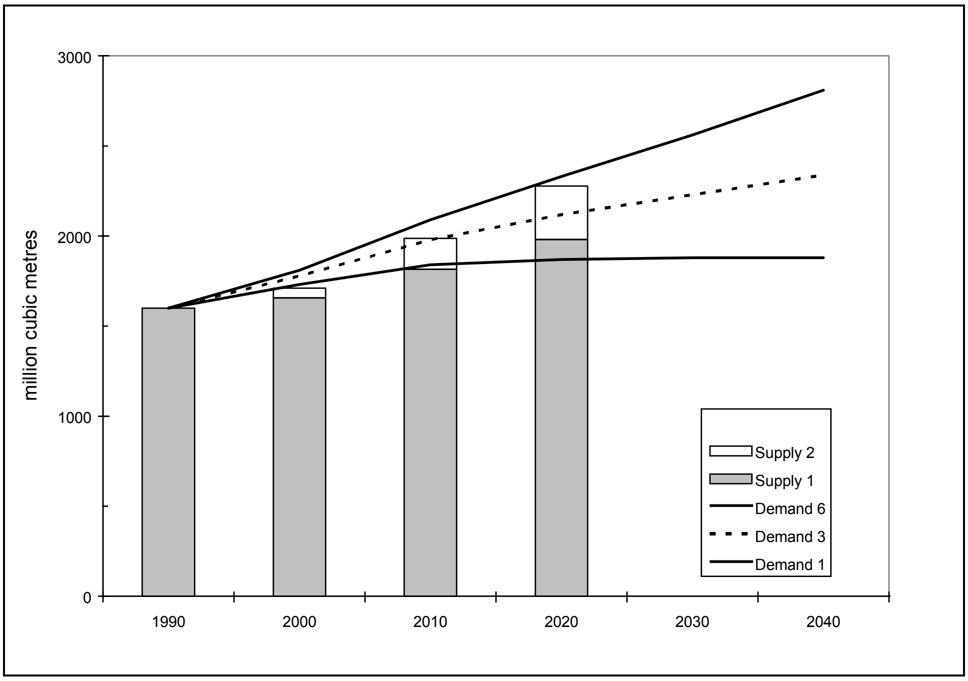


Figure 5. Modest but realisable gains in productivity will satisfy projected in global consumption in industrial roundwood (Data from Brooks *et al*. 1996).

Reducing impacts

There is a strong case to be made for further refinement of reduced-impact logging (RIL) technologies for application in the extensive areas of the tropics which we believe will be kept under forest primarily for environmental and amenity reasons but where timber production will continue to be a viable option. Most of the techniques embodied in RIL are not new, the innovation relates to the economics of using these technologies and to policies and incentives to promote their adoption. Increased use of these techniques should lead to a reduction in environmental impacts and greater productivity during future cycles. Thus, there is scope to promote the gains to be attained by reducing damage to trees and to the soil, by minimising breakage and waste, and by reducing capital and operating costs of machinery.

Offering alternatives

Technologies outside the forest sector may also make a contribution towards sustainable forest management by reducing pressure for conversion of forest lands to other uses, by relieving demand for forest products, and by increasing options available to forest managers. Developments in the wood-processing industries may contribute to greater efficiency and less waste in both the factory and the forest. Technology may enable the utilisation of a greater range of tree sizes and species, in turn creating new silvicultural opportunities for forest management. These may allow both commercial and environmental objectives to be realised with fewer compromises.

Reductions in per capita wood consumption need not imply a reduction in consumer satisfaction. Technology may reduce demand for wood without inconveniencing consumers by, for example:

- supplementing or replacing wood fibres (e.g., packaging) with agricultural by-products, straw);
- providing alternative energy sources (e.g., solar hot water, more efficient stoves);
- increasing re-use and recycling (more material, more cycles, greater recovery);
- improving office automation (better computer monitors, convenient 2-sided copying).

Our focus on technologies within the forestry sector does not diminish the importance of these and other initiatives in contributing to sustainable forest management by satisfying increasing consumer demands from smaller forest areas with less disturbance.

Providing information

Information is one of the keys to efficient forest management, and further progress towards sustainability may be achieved through better use of existing information technologies. Efficient management requires information that is relevant, timely, accurate and concise. In the past, forest managers have often relied on continuous forest inventory and similar monitoring systems to assess management impacts and sustainability. This is somewhat like driving a car with an opaque windscreen by monitoring the rear-vision mirror. Today, remote sensing enables early detection of many phenomena (fire, disease, logging, etc.) — allowing glimpses from the side windows. However, forward-looking or adaptive management requires prediction systems (computer models as well as field trials) to give adequate information for efficient decision making. The C&I work now in progress will offer further guidance for efficient provision of key information. Conflict resolution is now recognised as an important part of forest planning, and decision-support systems should be able to evaluate alternatives to provide a factual support to the conflict resolution process. The technology to do this already exists, but needs to be implemented (Vanclay 1993).

SOME STRATEGIC QUESTIONS

How much forest do we need for Biodiversity Conservation?

Market forces might be expected to be the main determinants of land allocation to agriculture and intensive forestry. However, experience over the past few decades has shown that markets are not efficient at achieving optimal allocation of land to maintain the environmental services of forests. The global environmental values of forests lie in their role in sequestering carbon and their role in maintaining biodiversity. Maximising carbon sequestration requires maintaining or creating as much vegetation as possible, but it does not really matter what type of vegetation it is. Optimising forests for biodiversity conservation presents more complex problems.

The nature conservation community is recognising the lack of realism of its vision for biodiversity conservation which dated from the 1970s and 1980s. There is an increasing realisation that it is unrealistic to aspire to extensive national parks in remote areas of developing countries from which all human use is excluded. Such parks are not viable in the current social and economic context of the countries concerned. At the same time, conservation biologists are demonstrating that the doomsday scenarios of biodiversity loss associated with macro-level fragmentation of forests (e.g., the chapter by Myers in Meffe and Carroll 1994) are not being realised in practice (Heywood and Stuart 1992; Boyle and Sayer 1995; Zuidema *et al.* 1997). Pulliam and Babbitt (1997) have shown that a remarkably small aggregate area of reserves would be adequate to conserve populations of most of North America's endangered species. Work currently underway at CIFOR, suggests that this will also be true for tropical moist forests. The logical conclusion of this research is that the areas of old-growth forest that must be preserved to maintain most of the world's forest biodiversity is much lower than much popular conservation literature (e.g., Myers 1989, Bryant *et al.* 1997) suggests. The challenge for biodiversity conservation is not to "halt deforestation"; it is to secure a minimum set of strategically located old-growth reserves in representative areas with high diversity and high endemism.

Such a set of reserves is a good beginning, but is unlikely to maintain biodiversity unless the land surrounding these "islands" also supports the conservation effort, while simultaneously meeting social and economic goals. Appropriate and effective policies and other incentives must be established to promote the role of biodiversity conservation outside protected areas, and this will be achieved only if adequate information is available. Not all areas within a landscape have equal conservation value, so technologies and methodologies to identify and manage critical parts of the landscape need to be developed. Similarly, since it is not possible to conserve all components of biodiversity, technologies to identify "keystone" species or other components of special ecological value are needed. Finally, the need to "manage" biodiversity means that information is required on the impacts of different human activities on components of biodiversity.

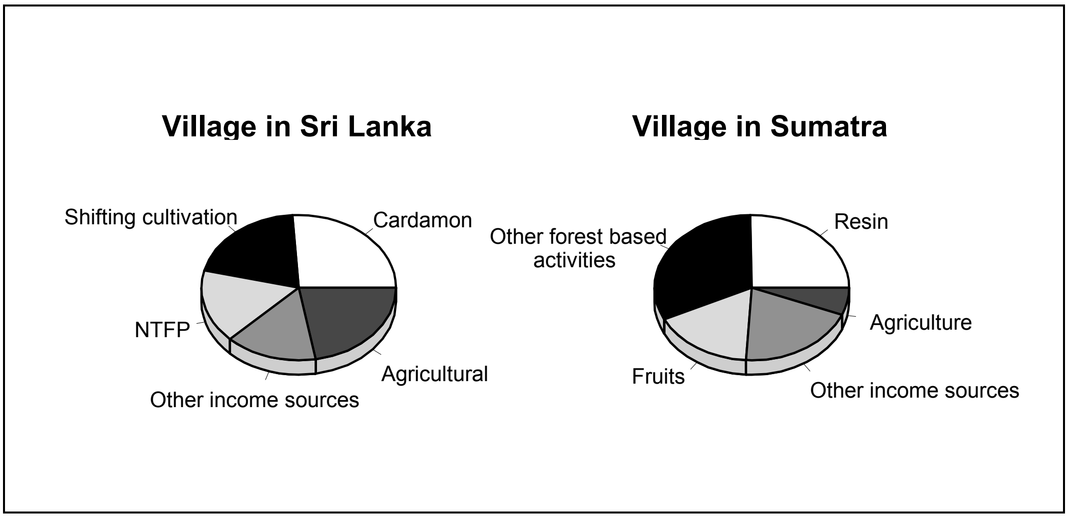


Figure 6. Contribution of forest-based activities to total income.

Recent reviews of the extent to which biodiversity can persist in logged forests (e.g., Sayer *et al.* 1996) further strengthens the case that most of the world's forest biodiversity can be retained without the draconian restrictions on all forest use that have often been the rallying cry of the conservation community (e.g., Myers 1996). The greatest utility of forest systems will be achieved by an appropriate balance between relatively small areas of old-growth reserves and high- yielding plantations, and relatively large areas of other forest systems managed for multiple goods and services. The importance of these near-natural multiple-use areas is illustrated by studies by CIFOR and others that indicate that hundreds of millions of people depend on forest products for a significant component of their livelihoods. Many of these people are perceived by governments as being "farmers" and the extent of their dependence on forests is often under-estimated in taking decisions on land allocation (Figure 6). Many conservation organisations are now taking a serious interest in multiple-use conservation areas as a matrix containing a core set of representative biodiversity reserves. This is being increasingly seen as the best option in situations where the poverty of local populations renders people less interested in incurring the opportunity costs associated with the vast reserves sometimes advocated to preserve obscure species of animals and plants whose utility has yet to be demonstrated.

A number of conservation organisations are now embarking upon projects to try and achieve forest use in a way that is consistent with the maintenance of biodiversity values. One of the more difficult technological challenges facing us is to determine the extent to which environmentally motivated logging programmes are indeed consistent with retention of all or most biodiversity. In particular, we need to establish which elements of biodiversity will be lost even under very low-impact logging systems. We also need to have sensitive indicators to tell us when the disturbance caused by forestry activities is beginning to have negative impacts upon biodiversity and to signal clear warnings when we are approaching thresholds beyond which there may be inflections in the biodiversity retention curve.

Trees on non-forest land

It seems inevitable that, within the foreseeable future, the area of forest world-wide will continue to decrease, and that agricultural production systems (including forest plantations) will become more intensive. Despite these pressures, we want to maintain the essential ecosystem functions performed by trees and forests, and to minimise the disruption caused by the reduction and fragmentation of forest areas. There are several important questions relating to this realisation:

- is there a threshold at which ecosystem services and functions are disrupted, or is there a gradual diminution of services and functions?
- how can one tell when a system is approaching a threshold or critical level?
- can planted trees on non-forest land help to maintain forest services and functions?
- what is the optimum configuration and spacing of trees and how does it depend on land use and distance to forest “islands”?
- how should trees on non-forest land be managed to maximise ecosystem services and functions?
- how can this information be best communicated to policy makers, planners and the community at large, and how can they participate in the process?

What are the appropriate scales of management

Optimising forest outcomes in these complex situations will require that decisions taken about forests should be in a context which goes beyond the conventional management unit or stand. The forest management unit must be seen and managed in the context of the broader landscape. Product optimisation is unlikely to be achieved by homogeneous treatments of extensive areas. Rather, it will require that different products are optimised in different parts of the landscape. This might lead us to a much finer balance in the allocation of land among its production, conservation and amenity functions. Some of the most exciting technologies which may emerge to address the needs of forest sustainability in the 21st century may be based upon models developed to predict outcomes of management interventions at a scale which is often referred to as the “landscape scale”. This has been a subject of considerable research in the Pacific North-west of the United States under the heading Forest Ecosystem Management. The Canadian Model Forest Program also seeks to reconcile the needs of multiple stakeholders in complex forest landscapes.

CONCLUSIONS

There is no “silver bullet” or golden rule that can be applied universally to ensure sustainable forest management, in part because what is defined as sustainable will vary with time and space as society’s expectations and aspirations change. However, a systematic approach to forest management offers an efficient way to progress towards sustainability. Such an approach should involve the usual planning cycle: formulation of objectives, preparation of a strategy, planning, implementing, monitoring and reappraisal. It also requires that managers understand their resource and their particular situation: this requires good resource assessment and decision-support systems. Social sustainability also requires that stakeholders participate in decisions, costs and benefits, and that effective procedures are used to resolve conflicts. Within an appropriate system, technical advances such as better machines and new implements may help to make a difference, but will not in themselves ensure sustainability. The important technologies for sustainable forestry are those relating to the broadest sense of the word; those that foster better communication between stakeholders and allow informed decisions spanning scales from the gene to the ecosystem. These technologies in themselves are not new; what is new is our realisation of their importance, and our understanding of their effective deployment. This remains an important challenge for forest managers in their search for sustainability.

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