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## Causes of Deforestation and Forest Fragmentation

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### Introduction

At the close of the twentieth century there remained an estimated 1700 million ha of tropical forests and 1600 million ha of temperate forests worldwide. These figures represent about 60% of the original forest cover that is estimated to have existed some 8000 years ago. Much of this loss can be directly attributed to human impacts over the last three millennia, with increased clearance in recent centuries, and even more recently in tropical regions.

Forests provide important resources and a multitude of natural services and their recent rapid destruction is causing increasing concern due to environmental, social, and economic problems across the globe. However, developing solutions is proving to be a highly complex task due to the variety of causes of deforestation and conflicting stakeholder interests.

Deforestation is the complete or almost complete removal of tree cover and conversion of the land to other uses. Technically, deforestation may be defined as the semipermanent depletion of tree crown cover to less than 10%. In this respect a distinction needs to be made between deforestation and forest degradation, which is the significant damage to forest ecosystems but without the total elimination of forest cover.

This article begins by describing current deforestation trends. The present causes of deforestation in recent years are discussed, followed by the consequences of deforestation for a variety of environmental parameters. Solutions to the deforestation problem are presented, and potential future trends are described with a brief discussion of the impact of projected climate change.

### Historical Deforestation and Land Clearance

At the advent of agriculture some 8000 years ago forests are thought to have covered approximately 40% of the world's land area, or about 6000 million ha. Up to 1500 AD the spread of agriculture across the globe resulted in the clearance of many forests, particularly those on the most accessible and fertile land. However, in the last 200 years deforestation rates have increased greatly. Between 1850 and 1980, 15% of the world's forests and woodlands were cleared. The world forest area has now shrunk to 3500 million ha as a consequence of human exploitation, most of which occurred in the latter half of the twentieth century.

### Contemporary Deforestation

Deforestation and land clearance in the twentieth century increased greatly, with the highest rates of clearance occurring since 1960. Most current deforestation occurs in the tropical regions, while in temperate countries there has been a net increase of forest cover by 0.1% due to reforestation and regeneration policies. In Canada the area of land under tree cover increased by 1.4 million hectares to 417.6 million ha in the late 1980s. The Food and Agriculture Organization (FAO) has estimated annual rates of forest clearance in developing countries at 15.5 million ha for the period 1980–1990, and 12.3 million ha for 1990–2000. Thus, the total area

of forest cleared during this 20-year period is approximately 280 million ha.

The causes of deforestation vary among regions. In Africa FAO reports that the major direct cause of deforestation is clearance by farmers driven by increasing population pressures. In Latin America settlement and infrastructure projects in forested areas result in clearance of land for cattle ranching and permanent agriculture, often combined with financial incentives such as subsidies and favorable tax policies. In Asia intensive timber harvesting and shifting cultivation as well as the expansion of large-scale agricultural projects and plantation crops such as oil palm and rubber and, to a lesser extent, transmigration projects, all contribute to deforestation. Forest land is often not suitable for sustainable agricultural development and, as soils become exhausted, new areas of forest have to be cleared. For example, 80% of the Amazon basin is ill-suited to sedentary farming. Desertification through unsustainable agricultural development has contributed to much deforestation in drier regions of Africa and Asia.

Most deforestation is concentrated in relatively few tropical countries. Fifty percent of global deforestation occurs in 10 developing countries (Table 1). Brazil is typical of tropical countries in that deforestation rates were low until the 1970s. Since then extensive spread of agriculture and ranching, encouraged by government subsidies, and clearance by landless farmers, has resulted in very rapid deforestation. Large-scale development and industrial projects such as mining and hydroelectric plants have contributed to these high deforestation rates in the tropics. Thus deforestation is largely a tropical issue (Table 2). As a large proportion of the world's biodiversity is found within tropical forests, tropical deforestation impacts also have very great relevance to global biodiversity.

**Table 1** 'Top 10' deforesting countries in terms of annual rate of forest loss (1995)

Country	Ranking	Annual loss (hectares)
Brazil	1	2 550 000
Indonesia	2	1 080 000
Congo	3	740 000
Bolivia	4	580 000
Mexico	5	510 000
Venezuela	6	500 000
Malaysia	7	400 000
Myanmar	8	390 000
Sudan	9	350 000
Thailand	10	330 000

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In temperate countries there is no overall deforestation in terms of net area but a small increase in forest cover owing to policies of afforestation. However, this statement disguises a steady and continuing transition from natural forest formations to managed and plantation forests. In this sense there is some clearance of natural forest in temperate regions with the consequent loss of biodiversity. This trend is likely to decrease as conservation priorities assert themselves, except in eastern Europe and Russia where the importance of forest resources as an accessible and tradeable commodity takes priority. Nevertheless, in Europe as a whole there is very little natural forest undisturbed by human intervention, the forest of Bialowiezca in Poland being one of the few extensive examples of reasonably extant forest not dissimilar to the ancient 'wild wood.'

## Causes of Deforestation

There is no single cause of deforestation but rather it is the result of the interaction of social, economic, political, and cultural forces with the environment. Several underlying socioeconomic causes create conditions that favor forest clearance by readily identifiable direct causes.

### Underlying Causes of Deforestation

The underlying causes of deforestation are the factors that give rise to conditions in which forest clearance becomes a rational or necessary behavior. They may be local or national socioeconomic or political forces, or they may be external global forces such as the state of the global market economy. They are generally beyond the control of an individual but strongly influence the decisions individuals make regarding the management and use of forests and forest resources.

**Table 2** The rate of annual forest loss (1995) expressed as a percentage of forest area in 10 important deforesting countries and regions

Country	Ranking	Annual loss (%)
Philippines	1	–3.5
Sierra Leone	2	–3.0
Pakistan	3	–2.9
Thailand	4	–2.6
Paraguay	5	–2.6
Central America	6	–2.1
Caribbean Islands	7	–1.7
Cambodia	8	–1.6
Ecuador	9	–1.6
Myanmar	10	–1.6

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**Population growth and poverty** Population growth is one of the most publicized but misleading underlying factors for tropical deforestation. Increasing populations place pressure on forests and the resources they supply. The rural poor have very few economic options and are often forced to seek short-term solutions to their economic problems. These solutions include clearing forested land to grow subsistence crops. Opportunities for improving livelihoods by other means are limited due to low political priority, the lack of rural capital, low capacity of subsistence farming to generate income, and the lack of infrastructure and education.

**Development policies and tax incentives** Debt repayments constitute a large proportion of the national budget of many tropical countries, and structural adjustment programs introduced as a result often favor the maximization of foreign exchange through direct and unsustainable exploitation of forest capital, and by conversion of forests to agriculture for export crops. Large-scale extensive agricultural development, frequently at the expense of small farmers as well as forest cover, is further encouraged through the provision of state subsidies for agriculture and livestock expansion, reduction in income and corporate taxes, and tax breaks on imports of equipment for new industries. Expansion of agricultural crops for export or to satisfy national demands destroys forest directly, but it also causes the displacement of subsistence farmers who are forced to relocate and clear new and often marginal lands elsewhere.

The privatization of public resources, advocated by the World Bank and some bilateral donor agencies, favors management strategies that maximize the short-term economic gain for the new owners, while nonmonetary forest services, such as soil conservation and watershed protection, are not valued highly in a market-driven environment. Government incentives and subsidies have allowed some otherwise uneconomical industries to prosper at the expense of forest cover, while development projects often fail to account fully for the value of forest capital lost.

A failure to understand the real value of forests' goods and services results in the establishment of poor policies. The institutional weakness of the national forest department or corruption within the government can lead to policy decisions that favor private interests at the expense of the benefits to society as a whole. In recent years there has been an improvement in the reformulation of forest policies of several tropical countries. Subsidies that promote cattle ranching have been withdrawn in Brazil, while

Costa Rica is now beginning to account for the destruction of forest capital in its national economic accounts.

**Tenurial policies** Much agricultural land in the tropics is owned by large landowners or corporations and improved agricultural production is obtained using chemical fertilizers and pesticides which, together with mechanization of labor, is most efficient on large-scale agricultural systems. This favors large farmers who have the capital to invest in such innovations and the land area to benefit from economies of scale. Small farmers who may not have legal title to their land are frequently displaced or forced to sell their land through mounting debts. These farmers often move to the forest frontier to clear a new plot of land, and it is usually politically easier for governments to ignore deforestation than to deal with the difficult issues of land redistribution or job creation.

Legal ownership of land has a great effect on the attitude people have to the land. Without legal land title there is little incentive to invest in increasing land productivity. It becomes economically logical to pursue short-term gain and to move on to clear new forest land once productivity declines. As most tropical forest lands are owned by the state, clearance is often illegal and governments are unwilling to grant legal title to small farmers for land acquired in this way. Lack of land ownership excludes farmers from obtaining credit to purchase seed or fertilizers and pesticides and discourages any long-term investment. In many Pacific-rim countries customary land ownership prevails. Precise boundaries are frequently unsurveyed and local communities and groups know only from tradition what is their land. Wholesale allocation of logging rights can be conveyed either by the local people themselves with relatively little outside control or, conversely, imposed from outside by governments that fail to account for local people's interests. In either case the land tenure system is a weak instrument in preventing unplanned deforestation and land clearance.

**Market demands** As populations grow and become more affluent the demand for forest products rises, particularly for industrial timber and pulpwood for making paper. However, while it can be readily demonstrated that some countries have significant forest product exports (Table 3), the extent to which international markets contribute to deforestation varies greatly from country to country. In the top 10 deforesting countries it is the national demand for forest products that accounts for most industrial deforestation. Furthermore, there is not a strong link

**Table 3** The importance of exports to the forest-based economies of the top 10 deforesting countries in 1996

Country	Timber products <sup>a</sup>			Paper and paperboard <sup>b</sup>			Charcoal and fuelwood			Total
	Production	Export	%	Production	Export	%	Production	Export	%	(%)
Brazil	107 360	5019	4.7	12 110	3396	28.0	135 652	63	0.05	3.3
Indonesia	64 711	9414	14.5	7021	2342	33.4	153 540	1039	0.7	5.7
Congo, DR	3554	227	6.4	3	0	0	45 142	0	0	0.5
Bolivia	1070	150	14.0	2	0	0	1419	0	0	6.0
Mexico	9063	557	6.1	3558	328	9.2	16 731	136	0.8	3.5
Venezuela	1790	52	2.9	900	50	5.6	918	0	0	2.8
Malaysia	50 923	16 143	31.7	777	41	5.3	10 035	186	1.9	26.5
Myanmar	3399	689	20.3	24	0	0	20 612	53	0.3	3.1
Sudan	2321	0	0	3	0	0	14 600	0	0	0
Thailand	3636	614	16.9	2744	335	12.2	36 894	53	0.1	2.3

All values in thousand m<sup>3</sup>.

<sup>a</sup>Includes industrial roundwood, sawnwood, and wood-based panels.

<sup>b</sup>Includes pulp for paper.

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between rising international demand for forest products generally and deforestation. This is, first, because almost all pulp and paper comes from temperate forests or specially established tropical plantations, since paper manufactured from mixed tropical forest is generally expensive and has poor quality owing to the lack of wood uniformity. Second, much of the world's industrial-grade timber is softwood, i.e., coniferous, and tropical forests are overwhelmingly broad-leaved hardwoods. Supplies of industrial lumber in tropical countries increasingly come from tropical conifer plantations, notably of pines and cypress. Clearance of forest for agricultural production also appears to be driven by growing national demand for agricultural crops (over and above those for crops). All of the important deforesting countries listed in **Table 1**, except for Thailand, remain net importers of rice or maize and for many of these countries self-sufficiency in agricultural production has been a primary development goal that has led to policies that encourage conversion of forests to fields. Over the past decade, for example, the domestic demand for palm oil in Indonesia has led to the widespread establishment of plantations even though palm oil exports have remained at between 6% and 8% of the total production. Similarly, rising production of beef in Central and South America to feed a growing domestic market has resulted in extensive deforestation by ranchers, farmers, and land speculators.

Deforestation due to agricultural and livestock production is therefore largely due to the growth in the domestic markets and only partially attributable to markets in the developed world. Although the importance of export markets should not be underestimated, national market forces appear to be more

important than international trade in determining the rates and extent of tropical deforestation. Consequently, it is likely that international trade offers only limited scope for reducing deforestation rates in most tropical countries.

#### Undervaluation of forests and forest products

Where logging has preceded wholesale land clearance, it is often because the value placed on the timber is no more than the cost of extraction and marketing. The value does not reflect cost of replacement nor cost of growing beyond what is often a nominal payment of royalty to the owner. If timber were valued to reflect its true cost of replacement, then growing trees to produce timber would become economically worthwhile and hence potentially a sustainable option. While it is not worthwhile, deforestation, especially in the tropics, is likely to continue because clearance and conversion are perceived as more profitable. However, undervaluation has a further dimension. The non-timber benefits and services trees and forests provide are often far more important than their timber products. Environmental benefits of soil protection, shelter, microclimate amelioration, and contribution to regional and global hydrological and carbon cycles all confer great benefits which are rarely quantified and hardly ever incorporated in economic assessments. Only when massive downstream flooding is traced back to wanton deforestation in the catchment are such connections made.

A major underlying cause of deforestation is this widespread failure to value sufficiently both forest products and the many environmental benefits forests bring. Regrettably, it is largely because simple and widely accepted approaches to such valuations in economic terms do not exist. For example,

stumpage, the charges that governments demand from loggers for state-owned timber, often under-values the resource, which encourages waste and makes other land uses more economically attractive.

**Weak government institutions** While almost all countries have explicit forest laws and policies designed to conserve forest, two features of forest conditions in tropical countries exacerbate the risk of deforestation. First, extensive forests are likely to be remote from towns and cities and hence far from the rule of law. It is easy for illegal logging and clearance to continue unseen and unchecked. Second, forest services are frequently the 'Cinderella' organization of government, being viewed as inferior to agriculture and even wildlife and tourism. Few resources are attracted and poorly paid staff often have difficulty both in ensuring that sustainable management practices are implemented and in imposing their authority on perhaps large private-sector interests. Quite apart from the risk of corruption that these circumstances afford, many staff, once trained, simply dislike the remoteness of forest management and supervision and prefer the white-collar work of the city office.

### Direct Causes of Deforestation

**Shifting cultivation** The contribution of small-scale shifting agriculture to tropical deforestation remains unresolved due to the widely variable agricultural practices that are encompassed by this term. Some types of small-scale agriculture undoubtedly cause deforestation, but the inherent stability and long-term viability of many shifting cultivation systems are unlikely to result in long-term forest clearance. The least destructive form of shifting cultivation is where land cultivated for 2–3 years is then left for a long fallow period. This long fallow shifting cultivation only occurs under conditions of very low human population density.

Expanding populations, land scarcity, and government policies have also created shifted cultivators who now form the typical slash-and-burn farmers of recent decades. Unlike the traditional farmers who have practiced shifting cultivation for decades, these shifted agriculturists have been forced by circumstances or government policy to cultivate habitats that are unfamiliar to them. Government resettlement and transmigration schemes such as those in Indonesia attract migrants for whom forest cultivation is an unfamiliar means of generating a livelihood and income. Similarly, in the Amazon, migrant cultivators are attracted to the forest frontier where they clear and cultivate land for a few years. This land quickly becomes exhausted due to unsuitable soils or farming techniques and the land is sold to

cattle ranchers while the 'farmers' move on to clear more land.

**Commercial agriculture** Large-scale commercial agriculture is most frequently practiced by large corporations or state enterprises. These large operations can dispossess local landowners and farmers of the best and most fertile agricultural land, indirectly leading to deforestation in areas to which the farmers relocate. The establishment of oil palm plantations in valleys of Honduras in the 1970s displaced thousands of farmers who were forced to clear forests from steep slopes to establish new farms.

Commercial agriculture often leads to direct conversion of large tracts of forest to plantation estates and rice fields. This has been particularly prevalent in Indonesia and other regions of Southeast Asia where oil palm, coconut, or rubber plantations have been established on cleared forest land. In Indonesia oil palm plantations have increased from about 4 million ha in 1980 to 5.8 million ha in 1995. Land clearance for agricultural development is often subsidized by governments and, because the owners of the agribusiness companies are politically well appointed, there is little interest in forest protection. Areas for conversion are frequently burnt as this is the least extensive method of clearance, and natural events such as the 1997–1998 El Niño are used as an opportunity to do so.

**Cattle ranching and livestock grazing** Intensive clearing of forest land in South and Central America has arisen from expansion of cattle ranching which was economically attractive due to low risk, little labor, well-established markets, and the availability of government subsidies. Cattle ranching expanded initially in response to the opening of large markets in North America, but has been sustained by the growing domestic markets for beef. Ranchers cleared forest land either by purchasing it directly and employing labor, or by purchasing land from slash-and-burn farmers and converted this land to grasslands. The shifting cultivators would move deeper into the forest to repeat the cycle. The area of pasture in Central America is estimated to have increased from 3.9 million ha in 1955 to 13.4 million ha in 1995 and has been largely at the expense of the area's tropical forests. Thus, deforestation in Latin America due to ranching is also associated with slash-and-burn agriculture and land speculation.

Livestock grazing causes deforestation in Africa wherever herds exceed the carrying capacity of the area. Such pressure is acute in the drier tropics such as the Sahel region of Africa and in the Middle East where large flocks of sheep and goats are maintained.

The history of deforestation around the Mediterranean is linked to grazing regimes, especially by goats, but past simplistic assumptions have given way to the recognition that climatic, sociological, and agrarian factors have also contributed to forest clearance.

**Infrastructural development** Through the 1970s and early 1980s, development of the Amazon, which is illustrative of similar strategies throughout the tropics, was actively encouraged by the Brazilian government through the building of roads, tax incentives and subsidies, massive resettlement, and large-scale development programs. The Trans-Amazonian highway opened up millions of square kilometers of inaccessible forest to colonization and allowed further expansion of the cattle industry. Such roads improve access to poorly developed areas and therefore tend to increase the adjacent land value for nonforest uses and encourage land speculation and deforestation. Recent slowing of deforestation is due to Brazil's economic recession and has been aided by changes in government policies on tax incentives and subsidies, and increased enforcement of environmental regulations. Logging roads in Asia also facilitate deforestation by allowing access to farmers and illegal loggers who follow and deforest an area that is otherwise merely degraded through selective logging.

**Plantations** Much forest has been cleared for commercial plantation crops such as rubber, oil palm, and the beverage crops of cocoa, coffee, and tea. Huge areas of dipterocarp forest in peninsular Malaysia have been converted to oil palm or rubber plantations and, while such perennial woody crops offer some soil protection, the loss in biodiversity is enormous. Indeed, it can be argued that the great bulk of the world's tropical plantation crops, about 26.5 million ha, are on former forest land.

A key principle of good forest stewardship is that forest plantations for timber production are only located on already cut-over, abandoned, or waste land and in this way can actually help deflect pressure away from natural forest. However, the subject is not quite as simple since many forests have enjoyed enrichment by planting or have arisen through tree-planting operations, such as many 'natural' forests in France, Germany, and elsewhere.

**Fuelwood collection and charcoal production** Fuelwood accounts for over 50% of global wood use and for some 80% of all wood use in developing countries. Dependence on fuelwood is expected to decrease gradually with the introduction of electricity, kerosene, and propane, but heavy dependence on fuelwood by the rural poor is expected to

continue well into the twenty-first century. Fuelwood collection as an agent of deforestation is particularly marked around urban centers and villages where continuous collection results in the gradual degradation and eventual deforestation of accessible areas. This is critical in the dry tropics along with domestic use of wood for other uses such as construction and fencing material.

**Logging** The most optimistic independent estimates of the amount of sustainably managed productive forest in the tropics are no more than 2% of the productive forest area. Most tropical logging consists of short-term exploitation of timber products with little concern for the future potential of the forest. This is largely due to insecurity of tenure and short concession periods. Although the intensity of logging in the tropics is usually low, removal of only 10% of the timber trees can result in damage to 55% or more of the remaining trees. Nevertheless, logging operations in the tropics usually result in degradation of the forest rather than its complete elimination. Deforestation does occur along logging roads, where forest is cleared for several meters either side, allowing the sun to dry the road surface. Poorly designed roads can result in severe erosion and landslides as well as facilitating movement into the area by illegal loggers and slash-and-burn cultivators, who often cause much greater damage than the initial logging operations. Logging continues to be one of the most important causes of forest degradation but not deforestation, although intensive logging in Southeast Asia has resulted in the conversion of thousands of hectares of forest to alang-alang (*Imperata cylindrica*) grassland that excludes almost all other vegetation.

Following industrial extraction of timber farmers, agribusinesses, ranchers, fuelwood collectors, and illegal loggers move in along logging roads to clear the land for other uses. Management plans and government policies oblige industrial foresters to prevent encroachment of this sort, but these rules are poorly enforced due to lack of will or staff.

The length of concessions is very often short, sometimes less than 10 years, and very rarely more than the rotation of the crop. In the absence of a long-term commitment the logging company has little incentive to invest in long-term forest management. Concessions are also granted for timber only with little regard for the other resources provided by the forest and the impact of the logging on local people.

**Fire** Serious losses in forest cover in Southeast Asia and South America have been reported as a result of forest fires in 1997 and 1998. The causes of these fires are new large-scale commercial agricultural

projects (including plantations) and shifting cultivation. The fires were exacerbated by the dry coarse woody debris left after logging operations and the very dry climatic conditions caused by the El Niño phenomenon. The area of forest consumed by fires in 1997–1998 has not been accurately documented but estimates vary from 170 000 ha to over 2 million ha. Extensive fires in tropical moist forests have been previously associated with El Niño phenomenon, as in 1982, but the underlying causes are clearance of forest to establish plantations of oil palm, pulp wood, and rice and, in South America, cattle pastures and shifting cultivation.

## Alternatives for Sustainable Development

### Protection and Management of the Remaining Forests

**Protected-area systems** Protected-area systems are needed to conserve habitat and biodiversity from encroachment and poaching. The majority of countries fall well short of placing 12% of their land surface within a protected area system as endorsed by the United Nations Conference on the Environment and Development (UNCED). To be effective, protected areas need to be sufficiently large to conserve all the biodiversity they contain and to include a broad range of naturally occurring forest types and all stages of natural succession. To be successful, protected-area systems need to be supported by adequate funding and legislation and managed by strong institutional departments. However, forest protection must be developed with the cooperation of the local communities that use forest resources, as alienation of them has led to failure or inadequate protection.

**Joint forest management** New approaches to managing forest resources involve partnerships between local communities and local or national governments. These partnerships provide for sensitive management that acknowledges the needs of all stakeholders by providing a wide variety of benefits in a sustainable manner. Forest management decisions are made at a local level and are informed by state-supported science and developmental technologies. Providing local stakeholders with access to and benefits from forest resources and empowering them with the management of these resources encourages sustainable development and investment in forests.

**Sustainable timber harvest procedures** Timber harvest practices that minimize damage to forests are well known but rarely implemented due to the perceived high cost. Indeed, over a short time scale,

reduced impact logging procedures are more costly, but over the longer term they are cheaper due to increased efficiency of extraction (by eliminating extraction of low-value trees and damage to high-value timber) and reduced damage to the remaining forest stand. National standards for logging operations, where they exist, are often flouted and enforcement is weak.

To encourage sustainable timber production, most timber-producing countries have adopted criteria and indicator systems for sustainable forest management. These systems provide tools for assessing the state of forests which can be used to promote and inform sustainable forest management. Their development has been hampered by the complexities of definition of sustainable forest management and how to interpret the information generated. However, inter-governmental processes and market-led certification schemes seek to encourage wise and sustainable forest management.

### Socioeconomic and Agricultural Development

**Improving the productivity of subsistence agriculture and ranching** Greater productivity from and improved use of existing agricultural land, through intensification of agroforestry, will lessen the pressure for clearance of new forested lands and will promote private investment into currently occupied land which in turn encourages sustainable use. State-supported investment in deforested marginal lands, fair credit schemes, and educational development are all needed to provide extension services to improve the efficiency of land use.

An estimated 200 million ha of degraded lands exist in upland watersheds of tropical countries as a result of deforestation. Restoration of these lands through tree planting or for agricultural production will further alleviate the pressure on forest lands from agricultural expansion. Multiple-use species provide both benefits directly and additionally serve to renew a watershed's ability to regulate groundwater and reduce soil erosion (Table 4).

**Tree plantations** Tree and forest plantations are not substitutes for natural forest but, appropriately sited, they can alleviate deforestation pressures. Plantations on already degraded land can be an excellent source of industrial-grade timber, pulpwood for paper-making, and fuel-solid firewood and charcoal. Thus they provide an alternative source of such products. In the tropics and subtropics there are estimated to be about 70 million ha of industrial plantations, of which probably 55 million ha are reasonably well stocked. This area is slowly increasing, is often more productive than temperate

**Table 4** Soil erosion rates

	Rate (t ha <sup>-1</sup> year <sup>-1</sup> )
Undisturbed natural forest	Negligible
Cut-over forest with litter and organic matter intact	1–5
Cut-over forest with litter and organic matter removed	30–100
Forest plantations with litter and undergrowth	0.5–3
Forest plantations with no undergrowth and litter removed	up to 100
Undisturbed or lightly grazed grassland	2–10
Cultivated arable land (depending on slope, terracing, and soil type)	20–400

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plantations, and represents a major new wood resource. Taking the world as a whole, nearly half of all industrial timber is likely to be sourced from plantations by about 2020.

Profitable plantations risk undermining the perceived value of natural forest and may accelerate conversion of these to plantations. If the primary cause behind deforestation is the conversion of land for agricultural development it is unlikely that plantations will reduce deforestation. However, tree plantations do offer an opportunity to reduce the pressure on natural forests if the latter are exploited primarily for wood products.

### Policy and Institutional Reform

**Forest valuation and the reformation of government policies and institutions** National policies need to promote the necessary framework that encourages sustainable forest use before community-level projects can have an effect. However, undervaluation of forests by governments and people undermines forestry institutions nationally and internationally, making it difficult to enact the necessary changes. The lack of forest-user taxes and low stumpage fees discourage sustainable management of forests by undervaluing the resource. Subsidies to competing land uses should be removed and effective natural resource accounting should be established to reflect true forest values. Opportunity costs and externalities associated with conversion need to be factored into assessments of forest values. Thus, the value of the ecosystem services as well as alternative income-generating businesses, such as tourism, should be considered. Furthermore, forest land value can be greatly increased by more efficient use of a greater range of forest resources, and by improved marketing of them. The absence of clear

policy guidelines and trends in forests and forest resources lead to a confusion of strategies among national and international organizations. Strengthening of these institutions and developing mutually agreed frameworks that provide for more effective policy development and monitoring is needed if deforestation is to be arrested.

**Provide education** Educating the public as well as political and economic decision-makers about environmental and socioeconomic issues related to forests is crucial if policies promoting forest preservation through sustainable use are to be heeded. Education must be based on thorough and demonstrable arguments about the economic, social, environmental, and biological benefits of using forests wisely, and the costs associated with deforestation.

### Conclusion

Deforestation is largely a tropical issue. The quality of data on deforestation rates has been improving but remains poor and a source of contention and debate. The causes of deforestation are complex and multifaceted, though socioeconomic factors and trade are foremost. Deforestation impacts on the environment through loss of biodiversity and disruption of ecosystem processes, as well as the economy by affecting ecosystem services and inefficient squandering of resources. Perhaps the most tragic consequence is the loss of traditional beliefs and customs and the displacement of forest-dependent communities. Solving the problem of deforestation requires a suite of strategies that include establishing an effective and global protected area network to preserve forest biodiversity, and the genuine implementation of good practice guidelines. Ultimately, a reformulation of policy and a change in the attitudes of decision-makers are needed to ensure that forests are correctly valued economically, socially, and biologically.

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This contribution is adapted with permission from Ghazoul J and Evans J (2001) Deforestation and land clearing. In: *The Encyclopedia of Biodiversity*, Levin SA (ed.) Academic Press.

**See also:** **Ecology:** Biological Impacts of Deforestation and Fragmentation. **Environment:** Environmental Impacts. **Harvesting:** Forest Operations in the Tropics, Reduced Impact Logging. **Landscape and Planning:** Perceptions of Nature by Indigenous Communities. **Plantation Silviculture:** Forest Plantations. **Silviculture:** Managing for Tropical Non-timber Forest Products. **Wood Use and Trade:** History and Overview of Wood Use.

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