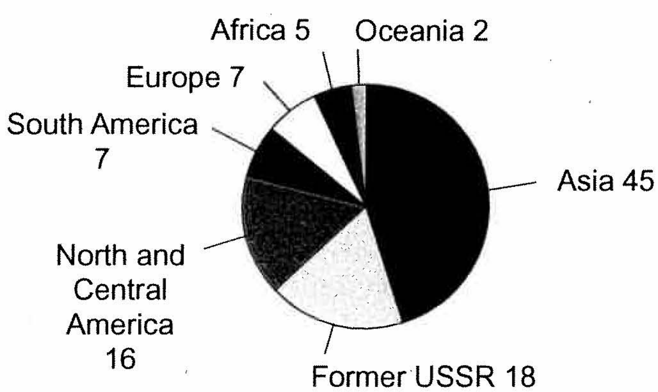
Wood *Eucalyptus* species, *Acacia* species, *Casuarina* species, *Gmelina arborea,* and *Pinus* species

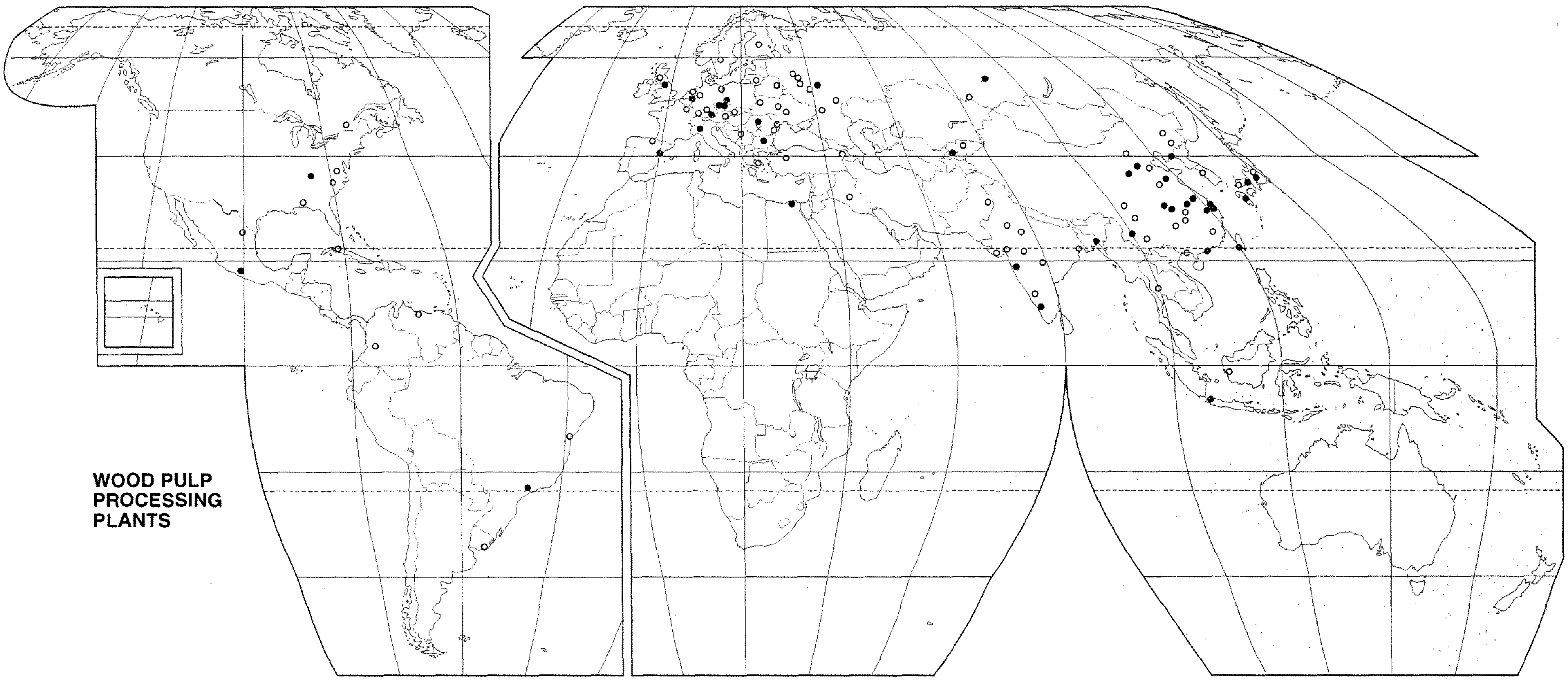
Production	
Area Under Cultivation	10 million ha
Global Production	323.0 million MT (Pulp) 189.0 million MT (Paper & board)
Average Productivity	15 m^3/ha/year
International Trade	
Share of World Production	12%
Exports	37.8 million cubic meters
Average Price	$440–620 per MT
Value	$20,720 million
Principal Pulp Producing Countries (by weight)	United States, Canada, China, Finland, Sweden, Japan, Brazil, Russia, Indonesia, Chile
Principal Plantation Growing Countries	China, United States, Russia, India, Japan
Principal Exporting Countries	Canada, United States, Brazil, Sweden, Chile, Finland, Russia, Indonesia, Portugal
Principal Importing Countries	United States, China, Germany, Italy, Japan, France
Major Environmental Impacts	Habitat conversion and degradation Pollution from agrochemical use and processing Burning during plantation establishment
Potential to Improve	Good Siting can reduce impact on biodiversity, natural habitat, and ecosystem functions. Planting and management can maintain soil fertility and reduce impacts. BMPs can reduce costs and increase benefits.

Sources: FAO 2001a, 2002; PPI 2001; Cossalter and Pye-Smith 2003. All data for 2000.

Percent of Global Tree Plantations



WOOD PULP PROCESSING PLANTS



• 2-3 plants
○ 1 plant

Chapter 13

Wood Pulp

Overview

Writing has long been associated with civilization. It is the basis for how we learn from others. The first known forms of written communication were petroglyphs and cave paintings from tens of thousands of years ago. Such communication, however, was not mobile. The Sumerians were the first to resolve this problem in about 4000 B.C. with the creation of clay tablets that, although heavy, could be transported. Since then wood, waxed boards, stone, ceramics, cloth, bark, bronze, silk, bamboo, and tree leaves have all been used to preserve the written word.

While there have been many other ways to write and communicate, paper has dominated the meteoric rise in communication and learning around the globe. The word paper is derived from papyrus (*Cyperus papyrus*), a plant found in African wetlands and particularly along the Nile River. Some 5,000 years ago the Egyptians created sheets of papyrus by peeling and then slicing papyrus stems into strips and laying them at right angles to form more sturdy mats. The strips were then pounded together and left in the sun to dry. The Egyptians, Greeks, and Romans used papyrus for record-keeping, spiritual texts, and works of art. The ancient Greeks also used a kind of parchment made from animal skins to create sheets for writing, but this proved to be expensive as it took many sheep skins to produce a single copy of any major work.

Similar materials were invented independently around the world. During the second century A.D., the Mayans fashioned a similar pounded bark product for bookmaking in Central America. In the Pacific, Islanders made a paper-like bark cloth that was decorated and used for clothing and ritual objects.

The invention of paper as we know it today did not come for another three thousand years, and even then it was slow to spread around the world. Ts'ai Lin is generally credited with inventing paper in China in 104 A.D. The first paper was made by pounding the inner bark of the mulberry tree and hemp, rags, or bamboo fibers in water until they formed a fibrous watery paste. The solution was then poured over a flat piece of coarsely woven cloth to let the water drain through. This left a thin layer of fibers on the cloth which, when dry, became sheets of paper. This substance was relatively cheap to make, lightweight, and portable, and it had a surface that was very good for writing. With the invention of paper, literature and the arts flourished in China. Equally important, paper allowed the kind of on-going communication that made possible the governance of larger areas.

Papermaking was common in China before it spread to Vietnam, Tibet, Korea, Japan, Nepal, present-day Uzbekistan (the center of Tamerlaine's empire), Iraq, and Syria. By the tenth century Arabs had begun to substitute linen fiber for wood and bamboo. This created an even higher quality of paper. The first paper mill in Europe was built in

Xátiva, Spain, by the Moors. When the European armies drove the Moors from the city in 1233, they captured the paper mill and learned the secrets of papermaking, which spread throughout Europe. Because of the Catholic Church's demand for paper, Italy quickly became the largest paper producer and exported the product throughout Europe. France and Germany followed suit, with Germany greatly improving the process and making the finest paper of the time.

Still, communication was complicated because all writing was done either by hand or by carved wood blocks. In 1450 Gutenberg invented moveable type and the printing press. This allowed documents to be reproduced quickly and in very large volumes, dramatically increasing the demand for paper.

As late as the nineteenth century paper was still made by hand. The first paper-making machine was invented in 1798, but no one would invest in the company to turn the prototype into a commercial reality. As the machinery improved, the major bottleneck was the supply of material from which to make paper. In 1850 Keller, in Germany, developed the first paper made from wood pulp, but the paper was of very poor quality. In 1852 Burgess perfected the use of wood pulp in paper making in Germany by using chemicals to break down the fiber. This process was improved further so that by the end of the nineteenth century economical, high quality mass-produced paper became a reality. Globally, paper production doubled to about 2.5 million metric tons per year by 1900. Newspaper, book, and magazine publishing flourished, as did literacy. Recently there have been many predictions that electronic media will create the paperless office; however, if anything, it has resulted in increased paper use.

The shift to wood pulp as the major ingredient in papermaking, combined with the ever-increasing demand for paper, put increasing pressure on forests. Forests are one of the few living natural resources that people still use in such large quantities. Forests cover 3.87 billion hectares, or 30 percent, of the Earth's land area. Only a small percentage of these forests are actually harvested commercially, however. By 2000 paper and paperboard products accounted for over 50 percent of the value of global forest product exports (FAO 2001b).

As demand for forest products, especially paper, has increased, there have been attempts to produce forest products from trees cultivated in plantations. The Food and Agriculture Organization of the United Nations (FAO) estimates that 5 percent of the world's forests are actually plantations rather than native vegetation. Plantations are tree "stands established by planting or seeding in the process of afforestation or reforestation" (FAO 2001a). Distinguishing between natural forests and tree plantations can be difficult, in terms of both calculating the amount of forest in a country and evaluating the habitat for biodiversity. Degraded native forests, stripped of economically important species, may provide no more ecosystem services than plantations. Conversely, abandoned plantations and those that are interplanted with native, long-maturing tree species such as mahogany or teak may contain considerable biodiversity and be more similar to natural forests than to other plantations.

Producing Countries

According to the Food and Agriculture Organization of the United Nations (FAO), the area planted to plantations increased from 17.8 million hectares in 1980 to 43.6 million hectares in 1990 and 187 million hectares in 2000 (FAO 2001a). One third of all tree plantations are in the tropics and two thirds are in temperate and boreal areas. China, the United States, Russia, India, and Japan, each with more than 10 million hectares of plantations, account for more than 65 percent of global plantation area (Cossalter and Pye-Smith 2003). Few of these plantations are of fast-growing trees used for pulp.

The extent and distribution of fast-growing pulp plantations, as well as their productivity and length of crop cycle are shown by species group in Table 13.1. By 2000, there were an estimated 10 million hectares of fast-growing plantations intended for pulp production with an additional 0.8 to 1.2 million hectares planted each year (Cossalter and Pye-Smith 2003). This trend is expected to continue well into the future. The sole purpose of these pulp plantations is to produce large volumes of uniform, small-diameter logs as quickly as possible and at competitive prices. Financially viable pulp wood plantations now are expected to yield at least 15 cubic meters of wood per hectare per year (Cossalter and Pye-Smith 2003).

Table 13.1 Fast-Growing Pulp Plantations by Species and Country

Species	Mean annual increment at an operational scale (m^3/ha/year)	Time to reach maturity (years)	Estimated extent of fast-wood plantations ('000 ha)	Main producing countries (in decreasing order of importance)
Eucalyptus grandis and various eucalypt hybrids	15–40	5–15	3,700	Brazil, South Africa, Uruguay, India, Congo, Zimbabwe
Other tropical eucalypts	10–20	5–10	1,550	China, India, Thailand, Vietnam, Madagascar, Myanmar
Temperate eucalypts	5–18	10–15	1,900	Chile, Portugal, northwest Spain, Argentina, Uruguay, South Africa, Austria
Tropical acacias	15–30	7–10	1,400	Indonesia, China, Malaysia, Vietnam, India, Philippines, Thailand
Caribbean pines	8–20	10–18	300	Venezuela
Pinus patula and *P. elliottii*	15–25	15–18	100	Swaziland
Gmelina arborea	12–35	12–20	100	Costa Rica, Malaysia, Solomon Islands
Paraserianthes falcataria	15–35	12–20	200	Indonesia, Malaysia, Philippines
Poplars	11–30	7–15	900	China, India, USA, central and western Europe, Turkey

Source: Cossalter and Pye-Smith 2003.

As late as 1900, because of the widespread availability of natural forests, there was no real need to plant tree plantations. During the last century this began to change and prior to 1950, tree plantations were started in Europe, the United States, Australia, and New Zealand, and developing countries such as South Africa, India, Chile, Indonesia and Brazil. In the 1950s, Japan, Korea and China also undertook massive tree planting programs. Between 1965 and 1980, the area devoted to tropical tree plantations tripled (Cossalter and Pye-Smith 2003).

According to Adams and Efransjah (2001) Asia accounts for about 45 percent of global pulp plantations, followed by the countries of the former USSR (18 percent), North and Central America (16 percent), South America and Europe (7 percent each), Africa (5 percent), and Oceania (2 percent). In the 1990s Asia dominated the establishment of new industrial tree plantations, many of them for pulp and paper production. By 1995 Asia contained 40 percent of the world's tree plantations and nearly 60 percent of all plantations established since 1985 (FAO 2001b).

Major countries with pulp plantations include Indonesia (with 4.3 million hectares thus far set aside for plantations, and 1.4 million hectares already planted), Brazil, South Africa, New Zealand, and Chile. In 1995 South African plantations produced 17.6 million cubic meters of timber, of which more than 35 percent was used for pulp. New Zealand produced the same amount of timber from plantations and used almost 30 percent for pulp (CCFM 2001). Brazil now contains the world's largest area of planted eucalyptus trees, although Australia contains more total trees as eucalyptus are native there (Mattoon 1998). Australia has an estimated 1.3 million hectares of tree plantations, and the government is proposing to triple the total area of plantations by 2020 (Ryan 2002a). Areas planted to trees for pulp are increasing in Malaysia, Vietnam, Thailand, Uruguay, Paraguay, Argentina, Venezuela, Colombia, Mexico, Congo, and Swaziland (World Rainforest Movement 1999). Temperate areas in China, Chile, Portugal, Spain, Argentina, Uruguay, and South Africa also have significant pulp plantations (Cossalter and Pye-Smith 2003).

Consuming Countries

In 1998 more than 40 percent of chemically produced paper-grade pulp shipments went to Western Europe, and more than 13.6 million metric tons of pulp were consumed in the countries of Western Europe (excluding Scandinavia). The United States was the second-largest consumer of pulp, using over 6.4 million metric tons (PPI 2001).

The main consumers of paper products are not necessarily the same as the primary pulp consumers. The United States is by far the largest consumer of paper and paperboard products, using over 90 million metric tons in 2000. Following the United States are China (36 million metric tons), Japan (32 million metric tons), Germany (19 million metric tons), the United Kingdom (13 million metric tons), and France and Italy (11 million metric tons). Following these are Canada, Korea, and Spain, at roughly 7 million metric tons each (PPI 2001). While developing countries such as China could potentially represent large markets for paper products as standards of living rise, industrialized countries still accounted for over 75 percent of consumption in 1998. Furthermore, the FAO predicts that industrialized countries will be largely responsible for growth in consumption through 2010 (Mattoon 1998).

Production Systems

Native forests initially supplied raw materials for the pulp and paper industry, but increasingly the industry is turning to monoculture plantations on a global scale to supply its mills. Old-growth and second-growth forests in North America's Pacific Northwest as well as Scandinavia, Chile, Indonesia, and elsewhere once served as important suppliers of raw materials to the paper industry. These regions have declined and continue to decline in importance as their forest resources have been depleted and as pressures from environmental groups and others to protect those forests have increased. The pulp and paper industry is currently shifting to other sources so that it can utilize previously unexploited natural forests; the industry is also planning for increasing reliance on industrial tree plantations. At present, industrial plantations supply an estimated 15 to 30 percent of the world supply of pulpwood (Mattoon 1998; World Rainforest Movement 1999), but the percentage is increasing rapidly.

Worldwide, plantations of fast-growing tree species are established for a number of reasons. Trees planted to provide people with fuelwood, to protect watersheds and halt soil erosion, or to offset carbon emissions can be considered "non-industrial" plantations. By contrast, "industrial" plantations yield raw materials for commercial products, including timber for processing into wood and wood products as well as pulpwood for making paper and paper products. Plantations may be established for a single use such as pulp production, or multiple uses if trees are harvested at different ages to feed into different product streams. In addition to the timber, the by-products (e.g. limbs, bark and live wood, cuttings, and trimmings) from industrial timber plantations as well as wild harvested wood are often fed into the pulp-manufacturing process. However, this chapter focuses only on pulpwood plantations, the industrial plantations of fast-growing tree species established to supply the pulp and paper industry with raw material.

Trees commonly grown in plantations include species of *Eucalyptus, Acacia*, *Casuarina*, *Pinus*, and *Gmelina arborea.* They are harvested on short rotations of six to nine years (pine rotations for timber are twenty to thirty years, but when grown for pulp it is harvested on shorter rotations, at least in the tropics). To give an estimate of the relative abundance in industrial plantations, the FAO (2001a) states that 10 percent of the world's 187 million hectares of plantations are eucalyptus species, 4 percent acacias, 20 percent pines, and 30 percent of all plantations were classified as "unspecified." Trees commonly grown on pulpwood plantations in Indonesia include *Acacia mangium* (which accounts for 80 percent of all plantations), *Acacia crassicarpa*, *Gmelina arborea*, and *Eucalyptus deglupta* (Barr 2001).

Pulp and paper plantations in the Northern Hemisphere are concentrated in Scandinavia and, to a lesser degree, in North America. Trees grown in northern regions are largely species of pine (*Pinus*), spruce (*Picea*), and fir (*Abies*) with long rotations of nearly thirty years. By contrast, more rapid tree growth in tropical climates allows tree rotations of as little as six years for eucalyptus (*Eucalyptus)* and acacia (*Acacia).* These species not only mature more rapidly, they also require less land to produce the same amount of pulp. Annual growth rates of 3 to 5 cubic meters per hectare in Canada and 10 cubic meters per hectare in the southern United States cannot compete with tropical yields of 25 cubic meters per hectare growing acacia in Indonesia and 30 to 40 cubic meters per hectare growing eucalyptus in Brazil (Mattoon 1998). Eucalyptus trees are often selected for cultivation for both their rapid growth and their pulp content; eucalyptus trees can grow as much as 30.5 meters (100 feet) in seven years. Commercial eucalyptus plantations in Brazil can produce an average of 40 to 50 cubic meters per hectare using some improved varieties. The potential, however, is thought to be as high as 100 cubic meters per hectare or greater (FAO 2001a; Strategic Environmental Associates 1996; WRI et al. 1998). Table 13.2 compares the productivity of two different forest plantation models: fast-growing eucalyptus in Brazil, and longer-rotation softwood in New Zealand (Cossalter and Pye-Smith 2003).

Table 13.2 A Comparison of the Volume of Wood Produced in Two Plantation Models

Plantation Type	Area of operation (hectares)	Mean annual increment at an operational scale (m^3/ha/year)	Time to reach maturity (years)	Wood produced per hectare (m^3)
Fast growing wood Aracruz Celulose S.A.	180,000	43	6.5 to 7	After 4 rotations: 28 years, +/- 1,000 m^3
Longer-rotation softwood New Zealand average	1,650,000	20	25 to 30	After 1 rotation: 28 years, +/- 560 m^3

Source: Cossalter and Pye-Smith 2003.

A number of factors combine with fast tree growth to encourage plantation establishment in tropical countries. Land is cheaper in developing countries, and fees to rent land in state forest reserves can run as low as U.S.$0.30 in Indonesia, $2.50 in Thailand, and $2.80 in Uganda (World Rainforest Movement 1999; Eraker 2000). A variety of other governmental subsidies may be available for establishing plantations; including direct subsidies, tax exemptions, special low-interest loans, and inexpensive labor. In addition, environmental regulations are often less stringent in developing countries, and as a result it is considerably easier and cheaper to establish plantations there.

Pulp is increasingly manufactured in the same countries where plantations are established. Pulp is a value-added product. Because wood represents 40 to 70 percent of the cost of making pulp, pulp produced in tropical areas is cheaper than that made in northern regions of the Northern Hemisphere (World Rainforest Movement 1999). The cost per metric ton of bleached hardwood pulp in Sweden is 185 percent higher than in Brazil (WRI et al. 1998).

Pulp is the most costly input in paper manufacturing, so less expensive pulp results in cheaper paper products. However, tropical countries still accounted for a relatively small proportion of overall global paper production. In 1999, tropical countries produced a large share of the world's raw pulp, but only 9 percent of paper and paperboard products (FAO 2001b).

Industrial tree plantations offer a number of advantages over natural forests. Plantations supply uniform raw material from a smaller area of land. The raw material from natural forests is varied, so pulp mill equipment must be able to handle different tree species of varying sizes. In Indonesia the pulpwood yields from natural mixed tropical hardwood stands are lower than those from *Acacia mangium* plantations by 50 to 150 cubic meters per hectare (Amec Simons Forest Industry Consulting 2001). Plantations are also more reliable and predictable pulp producers. They are planted and available for harvest on regular cycles. Production can be geared toward the supplies needed to maintain the pulp mill at peak capacity.

Pulp plantations can be established under a variety of conditions. Cultivation requirements vary between the prominent species used. Pulp plantations can replace crops, grasslands, peatlands, and degraded or old-growth forests, as well as virtually any other land use. In Indonesia, plantations have been established on areas of grassland, scrub or brush, peatlands, heavily logged and degraded forests, and forests in a more natural state (Amec Simons Forest Industry Consulting 2001).

Clearing methods depend on the type of vegetation on the area to be planted. Native forests are usually clear-cut prior to plantation establishment. In most instances, however, those forests are high-graded (harvested first for lumber-grade trees), and then the rest are cut and used in the pulp mills. Fire is often used in the clearing process to eliminate trees with no commercial value or trimmings left after harvesting timber or pulp wood. Bulldozing, plowing, and windrowing are intended to concentrate the remaining trees, branches, and roots into piles or windrows.

Seedlings are raised in nurseries in massive quantities. They are grown in black plastic bags filled with fertile potting soil and are normally watered by overhead spray. Seedlings are clones produced by tissue culture or other forms of vegetative propagation rather than from seeds. There is very little genetic diversity within the seedlings planted at any one time, although some variation occurs over time as the genetic stock is continuously improved. Seedlings are planted manually or mechanically, depending on the slope of the land and the amount of tree residue still in the area. Fertilizer is generally mixed into the planting holes for seedlings; soil amendments may be added as well to alter the pH. In peatlands, seedlings are sometimes planted higher than the surrounding area to avoid root damage from waterlogging.

As the trees start to grow, local plant species that sprout from seeds or roots are killed with herbicides or cleared manually or mechanically. Fertilizer is applied periodically, and pruning or thinning undertaken as needed to enhance growth. When plantation trees are harvested, they may be clear-cut or selectively felled, through either mechanical or manual labor (FAO 2001a). In general, it is more efficient to harvest all the trees in one area at a time than to cut them selectively. Some species will regenerate from their roots for as many as three cuttings before production declines to a point that it makes sense to replant the areas. Other species can only be harvested once and then must be replanted. Trees that can be harvested multiple times have lower overall production costs, everything else being equal.

Depending on the species, a production cycle can start anew after harvest without replanting. Some species of all of the main pulp plantation trees (species of *Eucalyptus*, *Acacia*, *Casuarina*, *Pinus,* and *Gmelina arborea*) resprout after being harvested. Aracruz Cellulose S.A. in Brazil replants eucalyptus after the second harvest (WRI et al. 1998), even though this is not always necessary.

Genetic manipulation and selective breeding have played key roles in altering productivity. Brazil's plantation industry is notable for its efforts to create genetic modifications that increase growth and/or pulp content. As a result, Brazil's eucalyptus plantations are considered the most productive in the world. Brazil's Aracruz Cellulose S.A., for example, is considered the world's leader in genetic refinement and silvicultural activities, in addition to being the world's largest producer of bleached eucalyptus pulp (WRI et al. 1998).

Selective breeding and genetic improvements can increase pulp yields by up to 30 percent. Transportation costs are also reduced by increasing the per-hectare wood volume and cellulose content through genetic improvements. Less land is needed to supply a mill, and plantations can be located closer to pulp mills. By 1998, as much as half of the delivered cost of pulpwood at pulp mills was the cost of transportation. Any increased productivity that occurs closer to the mills reduces overall costs dramatically. Conversely, it also makes it more difficult for producers of pulp from natural forests to compete.

Wadsworth (1997) reviewed more than fifty years of forestry research concerned with the potential deterioration of pulp yields from continual use of the same sites. Studies show that there is no significant decline in productivity for the second and third plantings of certain species (*Pinus radiata* and *P. patula),* while other species show a marked decline. Proving declining productivity is complex, and determining which factors cause that decline is even more so. For some species it is common for the second cutting to yield more than the first. Some have speculated that this is due to the benefits of an established root system; this appears to be the case for eucalyptus (Wadsworth 1997).

Wadsworth concluded that though there is clear evidence that habitat quality and soil quality of a natural tropical forest site decline after it is deforested, there is no conclusive evidence that successive plantations of timber crops inevitably result in further decline. He also writes that nutrient losses associated with repetitive harvests will eventually bring on such declines. Such declines, however, could also result from the loss of nutrient variety and a decline in the chemical composition of the litter and soil (e.g. one species of tree leading to less diverse soil, and erosion reducing the litter from the previous cover). Also, certain tree species appear to create more nutrient-rich soils. For example, soils that are created under oaks are apt to have more nutrients than those under pines (Wadsworth 1997).

While it is clear that plantations affect sites and under some conditions may cause deterioration, tree plantations have some potential for sustainable yields. The major causes of yield declines over time appear to be more related to management practices than to site deterioration. Careful harvesting techniques, the conservation of organic matter, and appropriate management of weeds and undergrowth can all minimize nutrient loss or damage to soil.

Theoretically, there should be no limit to the number of tree crops that can be produced on any given area. However, very little is known about how to produce unlimited crops. Too little research has been undertaken over a sufficient period of time to demonstrate the impacts of various production techniques. Production practices clearly affect the long-term productivity of any given area. Since companies typically own the land on which they have plantations, this motivates them to take measures to sustain the land's productivity (WRI et al. 1998). Large-scale, industrial monoculture plantations of trees, like other forms of monoculture agriculture, face an increased risk of disease and pest problems as compared to mixed-species, diverse plantations or natural forest stands (FAO 1999). While diseases and pests are certainly an issue, for the most part they have been relatively easily combated through careful selection of tree species and varieties plus chemical controls (McNabb 1994). The fewest disease outbreaks and highest yields are achieved when individual varieties are matched with the sites that are best suited for them. By matching traits to sites, producers can reduce their need for fertilizers, pesticides, and other inputs and activities—all of which not only have environmental impacts but also reduce profits.

Several viruses and other diseases are problematic on industrial plantations, though disease problems vary depending on the species. Various forms of heart rot, root rot, and rust diseases are the greatest danger to acacia plantations in Southeast Asia. Some diseases may do very little damage during the first planting of an area, but they can do far greater damage to subsequent crops. Another concern is that plantations of identical clones are more susceptible to diseases. By selecting varieties for desired traits and then using vegetative propagation to produce large numbers of identical trees for plantations, the natural disease resistance supplied by genetic variation is lost (Old 1997). Fungal diseases, for example, have been spreading through monoculture eucalyptus plantations in Vietnam (Lang 2002).

Birds, mammals, insects, and fungi can all be pests on pulp plantations. In some pine plantations in Chile, there has been a decrease in fox numbers; the resulting increase in rodents and rabbits has created pest problems (World Rainforest Movement 1999). Leaf-cutter ants have been problematic in eucalyptus plantations in Brazil, and companies now try to destroy ant nests before planting (McNabb 1994).

Well-run plantations are quite profitable. Aracruz Cellulose S.A., the world's largest producer of pulp from eucalyptus, is so efficient and has improved production of the species to such an extent that its pre-tax profit margins are more than 51 percent (WRI et al. 1998). Aracruz has increased production from 30 cubic meters to 45 cubic meters per hectare per year in only seven years. These yields compare favorably with Chile, where yields average only 20 cubic meters per hectare per year. When seedlings are ready for harvest, the trees are felled and trimmed and the undergrowth is knocked down. Aracruz has abandoned the use of chainsaws and now uses mechanical harvesters that improve yields and efficiencies. When the logs are taken to the mills, the crowns are left on site, but the larger branches are often removed to make charcoal (WRI et al. 1998).

Processing

Because the cost of wood pulp is to a large extent determined by the cost of transporting pulp logs to pulping mills, in many countries the two are increasingly located near each other. In fact, one of the main advantages of plantations is that the harvesting can feed the product into fixed mill sites much more cheaply than harvests from natural forests, which have longer cutting cycles. However, a hectare of natural forest in Indonesia, for example, produces more pulp at the time of the first cutting than a hectare of plantation trees. The difference is that the plantation pulp yields continue to be high after the initial cutting while natural forests take much longer to regenerate.

Processing of plantation trees begins in the field with harvest. Chain saws, heavy machinery, and transport vehicles are all required to cut down and remove trees. The harvested wood then passes through a debarker to remove most of the bark, which cannot be used for papermaking. The waste bark can be used as a soil amendment, mulch, or even burned as a fuel. Some companies remove bark in the field, not at the mill. Bark removal in the field is better for the environment. The bark eventually decomposes and returns nutrients to the soil, increasing the soil's productive potential; before decomposing, the shavings form a blanket on the ground that reduces erosion and helps protect soil from heavy machinery (WRI et al. 1998). The trunks are usually then passed through chipping machines, which chop the wood into 25-millimeter (1-inch) chips. At this point, the chips can either be processed through a digester or a refinery.

Wood consists of cellulose fibers stuck together with lignin that must be broken down to yield pulp. Wood pulp can be obtained chemically, by using chemicals to separate the fibers, or mechanically, by grinding the wood between stones or metal plates in the presence of water. Whole logs or wood chips can be used to make pulp.

In a digester, the wood chips are cooked using chemicals to remove the lignin. The by-products of the process are then used to provide energy for the mill and help with the recovery of the pulping chemicals. The resulting chemical wood pulp is then reconstituted with water to produce a coarse mixture.

Refiners use machines to grind the wood chips and separate the fibers. This process has a higher yield than chemical pulping, but it also has much higher energy costs. The mechanical wood pulp is then also reconstituted with water to make a coarse mixture. Once the pulp from all the different sources is made into a coarse wet mixture it can be blended into a single pulp. (Fiber sources may include waste paper, as described in the next section.) Blending at this stage is what will ultimately determine the final quality of the product. Dyes or other ingredients may be added at this stage to produce papermaking stock. The stock is then treated in order to separate and fray the wood fiber to the quality required for the final product. Finally, the product is run through a screen to remove any impurities such as chip remnants.

Mechanically and chemically produced wood pulp can be sold as a bulk commodity. However, Asian companies are increasingly processing pulp into paper as a way to add value to the pulp production. Brazil, by contrast, still exports a large volume of pulp to Europe and other countries.

Substitutes

There are at least three different product substitutes that affect the amount of virgin paper pulp used—other fiber substitutes, plastic, and electronic communication. As the availability of forest-based raw materials declines, producers have turned to innovative ways of expanding the fiber supply. The paper industry now uses shorter lengths, offcuts, residues, and waste (FAO 2001b). Nearly 60 percent of the fiber used in papermaking in 1998 came from virgin pulp; the rest came from recycled paper and nonwood fiber sources such as wheat straw. It is possible to increase the proportion of recycled paper—Germany, the United Kingdom, and Japan have increased it to 50 percent or more (Mattoon 1998). However, an added process to remove glues and inks must also be performed on waste paper for it to be used as a fiber source. In China, 11.3 million metric tons of nonwood pulp was produced in 1999. Over two-thirds of the pulp produced in China is made from bamboo, bagasse, reed, rice straw, wheat straw, and other nonwood sources (Ryan 2002b). By contrast, in 1998 nonwood fiber made up less than 1 percent of total fiber for paper in the United States (Mattoon 1998). Innovations, new technologies, and expanding use of nonwood sources of fiber have the potential to decrease the industry's reliance on wood.

Plastic and other wraps have made considerable inroads in the use of paper for packaging, at least in developed countries and urban areas. This is true of boxes and overall packaging of dry goods as well as most of the packaging used for fresh meat and produce in grocery stores. Unfortunately, while plastic wrap takes up less space in landfills than paper that is not recycled, very little plastic packaging is recycled in most countries. In addition, most plastic is made from petroleum, which is not a renewable resource.

The electronic era was introduced with considerable fanfare and seen by many as a way to create paperless offices. This has not been the case. In fact, electronic communications have actually increased per-capita paper consumption, both in developed and developing countries.

Market Chain

In 1996 an estimated 12 to 21 percent of wood pulp was traded internationally, while the large majority was consumed near the source of manufacture (Strategic Environmental Associates 1996). The market for pulp is characterized by a lack of product differentiation, and pulp moves duty-free around the globe. In the 1990s world shipments of chemically produced paper-grade pulp grew at an average of 2.4 percent per year. However, the export growth was low from the traditionally high producers in North America and Nordic countries, and the market share of the rest of the world (primarily Brazil and Asia) grew as their shipments increased at an average annual growth of 5 percent (PPI 2001).

The pulp and paper industry is truly global, involving the worldwide trade of pulp, raw materials, and paper. By 2001 paper and paperboard products accounted for more than 50 percent of the value of global forest product exports (FAO 2001b). Five large companies produced almost 9 million metric tons of chemical market pulp (which includes chemically produced paper-grade, fluff, and dissolving/specialty pulps) (PPI 2001).

From 1990 to 2000, the share of total processed wood exported has increased, with 34 percent of wood-based panels, paper, and paperboard exported (up from 25 percent in 1990), and 20 percent of pulp exported (up from 16 percent in 1990). However, tropical timber products (from plantations and native forests) accounted for less than 10 percent of global pulp, paper, and paperboard products exported in 2000 (FAO 2001b).

In the United States, approximately 25 percent of the timber harvest is used for pulp production. This 25 percent accounts for 45 percent of the material used in pulp production; recycled material accounts for 30 percent; and residues from sawmills, veneer mills, etc. account for the final 25 percent of pulp sources (Strategic Environmental Associates 1996). Globally, a significant share of pulp comes from the wood chips that are the by-products of sawmills.

Market Trends

Between 1961 and 2000 the international trade of pulp increased from 9.8 million metric tons to 37.8 million metric tons. The average price corrected to 1990 values decreased from U.S.$480 per metric ton to $446 per metric ton, with a total real decline of 7 percent over the period in question. Given the nearly fourfold increase in supply, the price of pulp has been buoyed by a dramatic increase in demand.

The contribution of eucalyptus to world pulp supply is likely to increase, as it has become a more popular plantation species in recent years. In 1996 less than 1 percent of wood pulp came from tropical hardwoods such as eucalyptus (Strategic Environmental Associates 1996). Because the financial incentives to apply genetic manipulation and breeding can be strong, the use of these techniques is likely to increase. Genetically modified trees have also been developed. In the future, as long as consumers accept the products, they will be used to establish plantations as well. The increasing productivity of pulp plantations also affects global prices. For example, the Brazilian pulp giant Aracruz Cellulose S.A. increased the average yield by 50 percent in only 8 years. Indonesian companies have done the same. Ultimately, genetics and climate will create the highest producing plantations.

Pulp wood has a long growing cycle when compared to other agricultural crops. As a result, the pulp industry is highly cyclical (once an investment is made, the producer has to wait years to harvest) and driven by high capital investments in pulp mills and supply that can vary tremendously based on weather and other conditions. Consequently, the price of pulp is prone to dramatic shifts. For example, from 1993 to 1996 the price of a ton of benchmark pulp rose from U.S.$390 to $1,000 per metric ton and then fell back to less than $500 (World Rainforest Movement 1999). Overplanting of pulpwood trees can lead to a glut on the world market, which is beneficial for paper manufacturers and users but makes pulpwood cultivation less profitable and less attractive to producers. In addition, increased globalization (improvements in technology, communications, and transportation) means that pulp producers can sell to a greater range of buyers. As a result, the pulp cycle has more frequent, steeper, and longer lasting price swings, and profit margins are low throughout the industry (WRI et al. 1998).

Mills with very large capacities were built in Indonesia in an attempt to avert the cyclical price declines of the pulp and paper market (Barr 2001). As expansion in tropical countries continues, northern countries struggle with more expensive raw materials, high production costs, and mills that are older and less efficient. British Columbia in Canada has been the most expensive pulp-manufacturing region in recent years due to high chip costs, labor, and other factors.

Current news releases announcing new pulp mills and plantations reflect the increase in the establishment of plantations used for pulp. At a time when plantations are increasing in number and area, new technology and innovations are reducing costs and increasing productivity. While the trends may be somewhat uneven globally, new technology will provide financial incentives to shift away from harvesting natural forests. Over the short term, such innovations increase the profit margin. Over the long term, they increase production and lower consumer prices (Sedjo 2001). Another strategy to mitigate cyclical variation on world markets has been to integrate paper production with pulp production. Since the mid-1990s, global production of paper and paperboard increased steadily, and was not affected by the Asian financial crisis of 1997–98. However, prices decreased considerably in 1998 and 1999 before recovering in 2000 (FAO 2001b).

Harvest of fast-growing plantation species is expected to increase dramatically over the first half of the twenty-first century. As of 2000, fast-growing industrial tree plantations accounted for approximately 10 percent of the global industrial wood harvest. By 2050 they are predicted to account for 50 percent of the harvest, while industrial plantations of native species are likely to account for an additional 23 percent of the harvest. These fast-growing plantations are predicted to cover approximately 200 million hectares, or 6 to 7 percent of the world's forested area as of the year 2000 (Sedjo 2001).

Indonesia has attracted global attention for massively expanding its pulp and paper industry in the last decade. Indonesia's pulp and paper production increased sevenfold from 1987 to 1997. Indonesia currently produces 20 million cubic meters of pulp, which requires some 4.3 times that amount of wood. Indonesia's natural forests can no longer supply this volume. While Indonesia's forests continue to be converted for pulpwood at an alarming rate, the industry is looking towards plantations as the only way to maintain profitability and a constant supply of raw material. The government has provided generous subsidies for the establishment of plantations and, in 1997, allocated 4.3 million hectares to be cleared of natural forests and planted with plantations. These mixed tropical hardwood natural forests are being clear-cut and fed into pulp mills prior to and during the establishment of plantations. However, the 4.3 million hectares of land allocated greatly exceeds the area of land needed to support the pulp industry, and it appears the generous allocation of land for plantation establishment was done primarily to supply producers with ample supplies of mixed tropical hardwood forests (Barr 2001). It will be several years before the established plantations are supplying trees at their full capacity. In 1998–99 less than 8 percent of the 100 million cubic meters used by the pulp industry came from plantations (Barr 2001).

In developing countries, governments have historically dominated the plantation sector of the pulp industry. This situation is changing in some countries, and the private sector (both individuals and corporations, often in partnership) is moving into the forest plantation industry. The private sector has assumed a major role in plantation development in Brazil, India, Indonesia, Malaysia, and Thailand. Issues of financial risk and economic viability are even more important when plantations are privately held. Governments are now making plans to "privatize" or sell their plantations to individuals or companies in Australia, Brazil, Chile, Indonesia, Malaysia, New Zealand, and South Africa. Out-grower schemes, in which private companies work in partnership with communities or small farmers, have also become more common. Foreign investments in plantations in Southeast Asia, Oceania, and South America are also increasing (FAO 2001b). These include commercial banks, investment funds, and pulp and paper companies from China, Japan, Europe, and North America.

Environmental Impacts of Production

The environmental problems resulting from forest plantations are a subject of much debate. Proponents of plantations maintain that they are environmentally beneficial, allowing efficient production of forest products on a small area of land and therefore easing pressures on natural forests. Some argue that plantations have many of the ecological attributes of natural forests (such as similar leaf fall, soil percolation, and accumulation of organic matter) and are more beneficial ecologically than non-forested areas (Wadsworth 1997). By definition, however, forest plantations are large monoculture areas, usually of exotic species, and so contain far less biodiversity than natural forests. One of the major environmental issues of concern, then, is whether plantations are created on areas recently cleared of natural forests or on pasture or degraded agricultural land. Globally, most plantations have been created after the conversion of natural forest or logged-over and degraded forest areas. Pulp plantations can have a number of negative environmental effects, primarily habitat conversion and deforestation, pollution from agrochemical inputs, and environmental degradation as soil quality and water cycles are altered. The increased burning associated with forest clearing is also a serious concern. These can be mitigated to some degree through good planning and vigilant management. The best standards of management are not always employed in developing countries (precisely where pulp and paper plantations are expanding most rapidly) because of constraints on resources and capacity as well as the lack of incentives and enforcement of existing laws and regulations that should affect such operations. Each environmental impact is discussed separately below.

Habitat Conversion and Deforestation

The establishment of extensive monoculture plantations results in a loss of biodiversity, irrespective of the vegetation type existing before the plantations were established. Indonesia's policy of clear-cutting native forests with outstanding biodiversity and then establishing plantations is an extreme example. Similarly, native or old-growth forests have been, and in some cases still are, being logged and chipped in Canada, the United States, Chile, and Tasmania; afterwards they are replaced by plantations. Conversion of natural forests to plantations accounts for 6–7 percent of all forest conversion each year (Cossalter and Pye-Smith 2003). According to some estimates, 15 percent of all plantations in the tropics were established on lands where natural forests were cleared immediately prior to planting the seedlings (Mattoon 1998). However, even if plantations replace degraded forest or grasslands, there is a loss of biodiversity when monoculture plantations of exotic, introduced species are planted.

The initial clearing is not the end of the process. After seedling trees are planted, other seedlings and sprouts of native vegetation are attacked aggressively to prevent them from competing with the desired species. This is done through hand or mechanical weeding or with the use of herbicides. Once tree plantations are established and branches extend to close the forest canopy, few other species will appear. In short, there is little biodiversity. Native flora and fauna may not be able to adapt to the new habitat. The intensive management of plantations means that epiphytes, parasites, and climbing flora common to tropical forests do not have an opportunity to develop. Soil flora and fauna also decline due to changes in soil composition and leaf litter. The use of agrochemicals affects leaf litter, and the lack of mature or dead trees results in less habitat available for fungi and insects. Crop pollinators and other ecosystem services offered by natural forests are no longer available. The few native insects and animals that do find a way to adapt to a specific niche within a plantation tend to increase exponentially because of the large size of industrial plantations. This often causes serious problems, resulting in the need for increased use of agrochemicals or, in severe cases, abandonment of the plantations. For example, the pine shoot moth (*Ryacionia buoliana*) proved such a problem for pine plantations in Uruguay that they were abandoned (World Rainforest Movement 1999).

Plantations are sometimes established on marginal or unsuitable lands, which may also increase environmental problems. In Indonesia, the Sinar Mas group intends to establish extensive plantations on peatlands, which will increase fire and environmental management risks. An independent audit concluded that these risks have not been adequately addressed (Amec Simons Forest Industry Consulting 2001). Furthermore, such lands are not as productive, so they will have financial implications that could affect the overall viability of the company.

Soil Erosion and Nutrient Loss

In plantations with intensive, short rotations, nutrients in the soil are depleted and soil becomes more acidic over time. Frequent management interventions, use of heavy equipment, and tree removal all disturb the soil, reduce organic matter, and increase erosion. Each of these impacts can contribute to other impacts as well. For example, soil erosion worsens the impacts of floods.

In Brazil, the policy of Aracruz Cellulose S.A. is to leave tree crowns and small branches on site after the harvest in order to help protect the soil (WRI et al. 1998). A study of fast-growing species in the tropics concluded that 70 to 80 percent of the nutrients in the tree were removed from the plantation when timber and bark were harvested. Removal of such large quantities of nutrients results in the need for large amounts of fertilizer to restore soil fertility. Leaving slash (branches and other residue) on the site after harvest could reduce nutrient loss by 25 percent. Leaving bark could reduce loss by another 5 to 10 percent. Extending the time of harvest also reduces nutrient loss, as shorter harvest-and-replanting cycles remove more nutrients. Harvesting *Gmelina arborea* every five to six years causes significantly more nutrient loss than harvesting every thirteen to fifteen years (Wadsworth 1997).

Increased Risk of Forest Fires

Severe forest fires burned around the world in 1997 and 1998, spurred on by El Niño-related drought conditions. In 1997–98 forest fires in Indonesia were extremely destructive. A total of 9.7 million hectares burned, with cost estimates ranging from U.S.$4.5 billion to $10 billion. An estimated 75 million people were affected by smoke or haze. Subsequent studies identified the use of fire to clear land for oil palm and pulpwood plantations as one of the main causes of these fires. Approximately 80 percent of the fires originated on industrial holdings (Mattoon 1998), and roughly 100,000 hectares of plantations burned in Kalimantan and Sumatra. *Acacia* and *eucalyptus* plantations are especially susceptible to fire because their leaves have a high oil content and young trees have thin bark that is not yet fire-resistant (Barr 2001). Most Indonesian companies have poor fire prevention and suppression practices. Fires were also widespread, although not as severe, in 1999–2000 (FAO 2001b).

Burning forests is a significant contributor to climate change. A recent study estimated that Indonesia's 1997 forest fires, most of which were started to clear land for agriculture, released between 0.81 and 2.57 Gigatons of carbon (Page et al. 2002).

Changes in the Water Cycle

The environmental impacts of plantations on the water cycle are not fully understood. However, it is clear that changes occur. The amount of water falling on the soil is different after a plantation is established because the new trees and foliage are uniform; they do not have the same diversity of size and shape as the flora found in native forests. Runoff and absorption of rainfall also vary in response to factors such as the amount of leaf litter generated by the plantation and the type of humus produced by that litter as it decomposes. Heavy equipment compacts soil, which increases the speed and amount of runoff and reduces absorption. Some plantation trees use a large amount of water per hectare, although some studies have shown that they consume no more water than other herbaceous vegetation (Wadsworth 1997). In Kenya, plantation softwoods managed on twenty-year rotations actually consume less water per hectare than natural forests, and only 10 percent more than perennial pasture grasses (Pereira 1967, as cited in Wadsworth 1997).

There is, however, a direct correlation between a species' rate of growth and total water consumption, so plantations that use fast-growing species such as eucalyptus have high water use. This high rate of water use can cause problems in areas surrounding the plantation, as less water is available for crops, freshwater ecosystems, and the generation of hydroelectric energy and other industrial activities.

Pollution from Agrochemical Inputs

Herbicides, pesticides, fungicides, and fertilizers are all used on tree plantations. Herbicides are used to remove native plants that return after land is first cleared. Monoculture plantations are susceptible to pest and disease outbreaks, which are typically controlled with insecticides and fungicides. However, some studies have suggested that eucalyptus plantations use fewer pesticides and fertilizers than crops such as corn, soybeans, or wheat (WRI et al. 1998).

The extent of chemical use varies depending on the company and region. The overall environmental impact depends not just on the quantity of chemicals used, but also on how and when they are used. Riocell S.A. in Brazil uses only the herbicide glyophosate (in targeted areas) and a single insecticide, which is widely applied (WRI et al. 1998). In New Zealand, however, more than thirty different pesticides have been used, including organochlorines (the class of highly toxic chemicals that includes DDT) (Mattoon 1998). Mechanized application, especially aerial spraying, can be inaccurate or drift and can result in the excessive use of chemicals.

Pollution from Processing Mills

No attempt will be made to address the full range of environmental impacts of pulp mills. Much is already known about this form of industrial pollution. However, since pulp processing mills are increasingly part of pulp plantations, it is important that their most significant impacts are mentioned here.

Pulp mills produce effluents that are high in solids, nitrogen, phosphorous, and organic compounds. In Europe the effluent released from pulp and paper mills has seen a reduction in its biochemical oxygen demand (BOD, a measure of pollution) by more than 70 percent since 1990. In Europe, some 95 percent of pulp and paper mill effluents receive primary and secondary wastewater treatment (Confederation of European Paper Industries 2000). While there are improved methods for treating effluents, they have not been uniformly adopted or enforced through government regulations throughout the world. In addition to organic matter and other natural substances in the effluent, in many places high quantities of chlorine are used to bleach pulp to a uniform color as well as to improve binding, printability, and reproduction capacity; increase strength; and reduce yellowing over time. There is currently a shift away from chlorine gas in favor of other bleaching techniques such as chlorine dioxide and ozone, but this is not true everywhere.

Air pollution has also been a problem of paper mills. The use of lower-quality fuel sources in the past caused major emissions from pulp mills, including carbon dioxide, sulfur dioxide, nitrogen oxides, and particulate matter. Sulfur emissions also occur as a result of the pulping process itself. Sulfur dioxide has been reduced by switching from heavy fuel oil to sulfur-free and low-sulfur fuels, replacing fuel oil with natural gas, or controlling the production process more carefully. In addition, the use of natural gas produces less carbon dioxide than the fuel sources used previously (Confederation of European Paper Industries 2000).

The amount of water used in pulp and paper mills varies depending on the quality of the paper or paperboard produced as well as the size of the paper machine. In Western Europe the paper industry uses, on average, about 35 cubic meters of water per metric ton of pulp produced. However, the amount of water used can exceed 100 cubic meters per metric ton for high-quality grades of paper (Confederation of European Paper Industries 2000).

Social Impacts

Industrial pulp plantations can have a number of negative social impacts if not properly planned and managed. When governments designate land for the establishment of plantations, the land is normally described as vacant or unused when in fact it may be inhabited, utilized, or claimed by local people. Sometimes these people are ethnic minorities or indigenous groups not fully integrated into the mainstream economy. In addition to being displaced by tree plantations, local people can also be affected by the application of chemicals such as herbicides and pesticides. Conflicts between plantation companies and displaced or local people are commonplace in many areas of the world (Barr 2001; Eraker 2000; Mattoon 1998). Social conflicts are likely to continue to rise in tandem with increases in plantation area planted and increases in human populations (WRI et al. 1998).

Because plantations occupy such large areas, they often monopolize local employment opportunities and fix wages with little room for negotiation. The actual contribution of labor to production costs in forestry operations may be as high as 75 percent in some cases (WRI et al. 1998). This means that most pulp plantations are very concerned about labor and, in particular, how to bring the costs down.

Some pulp plantations and mills rely on local communities to provide a significant proportion of their raw material, either from plantations of their own or through legal or illegal harvesting from natural forests. Increasingly, companies are establishing systems similar to contract farming. Communities neighboring pulp mills are encouraged or even supported financially to plant fast-growing species to sell to the mill. If there are not two mills nearby, then there is no competition and wood prices tend to be set at levels that are highly advantageous to the buyer. Local out-sourcing lowers a company's labor costs as well as its fixed investments in tree plantations.

Better Management Practices

There is increasing interest on the part of both investors and buyers in the overall environmental impacts of pulp plantations as well as what management is doing to reduce them. This is resulting in both investment screens and certification programs that are designed to reduce investment risks, improve product image, and increase the confidence of investors and buyers in the final product.

Investment screens are a mechanism to pressure pulp producers to improve environmental and social practices. Investors in the pulp and paper sector have been targeted on two fronts to adopt this approach: the risk bad investments pose to their corporate reputation and the financial loss from unsustainable business practices. Given the tiny profit margins of many pulp operations, banks that fund them are beginning to understand that the adoption of better practices is one way to insure that a pulp company will be more viable than its neighbor, all other things being equal. Increasingly, policies that explicitly consider environmental practices and social concerns help to guide finance decisions. Considering environmental and social issues can protect the corporate reputation and increase financial opportunities. Experiences from two companies in Brazil, Aracruz Cellulose S.A. and Riocell S.A., show that actively integrating social and environmental concerns into business strategies can create opportunities to increase efficiency and develop competitive advantages (WRI et al. 1998). Banks such as ABN Amro in the Netherlands have also developed specific pulp plantation investment strategies that require potential investments to be screened according to environmental and social criteria. Increasingly, such screens are seen as an integral part of the bottom-line analysis for a proposed investment and not just peripheral criteria evaluated afterward.

Forest Stewardship Council (FSC) certification of plantation forests offers another tool to promote better management practices. A number of pulp and paper companies have certified their forests and now can market their products as FSC-certified. The certification program now allows products with waste, recycled, or reused wood to be certified (FAO 2001b). Consumers, and in turn industrial buyers, are increasingly aware of environmental sustainability and social responsibility issues when making purchasing decisions. Some industrial buyers, particularly those purchasing pulp for well-known brands, will not buy any pulp from Indonesian acacia plantations because of their environmental problems. Some buyers have indicated that the situation might change if Indonesian acacia plantations obtain FSC certification. Such certification would indicate a major shift from current practices (Roberts 2002). This is a clear indication of the role some pulp buyers are willing to play to make the pulp industry more sustainable.

It is hard for companies to reduce their damaging environmental impacts, however, if they do not know what they are. Some countries require companies to report at regular intervals on soil erosion, suspended solids, and other water quality issues. In many cases, however, companies are measuring such environmental criteria themselves. This is seen as a scorecard, a way to know where they stand and monitor the impact of their performance. It is also important baseline data that can be used to show improved performance and quite possibly to reduce input costs. For example, some companies now recycle more than 90 percent of the chemicals used in the digestion phases of pulp processing. Companies have also been able to reduce the BOD levels of their effluent by as much as 90 percent and the levels of some of the toxic compounds even more (WRI et al. 1998).

Countless studies have been conducted on plantation management showing a number of practices that can increase productivity and at the same time increase the sustainability of plantations. These findings are summarized here.

Choose Appropriate Sites and Species

Where a plantation is sited can be the single largest contributor to its environmental impact. This is true both of where the entire site is located (e.g. on sloping land or in peat areas) as well as which areas within a plantation are planted and which are left in or returned to native vegetation.

Site selection can also affect plantation tree growth and productivity. Everything else being equal, the impact of a good or superior site on production can range from 28 percent to 139 percent more than the production from a mediocre site, depending on the tree species (Wadsworth 1997).

Some companies have found that by selecting species and varieties for specific sites and microenvironments yields can be increased. Aracruz Cellulose S.A. matches individual varieties with the sites best suited for them, reducing the need for fertilizer, pesticides, and other inputs or activities that have negative environmental impacts (WRI et al. 1998). More than 100 genetic varieties and clones of three major eucalyptus species and hybrids have been developed in order to find the varieties most suited to specific conditions of the sites being planted. Likewise, APP in Indonesia has developed eucalyptus clones that perform better in different circumstances.

Maintain Species Diversity

In some instances, yields have been increased by planting multiple species. In Hawaii, for example, eucalyptus planted with leguminous trees produced half again more dry weight than monocropped eucalyptus (Wadsworth 1997). In addition, mixed-species plantations can be better ecologically because they offer a better balance of soil nutrients and more variety of habitat for birds and other wildlife.

Most pulp plantations, however, are planted to a single species rather than a mix of trees. Even so, managers have found ways to reduce some of the negative impacts of large areas of monocrop tree plantations. Interspersing plantations with native reserves, especially if these are linked to form biological corridors, tends to maintain ecological balance and promote biodiversity within plantation estates. By supporting populations of natural predators and breaking up extensive monoculture stands, such areas help to control pests and diseases. Several plantations in Asia and the Americas have maintained 20 to 30 percent of their area in natural habitat.

In Brazil one company utilizes trees harvested from 162 different farms in 23 municipalities (WRI et al. 1998). While this increases transportation costs considerably, the company has decided to not concentrate the production of raw material in large plantations to avoid the environmental and social problems associated with such plantations.

Improve Planting and Replanting Techniques

While clearing forest areas for plantations, any plant material from the clearing process (such as felled trees and branches) should be pushed into rows that follow the contours of slopes on the site. In this way, the material forms barriers to minimize soil erosion and hold moisture; the barriers also retain organic matter and nutrients that are released over time as the materials decompose. Such windrows help protect soil even on nonsloping sites.

Areas that are being reclaimed from degraded agriculture land or pasture need to be planted to crops that build up the soil before any tree seedlings are planted. Careful choice of cover crops will increase overall organic matter, add nitrogen, and cover and hold the soil to reduce erosion.

Many companies plant rows of seedlings by hand in soil that is minimally prepared. They have found that minimizing the disturbance of soil during planting saves them money and reduces the need for fertilizers. Minimizing soil disturbance maintains microorganism communities in the soil, which in turn encourages healthier and more rapid root development. It also preserves the mulch and leaf litter on the surface, which protects the vitality of soil and retains moisture.

Reduce Agrochemical Use

Several ways have been identified to reduce the use of agrochemicals in the pulp industry. Often input use can be reduced relatively simply. The most important way plantations can reduce input use is to maintain organic matter on the surface of the land, which acts as a barrier to weed growth, holds moisture in the soil, and improves plant health. In addition, as the surface material decomposes it builds up levels of organic matter within the soil, which increases the soil's ability to retain nutrients and water. By minimizing the leaching of nutrients, soil organic matter can reduce the need for fertilizers. Many plantation pulp companies are beginning to consider the soil an asset that must be not only conserved but also maintained. For that reason, they should invest in protecting the soil. They could do this in a number of ways that have been discussed above. Another way would be to invest in science and dedicated laboratories to develop management techniques to monitor and improve soils. Finally, there is far too little information exchanged between companies; considerable money is invested in reinventing the wheel, rather than in replicating practices already known to improve overall soil health.

Some of the more progressive companies now use spotters to determine if there are specific disease or pest issues. The data is collected, stored, and recalled by quadrant. It is used as the basis for deciding whether pests or diseases have reached a point that requires chemical control. As a result, interventions can be used only where needed rather than for the entire plantation or prophylactically through the life of the plantation. Over time, managers can anticipate problems in areas that are more susceptible to pests and diseases. If such patterns persist over time, managers have sufficient information to retire them if operational costs exceed revenues. During plantation establishment, herbicides tend to be used only on the areas directly adjacent to the seedlings, and then only as needed.

Watering huge plantations is expensive in terms of labor, equipment, and volume of water used, so there are strong economic incentives to avoid watering. In the past, many plantations were forced to water their trees once or more after they were planted and additionally during times of drought. However, most companies find that if they plant trees at the beginning of the rainy season, they no longer have to water by hand or set up expensive and wasteful irrigation systems

Improve Harvesting Methods

High-technology harvesting equipment can increase the efficiency and productivity of harvest while leaving undergrowth and slash (harvesting residue) on the ground to protect the soil. Using machines with tires rather than metal tracks tends to reduce soil compaction as well.

Leaving bark and trimmings in the field is much better for the environment, as explained in the earlier discussion of processing. The bark and trimmings create a mulch that reduces soil erosion and builds soil organic matter. However, stripping the bark in the field costs more; it represents a 5.66 percent increase in the cost of forestry production compared to wood whose bark is removed at the factory. In the case of Riocell S.A. in

Brazil, bark removal results in an annual additional cost of about U.S.$1.5 million, or an increase of 1.23 percent in total production cost (WRI et al. 1998). To evaluate the financial impact of debarking on the plantation, one would need to know whether leaving the bark in the plantation fields reduces the cost of nutrients or increases overall growth sufficiently to make up for the added cost. This is a relatively straightforward calculation for pulpwood plantations, but so far such calculations have not been done.

Calculating the costs and benefits of bark removal is further complicated by the fact that some processing plants use the removed bark as fuel. Vertically integrated companies must determine if the savings from the mulch that is left behind exceed the savings from using the material in the processing mill to reduce overall energy purchases. Some vertically integrated companies produce up to 80 percent of their total energy needs by burning bark and other by-products. Other companies convert bark and other processing waste into marketable by-products. More than 99 percent of the solid wastes from processing in one mill in Brazil is used to make fertilizer, soil amendments, or added to cement (WRI et al. 1998).

Eliminate Burning

Burning increases carbon dioxide, degrades soil, decreases soil nitrogen, and kills soil microorganisms. In addition it creates significant amounts of air pollution and has devastating effects on biodiversity. Increasingly, plantations have adopted no-burn policies, either for plantation establishment or for harvests or both. In some cases, as in Indonesia and Malaysia, this has been regulated by governments. In Brazil, Riocell S.A. was one of the first pulp mills to eliminate post-harvest burning voluntarily (WRI et al. 1998). While the company's internal no-burn policy was not generally accepted in the early 1990s, companies now see the advantages. Producers have found that the retention of organic matter in the soil more than makes up for the additional costs by reducing the need for expensive fertilizers and irrigation. In fact, the benefits are felt for some time as the organic matter continues to reduce the cost of inputs and increase overall productivity.

Outlook

Globally, tree plantations are assuming increasing importance as a source of pulp. Paper and paperboard products will increasingly come from raw materials cultivated in plantations. Improved genetics for plantation species will make harvesting pulp from natural stands less economically viable. This should have a very positive impact on natural forest habitat unless an overall decline in value encourages people to convert the habitat to other uses. Programs of payments for ecosystem services (e.g. carbon sequestration or watershed management) could also be developed to help maintain natural forests. The area of industrial forest plantations will continue to increase. The economics of pulp production and processing are driving the industry to create larger plantations with attached pulp processing-mills. The Philippines, Mexico, and China are all planning significant expansion of industrial plantations, with China aiming to establish

9.7 million hectares of forest plantations between 1996 and 2010 (FAO 2001b). Plantations will increase in importance to supply not just pulp and paper products, but also to produce engineered wood products such as laminated veneer lumber (LVL) and glue-laminated timbers. As the supply of large logs decreases globally, these composite materials will increase in importance (FAO 2001b). Over time, lumber may well become the most valuable product from plantations currently dedicated to pulp production.

This trend will provide pulp at increasingly low prices, but there are other impacts of the evolving system that are not nearly as obvious. For example, it is quite likely that huge areas will be planted to monocrop plantations in the name of efficiency. These areas are unlikely to include biological corridors to support biodiversity *unless* producers can be shown that such corridors make sense financially. This can happen either because producers recognize the advantage of leaving native vegetation in areas that are not economically viable for planting, or because buyers demand that producers meet basic biodiversity and ecosystem criteria as a cost of doing business. Similarly, unless it proves economically advantageous, such plantations are likely to be established by clearing existing forests rather than degraded pasture or agriculture land.

Resources

Web Resources

www.paperloop.com
www.libsci.sc.edu/bob/class/clis748/Studentwebguides/PulpandPaperwebresources.html
www.agroforester.com
www.fao.org/forestry/index.jsp
www.fao.org/docrep/003/X8423E/X8423E00.htm
www.fao.org/docrep/003/X1607E/x1607E00.htm
www.wrm.org/uy
www.wrm.org.uy/countries/
www.wrm.org.uy/plantations/material.html
www.ffp.csiro.au
www.ffp.csiro.au/publicat/onwood/

Additional resources can be obtained by searching on "pulp" or "wood pulp" on the WWF International Intranet:
http://intranet.panda.org/documents/index.cfm

Contacts Within the WWF Network

Nazir Foead, WWF-Indonesia (nfoead@wwf.or.id)

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