# The Domestic Benefits of Tropical Forests: A Critical Review

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*Many forest conservation projects seek to preserve biodiversity by protecting habitats from exploitation or degradation. Although such efforts are often motivated by global concerns, habitat protection also yields domestic benefits. Some of these are intangible or difficult to quantify; others, such as watershed protection and the production of nonforest timber products, are immediate and tangible.*

*There are two rationales for quantifying the domestic benefits of habitat conservation. The first is motivational. Host countries capture only a small proportion of the global benefits which stem from biodiversity conservation. Demonstration of palpable local benefits could help to build support for biodiversity-oriented projects. Second, the magnitude of domestic benefits could influence project financing. Sufficiently large net domestic benefits could justify financing of a project on narrow economic grounds, with biodiversity conservation as a by-product.*

*This review finds that the quantifiable benefits of forest preservation in providing hydrological services and nontimber forest products are highly variable. Locally important in some situations, these classes of domestic benefits may in general be smaller than popularly supposed. This underscores the need for financing conservation from the Global Environmental Facility or other global sources rather than placing the burden entirely on domestic resources.*

This article focuses almost exclusively on forests in the humid tropics and on two of their potentially most important benefits: hydrological benefits such as erosion control and regulation of stream flows; and nontimber forest products, such as rubber, rattan, fruit, and nuts. Hydrological effects are emphasized for three reasons. First, forests are assumed to be economically important for preventing soil erosion and flooding, protecting the water supply, and maintaining rainfall patterns (Botkin and Talbot 1992, p. 51; Myers 1995). Second, these assertions are often made with little supporting

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evidence. The claims are often seen as a priori plausible or even obvious, although the scientific literature has been questioning some elements of this received wisdom for at least a decade (Hamilton and King 1983). Only a handful of economists have attempted to measure the value of these hydrological functions, and this small literature appears not to have been fully integrated with the scientific literature. Finally, hydrological impacts are potentially of great interest for domestic policy because they involve local externalities: upslope actions affect downslope populations. Also of interest are nontimber forest products, which are increasingly seen as a source of domestic benefits. The emergence of a more extensive literature on nontimber forest products offers an opportunity to assess the valuation of these benefits.

Two themes guide this review. Although these themes are not novel and in fact appear to be quite obvious, we believe that they have been insufficiently emphasized in the existing literature.

First, *benefits must be computed relative to an alternative land use.* The literature tends to treat the benefits of habitat protection as an absolute number irrespective of alternative uses of the land. This is ecologically and economically invalid. Hydrological functions of the land are strongly related to ground cover, as we discuss at length. Hence, the hydrological impact of converting a natural forest to a plantation might be quite different from converting it to annual cropping, and this will affect the value of maintaining the land as forest.

More generally, we are interested in protecting areas precisely because they are in current or future danger of being converted to an alternative use. Therefore, to argue that a particular area should remain protected for economic reasons, the benefit stream provided by the forest must be compared with the benefit stream that would result from the likely alternative. In other words, it is necessary to compute the net benefits of forest preservation: the gross benefits under protection less the forgone benefits from the alternative use (opportunity cost).

Second, *benefit levels are highly location specific and scale dependent.* Habitats in general—and forests in particular—are internally quite heterogeneous. Any sizable forest area is likely to contain many varieties and densities of species, types of soil and terrain, and areas that are more or less accessible to markets. This diversity in turn results in a continuous variation over the landscape in both the physical processes underlying forest benefits and in their economic value. For example:

- The value of forest products depends on the density of the valuable species and on the cost of transportation from the extraction site to the consumer.
- A forest's recreational value depends on its views, accessibility, and species mix.
- Its hydrological value depends on the slope, rainfall, type of soil, position in the watershed, and proximity to dams, fisheries, and irrigation systems.
- The opportunity costs of forest preservation depend on how accessible the land is to markets, and the suitability of the soil for crops.

Moreover, several hydrological processes are scale dependent: the dynamics of erosion and runoff, for instance, are quite different in 100- , 10,000- , and 1,000,000-hectare watersheds. Scale also affects markets for nontimber forest products: product prices may decline as the supply increases. As a result the values estimated for a small site cannot easily be extrapolated to a large area; simple scaling-up of site-specific estimates will yield inaccurate, and often biased, results.

## The Hydrological Benefits

Conversion of forest land to other uses can disturb the functioning of the forest ecosystem and ultimately its economic value. (This section draws heavily on Bruijnzeel 1990, and Hamilton and King 1983.) Table 1 shows how changes in land use that affect hydrology are linked to economic impacts.

The first set of links involves the effect of changes in land use on river sedimentation. Three questions are evaluated: First, under what conditions does deforestation increase erosion? Second, what is the relation between increased erosion and delivery of the resulting sediment to downstream economic activities? And third, what is the relation between sediment delivery and subsequent economic damage to dams, canals, harbors, and fisheries?

### *From Land-Use Change to Sedimentation*

There are two links here: from land-use change to erosion, and from erosion to sedimentation. The first is relatively well understood from experimentation and observation on relatively small plots, although most attention focuses on surface erosion as opposed to erosion that causes gullies and mass wasting (landslides). A review

Table 1. *Hydrological-Economic Links*

| *Possible hydrological changes* | *Economic impacts* |
|---|---|
| Increased sediment delivery | Siltation of reservoirs, canals, harbors |
| | Damage to fisheries |
| | Improved agricultural productivity from downslope soil depletion |
| Erosion | Loss of productivity for downslope farmers |
| Increased water yield (runoff and subground flows) | Flood damage to crops and settlements |
| | Benefits to downstream water consumers |
| Changes in the water table | Agricultural productivity and household water consumption |
| Climate change | Impacts on agricultural productivity |

*Source:* Authors.

of the best available summary of eighty studies on erosion is quite striking (Wiersum 1984, reproduced in Bruijnzeel 1990, p. 117). Ground cover, rather than canopy, is the chief determinant of erosion. Erosion rates are low in natural forests and in tree gardens, in the fallow phase of slash-and-burn cultivation, and in plantations where weeds and leaf litter are retained. Erosion rates in plots under current slash-and-burn cultivation are ten times as high as in natural forest. In plantations where weeds and litter have been removed, erosion is more than a hundred times as great as in natural forests (table 2).

In many cases erosion may result from road construction associated with logging in the forest rather than from a change in land use. For instance, Hodgson and Dixon (1988) find that the rate of erosion in Palawan, the Philippines, increased four times as a result of logging, but the conversion of uncut forest to road surface increased erosion by a factor of 260. Thus, although roads accounted for only 3 percent of the surface area in the area studied, they were estimated to account for 84 percent of the surface erosion.

Gully erosion and mass wasting are also important sources of sediment, but these processes are more complex than sheet erosion, and less is known about them. Still, it seems fair to conclude that little sedimentation-related damage results from converting natural forests to appropriately managed plantations, agroforestry, moderate grazing, and shifting cultivation with long rotation periods. Road construction, annual cropping, and plantations that remove litter can generate considerable erosion, however. To assess the potential damage, we turn to the next question: Will surface erosion induced by a change in land cover result in major increases in sedimentation?

Table 2. *Relation between Land Cover and Erosion*
(tons per hectare per year)

| | *Surface erosion* | | |
|---|---|---|---|
| *Type of land cover* | *Minimum* | *Median* | *Maximum* |
| Natural forests | 0.03 | 0.3 | 6.2 |
| Shifting cultivation, fallow period | 0.05 | 0.2 | 7.4 |
| Forest plantations, undisturbed[a] | 0.02 | 0.6 | 6.2 |
| Multistoried tree gardens[b] | 0.01 | 0.1 | 0.15 |
| Tree crops with cover crop/mulch | 0.1 | 0.8 | 5.6 |
| Shifting cultivation, cropping | 0.4 | 2.8 | 70 |
| Agricultural intercropping in young forest plantations | 0.6 | 5.2 | 17.4 |
| Tree crops, clean-weeded | 1.2 | 48 | 183 |
| Forest plantations, litter removed or burned | 5.9 | 53 | 105 |

a. Refers to forests for timber production, as opposed to tree crops.

b. A system in which various perennial and sometimes a few annual crops are cultivated simultaneously with trees.

*Source:* Wiersum (1984), reproduced in Bruijnzeel (1990), p. 117.

The answer depends on two factors. First, only a portion of the eroded soil makes its way into rivers and streams; the remainder is trapped (perhaps temporarily) downslope. The amount of sediment deposited varies inversely with the size of the catchment basin; larger basins have more places for the sediment to get caught than do smaller ones. Mahmood (1987) suggests that the sediment delivery ratio—the proportion of eroded material in a watershed that is carried by a stream—declines from almost 100 percent in basins measuring 200 square hectares to about 10 percent in basins of a million square kilometers. Sediment delivery ratios tend to be about 0.3 in basins measuring hundreds of square kilometers. And lower ratios are associated with longer sediment transport times, causing a lag between the change in the land cover and the downstream impacts.

Second, the induced sedimentation may be large or small relative to existing, or background, sedimentation levels, which vary depending on local geology and the current state of land use in the basin.[1] Background sedimentation is related to existing agriculture and the configuration of roads within a catchment basin and to unstable river banks, natural landslides, and commercial dredging for sand and gravel (Enters 1992; Bruijnzeel 1989, 1990). In general, background sedimentation levels are underestimated because sampling rates are too low to capture infrequent but highly erosive episodes (Mahmood 1987; Bruijnzeel 1990). When this bias is not recognized, higher-than-expected siltation rates at new dams are sometimes erroneously attributed to contemporaneous changes in land use.

Given the complexity of erosion and sediment transport processes and their sensitivity to biological and geological conditions, is it possible to calibrate the relation between changes in land use and the amount of sediment deposited in a watershed? One approach models erosion and transport over the watershed, using mapped data on precipitation, land cover, and topography. This approach has been used to derive the universal soil loss equation for temperate locations, a simple formula based on land cover, precipitation, and slope. It is generally poorly calibrated, especially for tropical areas, and its use is often criticized. Researchers are trying to build more sophisticated models to represent the physical processes of soil particle detachment, transport, and deposition (Rose 1993).

An alternative, purely empirical approach relates changes in the sediment load of a river to changes in land cover in the surrounding watershed. The empirical approach is an essential check on theoretical models, but lack of data usually makes it hard to apply. One exception is a study by Alford (1992) that assembled annual time-series data on sediment transport, streamflow, and precipitation for the Ping River in Northern Thailand from 1958 to 1985. Despite a decline in forest cover from 92 percent in 1973 to 73 percent in 1991 in Chiang Mai Province, sediment concentration in the Ping was approximately constant.[2] According to Alford, the near-linear relation between streamflow volume and total sediment transport "implies a sediment source within the stream channel rather than erosion from slopes

contributing sediment to this channel" (p. 267). This somewhat surprising conclusion—that significant deforestation was not accompanied by increased sedimentation—underscores the need for empirical studies to explore the role of local geology and topography in modulating the effects of changes in land use on sediment delivery.

### *Calculating the Extent of Economic Damage to Dams*

The accumulation of river-borne sediment deposited in dams reduces the active storage volume of the reservoir and by so doing slows the output of irrigation, hydroelectric, and flood control services (Mahmood 1987; Southgate and Macke 1989). Moreover, sedimentation limits the effective life of the dam by advancing the date at which capacity is exhausted (Southgate and Macke 1989). Silt also damages turbines and increases the need for dredging. The total costs of siltation are significant; Mahmood (1987) puts annual global costs of lost reservoir capacity at about $6 billion. Chunhong (1995) reports that sedimentation reduces the storage capacity of China's reservoirs by 2.3 percent annually. The relevant question, though, is the marginal effect of deforestation-related sedimentation. The benefits of forest preservation in a dam's catchment area depend not only on the amount of sediment generated but also on the per hectare benefits provided by the dam, whether sediment is directed past the dam, and the timing of sediment-related damage (if not averted).

Consider two hydroelectric plants with the same generating capacity, one in a small steep-sided watershed, the second in a broad, shallow, gently sloping one. Forest protection will prevent erosion and sedimentation in both. The benefits of saving a forest hectare will be greater in the narrow watershed not only because erosion rates are higher on hills and sediment delivery faster in steep narrow valleys, but also because the dam benefits per hectare of watershed are higher.

• *Sediment management.* A variety of engineering and operational "fixes" can be used to sluice incoming sediments past dams or to flush accumulated sediments out of reservoirs (Lysne and others 1995; Chunhong 1995). These techniques are not universally applicable and typically have opportunity costs (in downtime or diminished output) in addition to capital costs. They also shift the costs of sedimentation downstream. To the extent that dams can minimize sedimentation using these techniques, however, the value of erosion prevention strategies such as forest preservation are reduced.

• *Time path of benefits.* Because siltation is a gradual process, measuring the amount of damage it does depends on how much time elapses before the buildup reduces the dam's effectiveness. Three potential time lags can occur between the initiation of a change in land use and a diminution in the benefits provided by the dam. First, the rate of land-use change matters. Clearcutting or the construction of low-quality logging roads could generate substantial amounts of erosion quickly. Conversely, in-

creasing the intensity of shifting cultivation might take decades to make a substantial change in basin-wide erosion.

Second, it takes time for sediment to travel. An eroded soil particle works its way down a watershed through a process of redeposition and resuspension. The amount of time between initial erosion and arrival in the reservoir depends on the gradient of the stream as well as on distance. Harden (1993) notes in connection with the Paute watershed in Ecuador that "sediment eroded from agricultural lands in distant, low-gradient tributary catchments may not reach the reservoir in the next half-century, but increased sediment loads in proximal, high-gradient tributary rivers represent an immediate sedimentation hazard" (p. 183). Conversely, sediment may continue to flow into rivers for twenty to thirty years after source erosion stops (Bruijnzeel 1990, Mahmood 1987).

The third lag is the time between the arrival of the sediment at a reservoir and the drop in dam output. Although reservoirs are built with dead storage capacity designed specifically to catch sediment, significant amounts are deposited in the active storage area, potentially reducing output. Additional sediment would thus be expected to affect dam services immediately. Southgate and Macke (1989) found, however, that earlier retirement of the dam (as opposed to decreased output before retirement) accounted for 85 percent of the economic impact of an increase in sedimentation rates.

Although these processes are quite complex, a simple numerical example illustrates the sensitivity of economic impacts to assumptions about the timing of deposits and discounting of dam benefits. Assume that dam services are constant until the dam is retired and that the effect of watershed damage reduces the expected lifetime of the dam from 100 years to 61 years. Given a 10 percent discount rate, the net present value of watershed protection is about 2.2 percent of the annual flow of dam benefits. A modest increase in the discount rate, to 12 percent, decreases the present value of watershed protection by 75 percent. The introduction of a twenty-year lag between the change in land use and the onset of sediment inflows decreases the present value of protection by a further 95 percent, to just 0.04 percent of the annual benefit flow.[3] In short, the benefits of extending the life of a relatively young dam will tend to occur in the distant future and therefore will be highly discounted.

### *Empirical Studies*

The theoretical bent of this discussion on dams reflects a paucity of empirical studies. Only five estimates of the economic impact of changes in land use on dam performance can be found: Briones (1991); Cruz, Francisco, and Conway (1988); Southgate and Macke (1989); Veloz and others (1985); and Shahwahid and others (1997). The difficulty of gathering primary data on erosion processes is evident. Only the last study is based on empirical analyses relating actual sedimentation to

actual changes in land use. Only one study allows for a lag between the project's initiation and the impact of increased sediment. On the economic side, only one attempts to model in detail the process by which sediment reduces the life of a dam, and none incorporates the models used by dam engineers to describe the patterns of sediment buildup in reservoirs.

The per hectare benefits differ widely among these five studies. The highest value by far, more than $2,000, refers to a subset of the interventions envisioned for the Dominican Republic's Valdesia watershed management project, namely, the reforestation of the steepest slopes in the watershed. Some of the assumptions underlying this estimate are open to question, and the 5 percent discount rate elevates the value compared with some of the other studies. Nonetheless, this example illustrates the potential for very high levels of domestic benefits from protecting critical watershed areas.

In contrast, Cruz, Francisco, and Conway (1988) found that erosion around the Pantabangan dam in the Philippines resulted in loss of dam services equivalent to about $4 a year per hectare of converted forest. The implication is that forest protection would have provided benefits of that magnitude—somewhat less than $80 per hectare if capitalized at 5 percent.[4] These forest benefits, however, are not netted against the opportunity costs of restricting agricultural use, so net domestic benefits are lower. At the same time, Cruz, Francisco, and Conway argue that maintenance of forest cover would also have yielded substantial additional benefits by allowing the dead storage capacity of the dam to be converted to active storage for irrigation.

The lowest net value for forest protection is reported by Shahwahid and others (1997) in an analysis of the Hulu Langat Forest Reserve in Malaysia. Here the alternative to complete forest protection is permitting low-impact logging of the forest. (A noteworthy feature of such logging is that it prohibits cutting within twenty meters of a river or stream; according to the authors, this restriction reduces logging-related sedimentation by 60 percent, even though the stream buffers occupy less than 20 percent of the forest area.) In this case forest protection yielded a gross annual benefit of $44 per hectare. The opportunity cost of prohibiting logging was about $1,400 per hectare, however, reflecting the high density of commercial tree species in Malaysian forests. Thus the net benefits of forest protection, relative to low-impact logging, are –$1,356. Low-impact logging, as a land use, might have high benefits relative to alternative land uses, however; these have not been evaluated.

### *Impact on Fish and Aquatic Organisms*

In an analysis of carefully gathered primary data, Hodgson and Dixon (1988) examined the impact of sedimentation on marine life in Palawan, the Philippines. They found that logging in the area had led to the construction of highly erosion-prone roads quite close to the Manlag River, within a few kilometers of Bacuit Bay. The

consequence was a very large and immediate increase in sediment that was "often more than 1,000 milligrams per liter," while sedimentation levels in a control river "rarely exceeded 10 milligrams per liter." The increased sedimentation destroyed nearly 50 percent of the coral cover on the reef nearest the mouth of the river. Although the levels of sediment were not high enough to kill the fish directly, coral mortality severely disrupts the ecosystems on which the fish depend.

Hodgson and Dixon impute the per hectare value of forest protection at a high $3,200, which overestimates the social gain because it is based on gross revenues from fisheries and tourism rather than on net profits. It is also worth noting that the authors rule out, as infeasible, interventions to reduce road-generated erosion, even though such interventions may save the loggers money by reducing maintenance costs. Because roads generate the bulk of all sediment, improved road-building techniques might make logging, fisheries, and tourism mutually compatible.

### *Erosion and Agricultural Productivity*

If deforestation causes an increase in on-site erosion and a loss of agricultural productivity, can that loss be translated directly into forest preservation benefits? The answer is no, if forests and crops are mutually exclusive land uses. Once the forest has been converted to agriculture, erosion diminishes agricultural yields. But that rate of diminution is not the benefit of forest preservation.

Forest preservation, however, can yield agricultural productivity benefits through erosion reduction in two situations. First, some woodlands or open forests are used for grazing or cropping. Removing the trees in these areas to intensify production could be self-defeating if erosion increases drastically. Second, deforestation could result in increased runoff and thereby increase erosion on downslope croplands. This seems plausible and may be important in some areas, but we can find no relevant studies. Deforestation might also cause downslope damage from landslides. Conversely, erosion sometimes delivers valuable soils from uninhabited hillsides to farmers' fields (Enters 1992). Where that is true, forest preservation imposes external costs on those farmers. But these effects may be limited to exceptional soil conditions.

### *Impact of Land-Use Changes on Water Yield*

Popular belief and casual empiricism link deforestation with flooding. If it is true that upslope deforestation threatens downstream cities and croplands with flood damage, the gains to forest preservation might be quite large. In fact, extensive scientific evidence links deforestation to annual increases in water yield (that is, the total volume of surface runoff and subsurface flows). As in the case of erosion, the increase depends on how the land is used (Bruijnzeel 1990, pp. 82–92). But increases in the

average rate of flow do not necessarily correspond to increases in peak flow or storm flow, which cause floods.

Surprisingly, the scientific literature supports a link between deforestation and flooding only at a local level—within a drainage basin of less than about 50,000 hectares (Bruijnzeel and Bremmer 1989). In small watersheds increases in water yield translate directly into increases in storm flow. For larger drainage basins, however, the limited number of studies using long time-series data on floods show no link between deforestation and flooding. Bruijnzeel (1990) cites studies of medium-size drainage basins (up to 1.45 million hectares) in Taiwan (China), and Thailand, which show that extensive deforestation had no effect on flooding, and three studies of India for the period 1871–1980, which show no trend in the frequency of flooding despite massive changes in land use during this time. Bruijnzeel and Bremmer (1989) also argue that there is no relation between changes in land use in the Himalayas and flooding in the Ganges-Brahmaputra basin, although they do not present time-series data. And Anderson, da Franca Ribeiro dos Santos, and Diaz (1993), who analyze eight decades of time-series data on rainfall and storm flow in the Parana-Paraguay river basin, report no structural shift in the relation between intense rainfall and floods, despite the significant conversion of forests over that period to pasture and cropland.

At first glance, these results seem paradoxical: How can deforestation cause flooding in small basins but not in large basins? The hypothesis is that basin-wide flooding depends more on intensity of the rainfall than on the way land is used. Most storms are small and transient. Individual subbasins tend to flood in sequence, as the storm passes over, rather than simultaneously. Local floods are thus averaged out over space and time. Only extremely severe and long-lasting storms affect all the tributaries of a major river at once. Storms of that magnitude would be large enough to saturate the soil's absorptive capacity and cause rapid runoff even if the land were still forested (Hamilton 1987; Bruijnzeel and Bremmer 1989; Bonell and Balek, 1993, pp. 227–28).

### *Impact of Land-Use Change and Dry-Season Flows*

Since the time of Plato, it has been assumed that deforestation results in lower water tables and reduced flows of water during the dry season (Grimble, Aglionby, and Quan 1994). This belief is still current; Huntoon (1992) links the loss of the "green reservoirs" of hillside forests in South China to severe reductions in the availability of groundwater during the dry season.

According to current hydrological science, however, the effects of deforestation on dry-season flows are ambiguous but likely to be counterintuitive. (Bonell and Balek 1993; Bruijnzeel 1990). This is because the conversion of forests to other purposes has two opposing effects on the water table. On the one hand, it increases

runoff and decreases the absorption of water into the ground. This by itself would lower the water table. On the other hand, trees are highly effective water pumps, removing water from the soil and transpiring it into the air. The replacement of trees by vegetation with shallow roots and lower transpiration rates (such as grass, annual crops, or early stages of secondary regrowth) therefore tends to reduce groundwater loss and raise the water table. Dozens of controlled experiments have been conducted showing that, contrary to expectations, the net immediate effect of tree removal is a rise in the water table, and therefore a probable increase in dry season flows (Hamilton and King 1983). Similar results have been found in studies of actual sites. Nepstad and Schwarzman (1992) compare deep-rooted evergreen forests to an adjacent degraded pasture in Pará, Amazonia. At the end of the dry season, the water in the top eight meters of soil available for plants was 370 millimeters higher in the degraded pasture.

In an interesting case study on Thailand, Vincent and others (1995) found that reforestation reduced, rather than increased, dry season flows and imposed costs on downstream users. Starting in 1967 Thai authorities promoted reforestation and sedentary agriculture in deforested areas of the Mae Theng watershed. These efforts involved two water-consuming interventions: the construction of irrigation systems and the establishment of pine plantations, which transpire more water than the deciduous forests that originally covered the area. An analysis of monthly stream flow records showed no change in dry season flows from 1952 to 1972 but registered a significant reduction from 1972 to 1991, when annual stream flows slowed by an additional 2.9 million cubic meters each year. These reductions resulted in the seasonal closure of one of Chiang Mai's water treatment plants and forced downstream farmers to switch from rice to soybean cultivation. The marginal costs of these reductions in water availability ranged from about 1 baht per cubic meter for agriculture to 7 baht for industrial users. These results imply that upslope deforestation, while highly undesirable on many grounds, yielded external benefits rather than costs for downstream water users.

Under some circumstances, however, deforestation may indeed reduce water tables. Bruijnzeel (1990) and Bonell and Balek (1993) point out that many processes involved in forest conversion compact the soil and cause gullying. Such processes include overgrazing, road construction, and the use of heavy machinery for land clearance. Compaction and gullying, in turn, increase runoff and decrease infiltration. If infiltration is reduced more than transpiration, the water table could drop.[5] Hamilton and King (1983) cite Australian studies showing severe reductions in infiltration following heavy grazing. They also cite a Fiji study finding runoff rates of 90 percent on grassland. They were unable to find analogous results, however, after forests were converted to annual cropping. A different situation is described by Kumari (1995). In this case, selective logging of a peat swamp forest entailed the construc-

tion of drainage canals. Expansion of the drainage network could reduce water storage sufficiently to imperil dry-season rice production in adjacent fields.

### *Climate Maintenance*

There is a long-standing belief that deforestation reduces rainfall. Grove (1994) provides a fascinating account of scientific and policy interest in the topic dating to the seventeenth century (see, for example, Halley 1694). To the modern observer, too, it seems intuitively obvious that tropical deforestation reduces rainfall. Because evapotranspiration from tropical forests makes up between 20 percent (Southeast Asia) and 80 percent (Africa) of incident rainfall (Wilkie and Trexler 1993), it seems logical to expect that forest removal would break this recycling process, resulting in a drier climate.

Modern climate theory, however, introduces a host of additional complexities. Changes in land cover introduce not only changes in evapotranspiration, but also in albedo (surface reflectivity) and aerodynamic drag. These changes directly affect temperature and precipitation and also set off a whole round of positive and negative effects involving changes in cloudiness, air circulation patterns, and even plant transpiration. The result is a highly nonlinear, scale-dependent, dynamic system. No longer is it clear a priori that deforestation reduces local rainfall. Eltahir and Bras (1992) suggest, for example, that deforestation on the scale of hundreds of square kilometers increases convection and therefore rainfall, while deforestation on the scale of millions of square kilometers reduces rainfall. In any case the magnitude and spatial distribution of climate effects will be sensitive to local conditions, especially to the nature of the vegetation that replaces the forest.

Theoretical analysis of the climatic impact of changes in land use therefore requires sophisticated models. During the past ten years, general circulation models of the earth's atmosphere have been used to analyze the effect of large-scale deforestation on global climate. Several exercises have examined the implications of converting the entire Amazon or Southeast Asian rainforests to savanna. In principle, these exercises might be used to evaluate the domestic benefits of forest preservation for large countries such as Brazil or Indonesia. Henderson-Sellers and others (1993) predict that complete deforestation of the Amazon would reduce precipitation in the rainy season by 30 percent, while complete deforestation of Southeast Asia would have no effect on precipitation. Lean and Rowntree (1993) predict that total deforestation of the Amazon would reduce local rainfall by 14 percent, but increase rainfall in Eastern Brazil by 20 percent.

These results must be interpreted with caution for several reasons. First, the scale and permanence of the deforestation simulated in these exercises is unrealistic. Shukla, Nobre, and Sellers (1990), for instance, assume that the entire Amazon would be reduced to degraded pasture. Many of the deforested areas in the Amazon in fact

revert to secondary forest (Moran, Mausel, and Wu 1994), whose climatological properties are much closer to primary forest than to pasture. Second, despite their sophistication, general circulation models omit a range of physical processes and rely on a great many assumptions about parameters. How sensitive the results are to these omissions and assumptions is unknown, however. Third, these models divide the planet's surface into a very coarse grid and can only be applied to deforestation processes at the scale of tens of thousands—or more—of square kilometers. Results at this scale cannot be generalized to deforestation patches of tens or hundreds of square kilometers. Work on more appropriate mesoscale models is still in its infancy.

Empirical work in this area is as inconclusive as the theoretical work. Bruijnzeel (1990) reviews the thin literature. There are a great many microstudies of temperature and soil wetness changes in small clearings, but these cannot be generalized to larger scales and are useful mainly to establish the parameters for general circulation and mesoscale models. A limited number of mesoscale empirical studies try to relate changes in forest cover to changes in recorded precipitation (see, for example, Meher-Homji 1988), but Bruijnzeel notes that these are lacking in rigor and data consistency.

Current research is just beginning to use remote sensing data to track climatic and land-use changes, resulting in more rigorous studies. Complementing twenty-two years of data from twenty climate stations in the Selva Lancondona region of Chiapas, Mexico, O'Brien (1995) used remote sensing data from 1979 and 1989 to track deforestation around each station. Preliminary analysis indicates that deforestation increases minimum temperature, decreases maximum temperature, and has no significant effect on precipitation. Cutrim, Martin, and Rabin (1995) use satellite data to show increases in cloudiness (not necessarily implying increased precipitation) following large-scale deforestation in Rondonia, Brazil.

In sum, the assumption that deforestation affects local climate is plausible, but the magnitude (and indeed sign) of the effect remains to be demonstrated. The potential economic significance of climatic effects should make them an early priority for research.

## Commercial Value of Nontimber Forest Products

The value of tropical nontimber forest products, such as fruits, nuts, latex, resins, medicines, and animals, has been reviewed by Godoy, Lubowski, and Markandya (1993) and Lampietti and Dixon (1995). In a survey of twenty-four studies, Godoy, Lubowski, and Markandya report per hectare values ranging from $.75 to $422 a year, with a median of about $50. But these studies, as a group, exaggerate the level of benefits that would accrue to the domestic economy from a typical natural, or old growth, forest. They do not distinguish between agroforestry and pure extraction, nor do they take into account the costs of extraction. Furthermore, they do not allow

for spatial differences in the densities and therefore quantities of the product or in the rate of extraction. And they fail to allow for competition in the markets for these products in the long term.

### *The Distinction between Agroforestry and Extraction*

Nontimber forest products can be produced at different levels of intensity, with correspondingly different degrees of disturbance of the original ecosystem. At one extreme are purely extractive systems, where extractors harvest products from an otherwise undisturbed forest. In a slightly more intensive approach, extractors may artificially enrich the forest with a desired plant species. Still more intensive are a range of agroforestry techniques that replace the primary forest with carefully manipulated multispecies plantations to provide raw materials for trade and industry.

To give a true picture of the benefits of preserving "natural" forest, nontimber forest product valuation must be based on the profits from purely extractive systems, rather than profits from agroforestry systems. It is tempting to rely on the latter. Agroforestry systems typically generate higher values per hectare because commercial species are planted more densely and extraction and processing costs are lower. But although these systems are attractive for many reasons, including their relatively high degree of biodiversity, they are not the same as the natural ecosystems they replace and therefore should not be used to justify preservation of the natural forest.

At the same time, it is worth stressing that agroforestry systems may offer both greater biodiversity and higher economic benefits than other uses of the land. This is true of a Sumatran system in which slash-and-burn farmers create rubber-rich secondary forests. After the rubber trees reach maturity (about ten years), they yield about 600 kilograms per hectare annually of dry-equivalent rubber (van Noordwijk and others 1995, p. 88) with no inputs other than labor (current rubber prices are about $1.60 a kilogram). Extraction can continue for twenty years or more before another cycle of clearing. Because the owners' share in the typical tapping arrangement is one-third, per hectare rents are substantial. At the same time, ecological studies show fairly high levels of species richness (Michon and de Foresta 1995; Thiollay 1995). Moreover, these rubber forests should have the same hydrological properties as primary forests. Thus agroforests may in some cases offer both net domestic economic benefits and global or nonmarket benefits relative to competing land uses.

### *Allowing for the Costs of Extraction*

Conceptually, the value of a hectare of forest for nontimber products is equivalent to the rent that would be paid for the right to harvest that hectare. Clearly that amount is less than the final value of the product in the marketplace because the costs of

extraction and transportation must be netted from the sales price to yield profit or rent. This elementary point has been made many times in the literature and must be applied to the cases presented by Godoy, Lubowski, and Markandya (1993). For instance, they find the highest documented value of a hectare of forest based on actual extraction rates is Chopra's (1993) estimate of $117–$144 a year for fuelwood, fodder, and miscellaneous products from tropical deciduous forests in India. In the absence of market prices for these goods, Chopra values them either by their cost of extraction or by the price of substitute commodities. For instance, he values labor to gather fuelwood at $18.87 to $24.17 a hectare (while its equivalent in softcoke, an alternative fuel, would cost $9.50 to $17.33). Chopra concludes that the value of forests for fuelwood must lie between $9.50 and $24.17 a hectare. But this conclusion confuses costs, benefits, and rents. If softcoke is in fact a close substitute for fuelwood, then the data imply that villagers are expending labor worth more than $18.87 to produce fuelwood worth less than $17.33. Clearly the estimates are crude, but the main implication is that the net per hectare value of the forest for firewood production is close to zero. Similarly, labor expenditures to produce miscellaneous goods such as lacquer and dyes amount to $66.67 a hectare. To calculate the value of the forest in producing these goods, it is thus necessary to subtract $66.67 a hectare from the price paid for the lacquer and dyes.

### *Spatial Variation in Density and Extraction Cost*

Forests tend to be large and heterogeneous. Estimating the value per hectare for a small plot and attributing that value to the forest as a whole (let alone to any other forest) is inappropriate. This point is obvious but is almost universally ignored in practice.

Three difficulties arise in generalizing small-plot estimates. First, transport costs are important for some nontimber forest products; açaí fruit, for example, spoils within twenty-four hours of harvesting. The high costs of transporting bulky or perishable goods through the forest means that the value at the point of collection will fall off steeply with distance from the road and from the market. Large portions of the forest will not be economically exploitable for this class of commodities and will thus have zero value for that use. At the same time high-value, less perishable commodities, such as rubber, will be economically viable over a larger area.

Second, the density of exploitable species can vary dramatically within and between forests. For instance, two of the highest per hectare values cited in Godoy, Lubowski, and Markandya (1993) refer to oligarchic forests, that is, those dominated by a few, highly commercial species (Anderson and Ioris 1992; Anderson and Jardim 1989). Although interesting and locally important, such examples are quite atypical of tropical rainforests, whose hallmark is very high diversity and thus very low densities for any individual species.

Third, consumption of some nontimber forest products may tap only a small fraction of the potential supplying area. In Ecuador, for instance, Grimes and others (1994) studied a resin derived from a *Protium* tree. Harvesting the trees yielded an average potential net return per hectare (after collection, transport, and marketing) of $61 a year in the three forest plots surveyed. The resin, however, is used exclusively for finishing local ceramic handicrafts, which are presumably in limited demand. We surmise that the total number of hectares being harvested is a small fraction of the total area from which the trees could be economically harvested.[6] If so, it would be a gross error to apply the $61 value to the entire range of the species. The same situation may apply to valuable medicinal plants.

### *Long-Run Competitive Supply*

For most commercially attractive products, pure extractive reserves cannot compete with synthetic or domesticated substitutes (Richards 1993; Browder 1989). Many nontimber forest products follow a life cycle in which they start out as extractive products, attain a world market and a high price, and are then domesticated in intensive plantation or agroforestry systems. Intensive cultivation reduces labor, land, and capital costs; permits product standardization; facilitates processing; ensures a reliable supply; and takes advantage of scale economies in marketing. As a result, the supply price of the product falls below the viable level for extractive supply. The prime example is rubber. In the early part of this century, Brazilian rubber prices (and extraction volumes) collapsed as Malaysian plantations came on line. In recent years Brazil's extractive reserves have been supported by subsidies. Currently, extractivists in that country's Chico Mendes reserve are being driven out of business by lower-priced latex produced by plantations in São Paulo State. Labor productivity in the plantations is about ten times that in the reserve (Brooke 1995).

The implication is that lower-cost domesticated or synthetic substitutes greatly reduce—or even eliminate—the rents from extractive reserves. Nontimber forest products provide domestic benefits only when the products are difficult to domesticate or duplicate.

This gloomy statement requires some qualification, however. First, those forests in which a few commercially valuable species grow may be able to compete with plantations, especially with some small interventions such as pruning (Anderson and Jardim 1989). Second, agroforestry systems such as jungle rubber may in some cases be competitive with plantations while also preserving some biodiversity. Third, and most important, the success of large-scale plantations for nontimber products increases the global urgency of preserving genetic diversity. This may often be best accomplished through preserving natural forests. The implication is that the global benefits of forest preservation may increase even as the domestic benefits decline.

## The Opportunity Costs of Preservation

The sustainable benefits associated with forest preservation can be thought of as the gross benefits. The existence of a threat to a forest tract usually implies an economic motive for converting the forest or exploiting it, and these potential benefits are the opportunity costs of preservation. These opportunity costs must be deducted from gross forest benefits to yield the net domestic benefits of preservation.

Opportunity costs are highly sensitive to land characteristics. The returns to agricultural use of a plot depend on the physical characteristics of the land, current vegetation, market access, and land tenure. Physical characteristics such as slope, drainage, and soil fertility determine the land's relative physical productivity for different crops, the need for inputs, and the degree to which output can be sustained over time. The density of commercial tree species also affects the net cost of clearing; in some cases the value of timber may outweigh the benefits from agriculture. Market access—the cost of transport to the nearest market—determines the potential price paid to the farmer for crops or cattle and their inputs. Land tenure and ownership, together with land-related tax and subsidy rules, affect the incentives to invest in land preparation and in perennial crops.

The opportunity cost of land—that is, the forgone benefits of conversion—can be obtained through Geographic Information Systems data and techniques. Using such data Chomitz and Gray (1996), for instance, found that the type of soil and the accessibility to roads strongly influence the probability that a forest will be converted. Magrath and others (1995) used farm budgets and a land capabilities assessment to impute land values in West Kalimantan, Indonesia. The land capabilities assessment divided the province into 1,682 polygons and assessed the suitability of each polygon for a variety of crops. (For lack of data, however, no adjustments were made for the cost of transporting crops to markets or for benefits from timber marketing.) The results are quite striking: much of West Kalimantan's land has little value for agricultural production. Of the province's 14.65 million hectares, 3.7 million have an opportunity cost of less than 20 cents a hectare a year (1991 prices). About 95 percent of the province has an agricultural opportunity cost of less than $2 a hectare annually. Were transport costs factored in, the opportunity costs would be far lower.

## Summary of Findings

The level of net domestic benefits from forest preservation depends on the alternative land use as well as local climatic, biological, geological, and economic circumstances. When the alternative use is agroforestry or forest plantations (depending on

the management system), preservation of the natural forest may not offer net benefits from hydrological benefits or the production of minor forest products. At the same time, some agroforests may offer both biodiversity benefits and net domestic economic benefits relative to other land uses.

The prospects for economically significant hydrological benefits from forest preservation appear to be smaller than popularly supposed.

- Deforestation has not been shown to be associated with large-scale flooding, although it may cause serious local flood damage.
- Nor is it associated with diminished dry season flows; on the contrary, it is usually associated with greater flows.
- Although it is a priori plausible that deforestation should affect local precipitation, the magnitude and even the direction of the effects are not known, except in the special case of cloud forests, which "harvest" passing moisture.
- The link between deforestation and downstream sediment damage is sensitive to the basin topography and geology. Where sediment transport is slow—as in large, low-gradient basins—downstream effects may occur far in the future, so that the net present value of damages is small.

Conversely, forest preservation can yield substantial domestic benefits where it averts erosion-generating changes such as road building, annual cropping, or overgrazing; where affected areas impinge directly on streams, reservoirs, coral reefs, or inhabited areas; and where affected watersheds are small, steep, and erosion prone.

The measurement of benefits from harvesting minor forest products is still rudimentary. Current valuation exercises tend to be specific to particular plots and cannot be generalized to significant forest areas for one of several reasons: a) they are based on inventories of salable products rather than actual extraction; b) their value is based on gross market prices rather than prices net of extraction and transport costs; c) the study describes agroforestry products rather than true extractive products; d) the study describes products of unusual forests dominated by a few commercial species rather than a typical species-rich rain forest; and e) the value of the forest for extractive production of commercial nontimber forest products is undercut by competition from domesticated or synthetic substitutes.

We stress again that our review of benefits is not comprehensive. Potential domestic benefits not reviewed here include ecotourism services, sales of bioprospecting rights, and carbon sequestration services, should a carbon offsets market come into existence.[7] Moreover forest preservation can yield substantial global or ecological benefits. Also note that these conclusions apply only to tropical moist forests. It may be the case that for other ecosystems, such as wetlands, the links between land use change and economic benefits are both better understood and stronger.

Domestic economic benefits provide an uncertain rationale for conservation—and especially for funding forest preservation through market-rate loans. Undoubt-

edly this rationale is clearly justified for some forest preservation projects, and these should be vigorously pursued. For many projects, however, net domestic benefits either do not exist or cannot be quantified with sufficient rigor to support a market-rate loan or a convincing cost-benefit analysis. Hence the domestic benefits argument—save your forests because they bring palpable economic benefits to your country—cannot be the mainstay of forest preservation in all countries. For many—possibly most—tropical forests, the more compelling rationale for preservation is based on global values. This underscores the need for financing conservation from the Global Environment Facility or other global sources, rather than placing the burden entirely on domestic resources.

The hopeful converse, however, is that the net domestic costs of forest preservation may also be small. The argument is: Save your forests because the out-of-pocket costs of doing so are small, and the noneconomic benefits are large. Many biodiverse, carbon-rich forest areas are poorly suited to agriculture because of isolation and poor soils. These areas can be preserved through a three-pronged strategy. First, the opportunity costs of preservation should be kept low by directing regional development toward more economically promising districts. Above all, uneconomic road-building should be avoided in these areas. Once roads are in place, the opportunity costs of preservation can increase substantially. Second, where pressures for logging are politically and economically irresistible, low-impact techniques can be required as a condition for access. This approach would entail disabling main access roads after logging was completed. Third, direct and ongoing compensation can be paid, or alternative livelihoods set up, for land users or stakeholders who would otherwise convert the forest to other uses.

## Notes

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1. Induced sedimentation may be a concern even when background sedimentation levels are higher if marginal increases in sediment result in further damage and if the costs of averting such sedimentation are smaller than those of remedying background sedimentation.
2. Forest cover data supplied by Charles Griffiths, U.S. Environmental Protection Agency.
3. The assumption that dam life with lagged sediment delivery is eighty-one years is very crude but will suffice for illustrative purposes. Also, note that a ratio of 0.04 percent does not necessarily imply that a watershed protection project is uneconomic—the project's value depends on the cost of protecting the watershed, which might be relatively small.
4. Authors' calculations based on Cruz, Francisco, and Conway data.
5. This does not explain Huntoon's reports for South China, because the deforestation resulting from the felling of trees would not be expected to result in soil compaction.
6. What then sustains the net return of $61 a hectare? Why doesn't competition drive these returns toward zero? Three answers are possible: the producing plots are to some extent, perhaps

informally, privatized, and the return reflects the opportunity cost of the land; the $61 figure includes returns to the expertise of the collector, who knows how and where to find it; or in fact all economically exploitable areas are being harvested, and the $61 measurement is based on inframarginal plots.

7. But see Simpson, Sedjo, and Reid (1996) for a pessimistic view.

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