Global Environmental Change Vol. 1(4):313-320

Environmental impacts of resource exploitation in Amazonia

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Development pressures are triggering rapid ecological, cultural, and economic changes in Amazonia, one of the world's largest remaining forest frontiers. Some of the environmental effects of development schemes and spontaneous settlement have local and potentially regional and global repercussions. Ecological issues surrounding human activities in Amazonia include pollution from mining activities; deforestation and climate change; accelerated erosion and declining soil fertility; soil erosion and flooding; and the impact of hydroelectric dams on fisheries. It is important to develop sustainable agricultural systems to relieve pressure on the remaining forest.

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This study is part of a larger project, *Critical Zones in Global Environmental Change*, coordinated by the Center for Technology, Environment, and Development at Clark University with support from the National Science Foundation.

Amazonia is undergoing widespread ecological and cultural change as a result of development schemes and a large influx of settlers. For centuries Amazonia lingered as a relatively isolated backwater, but now the region is rapidly being integrated into the economies of countries with territory in the region as well as global markets. Farmers, cattle ranchers, miners and plantation operators are penetrating even more remote areas of the basin along pioneer highways (Figure 1) and are opening up formerly forested areas. A desire to tap natural resources for development is resulting in the rapid removal of the world's largest tropical forest. Concern is mounting that such changes may have regional or even global impacts, particularly on climate.

Many of the landscape changes underway in Amazonia have both local and regional impacts. For example, dam building not only affects local fisheries, but eliminates fish populations that formerly migrated in and out of the dammed river. Soil erosion in the headwater region of a river can trigger increased flooding downstream. In this article, both the local and regional or global impacts of mining, deforestation, soil erosion and hydroelectric dams are explored. Mercury contamination in Amazonia as a result of gold mining is discussed first because it is arguably the most serious ecological threat to the region at present.

Pollution from mining operations

Mercury pollution caused by itinerant gold miners has recently emerged as a major threat to Amazonian ecosystems and human health. *Garimpeiros*, as the wandering miners are called in Brazil, use the toxic element to precipitate gold when washing gravel. Between 5% and 30% of the mercury is lost during this process, and much finds its way back to water.[1] A further 20% vaporizes when the amalgamate is torched to obtain the gold. The high rainfall and humidity of Amazonia facilitates reoxidation of vaporized mercury which is then available for capture by the surrounding forest. Gold miners operate throughout the year.

Mercury has been employed in gold and silver mining in Latin America since early colonial times, but the current scale of mercury use for mining is unmatched. A Mexican miner, Bartolomé de Medina,

[1]Olaf Malm, Wolfgang C. Pfeiffer, Cristina M.M. Souza and Rudolf Reuther, 'Mercury pollution due to gold mining in the Madeira River basin, Brazil', *Ambio*, Vol 19, No 1, February 1990, pp 11–15.

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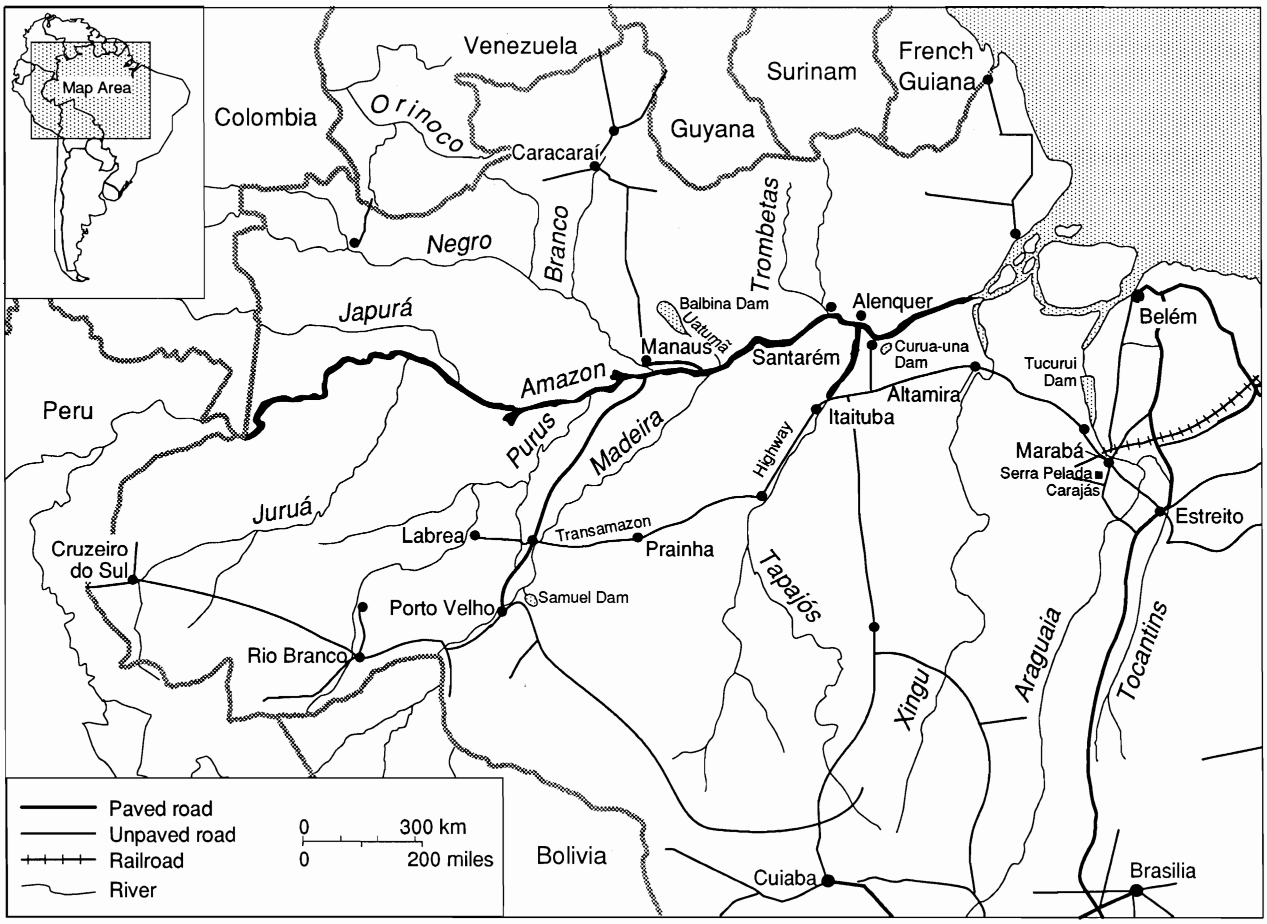

Figure 1. Brazilian Amazon with major highways, railroads and dams.

devised a process for extracting silver from its encasing ore with mercury in 1554 or 1555.[2] Mercury was used extensively as an amalgam in silver mining in Mexico and Peru during the 16th and 17th centuries. The Spanish employed quicksilver to refine a little gold in Hispaniola in the 16th century. During the colonial period in Colombia, placer miners separated gold from sediment rich in iron oxide by employing the glutinous sap of several plants, including crushed leaves of cordoncillo (*Piper* sp), encinillo (*Weinmannia* sp), and chica (*Jacquinia aurantiaca*).[3] When mixed with water, the foamy sap captured the iron oxide flakes, allowing the gold particles to settle to the bottom of the pan. Organic precipitates would be much more environmentally benign than mercury, although *Jacquinia aurantiaca* is a piscicide. Such ancient practices are worth investigating, particularly to compare gold recovery rates with mercury.

Although gold has been panned from alluvial deposits in the Tapajós Valley since the 1950s, the Amazon gold rush started in earnest in 1980 when gold prices soared. As many as half a million itinerant miners have fanned out through the forest in search of alluvial gold.[4] Gold fever virtually levelled Serra Pelada, a small mountain in southern Pará, within a decade (Figure 1). By the late 1980s, about 100 tonnes of gold were being exported annually from the Brazilian Amazon, worth some $1 billion. For every kilogram of gold produced, at least 1.32 kg of mercury is lost to the environment.[5]

[2]Lyle N. McAlister, *Spain and Portugal in the New World 1492–1700*, University of Minnesota Press, Minneapolis, MN, 1984, p 228.
[3]Robert C. West, *Colonial Placer Mining in Colombia*, Louisiana State University Press, Baton Rouge, LA, 1952.
[4]David Cleary, *Anatomy of the Amazon Gold Rush*, University of Iowa Press, Iowa City, IA, 1990.
[5]*Op cit*, Ref 1.

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Garimpeiros are penetrating Indian reserves, national forests, and biological preserves where they pollute waters with mercury and sediment, and hunt out game. One of the most worrisome aspects of mercury pollution in Amazonia is that few hard data are available to gauge the dimensions of the problem. But by piecing together glimpses of damage already done, an alarming picture emerges. In eastern Amazonia, some Kayapó Indians have dangerously high levels of mercury, presumably from eating fish and drinking water from polluted rivers and streams.[6] Along the Madeira River where teams that operate from rafts are pumping up bottom sediment to obtain gold, high concentrations of mercury have been found in bottom sediments of tributary streams, in fish, and in human hair.[7] The huge volume of many of Amazonia's rivers may mask a gradual build-up of mercury in many fishes important for subsistence and commerce.

Fishing is an important source of dietary protein and income for many people in Amazonia. Mercury contamination of fish would particularly affect the poor, who are less able to switch to higher-priced sources of protein. Predatory fish, such as tucunaré (*Cichla ocellaris*), pirarucu (*Arapaima gigas*), aruanã (*Osteoglossum bicirrhosum*), most species of piranha, and many species of catfish are likely to accumulate mercury more rapidly than herbivorous species. Far more people eat piranhas than fall victim to the fish equipped with razor-sharp teeth.

In the Madeira river system, several species of predatory fish, such as dourada (*Brachyplatystoma flavicans*), filhote (*B filamentosum*), and other catfish species (*Pseudoplatystoma*), have accumulated high levels of mercury (up to 2.10 μg mercury/g^{-1} ww).[8] These large catfish are frozen and sent to markets in the USA and central and southern Brazil.[9]

Gold mining in tropical forests is not confined to Amazonia. Large numbers of itinerant miners are operating with mercury in other regions, such as southern Guyana, Venezuela, and parts of Central America.[10] Apart from poisoning the environment with mercury and increasing the turbidity of rivers, miners are also helping to spread virulent strains of malaria around Amazonia. Some of the worst hot spots for malaria are temporary mining camps, since they are often not accessible to malaria eradication teams. Infected miners spread new strains of malaria parasites to areas where locals may have little resistance to the pathogens – the Yanoama Indians in Northern Amazonas, Brazil, are suffering from a severe outbreak of malaria as a result of gold mining activities on their land.

Large-scale corporate mining operations, in contrast, are causing very little aquatic or atmospheric pollution. After initial sediment discharge problems in Lake Batata at the Trombetas bauxite mine,[11] a large retaining pond was built and the lake is being restored. The Trombetas mine, in which Royal Dutch Shell has a stake, has invested heavily in recovering mined areas with a combination of native and exotic trees.

The Carajás range, which contains the world's richest deposit of iron ore as well as substantial quantities of manganese, bauxite, and copper, is being mined by Companhia Vale do Rio Doce (CVRD), a partnership between private capital and the federal government. CVRD minimizes forest clearing on its 411 000 ha Carajás concession, and stabilizes soil along road and railroad cuts with *Brachiaria humidicola*, an aggressive pasture grass. A series of settling reservoirs effectively trap effluent from mining activities (Figure 2). Outside the mining concession area, however, forest clearing is rampant.

[6] Susanna Hecht and Alexander Cockburn, *The Fate of the Forest: Developers, Destroyers, and Defenders of the Amazon*, Verso, London, 1989, p 143.
[7] *Op cit*, Ref 1.
[8] *Ibid.*
[9] Michael Goulding, *Man and Fisheries on an Amazon Frontier*, W Junk, The Hague, 1981.
[10] J.J. Parsons, 'Gold mining in the Nicaraguan rain forest', *Yearbook of the Association of Pacific Coast Geographers*, Vol 17, 1955, pp 49–56.
[11] Margaret Mee, *In Search of Flowers of the Amazon Forests*, Nonesuch Expeditions, Woodbridge, Suffolk, UK, 1988.

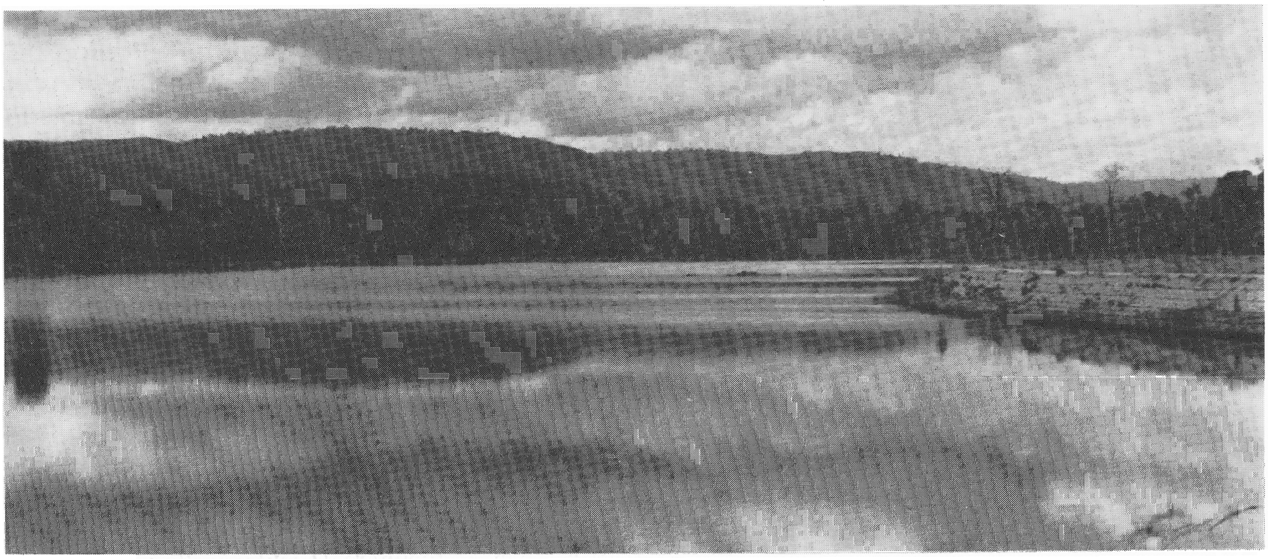

Figure 2. A settling pond (Barragem Esteril Norte) to trap sediment from mining operations at Serra dos Carajás, Pará, Brazil, February 1990.

Climatic change

Deforestation and its potential impact on regional and global climate has received the most attention in discussions of human-induced environmental change in Amazonia.[12] Tropical deforestation is often pinpointed as a major culprit in the purported global warming trend, and since Amazonia is the largest stretch of tropical forest, its fate is thought to have a major bearing on the future of the world's climate.

It is well known that increased levels of carbon dioxide and other gases, such as methane, nitrous oxide, and chlorofluorocarbons in the atmosphere can lead to the greenhouse effect.[13] But claims that a global warming has already begun may be premature.[14] No firm evidence has yet emerged that the world has become significantly warmer over the past ten or even hundred years.[15] Even if such changes will soon be documented, it will be difficult to separate natural climatic cycles from any greenhouse effect and the role of clouds and oceans on global temperature changes is imperfectly understood.[16]

In the event that the greenhouse effect takes hold, tropical deforestation will be only partly to blame. Deforestation accounts for less than 20% of greenhouse-gas emissions.[17] Carbon dioxide from the burning of fossil fuels, which occurs mostly in temperate countries, is the largest component of greenhouse gases. The release of chlorofluorocarbons, used to make aerosols, refrigerants, and solvents, is responsible for a larger proportion of greenhouse gases entering the atmosphere than carbon dioxide emissions from burning forests. Industrial countries are responsible for most of the chlorofluorocarbon emissions. The idea that Amazonian countries should arrest forest clearing to save the world's climate while North Americans and Europeans continue to drive their cars and burn natural gas and coal, does not rest well in Brasília, Bogotá, or Lima.[18]

Deforestation in Amazonia is often considered a threat to rainfall. Some have even suggested that deforestation in Amazonia could lead to a sterile desert.[19] The linkage between the loss of forests and reduced

[12]Mark Collins, *The Last Rain Forests: A World Conservation Atlas*, Oxford University Press, New York, NY, 1990; R.E. Dickinson, 'Introduction to vegetation and climate interactions in the humid tropics', in R.E. Dickinson, ed, *The Geophysiology of Amazonia: Vegetation and Climate Interactions*, John Wiley, New York, 1987, pp 3–10; Norman Myers, 'Tropical deforestation and climatic change', *Environmental Conservation*, Vol 15, 1988, pp 293–298; Ghillean T. Prance, ed, *Tropical Forests and World Atmosphere*, Westview Press, Boulder, CO, 1986; William B. Wood, 'Tropical deforestation: balancing regional development demands and global environmental concerns', *Global Environmental Change*, Vol 1, No 1, 1990, pp 23–41.

[13]A. Raval and V. Ramanathan, 'Observational determination of the greenhouse effect', *Nature*, Vol 342, 1989, pp 758–761.

[14]G. Byrne, 'Let 100 million trees bloom', *Science*, Vol 242, 1988, p 371; S.H. Schneider, 'The greenhouse effect: science and policy', *Science*, Vol 243, 1989, pp 771–780; Andrew R. Solow and James M. Broadus, 'On the detection of greenhouse warming', *Climatic Change*, Vol 15, 1989, pp 449–453.

[15]Philip H. Abelson, 'Uncertainties about global warming', *Science*, Vol 247, March 1990, p 1529; T.P. Barnett, 'Beware greenhouse confusion', *Nature*, Vol 343, 1990, pp 696–697; James E. Hansen and Andrew A. Lacis, 'Sun and dust versus greenhouse gases: an assessment of their relative roles in global climate change', *Nature*, Vol 346, 1990, pp 713–719; Roy W. Spencer and John R. Christy, 'Precise monitoring of global temperature trends

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rainfall has been discussed for centuries, and was a paramount concern in India and parts of the Caribbean in the last century.[20] Evapotranspiration is thought to account for about half of the rainfall in Amazonia.[21] Continued deforestation could therefore lead to a drier regional climate.[22]

Some models predict a sharp drop in rainfall with large scale deforestation in Amazonia, but such models typically assume that Amazonia will be turned into a barren landscape. It is highly unlikely that substantial areas of Amazonia will be converted to asphalt or barren land. Second growth soon begins the regeneration path to forest in all but the sandiest soils. Degraded landscapes with disclimax vegetation, rather than arid deserts, are the result of mismanaging the land. Also, more rainfall may be due to water vapour transport from the Atlantic than has previously been supposed.[23]

How much forest can be removed without affecting rainfall is not known. Realistic predictions of climatic change due to landscape changes in the humid tropics are fraught with difficulties.[24] Evapotranspiration from groves of perennial crops and silvicultural plantations may be close to that of forest. Even pastures release substantial quantities of water to the atmosphere during the rainy season. Should landscape changes in Amazonia result in a significant reduction in evapotranspiration rates, then latent heat exports to temperate areas in the form of water vapour may eventually affect the global climate.

No evidence is available to prove that deforestation in Amazonia has led to reduced rainfall in the region or elsewhere. The dry season around Manaus was accentuated in 1976, and again in 1979, when no rain fell for 73 days.[25] Yet, after two particularly heavy burning seasons in Amazonia in 1987 and 1988, 1989 was a very wet year in many parts of the basin. So much rain fell in eastern Amazonia in 1989 that the dry season virtually disappeared. The rainy season has also been intense in much of the Brazilian Amazon in 1991.

Rainfall patterns are highly variable in Amazonia, thereby complicating the task of identifying trends. In 1774, a severe drought assailed the Rio Negro watershed when deforestation rates were much lower than at present.[26] In 1958, 64 days passed without any rain in the Bragantina zone east of Belém.[27] The big 'push' to develop and open up the Amazon started only in the late 1960s.

Environmental impact of smoke

Smoke from forest cut for agriculture and ranching may have global as well as regional and local impacts. One component of biomass burning, methyl chloride, attacks ozone. Human-induced fires account for 5% of the ozone-destroying chemicals in the atmosphere.[28] Nevertheless, industrial countries release far more ozone-depleting aerosols into the atmosphere than farmers and ranchers in the tropics.

Excessive smoke could lead to temporary climatic disruptions. Smoke reflects some incoming radiation back into the atmosphere, thereby helping to mitigate any greenhouse warming. The reduction of solar energy reaching Earth's surface could lead to reduced convectional activity and less rainfall in some areas.[29] The burning season in most of Amazonia extends from July to October; little smoke is generated during the rainy months.

At the regional level, smoke is thick enough to temporarily close

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from satellites', *Science*, Vol 247, 1990, pp 1558–1562.

[16]Philip H. Abelson, 'Global change', *Science*, Vol 249, 1990, p 1085; J.F.B. Mitchell, C.A. Senior and W.J. Ingram, 'CO_2 and climate: a missing feedback?', *Nature*, Vol 341, 1989, pp 132–134.

[17]C. Flavin, *Slowing Global Warming: A Worldwide Strategy*, Paper 91, Worldwatch Institute, Washington, DC, 1989.

[18]E.G. Nisbet, 'The business of planet management', *Nature*, Vol 333, 1988, p 617.

[19]A. Anderson, 'Farming the Amazon: the devastation technique', *Saturday Review*, Vol 40, 1972, pp 61–64; R.J.A. Goodland and H.S. Irwin, *Amazon Jungle: Green Hell to Red Desert?*, Elsevier, Amsterdam, 1975.

[20]Clarence J. Glacken, *Traces on the Rhodian Shore*, University of California Press, Berkeley, CA, 1967; Richard Grove, 'The origins of environmentalism', *Nature*, Vol 345, 1990, p 11–14.

[21]Luiz Carlos B. Molion, *A Climatonomic Study of the Energy and Moisture Fluxes of the Amazon Basin with Considerations of Deforestation Effects*, PhD dissertation, University of Wisconsin, Madison, WI, 1975, p 101; Luiz Carlos B. Molion, 'The Amazon forests and climatic stability', *The Ecologist*, Vol 19, No 6, 1989, pp 211–213; E. Salati, 'The forest and the hydrological cycle' in R.E. Dickinson, ed, *The Geophysiology of Amazonia*, John Wiley, New York, NY, 1987, pp 273–296; E. Salati and P.B. Vose, 'Amazon basin: a system in equilibrium', *Science*, Vol 225, 1984, pp 129–138; E. Salati, J. Marques, and L. Molion, 'Origem e distribuição das chuvas na Amazônia', *Interciencia*, Vol 3, No 4, 1978, pp 200–205.

[22]*Op cit*, Ref 6.

[23]J. Paegle, 'Interactions between convective and large-scale motions over Amazonia', in R.E. Dickinson, ed, *The Geophysiology of Amazonia: Vegetation and Climate Interactions*, John Wiley, New York, NY, 1987, pp 347–387.

[24]A. Henderson-Sellers, 'Effects of change in land use on climate in the humid tropics', in R.E. Dickinson, ed, *The Geophysiology of Amazonia: Vegetation and Climate Interactions*, John Wiley, New York, NY, 1987, pp 463–493.

[25]P.M. Fearnside, *Human Carrying Capacity of the Brazilian Rainforest*, Columbia University Press, New York, NY, 1986, p 50.

[26]John Hemming, *Amazon Frontier: The Defeat of the Brazilian Indians*, Harvard University Press, Cambridge, MA, 1987.

[27]A.R. Penteado, *Problemas de Colonização e do uso da Terra na Região Bragantina do Estado do Pará*, Centro de Estudos Vasco da Gama, Sociedade de Geografia de Lisboa, Lisbon, 1968.

[28]Christopher Anderson, 'Methyl chloride gas implicated', *Nature*, Vol 348, 1990, p 377.

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some regional airports during the dry season, particularly in Rondônia and Acre. Temperature inversions may exacerbate smoke pollution. In the dry season, cloudless skies facilitate radiative cooling of the land, thereby helping to creat a layer of warmer air above that traps pollutants.

Smoke from cleared fields has been implicated in poor harvests of Brazil nut (*Bertholletia excelsa*) in Pará. Smoke may interfere with bee pollinators of Brazil nut, but such a linkage has not been demonstrated conclusively. Yield variation in Brazil nuts is more likely attributed to the severity of the dry season when flowers are formed. If the dry season is not pronounced, flower sets will be poor.

The declining harvest of Brazil nuts during the 1980s has been attributed largely to widespread destruction of Brazil nut groves and smoke interference with pollination, particularly along the Tocantins River and its affluents.[30] In the 1950s and 1960s, annual Brazil nut production in the vicinity of Marabá averaged about 8000 tonnes. In 1970 and 1975, production reached 17 732 tonnes and 12 273 tonnes, respectively, in large part because of linkages to new roads such as PA 332 (then PA 70) to the Belém–Brasília Highway. In 1980 and 1985, however, production fell to 8823 tonnes and 2000 tonnes, respectively. Although deforestation is rampant in the Tocantins watershed, gold fever is a more likely explanation for the decline of Brazil nut production in the 1980s. Honeycombed Serra Pelada, for example, served as a magnet for rural folk in the region and further afield. In the early 1980s, 100 000 earth-caked men were digging out the interior of the mountain in search of gold.

Soil erosion and floods

Soil erosion is one of the most serious threats to the sustainability of agriculture, silviculture, and forestry in Amazonia. Although many Amazonian soils are deep, extending down several thousand metres in some cases, fertility is usually concentrated in the first few centimetres of topsoil. The need to protect the soil is a major reason why perennial crops, silviculture, and properly managed pastures are among the more viable options for rural development.

Soil erosion can lead to more severe floods by depositing sediment on river and stream beds. River levels in Amazonia fluctuate annually in response to the seasonal pulse of wet and dry seasons.[31] Some unusually heavy floods along the Amazon in the mid-1970s raised the spectre that deforestation in the foothills of the Andes was having a tangible impact downstream.[32] But statistical analyses of flood peak levels do not reveal any trend to more intense flooding along the Amazon.[33] Destruction of forests is surely affecting water quality and flow in some areas, but the enormous volume of the Amazon River appears to be masking such signals.

Soil erosion is not yet significantly shortening the lives of any reservoirs created for hydroelectricity in Amazonia. Although the Tocantins appears to be cloudier than formerly, particularly for a 'clear' water river draining the Brazilian shield, no hard data on silt loads over an extended period are available. About half of the 2000 km^2 Tucurui Reservoir is 'dead storage' due to depressions, thus siltation is unlikely to affect capacity for electricity generation in the near future.[34]

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29 Paul J. Crutzen and Meinrat O. Andreae, 'Biomass burning in the tropics: impact on atmospheric chemistry and biogeochemical cycles', *Science*, Vol 250, 1990, pp 1669–1678.

30 C. Miller, *Natural History, Economic Botany, and Germplasm Conservation of the Brazil Nut Tree (Bertholletia excelsa, Humb & Bonpl)*, unpublished MS thesis, Department of Geography, University of Florida, Gainesville, FL, 1990.

31 Hilgard O'Reilly Sternberg, 'The Amazon River of Brazil', *Edrkundliches Wissen*, Vol 40, 1975, pp 1–74.

32 A.H. Gentry and J. Lopez-Parodi, 'Deforestation and increased flooding of the Upper Amazon', *Science*, Vol 210, 1980, pp 1354–1356; N.J.H. Smith, *Man, Fishes, and the Amazon*, Columbia University Press, New York, NY, 1981, p 122.

33 J.E. Richey, C. Nobre, and C. Deser, 'Amazon River discharge and climate variability', *Science*, Vol 246, 1989, pp 101–103; Hildgard O'Reilly Sternberg, 'Aggravation of floods in the Amazon River as a consequence of deforestation?', *Geografiska Annaler* (Series A, Physical Geography), Vol 69A, No 1, 1987, pp 201–219.

34 Chris Barrow, 'The impact of hydroelectric development on the Amazonian environment: with particular reference to the Tucuruí Project', *Journal of Biogeography*, Vol 15, 1988, pp 67–78.

Hydroelectric dams

Disruption of fisheries as a result of dam building is a potentially serious threat to the livelihoods of many rural and urban folk in Amazonia. A number of fish important in commerce and subsistence, such as jaraqui (*Semaprochilodus* spp) and dourado catfish (*Brachyplatystoma flavicans*) migrate from the Amazon to tributaries.[35] Changes in water quality and a reduction or elimination of fluctuating water levels may also interfere with the reproduction and feeding of at least some of the 2000 or more species of fish inhabiting the myriad waters of Amazonia.

Little is known about the impact of dams built thus far on Amazonia's fisheries.[36] The Curuá-Una reservoir spawned a population explosion of piranhas (*Serrasalmus* spp), at least during the first two decades of operation. Some fish were killed by the lack of oxygen and hydrogen sulphide when the Tucurui dam closed in 1984,[37] but the reservoir has become a significant fishery for the highly prized tucunaré. Tucunaré from the Tucurui reservoir are being marketed at least as far south as Carajás. The 2100 km^2 Balbina reservoir on the Uatumã river, recently completed to provide electricity for Manaus, has also become a significant fishery for tucunaré.

The predatory fish, known as peacock bass to English-speaking sport fishermen, may be contaminated with mercury from gold mining near the Carajás range. Also, tucunaré in the Curuá–Una reservoir near Santarém, Pará, became so heavily infested with parasitic nematodes that some locals declined to eat the highly prized fish.[38]

Some fisheries downstream from the Tucurui appear to have suffered from the dam.[39] The productivity of fisheries appears to have been affected mostly in the lower regions of the Tocantins in the vicinity of Cametá. One migratory species, *Anodus elongatus*, has virtually disappeared from the lower Tocantins.[40] Populations of *Curimata cyprinoides* have also suffered, at least temporarily. Although the composition of fish communities has shifted downstream from the dam, the overall impact of the dam on fisheries has not proved especially serious from the perspective of local nutrition. A freshwater shrimp fishery based on *Macrobrachium amazonicum* along the lower Tocantins was on the decline well before the Tucurui dam closed. Furthermore, the shrimp, which is used in a variety of regional dishes, is thriving in the Tucurui reservoir.[41] The Samuel Dam on the Jamari river in Rondônia which filled in 1989 to supply electricity to Porto Velho, has reportedly disrupted upstream migration of some large catfish.[42]

Prospects for environmentally sound development

Although the impacts of environmental changes underway in Amazonia appear to be largely confined to the regional or local scale, forces of destruction are likely to increase in the future. Brazil's population is growing by some three million people a year, and efforts to open up Amazonia for settlement and development will intensify.

Given the inevitable pressure to develop and occupy the Amazon further, careful management of forest resources and agricultural activities will become ever more urgent.[43] Thus far only 2% of the Brazilian Amazon's 500 million ha are in parks, reserves, or national forests. If Indian reserves are included, still less than 4% of the region is nominally protected.

Sizeable tracts of forest will survive in the next century only if forests

[35]Michael Goulding, *Amazon: The Flooded Forest*, BBC Books, London, 1989.

[36]Peter B. Bayley and Miguel Petrere, Jr, 'Amazon fisheries: assessment methods, current status and management options', in D.P. Dodge, ed, *Proceedings of the International Large River Symposium, Can Spec Publ Fish Aquat Sci*, Vol 106, 1990, pp 385–398.

[37]Harald Sioli, 'Tropical continental aquatic habitats', in Michael E. Soulé, ed, *Conservation Biology: The Science of Scarcity and Diversity*, Sinauer Associates, Sunderland, MA, 1986, pp 383–393.

[38]Wolfgang J. Junk and J. Nunes de Mello, 'Impactos ecológicos das represas hidreléricas na Bacia Amazônica Brasileira', *Tubinger Geographische Studien*, Vol 95, 1987, pp 367–385.

[39]P. Magee, 'Peasant political identity and the Tucurui Dam: a case study of the island dwellers of Pará, Brazil', *Latinamericanist*, Vol 24, No 1, 1989, pp 6–10.

[40]Bernard de Merona, Jair L. de Carvalho, and Maria M. Bittencourt, 'Les effets immédiats de la fermeture du barrage de Tucurui (Brésil) sur l'ichtyofaune en aval', *Revue de Hydrobiologie Tropicale*, Vol 20, No 1, 1987, pp 73–84.

[41]Olga Odinetz-Collart, 'La pêche crevettière de *Macrobrachium amazonicum* (Palaemonidae) dans le Bas-Tocantins, après la fermeture du barrage de Tucurui (Brésil)', *Revue de Hydrobiologie Tropicale*, Vol 20, No 2, 1987, pp 131–144.

[42]João Paulo Viana, personal communication.

[43]N.J.H. Smith, P. Alvim, A. Serrão, A. Homma, and I. Falesi, 'Amazonia', in Jeanne Kasperson and Roger Kasperson, eds, *Critical Zones in Global Environment Change*, UNU Press, Tokyo, in preparation.

can be managed on an economically and ecologically sustainable basis and farms, pastures, and plantations are made more productive. Sustainable agriculture and forestry that provide cash income will be crucial to the survival of substantial tracts of forest in the next century.

Fortunately, a wide array of organizations concerned with Amazonian development are increasingly aware of the need to consider the ecological dimensions to development. In this regard, the prospects for constructive change in Amazonia are better now than two decades ago when little discussion of the ecological dimensions to landscape changes occurred. Now government institutions, such as Brazil's agricultural research system (EMBRAPA), scientific research institutions within the region (particularly INPA in Manaus and Museu Goeldi in Belém), and burgeoning non-governmental organizations (NGOs) are grappling with issues related to sustainable development.

To foster this growing awareness of environmental issues in Amazonia and increase research into ways to devise strategies for sustainable development, development agencies, research organizations, and NGOs need to work together more closely. Some 400 to 700 NGOs have surfaced in Brazil within the past decade to address a broad range of issues, often with an environmental component. Many of these NGOs have received start-up funds from international donors because of the perceived inefficiency of research organizations in Amazonia and their lack of relevance to pressing social and ecological problems. But most NGOs have little if any research capacity. The skills of NGOs and their close contact with people could be more effectively tapped to understand better the environmental, socioeconomic, and cultural dimensions to sustainable development as research organizations are strengthened.

While promoting networking between NGOs and research organizations within Amazonia, greater emphasis is needed on training nationals who are committed to working in the region. Brazilians, Peruvians, Colombians, Bolivians, Ecuadorians, and Venezuelans will ultimately determine the fate of Amazonian ecosystems. More local scientists and extension agents, sensitized to an interdisciplinary approach to development, will help ensure that much of the region's cultural and biological diversity is safeguarded for future generations.